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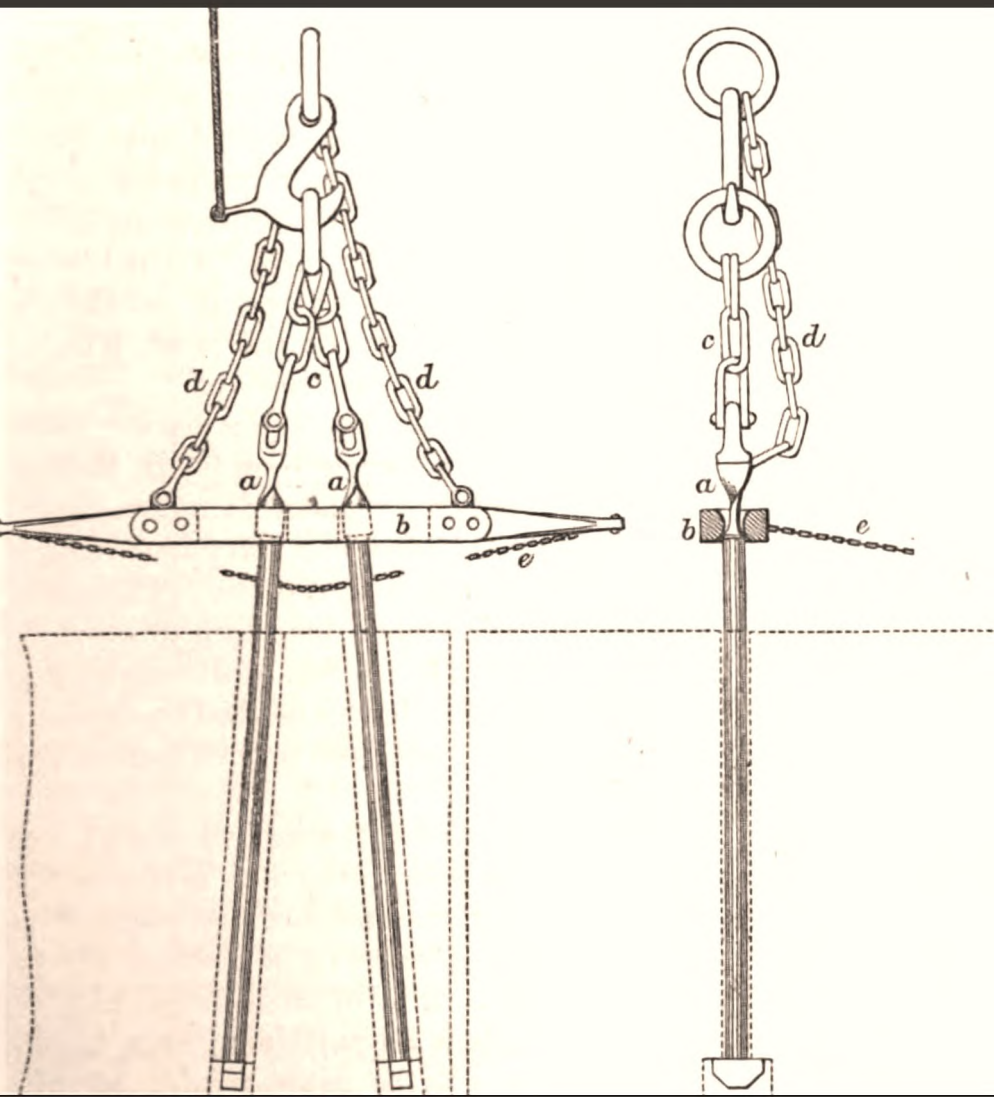

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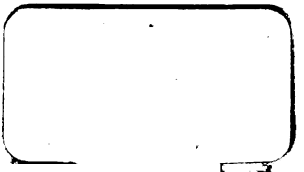

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MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. LXII.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

LONDON:

Published by the Institution,

25, GREAT GEORGE STREET, WESTMINSTER, S.W.

1880.

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CONTENTS.

SECT. I.—MINUTES OF PROCEEDINGS.

27 *April*, 1880.

PAGE

"The Amsterdam Ship Canal." By H. HAYTER (3 plates, 5 woodcuts) . 1

Discussion on ditto (7 woodcuts) 27

Correspondence on ditto 56

4 *May*, 1880.

Transfer of Associate Members to class of Members 66

Admission of Students 66

Election of Members and Associate Members 66

11 *May*, 1880.

"The Manufacture and Testing of Portland Cement." By Major-Gen. H. Y. D. SCOTT, C.B., R.E., and G. R. REDGRAVE (2 plates) 67

"Portland Cement Concrete and some of its Applications." By E. A. BERNAYS. (1 plate) 87

"Portland Cement; its Nature, Tests, and Uses." By J. GRANT (1 plate, 33 woodcuts). 98

Appendix: Tables (1 woodcut) 126

Discussion on Portland Cement and Portland Cement Concrete (1 plate, 1 woodcut) 180

Correspondence on ditto (1 woodcut) 208

Resolution to adjourn over Whitsun Tuesday 249

25 *May*, 1880.

Transfer of Associate Members to class of Members 250

Admission of Students 250

Election of Members, Associate Members, and Associates 250

23 *June*, 1880.

Conversazione 250

Digitized by Google

Sect. II.—OTHER SELECTED PAPERS.

PAGE

"The Practical Strength of Beams." By B. Baker (4 woodcuts) . . . 251

"Earthwork Slips in the Cuttings and Embankments of various Railways, with their Causes and Modes of Treatment." By J. B. Squire (1 plate) 272

"Earthwork Slips on the Castle Eden and Stockton Railway." H. M. Whitley (2 woodcuts) 280

"Earthwork Slips on the Leeds and Wetherby Branch Railway." By H. Copperthwaite (3 woodcuts) 285

"The Seven Stones Light Vessel." By J. N. Douglass (1 plate) . . . 288

"Small Motive Power." By H. S. H. Shaw (1 plate) 290

"Light Draught Steel P.S. 'Terranora,' for Ocean and River Navigation." By J. A. Thompson (1 plate) 334

"Notes on the Principal Systems of Electric Light in use in England and in the United States." By K. W. Hedges 339

Memoirs of Deceased Members 349

General Arthur Jules Morin, 349; John Lawton Haddan, 352; William Johnstone, 354; Edward Tickell Lang, 355; David Llewellin, 356.

Sect. III.—ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Regulations for the Uniform Testing and Nomenclature of Roman Cement. 357

Experiments with Appliances for Testing Cement. A. Noble 359

On the Extension of Metals under Tensional Stress after Rupture. J. Barba 360

Tests of Iron and Steel Shafting. J. Howard 361

Report on the Island of Cyprus. L. Luiggi 362

State and Communal Expenditure on Public Works in Italy 365

Report on Belgian Public Works. M. le Hardy de Beaulieu 367

Note on the Port of Cette 370

Repair of the Sill of the Duquesne Lock at Dieppe Harbour. M. Alexandre 372

Clip Calliper for Lifting Waste Weir Planking. A. Hayes 373

The Mulatière Weir on the Saône at Lyons 374

Canalisation of the Meuse between Namur and the French Frontier. M. Hans 375

M. de Lesseps' Project of an Interoceanic Canal at Panama 377

Digitized by Google

PAGE
Ice-Breaking in the Vistula. Hr. Düsing 379
A Storage Reservoir in the Achterfeld. J. G. Gamble 380
The Pumping Machinery for the New Waterworks at Hanover. H. Berg . 382
On the Causes of the Internal Corrosion of Steam Boilers. M. Lodin . . 384
Comparative Experiments on Woolf-Engines and Marine Compound Engines. O. Hallauer 385
Balancing Locomotive Engines. C. A. Smith 386
Surmountable Gradients. C. Boissay 388
The most suitable Dimensions for and Number of the Piers of Iron Railway Bridges 389
On the Durability of Railway Sleepers. Hr. Funk 390
Central Pacific Railroad Company's Transfer Boat "Solano" 393
Continuous Electric Railway Brake. M. Achard 394
Electrical Inter-communication in Trains. G. K. Winter 394
A Comparison of Different Methods of Colliery Ventilation. J. Mayer . 396
Influence of Temperature in Tunnelling through High Mountains. Dr. F. M. Stapff 399
Warming and Ventilation of the Monge School. S. Périssé 407
Apparatus for Supplying Drinking-Water at the Harbour of Flushing. F. Kapaun 408
Dervaux's Boiler Feeder. J. Henin. 409
Consumption of Steam in the Rolling of Steel Rails. J. Kraft . . . 411
The most suitable Diameters for Steam-pipes. H. Fischer 412
Snow Clearing in Milan. E. Bignami Sormani 413
Improvements in the Desilverising of Lead by Zinc. C. Schnabel . . . 415
The Preparation of Salts of Uranium and Vanadium at Joachimsthal. C. Lallemand 417
Schwandorf Continuous Kiln with Gas Furnace 418
The Clearing of Coal Slack by an Air-Blast 419
On the Determination of Phosphorus and Silicon in Iron and Steel. A. E. Haswell 421
On the Weighing of Steel Ingots during Casting. F. Moro 421
On the Mechanical Equivalent of Heat. Prof. H. A. Rowland 422
Sensitive Thermometer for Small Measurements. M. Thouvenot . . . 424
On Telephonic Effects Resulting from the Percussion of Magnetic Substances. Count du Moncel 425
A New Form of Constant Electric Battery without Acid. E. Reynier . 426
Comparison of the Power of Hollow and of Solid Magnets. W. Holtz . . 427
Improvement of Siemens Armature. G. Trouvé 428
On Electrical Expansion. G. Quincke 428

Digitized by Google

PAGE

Martelli's Altiplanimetrograph 429

Novel Domestic Motor 430

A Ballistic Apparatus for Registering the Law of Motion of a Projectile. M. SEBERT 431

Note on the Stability of Ships. L. DE BUSSY 432

INDEX 435

ERRATA.

Vol. xlviii., p. 103, lines 4, 19 and 33, *for* "Gatwell" *read* "Gatmell."

„ lvi., p. 370, line 1, and p. 371, line 18, *for* "Lanbereau's" *read* "Laubereau's."

„ lix., p. 190, line 35, *for* "*James* Bower Mackenzie" *read* "*John* Bower Mackenzie."

„ lxi., p. 273, lines 15 and 16, *for* "Kussmere" *read* "Kussmore."

„ lxii., p. 176, bottom. The figures 215, in test No. 40, column for 13 weeks, on a line with 512, should be on a line with 163.

„ p. 189, line 20, *for* "Professor of Chemistry" *read* "Director or Manager of the Cement Works at Goessnitz."

„ the Table, p. 212, refers to Mr. Dyce Cay's remarks on the previous page.

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THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1879-80.—PART IV.

SECT. I.—MINUTES OF PROCEEDINGS.

27 April, 1880.

WILLIAM HENRY BARLOW, F.R.S., President, in the Chair.

(*Paper No. 1667.*)

"The Amsterdam Ship Canal."

By HARRISON HAYTER, M. Inst. C.E.

THE Author proposes to describe the Amsterdam Ship Canal, which embraces the construction of the North Sea harbour and breakwaters, and the reclamation of land on an extensive scale, the undertaking being one of the largest and most useful of modern times. The chief object of this canal is to provide Amsterdam, which is situated on Lake Y,[1] an inlet of the Zuider Zee, with a direct and improved deep water communication with the North Sea.

The city of Amsterdam has for centuries been one of the great commercial centres of Europe; but the trade suffered, owing in a great measure to the gradual increase in the size of merchant vessels, the sea approaches to Amsterdam being shallow.

As a remedy the North Holland Ship Canal, from Lake Y, opposite Amsterdam to Niewediep, at the Texel Roads, was completed in 1825, previous to which Amsterdam had no communication with the ocean excepting by the Zuider Zee and through the Texel Roads. This canal traverses the low lands of North Holland, and has been extensively used. Its length is 52 miles, its width at the bottom 31 feet, and at the water-level 123 feet 6 inches, the depth being 18 feet 6 inches. An account of this

[1] In Holland this is written Lake IJ. Anglicised it is usually written Lake Y. It is pronounced Lake I.

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work was presented to the Institution in 1847, by Mr. G. B. W. Jackson.[1] The rapid increase of trade, fostered by the introduction of railways, and the still growing size of vessels, made it imperative for Amsterdam to provide still better communication with the North Sea. The North Holland Canal also was frequently closed in winter by ice, whilst hitherto it has not been difficult to keep open the Amsterdam Canal, on account of the great traffic and of the large ships that navigate it, which break up ice as it forms.

The distance from Amsterdam to the North Sea, in a direct line, is only 15½ miles, the intervening narrow neck consisting of two shallow fen lakes—Lake Y and Lake Wijker Meer, inlets of the Zuider Zee—and of the belt of sand hills, here about 3 miles wide, which protect the low lands of Holland from the inroads of the sea. This is the route that has been chosen for the Amsterdam Ship Canal, and it may appear strange that it was not selected by the promoters of the North Holland Canal. But at the sea end of that canal at Niewediep there is deep water and a quiet sea, whilst at the entrance of the Amsterdam Ship Canal from the North Sea the coast is exposed, flat, and sandy, necessitating the construction of large piers or breakwaters founded on sand, and the formation of an artificial harbour—a work which fifty years ago was considered, if not impracticable, at least too formidable to be undertaken.

Three centuries ago it had been proposed to connect Amsterdam directly by the shortest passage with the North Sea. The proposal remained for a long time dormant, and the idea, although often entertained, was not seriously revived until 1852, when the city authorities appointed a committee, which made a report, allowing fifteen years for the completion of the project; for this reason it was not received with favour. In 1854 the city of Amsterdam announced a premium of 2,000 florins for a design for a North Sea canal which would fulfil the requirements, and especially that concerning the "time of construction;" but the premium was not awarded to any of the ten projects sent in competition. In 1852, two English engineers, Mr. B. W. Croker and Mr. Charles Burn, had, in conjunction with Mr. J. G. Jäger, of Amsterdam, suggested the establishment of a private company for its execution; and on the 17th of April, 1853, the design was presented to the Minister Thorbecke, who received it favourably. But it was necessary to hear the communities interested in Holland on questions affecting the drainage and sea protection, and thus the consideration of the plan was protracted,

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. vi., p. 81.

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commission after commission reporting upon it. In the meantime the proposed canal became more and more popular. Memorials were presented to the King, the city of Amsterdam appointed a committee to promote "the canalisation of Holland at its narrowest part;" and in April 1859, the Minister Van Taets appointed a Board of the Waterstaat, by whom the general plan of 1852 was adopted. A project of law authorising the execution, prepared by the Ministers Van Taets and Van Bosse, was withdrawn by their successors, to be followed by new projects, which were also withdrawn. Notwithstanding the manifold discussions and reports, the idea which really became the key of the present undertaking had not yet been put in the foreground, viz., the exclusion of the water of the Zuider Zee from Lake Y, and, of course, from the canal, by a dam or dyke eastward of and shutting in Amsterdam. To leave the canal open to the fluctuating level of the Zuider Zee, to interfere by its construction with the drainage system of the rich regions bordering the Y, while exposing them to danger from which they were before exempt, involved so much that was objectionable, and militated against so many interests, that projects otherwise sufficiently meritorious to receive the sanction of the commissions failed for years to secure legislative sanction. The execution of the dam across a tidal channel nearly a mile wide, involving the construction of an extensive system of locks, sluices, and pumping machinery, is one of the most remarkable features of the enterprise.

By 1861 the difficulties were sufficiently overcome, and in December of that year Mr. Jäger accepted a concession, which was ratified with some modification of details by the law of the 24th of January, 1863, and in 1865 a company was formed for the purpose of constructing the Amsterdam Ship Canal. Sir John Hawkshaw, Past President, Inst. C.E., was appointed consulting engineer, and in conjunction with Mr. J. Dirks, of Amsterdam, the resident engineer, undertook the general control and superintendence of the works. A contract was signed on the 31st of March, 1865, by Messrs. Henry Lee and Sons, of Westminster, for the construction of the whole of the works. The Author has been associated with the works throughout, and Mr. J. Waldorp, of the Hague, locally represented Sir John Hawkshaw, and the following gentlemen on behalf of Messrs. H. Lee and Sons, respectively took local charge, Mr. T. C. Watson, M. Inst. C.E., of the dyke or dam across Lake Y, and of the Zuider Zee locks; Mr. Darnton Hutton, M. Inst. C.E., of the North Sea harbour and breakwaters; and the late Mr Samuel Tate Freeman, Assoc. Inst. C.E., of the works

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between Amsterdam and the North Sea Harbour, up to the time of his death at the end of 1871, when his place was occupied by Mr. David Lindsay, and afterwards by Mr. T. C. Watson.

Nearly the whole of Holland is alluvial, the greater part of it being flat, highly-cultivated land below the level of the sea. Along the coast nature has erected an almost uninterrupted barrier of sand dunes or hills, thrown up by the action of the sea, and drifted landward by winds. These sand hills sometimes attain an elevation of 40 or 50 feet, and vary in width from 1 mile to 3 miles. The dunes near the sea are frequently altered in shape by the wind drifting the sand, and where this occurs there is but little vegetable life, but further inland they become tracts of pasture and arable land. At places the sand hills, which would otherwise drift, are sown with plants which take root in such barren soil, especially the reed or helm grass (*Psamma arenaria*). In course of time the roots of these plants spread and consolidate the sand, which thus becomes capable of supporting richer vegetation. A stratum of vegetable soil once formed, portions of the sand hills are converted into pasture or arable land. Besides these dunes, the safety of the country is dependent on the dykes or embankments, by which sea and river encroachments are prevented, and the preservation and upholding of which is systematically organised, and subjected to the strictest supervision.

In order to understand the following description, it is necessary to state that throughout Holland all levels are referred to one datum called A.P., which are the initial letters of the Dutch words "Amsterdam Peil," meaning Amsterdam standard level. By a Royal Decree of the 18th of February, 1818, A.P. is fixed as the basis for the observations of the water heights in the principal rivers of the kingdom of Holland, and even outside the limits of that country this datum is observed. A.P. may be taken to be mean tide level at the North Sea end of the canal, and about high water at the Amsterdam end, where the range of tide is very small.

The following are the correct levels at these places:

North Sea ordinary high water . .	0·790 mètre	(2 ft. 7 in.)	+ A.P.
„ low water . .	0·850 „	(2 ft. 9½ in.)	− A.P.
Amsterdam ordinary high water . .	0·026 „	(1 in.)	+ A.P.
„ low water . .	0·356 „	(1 ft. 2 in.)	− A.P.

The principal works of the Amsterdam Ship Canal (Plate 1, Figs. 1, 2), besides the earthworks, consist of the dam or dyke across Lake Y, to the eastward, to exclude the waters of the Zuider Zee from the canal, and which is pierced by the Zuider Zee locks and sluices;[1] of the North Sea locks,[2] situated about ¾ mile from

[1] Now called the "Orange Locks." [2] Now called the "Ymuiden Locks."

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the North Sea, and shutting out the waters of the North Sea from the canal; of the land reclamations intersected by branch canals to maintain existing drainages and navigations, and dividing the reclamations into polders; of the pumping machinery; and of the North Sea harbour and breakwaters.[1] The canal, therefore, consists generally of one long reach between the Zuider Zee locks at one end, and the North Sea locks near the other end, and of a short tidal reach of ¾ mile between the North Sea locks and the North Sea harbour. An important stipulation was that the long reach of the canal between the locks at each end is required to be maintained by sluices and pumping at a level of ½ mètre (1 foot 7½ inches) below Amsterdam Peil, that is, about 14 inches above ordinary low water of the North Sea, for the purposes of drainage, and for the protection of the district of Amsterdam.

Earthworks.

The cross section of the Amsterdam Ship Canal through the sand hills, and through the lakes Y and Wijker Meer is shown in Figs. A and B (see next page), and for the sake of comparison the cross section of the Suez canal is given in Fig. C, and that of the North Holland canal in Fig. D.

As shown by the cross sections the depth of water of the Amsterdam Ship Canal is 23 feet, and that of the Suez Canal 26 feet. The depth of water in the Amsterdam Canal is fixed, whilst that given of the Suez Canal is the average, and is subject to variation owing to the tide, which although it has a maximum range of only about 2 feet at the Mediterranean end, at the Red Sea end has an ordinary spring range of 3 feet, and an extraordinary spring range of 5 feet 6 inches, which influences the level of the water as far as the Bitter Lakes, or for a distance of 20 miles.

The excavations through the sand hills on the sea margin were the first works commenced, the material being conveyed by wagons or barges, and deposited to form the nucleus of the canal banks through the lakes. The banks are coated with the material excavated from the lakes, and are protected to the extent necessary with fascines. When the sand nucleus was far enough advanced, the deep-water channel of the canal was excavated by dredging, and the material deposited on the banks. The banks are generally 443 feet apart, and their total length is 38½ miles. In excavating the canal, ordinary dredging machines were employed at the outset, the material excavated being deposited in barges, and removed by barrows

[1] Now called the "Ymuiden Harbour."

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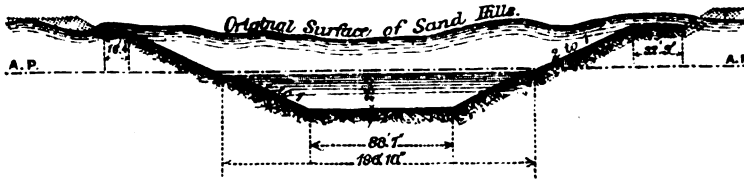
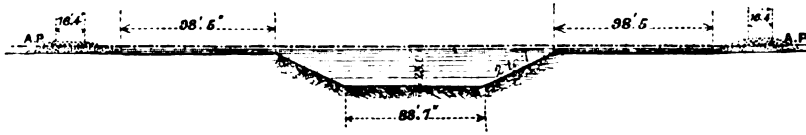
on to the banks. A novel and better mode of delivering the material was subsequently adopted; the material falling from the buckets of the dredger was received into a vertical cylinder fitted to the dredger, in which a Woodford pump 3 feet 6 inches in diameter revolved, and being mixed with a sufficient quantity of water to reduce it to a semi-fluid state, it was forced by the

FIG. A.



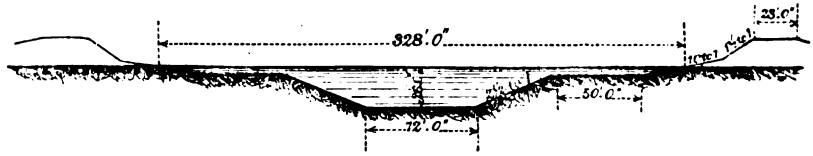
Amsterdam Ship Canal through Sand Hills.

FIG. B.



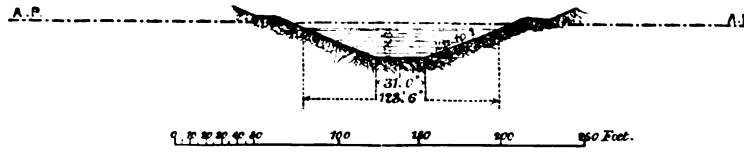
Amsterdam Ship Canal through Lakes Y and Wijken Meer.

FIG. C.



Suez Canal.

FIG. D.



North Holland Canal.

pump through a line of wooden tubes 15 inches in diameter, connected by leathern joints. These tubes were fitted with buoying pieces to enable them to float on the surface of the water, and passing on to the banks, deposited the stream of mud. The pump, which was driven at the rate of two hundred and thirty revolutions per minute, was fixed to the side of the dredger at the level of the

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water; it had a reservoir at the top for the reception of the dredged material, and an inlet at the bottom for the admission of the water, both the openings at the pump being furnished with valves. The longest length of tubes employed was 300 yards, and the greatest height of the discharge above the water has been 8 feet. As the pumps absorb more power than is required to work the buckets in the ordinary way, considerable engine power is required to work these dredgers.

Altogether about twelve dredgers were employed in the excavation of the canal earthworks, to six of which the delivering apparatus was fixed. Two of the most powerful dredgers were made by Messrs. Simons and Co., and the delivering apparatus was designed, and fitted to the dredgers by Messrs. Burt and Freeman. The two large dredgers, under ordinary circumstances, were each capable of lifting and depositing on the banks, through the tubes, about 1,700 tons, or 1,300 cubic yards of material per day of twelve hours, at a cost of about 1½*d.* per ton. If the delivering apparatus had not been adopted the time necessary to dredge the canal and to make the banks would have been greatly increased, and the cost also, because, owing to the shallowness of a great portion of the lakes, barges could not in many places have been worked. The wide and shallow berms through the lakes were designed to prevent the banks being injured by the wash from vessels. This they effectually do when overgrown by reeds; the banks only require a slight protection of fascine work until that growth is established. Through the sand hills a more substantial protection, consisting of short piles backed with planks and broken bricks, was constructed near the water level.

The tidal reach of the canal between the sea and the North Sea locks has been still further widened, especially at the end next the sea, so as to form an excellent and well sheltered inner harbour, where vessels can wait to pass through the North Sea locks. This widening has entailed but little expense to the Canal Company, as most of the material has been removed without cost to the Company for the formation of railway and other embankments at Amsterdam.

The profiles of the side or branch canals are generally similar to those of the main canal through the lakes. They, however, are shallower, and of variable depth, and the berms on each side are 20 mètres (65½ feet) wide, instead of 30 mètres (98½ feet).

Altogether the quantity of material excavated, including the dredging, in the North Sea to form the harbour has been about 21,000,000 cubic yards.

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The Dam across Lake Y.

In order to keep the waters of the Zuider Zee from overflowing and washing away the banks of the Amsterdam Canal, and so flooding the lands drained by it, and also to be able to maintain the water in the canal to the level of ½ mètre (1 foot 7½ inches) below A.P., the dam (Plate 1, Fig. 3) was constructed across Lake Y at a spot about 2 miles eastward of Amsterdam, extending from the existing land dike at Paardenhoek, on the Amsterdam or south side of Lake Y, to the land dike called Waterland's Dike, at Schellingwoude, on the north side, its total length being 1,360 mètres (4,462 feet). In this dam are the Zuider Zee locks, at a distance of 300 mètres (984 feet) from the Waterland's Dike, on the northern shore of the lake. It was at first proposed to throw the dam across at Pampus, considerably further to the eastward, from the lighthouse to Battery Point, where the length, including Buiten Ydorn Polder, across which the dam would also require to have been carried as far as Waterland's Dike (Plate 1, Fig. 2), is 3,500 mètres (11,483 feet), and there the bottom is much worse, so bad indeed that two men boring with a hand auger penetrated to a depth of 50 feet in twenty minutes. The object sought to be attained by placing the dam so far to the eastward was to procure more harbour room for Amsterdam; but the increased length of dam, and the unfavourable character of the bottom, led to this site being abandoned for the present one, although the bottom is not favourable even there, the mud being soft and the material treacherous. To lessen the sinkage, huge mattresses of fascines, about 2 feet 6 inches thick, were laid over the whole breadth of the dam, and were so woven together as almost to resemble basket work. Exterior dams of fascine work were then built to low-water level, the space between them being filled with clay and sand.

The following are the leading dimensions of the dam:—Extreme width at the base about 45 mètres (147½ feet); width at the top, 4 mètres (13 feet 1½ inch); level of the top at the edges, 3·50 mètres (11½ feet) above A.P., rounded in the middle to the extent of 0·15 mètre (6 inches). The outside fascine work at the toe of the bank on the seaward side is laid to a slope of 1¼ to 1, and the inner fascine work on the canal side to a slope of ¾ to 1. Above the fascine work on the outer side there is a slope of 2½ to 1 to the level of 0·50 mètre (1 foot 7½ inches) above A.P., a berm of 3 mètres (9 feet 10 inches) broad, and a slope of 3½ to 1 to the top. Above the fascine work on the inner side, there is a slope of 2 to 1 to the level of 0·50 mètre (1 foot 7½ inches) above A.P., a berm 5 mètres (16 feet

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5 inches) broad, and a slope of 2 to 1 to the top. The slopes, berms, and top of the dam are faced with a layer of at least 1 mètre (3 feet 3 inches) of puddled clay, and both sides were protected from the top to 0·5 mètre (1 foot 7½ inches) below A.P., against the action of the waves by temporary fascines loaded with stones. When the dam was closed, the fascines were replaced on the outside by stone pitching covering the slope from 0·50 mètre (1 foot 7½ inches) below A.P. to the top, and the inside slope from 0·50 mètre (1 foot 7½ inches) below A.P. to the berm. The pitching is nowhere less than 0·30 mètre (1 foot) thick, and is laid on broken bricks 0·20 mètre (8 inches) thick.

The Author would here give a description of the celebrated fascine work, so much adopted in Holland, and known there under the general name of "ryshout," and the mode of putting it together and of laying it in place. But Mr. T. C. Watson, who had the local charge of the dam during its construction and of other works of the canal, has already described very fully this class of work in the "Minutes of Proceedings."[1] It is, however, desirable briefly to remark that fascines under water are nearly always used in the form of "grondstukken" or "zinkstukken," both being made in the same way. The lower zinkstuk is that which reposes on the bottom, hence called "grond" or ground piece. The successive layers are called zink or sinking pieces. It was contemplated at the outset to put two grondstuks under the dam instead of one, but it was considered that it might cause a leakage. The dam, however, actually broke through the one grondstuk in two places, and where this occurred the dam sank vertically, and the lower portion spread out in an irregular manner, the vertical sinking being attributable to a considerable quantity of earth going through the gap in the grondstuk. In one case the occurrence happened suddenly, a portion sinking 2 mètres (6 feet 6½ inches) during the time the men were having dinner, and in the other it took place gradually. In a small length of dam, begun at a later period, a double grondstuk was used, the result being satisfactory.

Zuider Zee Locks (Plate 1, Figs. 1, 2, 3, 4).

These consist of three locks, one passage or large sluiceway, and three small sluiceways. Being situated in Lake Y, they were built within a circular cofferdam. The largest lock has a length of 315 feet and is 60 feet wide; the other two locks, one on each side of the largest lock, have each a length of 238 feet and are 47 feet

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xli., p. 158.

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wide. The large sluiceway is 34 feet wide, and the three small sluiceways are each 110 feet long and 13 feet wide. The three locks have each five pairs of gates, two pairs, pointing in opposite directions, being placed at the ends of each lock, and one pair in the middle, pointing towards the Zuider Zee. The sluiceways have each three pairs of gates, two pairs pointing towards the Zuider Zee, and one pair towards the canal. It was necessary before closing the dam to complete and open the Zuider Zee locks for traffic, otherwise the communication between the Zuider Zee and Amsterdam, and places to the westward, would have been cut off. The foundation or memorial stone of these locks was laid by the King of Holland on the 29th April, 1870.

The whole of the masonry and brickwork was founded on bearing piles, upwards of ten thousand being used, and the foundations of the sills and of the lock walls were enclosed in close sheet piling. The three sluices, as well as the powerful pumping machinery fixed upon them, were erected in order to maintain the canal at the prescribed level of 0·50 mètre (1 foot 7½ inches) below A.P., the only other outfall for the rainfall of the district being through the sluices at the North Sea locks into the North Sea at low water. The Zuider Zee locks are on a larger scale than the North Sea locks, it being necessary to provide at the former not only for the traffic to and from the North Sea and the Zuider Zee, but also for that from Amsterdam to the ports on the Zuider Zee. It was incumbent on the Canal Company to enable the shipping of Amsterdam, that would otherwise have been cut off, to get to the North Sea by the Texel Roads instead of through the canal; for although the distance is great, yet the canal tolls could thereby be saved. According to the terms of the concession the locks were to offer ample space for the accommodation of three hundred vessels per day, of such size as, at the date of the concession, traded in the Zuider Zee; but after the work had been contracted for, it was decided to add the third lock. Since these locks were opened it has not been unusual for five hundred vessels to pass through in one day, including small craft, such as fishing-boats; the greatest number registered in twenty-four hours having been six hundred and eighty-one.

In these locks the walls are of brickwork. The Dutch bricks are generally of small size; as a rule they are hard, good, and make excellent work. The hollow quoins, pointing sills, steps, and copings are of limestone ashlar, the stone being obtained from Belgium. The bottom of the lock chambers and the eastern and western aprons outside the gates are of fascine work and basalt pitching. The lock gates (Plate 2, Figs. 5, 6, 7) pointing towards

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the Zuider Zee, including those at the south sluice, that is, the sea gates, are of iron; and the gates (Plate 3, Fig. 10) pointing towards the canals, or the ebb gates, as well as the small sluice gates, are of red pine or American yellow pine, creosoted. Iron was considered by the Dutch authorities more trustworthy for the sea gates than wood. The existence of the country being dependent upon the effectual exclusion of the sea, nothing is neglected that in this respect would be likely to add to security, and this also is ensured at the locks by the introduction of additional sea gates.

The lock and large sluice gates are worked by crabs, there being one machine to every leaf for each operation. The gates of the pump sluices are each opened and closed by a wooden lever attached to the gate. In these sluices the bottoms have inverts of brickwork, and provision is made by additional arching and brickwork to carry the pumping machinery and buildings connected therewith.

The mortar is made either of 3 measures of sharp sand and 1 measure of Portland cement, or of 3 measures of Tournay third-class stone lime slaked on the works, 2 measures of Andernach trass, and 1 measure of sharp sand. The concrete is composed of 1 measure of Portland cement, 4 measures of sand, and 5 measures of shingle.

Cofferdam for constructing the Zuider Zee Locks.

This circular cofferdam was 160 mètres (525 feet) inside diameter, and consisted of two concentric rows of sheet piles, with a clear space between them of 6 feet 6 inches. The outer row of piles was of whole timbers sawn to 12 inches wide on the surfaces of contact; but the inner row, excepting the gauge piles, which were of whole timbers, was of piles sawn to 8 inches wide on the surfaces of contact. The timber was Dantzic white pine. The puddle clay between the piles was carried up to the level of ordinary high water, and a mound of sand was deposited on the inside as a counterweight to the pressure of the water. The outer row of piles projected 8 feet above ordinary high water, as at times the height of this ordinary tide level was much exceeded. The inner gauge piles came up to the same level, but the inner row of sheet piles, 8 inches wide, was only carried up to the level of ordinary high water. The walings were arranged as shown in Plate 1, Figs. 5, 6, the lower waling on the inside consisting of laminated timbers breaking joint. The cofferdam would have been more efficient had the inner piles been of whole timbers carried up to the same height as the outer row, and if the upper inside waling

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had been made of the same strength as the lower laminated waling. The timbers for the piles, however, were of exceptional length, and so many were needed that it became a difficult matter to procure a sufficient number of the right size; hence it was an object with the contractors to adopt a design which would allow of shorter timbers being used. In order to construct the cofferdam a dolphin was first erected in the centre of the area to be enclosed, the centre pile of which was driven on the 9th of July, 1866. At the commencement some difficulty was experienced in getting the piles of the exterior ring of the cofferdam set out correctly, and it was important for resisting pressure that the cofferdam should be an accurate circle. First, a hempen rope, previously strained, was fastened to the central dolphin, but the rope stretching irregularly, the piles were not true to a circle. Afterwards floating rods were resorted to, but the wind and tide deflected them sideways. At last a light iron wire rope about $\frac{1}{4}$ inch in diameter, kept strained by a weight, was used. For a few days it gave irregular results, but soon acquired its maximum stretch and became sufficiently accurate. It was found, however, that if the guide piles were set out in this manner, as close as 10 feet apart, the resulting curve was not very regular, so they were spaced 40 feet apart. Three pile engines were then set to the curve on a radial lighter, 40 feet broad at one end and 20 feet broad at the other end (Plate 1, Fig. 7), and these drove three piles equidistant in the 40-feet space, leaving intermediate spaces of 10 feet. Three pile engines on the lighter were driven by an 8-HP. engine, with triple purchase gear on to a long shaft. On this shaft were three drums, each of which could be thrown out of gear at any moment.

In order to drive the sheet piles two other lighters were provided, with one pile engine on each, driven by an Appleby steam crab. In every bay the last pile but one was wider at the base, the last being, as usual, a key-pile to close the other piles up. One circular-saw table, driven by a 14-HP. engine, just kept the work going. The ground was of a variable character. Many of the piles could be driven in about ten minutes, whilst others could not be got down without being split, and some could only be kept down by letting the monkey rest on them after the blow had been struck, as they rose 1 foot or 18 inches if the monkey was lifted immediately after the blow. It was subsequently found that this occurred where the layer of peat was thickest and the substratum of sandy clay the softest.

To prevent the ground being scoured on the south side of the cofferdam, where there was at one time an extraordinary current

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due to the dam narrowing the lake, long mattresses of fascine work were sunk against the cofferdam. As soon as the cofferdam was pumped dry, the dam, which had then been brought up close to the cofferdam on both the north and south sides, began to push it inwards, distorting the circle by the unequal pressure which had taken no effect as long as the water was inside the cofferdam. The contractors removed some of the clay of the dam to the inside of the cofferdam, but it still continued to move, and the water was let in again, not, however, before the cofferdam had bulged inwards on both sides. More sand was then deposited inside the cofferdam where it had bulged, and the water was pumped out. However, the Canal Company about that time found it necessary to limit the rate of expenditure, so the water was again let in, though not quite to so high a level as outside, to obviate the risk that would be incurred were the cofferdam kept dry. This was done by a siphon, 16 inches in diameter, with a foot-valve outside and a screw sluice inside.

At one time the cofferdam was subjected to a different kind of strain from any which it had been calculated to resist. The water outside, owing to a violent south-west wind, fell to 2·63 mètres (8 feet 7½ inches) — A.P., leaving 2·13 mètres, or nearly 7 feet, head of water inside. An attempt was made to reverse the siphon, so as to run off water from the inside, but this being unsuccessful, the water bent the cofferdam outwards, and the laminated waling as well as the other walings opening at the joints to the extent generally of 2 or 3 inches, but no actual rupture occurred sufficient to cause leakage. These openings in the walings were afterwards filled up with blocks of wood, and when the water was again pumped out, the outside pressure effectually tightened the work. A second laminated waling of four half baulks of Riga red pine was also added just above the original laminated waling, and was secured with 1½-inch bolts to the inside ring only of the piles, in order to avoid increasing the number of through bolts. More sand also was deposited inside, until altogether the quantity reached some 13,800 cubic mètres (about 18,500 cubic yards), or about 27½ cubic mètres per lineal mètre (about 33 cubic yards per lineal yard) of the cofferdam.

At one time, subsequently, the water found its way into the cofferdam and overpowered the pumps. It first made its appearance as a small stream at the bottom of the pump well. By filling the hole with straw, clay, and stones, and depositing sand against the cofferdam on the outside, the leak was stopped; but it soon burst out again in the pump well, a little on one side of the spot

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where it first appeared, so to prevent disaster the two sluices in the cofferdam were opened and the water let in. These sluices were about 4 feet long by 15 inches deep, their top being at the level of high water. The sheeting piles of the pump well were at once drawn, and a row of sheeting piles of whole timbers was driven at a distance of 5 mètres (16 feet 5 inches) inside the second ring of the cofferdam across the bad place, and tied to the cofferdam with whole baulks, and 3,600 cubic mètres (about 4,700 cubic yards) of sand were deposited between this sheeting and the cofferdam. Believing that the vibration from pumps working on a stage connected with the cofferdam had an injurious effect, the contractors erected a new pump stage in a position apart from the cofferdam. Not long after, the water was again pumped out, and the excavation for the lock was proceeding, when a huge mass of earth broke off inside the cofferdam at a distance of about 10 mètres (33 feet) from the inner ring of piles, in the line of a small grip which had been made for drainage. The sluices were opened immediately, the water from them being allowed to fall on a bed of fascines laid for the purpose at the spot; however, the ground between where the mass of earth had slipped and the cofferdam soon fell in, leaving the piles bare for a depth of 30 feet, and causing a breach in the cofferdam. An interval of two minutes elapsed from the time the cofferdam first began to bend until the breach opened, and in about three minutes the space inside the dam was filled with water. Seven boats were drawn in by the current, and were swept round the cofferdam with great rapidity. The stream also rushing across the cofferdam, knocked the opposite side with such force as to bulge it permanently outwards. The radial lighter, which was moored inside the cofferdam with four strong 3½-inch ropes, broke adrift and went down head foremost. No one was injured, but it became evident that the cofferdam needed further strengthening. This was done chiefly by depositing more sand both on the inside and on the outside, and driving a fresh row of close piles on the inside at a distance of 9 mètres (29½ feet) from the inner of the two concentric rows of piles, to keep the sand in place. Sand-bag buttresses with layers of fascines were also constructed inside the cofferdam where there was sufficient space between the cofferdam and the brickwork. It always proved difficult to keep the sand outside the cofferdam from being disturbed by the wash of the waves. Three groynes of pilework driven on the most exposed side had a useful effect, but the waves still continued to disturb the mound, and it was some time before the contractors could raise it to water level and cover it with fascines.

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Much trouble was also experienced in winter from floating ice. Raking round piles were driven outside the cofferdam every 10 feet apart, but they frequently broke when large masses of ice came against them. On one night the drift ice accumulated against the cofferdam with the flood tide until it was level with the top, some pieces of ice being actually pushed over. The cofferdam creaked loudly, but stood the strain without distortion, the water inside being at about 0·50 mètre (1 foot 7½ inches) + A.P. Triangular chocks were spiked at intervals under the outer lower waling, so that the ice might the more readily slide up the waling and not lift it. When the lake was frozen over, the ice was always kept broken around the cofferdam. The result of these precautionary measures and expedients was, that no damage resulted to the cofferdam from ice.

Much of the trouble experienced with cofferdams is occasioned by the through bolts almost always introduced, and this was the case with the cofferdam under consideration. At every high tide there was trouble with leakage at the through bolts placed at the level of 0·45 mètre (1 foot 5¼ inches) + A.P., owing to the settlement of the puddle. To remedy this as much as possible every conceivable expedient was resorted to. This leakage tended to disturb the mud and peat under the inside artificial bank of sand.

There can be no doubt that intermediate through bolts in cofferdams should be avoided as much as possible. The puddle sinks and leaves vacuities about them, and although the clay may be well puddled, and when in place well rammed, the Author's experience is, that cofferdams, with through intermediate bolts, invariably leak in a greater or less degree. In some large cofferdams with which the Author has been associated, subsequently to the cofferdam under consideration, for the purpose of constructing the East London railway through the London Docks, intermediate through bolts were dispensed with by Sir John Hawkshaw with marked advantage, and the thickness of the puddle between the rows of piles was reduced to 4 feet 6 inches. Instead of through bolts buttress piles were driven at intervals outside this cofferdam (the inside being strutted) to withstand the pressure of the puddle.[1] Owing to the treacherous nature of the ground at the cofferdam in the Zuider Zee trouble was expected, but an essential element in this cofferdam was its arched form, and as such the abandonment of through bolts and the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. li., p. 151.

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introduction of buttress piles might have been inadmissible. Could through bolts have been dispensed with, and the puddle reduced in thickness, fewer difficulties would probably have been encountered. They were all, however, eventually overcome, and the locks and sluices finished.

The North Sea Locks (Plate 3, Figs. 1, 2, 3, 4, 5, 6).

The North Sea locks are two in number, and there is one passage or sluiceway. One of the locks is 390 feet long and 60 feet wide; the other lock is 227 feet long and 40 feet wide. Each lock is furnished with five pairs of gates arranged as in the Zuider Zee locks. The sluiceway is 34 feet wide, and has three pairs of gates.

The locks are built on sand, which rendered bearing piles unnecessary, but the whole of the foundation of the sills and of the walls is enclosed in close sheet piling. A great deal of water was met with in the foundations, a large spring having been tapped at the westernmost end of the locks. The bottom part of the concrete under the walls, cills, and aprons, was therefore put in place in the form of blocks laid with spaces of about 4 inches, into which concrete was rammed. The remainder of the concrete was carried up in the ordinary way.

As in the Zuider Zee locks, the gates of the North Sea locks, pointing towards the North Sea, are of iron, and the gates pointing towards the canal are of red or American yellow pine creosoted. The design is the same in both places.

The general character of these locks is similar to the Zuider Zee locks, and the materials used in their construction are of the same kind.

The Land Reclamation (Plate 1, Fig. 2).

An important feature of the undertaking was the reclamation of lands from Lake Y and Lake Wijker Meer. By the formation of the canal a great portion of the area before covered with the water of these lakes has been drained and brought under cultivation. The area intended to be reclaimed was not to be less than 5,000 bunders, or hectares, equivalent to 12,500 acres. The quantity actually reclaimed has been upwards of 13,000 acres, and this has effected a considerable change in the physical features of the country. Lake Y was formerly the recipient of the drainage of an extensive district bordering it, called Rhineland, which includes the Haarlem Meer reclamation, made not many years ago; and

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hence the water from Rhineland, or at any rate a great portion of it, has now to be conducted to the canal. This is effected by the branch canals; and that water, as well as the water from the new reclamations, has to be lifted by pumping machinery into the canal. It is to facilitate good drainage and to prevent flooding that the surface of the water in the canal has to be maintained at 0·50 mètre (1 foot 7½ inches) below A.P. A considerable portion of the canal water can be discharged through sluices at the North Sea and Zuider Zee locks at low tides; but the main reliance for keeping the water under is on the pumping machinery at the Zuider Zee locks.

The extent of pumping power to be provided for the reclamations was fixed at the rate of 12 HP. for each 1,000 hectares (2,500 acres), and for each mètre (39·4 inches) in vertical height to which the water has to be raised, and for reducing the level of the water to 1 mètre (39·4 inches) below the lowest level, or surface of the land in each section.

The reclaimed land is divided into twelve polders, the main drains separating the polders being, for the most part, branch navigations. In order to drain the land, main, lateral, and catch drains, with the necessary grips, were excavated or dredged, and it was provided that these together were not to exceed one-fifteenth part of the whole of the land to which they pertained. Plate 1, Fig. 4, represents a reclaimed polder, with the drains and grips.

The following are the different polders and their superficial area, those bracketed being united together for pumping purposes by siphons under branch navigations:—

	Acres.
East Wijker Meer Polder West Wijker Meer Polder	1,207
East Spaarndam Polder West Spaarndam Polder	1,305
Houtrak Polder	3,232
Polder III.A	4,125
Polder III.B	1,150
Polder IV. Polder V. Polder VI.	1,110
Polder VII.	63
Polder VIII.	950
	13,142

Pumping Machinery.

The pumping machinery consists of the extensive system erected at the Zuider Zee locks for keeping the water of the canal at the prescribed level of 0·50 mètre (1 foot 7½ inches) below A.P., and of the pumps for draining the polders.

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All the pumps and pumping machinery were made by Messrs. Easton and Anderson of Erith. The pumps are centrifugal, varying in power from 24,000 cubic feet (670 tons) of water lifted 7 feet 2½ inches per minute at the Zuider Zee locks, to 812 cubic feet (23 tons) of water lifted 8 feet 10 inches per minute at Polder VIII.

The general arrangement of the pumping machinery varies considerably, the largest at the Zuider Zee locks having combined pumping engines similar to those erected at Lade Bank, near Boston, Lincolnshire;[1] and the smallest having merely an ordinary case pump, with horizontal fan spindle, driven by a belt.

There are three pumps at the Zuider Zee locks, all precisely similar. The fans have vertical spindles, and are of the double inlet kind, 8 feet in diameter, and 2 feet 11 inches clear depth, with inlets 4 feet 10 inches in diameter, forming waterways of 37 square feet. The fans are driven from the horizontal crank shafts of the engines by mortice bevel gear, proportioned to run the engines at a nominal speed of forty, the fan at seventy-one, revolutions per minute. The crank shafts bridge the pump wells, and are carried by massive A frames resting on cast-iron bed plates, which form frames round the pump wells and support the cylinders, air pumps, condensers, and feed pumps. Each pump is actuated by a pair of cylinders 30 inches in diameter and 2 feet 6 inches stroke, working under 50 lbs. pressure per square inch in the boilers, and cutting off steam by double slide expansion valves at points varying from ¼ to ¾ the stroke. Expanding four times, the pairs of cylinders would indicate 260 HP. Steam is supplied by eight boilers 23 feet long and 6 feet 6 inches in diameter, each provided with two 2 feet 6 inches furnace flues. The inlet and outlet culverts are 13 feet wide, and from 10 to 12 feet deep; the current therefore has a velocity of somewhat less than 3 feet per second. The mouths of the delivery sluices, or culverts, are closed by self-acting gates, and means are provided for fixing dams to facilitate repairs.

The Houtrak Polder, Polder III.A and Polder III.B, also Polders IV., V., and VI., are drained by pumps of the following general description. The pump cases are built into brick wells; they are of cast iron, each containing a vertical-spindle double-inlet fan, together with the upper suspended bearing of the spindle, the intermediate bearing, and an A frame, carrying the outer end of the steam-engine crank shaft, and the mortice bevel gear by which it drives

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxiv., p. 178.

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the fan. The steam engines are horizontal, condensing, and expansive; the air pumps being on the same level as the cylinders, and actuated by the prolongation of the piston rod through the rere cover. Steam is supplied, at 50 lbs. pressure per square inch, by Cornish boilers. The Table (page 20) gives the main dimensions of the pumping machinery, together with the quantity of water pumped per minute, and the height to which it is raised.

The East and West Wijker Meer Polders, and the East and West Spaarndam Polders, are drained by 20-inch case pumps driven by belts, by horizontal engines of the same kind as those above described. Polder VIII. has a pump of the same general form as the other vertical-spindle engines, but with important improvements in the arrangement of the fan, which has only a single inlet opening downwards, the pressure of the water in the pump case being taken by a fixed inlet piece, round which the fan revolves. The stream of water issuing from the fan is received by guide curves, arranged so as to diverge gradually, thereby reducing the velocity of the water without permitting it to eddy and consequently absorbing the momentum in doing useful work.

No attempt was made to introduce steam engines working at high rates of expansion with high pressure steam and jacketed cylinders. It was thought that machinery which would only be used intermittently, and would moreover be placed in isolated positions, and attended by an inferior class of driver, should be of the most simple character. It was important also that the pumps should occupy the smallest possible area, to diminish the cost of the foundations and the buildings.

North Sea Harbour (Plate 1, Figs. 9, 10, 11).

The largest adjuncts to the canal are the harbour and breakwaters in the North Sea, forming and protecting the approach from the sea.

The harbour is enclosed by a north and by a south breakwater, each nearly 1,550 mètres (1,695 yards), or together nearly 2 miles long. They shelter an area of about 250 acres, through the centre of which a channel 225 mètres (738 feet) wide has been dredged. At the landward end this channel has at its junction with the canal a guide pier on each side, the northernmost being called the North Mole, and the southernmost the South Mole, each being 335 mètres (366 yards) long.

The north and south breakwaters are similar in design (Figs. 10

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Name of Reclamation.	Mean Lift.	Mean Quantity to be Pumped per Minute.	HP. of Water Lifted.	Diameter of Fans.	Engines.			Number of Boilers.	Boilers.				Size of Engine House.	Acreage.
					Diameter of Cylinders.	Length of Stroke.	Number of Revolutions of Engine.		Length.	Diameter.	No. of Flues.	Diameter of Flues.		
	Ft. Ins.	Cubic feet.		Inches.	Inches.	Ft. Ins.			Feet. Ins.	Feet. Ins.		Feet. Ins.	Ft. Ins. Ft. Ins.	
East Wijker Meer Polder and West Wijker Meer Polder	6 10	903	11·6	28	12½	1 8½	..	1	17 6½	4 9½	1	2 9	..	1,207
East Spaarndam Polder and West Spaarndam Polder	6 10	903	11·6	28	12½	1 8½	..	1	17 6½	4 9½	1	2 9	..	1,305
Houtrak Polder .	8 6	2,331	37·4	39	25	2 6	60	1	28 7½	6 6	2	2 6	40·0 × 27·0	3,232
Polder III.A (2 pumps) No. 1	8 10	1,870	32·0	39	19	2 6	60	2	22 11½	6 6	2	2 6	50·0 × 36·0	4,125
Polder III.A (2 pumps) No. 2	8 10	1,870	32·0	39	19	2 6	60	2	22 11½	6 6	2	2 6		
Polder III.B . .	10 10	1,030	19·5	34	15	2 0	68	1	20 1½	5 9	1	3 0	34·3 × 24·6	1,150
Polders IV., V., and VI.	9 10	1,018	18·8	34	15	2 0	68	1	20 1½	5 9	1	3 0	32·10 × 26·3	1,110
Polder VII. (This small polder has not yet been reclaimed) . . .	..	..	..	..	..	..	..	..	..	..	..	..	.. ..	63
Polder VIII. . .	8 10	812	14·1	32	13	1 9	62	1	20 1½	4 8	1	2 6	34·3 × 24·6	950
		10,737	177·0											13,142

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and 11). They were built on a very unfavourable foundation, consisting of very fine sand.

The Author has previously given to the Institution a brief account of these breakwaters,[1] and the plan of foundation which finally answered. It was attempted in the first place to construct them by a staging of screw piles, but a slight disturbance of the sea excavated a hole round the piles, laying them bare or sufficiently so to destroy the staging. This plan was abandoned, and it was then tried, after partially excavating the sand, to set the concrete blocks by an overhanging travelling crane which was to advance on the pier as the work was brought up. It was hoped that when the bottom blocks had been set they would, notwithstanding the disturbance of the sand, form a bed which could be levelled and upon which the structure could be raised. This mode of procedure did not answer. It was then determined to substitute for the bottom course a layer of loose material consisting for the most part of basalt from the Drachenfels and limestone from Belgium, thrown in as random work. This was the plan finally adopted to secure a foundation. The mound of stone was deposited about 1 mètre (3¼ feet) thick, and to a width about three times that of the pier at the base, so that when, by the disturbance of the sea, a trench was excavated at the sides of the mound, as was always the case, the loose deposit fell into the hollow until the normal slope was attained (Plate 1, Figs. 10, 11), leaving a central portion upon which to build the pier. By this plan, when the piers advanced, the trench, which in places had been no less than 14 or 15 feet deep, gradually filled up. The stones of the deposit varied in size from about 1 cubic foot and under. In levelling the deposit for the reception of the first course of blockwork, the interstices were filled with hard broken bricks, big shingle, or stone broken to sizes of about 3 inches square. When possible the deposit was exposed for twelve months to the action of the sea before being built upon, by which time the surface became covered with mussels, and was very hard, so that it was difficult to disturb it by iron bars or otherwise.

The concrete blocks, of which the chief portion of the solid structure of the piers is composed, varied in weight from 6 tons to 12 tons, and were made of 1 measure of Portland cement, 3 measures of coarse river sand, and 5 measures of shingle, the sand being obtained from the Rhine at Vreeswijk and the shingle being dredged from the Rhine, chiefly in the neighbourhood of Nymegen.

The concrete blocks were put in place for the most part by

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xliii., p. 34.

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powerful overhanging travelling cranes, there being one such crane or "Titan" to each breakwater. Several designs of Titan were tried, which generally answered very well; but the north breakwater being more exposed, it was decided after the works had been considerably advanced and two Titans had been swept away, to employ a steam travelling crane, which was run out to its work by a locomotive engine, and brought back every evening for security in case of storms.

The rubble deposit was levelled and the blocks under water laid by divers. Laying the blocks was much facilitated by the use of a self-disengaging apparatus designed by Mr. Hutton. Below low water the blocks were set dry, but above low water they were set in Portland cement mortar, and were well cramped together. The upper portion of the structure was formed of concrete *en masse*.

The pier heads are square with rounded corners, and are 1 mètre (3¼ feet) higher than the adjoining length of pier, which slopes up to the head with a gradient of about 1 in 100. The heads are in line with the piers on the seaward side, but on the harbour side they have a projection of 6 feet.

The concrete mixers were designed by the contractors, and answered perfectly. Similar mixers had before been used by Messrs. Lee in the construction of the Admiralty pier at Dover.

When the piers were originally designed, the information supplied as to the rise of the tides was inaccurate, the tidal range being at times much greater than was then assumed. Partly in consequence of this, the design proved too near the margin of safety for a sea work, and when the breakwaters were considerably advanced seawards, the "wave-breaker" on the sea side was added. The extent of the wave-breaker on each breakwater is shown in Plate 1, Fig. 9. It begins about 100 mètres (328 feet) nearer the coast-line on the north breakwater than on the south breakwater, on account of the former being exposed to seas somewhat heavier than the latter. Gales of wind affecting the breakwater begin from the south-west and strike upon the south breakwater, and almost invariably end from the north-west, striking on the north breakwater, the latter part of the gale being generally more destructive than the former.

The wave-breaker consists of concrete blocks deposited *perdue;* the weight of the lower blocks is about 10 tons, and of the upper blocks 20 tons. These blocks are disturbed by the sea until they form a slope of about 1½ to 1.

The interior moles are constructed of fascines, broken bricks, and stones, following a mode common in Holland.

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The dredged channel in the harbour has a bottom width of 225 mètres (738 feet), and a depth varying from 8·50 mètres (27 feet 10½ inches) below A.P. opposite the pier-heads, to 7·50 mètres (24 feet 7¼ inches) below A.P. at the north and south moles, which is the depth of the canal. The quantity of material originally intended to be dredged amounted to about 1,800,000 cubic mètres (2,350,000 cubic yards); but owing to the necessity imposed by the authorities of prosecuting the dredging before the breakwaters were finished, and the enclosed area made quiescent, and owing to some materials from the excavations of the canal being carried into the harbour, the quantity dredged has amounted to about 4,000,000 cubic mètres (5,230,000 cubic yards), which had for the most part to be taken out to sea and deposited at a minimum distance of 3,000 mètres (3,300 yards) from the coast-line.

The machines used for removing this large quantity of material were principally sand pumps designed and arranged by Mr. Hutton, and worked by steam engines (Plate 3, Figs. 7, 8, 9). The sand pump consisted of a centrifugal pump with a fan 4 feet in diameter, and with suction and delivery pipes each 18 inches in diameter attached to an open wrought-iron framework. The machine was suspended between guide timbers fixed to the end of a vessel, and was free to follow the movement of the vessel, which was fitted with tackle for raising, lowering, and adjusting the machine. The vessel contained the steam engine and boiler for working and manipulating the pumps, and the head and side chains for the guidance of the dredger. The engine was of 70 HP., made by Messrs. Maudslay, but was seldom worked above 55 HP.

The cost of each sand pump, with engine, vessel, and appliances complete, was about as follows:—

	£
Vessel, steam engine, boiler, and sand pump complete . .	5,000
Two barges with each machine for the reception of the material, at £1,000 each	2,000
Steam-tug for towing barges to sea = £2,000, but as this served for two sand pumps, for each	1,000
Total cost for one machine	8,000

The number of hands required for the sand pump were one captain, one engineer, one stoker, and four sailors; for the two barges two men each; and for the steam tug five men. As this latter served for two sand pumps, it was equal to two men and one-half per machine, so that the average for each machine was thirteen and a half hands. The consumption of coal was about 1½ ton per day for each machine.

When at work the suction pipe tended to bury itself in the

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sand, being held by the lifting chain at the most effective point, which was generally found to be from 3 to 4 feet below the surface of the ground. Each machine was capable of raising about 1,300 tons of material per day, the engines working at 60 and the pump at 180 revolutions per minute.

The cost of raising the material and of depositing it in barges was somewhat under one penny per ton when the sand pumps were working, but as the number of working days in the year averaged only about 150 this cost was much exceeded. But few repairs were needed. Twelve of the machines were at work up to the 1st of January, 1877, when the Canal Company took the dredging into their own hands, still continuing the use of the sand pumps. They afterwards added some ordinary bucket dredgers, one being a large dredger hired from the River Tyne Commissioners with two steam hopper-barges, the original cost of which was about £40,000, and which required to work it eighteen men in the dredger and eight men in the steam barges, being four men to each barge. The cost of raising the material with the bucket dredgers was certainly more than with the sand pumps. In addition to sand, some silt was met with of so fine a character that it did not settle when pumped into the barges, and it was accordingly removed by the bucket dredgers, although probably some arrangement might have been contrived to utilise the sand pumps for silt as well as for sand.

The width of the entrance between the built blockwork of the breakwater heads is 260 mètres (853 feet); but the navigable width is not above 200 mètres (656 feet), on account of the blocks of the wave-breaker. The available space, however, affords room for easy access to the harbour. The currents at the entrance and inside are of the usual kind in harbours similarly situated. They run parallel to the coast, and therefore across the harbour mouth, the flood current being the stronger. This flood current runs north, and being barred by the south breakwater causes some accumulation of water, which flows off along the breakwater. After passing the bend of the breakwater it sets a little in the direction of the outer wing or kant, bending again towards its normal course and partly flowing into the harbour and along the inside of the north breakwater with diminishing speed, and across the inner moles, is lost in the southern part of the harbour. The ebb current is less powerful, so that there is no current across the moles. The currents, both flood and ebb, are somewhat weaker with the wind from the shore, there being then less accumulation of water along the coast.

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During the flood vessels enter the harbour close to the south breakwater, and during the ebb close to the north breakwater. The harbour instructions direct attention to the fact that the forepart of a vessel reaches beyond the tidal current even before it gets between the breakwater heads, whilst the afterpart remains exposed to its full force. With a strong flood a velocity of 6 miles an hour is necessary to enter the harbour. Not being sufficiently acquainted with the force of the current, or not being able to get enough speed, or with a ship that works badly, it is advisable to await high water, which is signalled from the semaphore station on the shore. After passing the heads the speed of the vessel should be slackened to 4 or even 3 miles an hour, so as to approach with care the end of the moles, which are about 1,000 mètres (1,094 yards) from the entrance. Inside the moles there are mooring posts where ships can be stopped, moored, or manipulated. In entering the harbour it is almost always desirable for sailing vessels, unless they be small, to engage a tug. For steam vessels the entrance offers no difficulty.

The channel of the canal between the north and south moles and the North Sea locks being well sheltered by the sand hills, and enlarged as before remarked, forms an excellent basin for ships intending to pass the locks to Amsterdam.

Concluding Remarks.

In describing works it is always desirable to give their cost. In the case of the Amsterdam canal it is not easy to do so with precision, inasmuch as, owing to necessary financial arrangements, the cost of the work was much enhanced beyond that due to the actual construction.

The following is the contract sum for the several works, or rather the assumed equivalent money value of the cost of the works:

	Florins.	Florins.
1. Piers	9,644,965	
Wave-Breaker	3,341,170	
		12,986,135
2. Harbour Dredging		1,401,203
3. Excavations and Dredging in Canal		9,049,648
4. North Sea and Zuider Zee Locks pumping engines and Velsen Bridge		4,208,975
5. Dam across Lake Y		1,208,732
6. Protection to slopes		259,200
7. Channels to Zuider Zee Locks		65,237
8. Land reclamations		1,484,600
9. Towing paths		306,400
10. Mooring posts		84,240
11. Lighthouses		26,800
		31,081,170

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There are 12 florins to £1 sterling, so that the above total sum is equivalent to £2,590,097. Besides this expenditure in the works the company spent various sums of money, and altogether the cost of the canal has amounted to somewhat under £3,000,000, without taking credit for the sale of the reclaimed land, which realised on an average about £70 per acre. The cost of the work in detail was also influenced by financial arrangement, but it may be stated that the price of work in Holland differs but little from rates paid in England; for though labour may be somewhat less costly, most materials are somewhat dearer.

The canal is spanned by three swing bridges. Two of these are near Velsen, one bridge carrying the Holland railway across the canal, and the other a roadway. These bridges are only a short distance from each other. The third bridge is situated near Zaandam, and carries the States railway from Amsterdam to the north across the canal. All these bridges are of one type common in Holland when headway can be obtained, the arms of the swing portion being of equal length, and the roadway being on the top of the superstructure, which turns on a long central pivot passing through to the underside of the roadway platform.[1]

The canal was opened for traffic on the 1st of November, 1876, by the King of Holland. The contract having been let to Messrs. Lee in 1865, twelve years elapsed before the undertaking was completed, a longer time than would have been necessary had it been possible to prosecute the works without interruption. Financial and other difficulties, and protracted negotiations impeded operations. The keys of the work were the North Sea breakwaters, and the construction of these would doubtless have absorbed the greater part of the time; but the canal might have been opened before this portion of the work was completed.

From the outset a large traffic has passed through the canal, and this is rapidly increasing. It is encouraged by low rates, which are raised chiefly to meet the cost of maintenance and repairs, as the Dutch Government guarantees interest on a portion of the expenditure. Indeed, the undertaking is of such advantage to Holland in general, and to Amsterdam in particular, that in all probability the navigation will shortly be made free to all the world.

The Paper is illustrated by numerous drawings, from which Plates 1, 2 and 3 and the woodcuts have been engraved.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lvii., p. 40.

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Discussion.

Mr. HARRISON HAYTER desired to thank Messrs. Easton and Anderson for having prepared and furnished him with drawings of the pumping machinery, and also with the Table embodied in the Paper, giving the details of the pumping machinery of the Mr. Harrison Hayter.

FIG. 1.

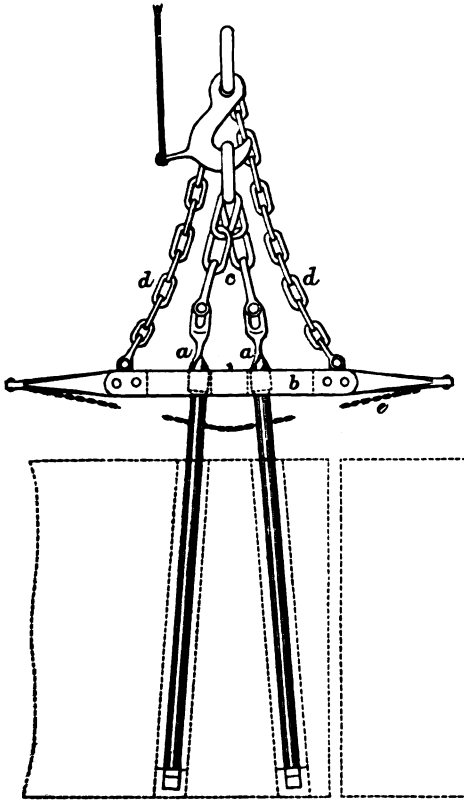
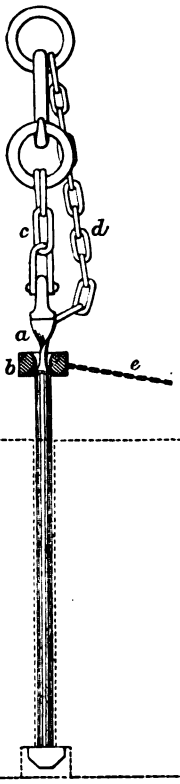


FIG. 2.



land reclamations. The particulars of the cost of the works were not quite so full as he should have liked to have made them. It had, however, been difficult to arrive at this information, as the works had been hampered by financial complications and protracted negotiations. With reference to the lock gates, of which it would

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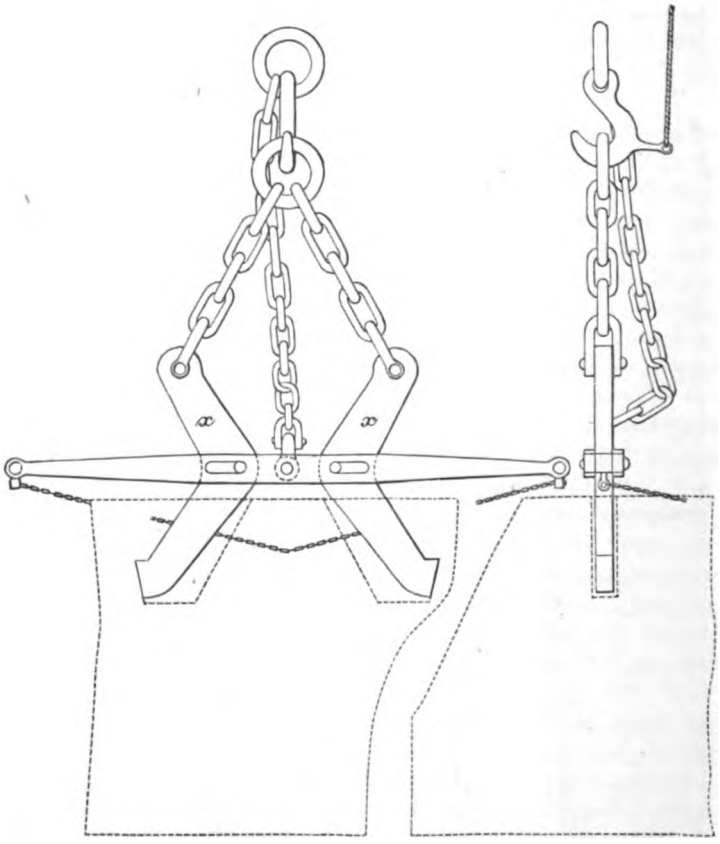
Mr. Harrison Hayter.

be observed there were no less than forty pairs, including the sluice-gates, the question of such gates had been discussed so recently[1] that he would only allude to peculiarities connected with the lock gates of the Amsterdam ship canal, which were

FIG. 3. FIG. 4.



departures from the practice usually followed in this country. It was stated in the Paper that the gates pointing towards the sea were of iron, and those pointing towards the canal were of wood; and reasons were given why they were so made. That opened up the question as to the comparative merits of those two kinds of

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lviii., p. 154, and lix., p. 2.

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material for lock gates; but the subject had been alluded to in the course of the discussion referred to. There were three departures from the practice usually followed in this country in the lock gates of the canal. The first was in the method of forming the water-tight joint between the gate and the masonry at the hollow quoin, which in this country was usually done by the contact and accurate fitting of the heel-post of the gate with a portion of the surface of the circular hollow quoin. It was difficult to make such a joint quite water-tight, and there was generally some leakage. The method adopted in the gates under consideration is shown in Plate 3, in which an iron gate is represented as closed. The water-tight joint was made by a vertical piece of timber attached to the heel of the gate shutting against a vertical projection about 8 inches wide on the stonework, which was polished from top to bottom. The gate cleared the circle of the hollow quoin, excepting in the line of thrust, which was communicated to the wall also by the interposition and accurate fitting of a piece of timber about 8 or 9 inches wide. The plan was effectual, but a little more costly than the one usually adopted, inasmuch as the stone projection at the water-tight joint being clear of, and on the water side of, the circle of the hollow quoin, it rendered it necessary to bring the wall more into the lock, so that there was a somewhat greater thickness of masonry or brickwork than would otherwise be required. If the heel-post of the gate were of wood and was not of iron, the heel-post would shut and thrust direct against stone projections, the interposition of pieces of timber being then unnecessary. The second departure was that the gates turned on pivots placed a little out of the centre, so that immediately the gate was moved it cleared the hollow quoin, and thus there was a relief from friction. On the other hand, it left a space round the hollow quoin, and loose material might get in between the heel-post and the wall, in which case the gates might not close with the required accuracy. The third departure was that there were no rollers in connection with the gates; but on this point he had given his views previously.[1] He wished to draw attention to an ingenious apparatus invented by Mr. Darnton Hutton, which was extensively used in setting the blocks at the North Sea breakwaters, and which was shown in Figs. 1 and 2. The apparatus consisted of two round bars with T ends. At the neck *a* of the bars there was a twist, of a quarter turn. The bars were placed into oblong holes with

Mr. Harrison Hayter.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lix., p. 4.

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Mr. Harrison Hayter.

square ends made in the blocks, and there was a cross bar *b*, which, when down, gave the quarter turn, when the block could be lifted by a chain *c* attached to the top of the two round bars. When it was desired to disengage the apparatus, the chain *d*, attached to the cross bar *b*, was pulled up, and it raised the cross bar, which, giving the quarter turn to the round bars and ⊤ ends, enabled the apparatus to be lifted out. To another chain *e*, at the extreme ends of the cross bar, a rope or small chain was attached, so that the block, when suspended, could be slewed into any position. There was another contrivance, Figs. 3 and 4, generally on the same principle, and also extensively used, but in which, instead of two vertical bars, there were two nippers *x*, which, when the block was lifted by the chain, pressed tightly against the side of the holes in the block, so that it could be raised. He had shown these contrivances in justice to Mr. Hutton, who did not care to exhibit them himself, and he did not think the Paper would have been complete if he had not described them, inasmuch as they were useful, saved cost, and facilitated the setting of the blocks.

Mr. Watson.

Mr. T. C. WATSON said he could only speak of those parts of the work which had come under his own supervision—the dam and the cofferdam, with regard to which there had been a full discussion on the disasters that arose at various times during the construction of the locks. It had been correctly pointed out that the chief source of the misfortunes was the bolts. The infirm and treacherous ground had caused the puddle to sink, and there was a continual leakage from below the bolts. The attempts to combat with it were of no use, and it became necessary to remove the bolts entirely, and put them up above the flood-water, introducing a third ring, and immensely increasing the amount of sand, to resist the pressure of the water. There were all sorts of devices besides. Of course it was to the advantage of the Institution to know the faults in the original design, and how, if the works had to be carried out again, those faults would be remedied. There was one peculiarity about the works to which the Author had not adverted. None of the plans were designed at the time of taking the contract. A lump sum had been put down for the North Sea locks, and other lump sums for other things, and the best had to be done for the money. Cheapness had to be studied as much as possible, having regard to the interests of all concerned, especially the contractor, whom he represented, and perhaps the tendency was a little too far in that direction. If the works had to be made over again, no doubt an immense number of improvements would be introduced. Too much reliance was placed on the circular

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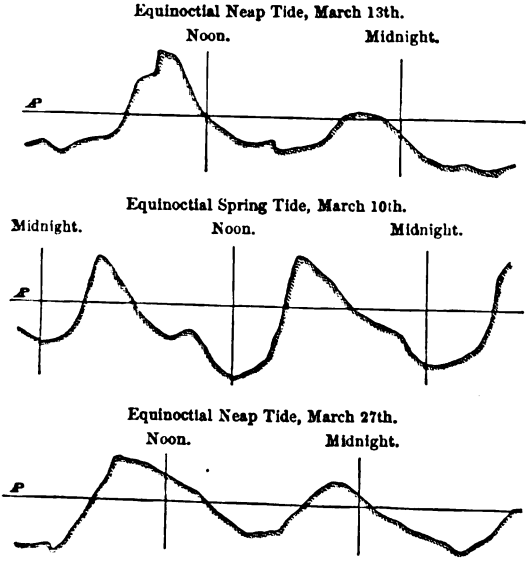
form; each of the piles could not be made a correct component part of the arch. The principle relied on did not succeed, although of course it gave some support. The dam was let out to some Dutch contractors, who carried out the work on the Dutch principle, by sinking fascines and mattresses, and there was no doubt that it was a splendid success. That success had been purchased with a great deal of trouble. The pressure of the bank broke through the supporting medium, and there was no other resource but to completely fill up the site until a firm bottom was obtained, 50 or 60 feet below the surface. It took the contractors a year and a half to do the work; but they succeeded in the end, and the bank was as good as any that could be seen. There had been no sinking since the work had been completed. Mr. Watson.

Mr. SHOOLBRED wished to draw attention to two diagrams prepared at Mr. Hayter's suggestion; one (Fig. 5) in reference to Mr. Shoolbred.

FIG. 5.



the tides at the North Sea entrance of the canal, and the other (Fig. 6) as to the Dutch official datum, and its position with regard to the datum levels of other countries. Those diagrams represented in part the labours of a Committee of the British Association, of which Sir William Thomson was the chairman. The tidal observations were taken for the committee by Mr. Hutton, at the entrance to the North Sea canal. Fig. 5 showed the equinoctial spring tide in March 1878, and two equinoctial

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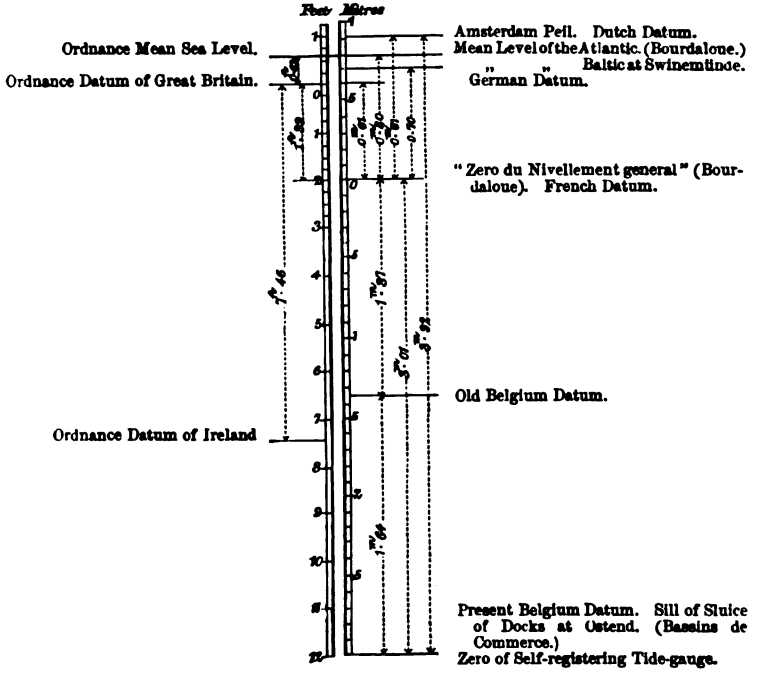
Mr. Shoolbred. neap tides; it would be seen how little difference in tidal range there was between them, 4 feet 4 inches being the average range of the neaps, and 6 feet 5 inches that of the springs. They formed a part of a number of simultaneous observations taken in 1878 along that coast, extending from the entrance to the Amsterdam canal to Havre, and also on the English side from Yarmouth to Portland. The reason for the construction of the other diagram was, that when the various observations were taken it became necessary to reduce those observations to one common datum, and then the difficulty arose of connecting the observations on the two sides of the channel. It was done on the assumption, that the mean sea level was uniform

FIG. 6.



on the two sides of the channel, and on that view the various datum official levels of the different countries had been collected, and were grouped upon the diagram. The information had been obtained as correctly as possible from official sources in each country. As the diagram showed clearly the position of the "Amsterdam Peil," so often referred to in the Paper, relatively to the official datum-plane of France, Germany, and of Belgium, as

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also of Great Britain and of Ireland, probably it would be of interest to the Institution. Mr. Shoolbred.

Mr. GREGORY, C.M.G., Past-President, hoped the Author would supplement his interesting Paper by some information as to the amount of dredging necessary for the purpose of keeping open the canal itself and the harbour at its sea end; also as to the effect of the tidal current and the sea action upon the influx of sand from the sea, and generally as to any circumstances affecting the maintenance of the channel, or of the harbour space within the breakwater. It would also be interesting to know what effect the formation of the dam had produced in the depth of water in the lake Y. Mr. Gregory.

Sir JOHN COODE desired to ask a few questions, not at all in a captious spirit, but in order to obtain a little more information than was contained in the Paper itself on two or three points. He should like to know the reason why the locks in the Y dam were placed so far towards the northern side. Perhaps it was the nature of the foundation; he should be glad to know whether that was the case or not. The Author had mentioned that the fascine work of the apron was covered with a sort of pitching; he should like to know whether there was anything between the pitching and the fascine. With regard to the peculiarity of the piles recoiling to the extent of 18 inches after the blow unless the monkey was allowed to rest on their heads, could the Author give an idea of the weight of the monkey? He asked the question because a great deal of trouble was often encountered in pile-driving, simply for want of a sufficiently heavy monkey. He observed that the jetties or moles at the mouth of the North Sea reach of the canal were somewhat canted with regard to the direction of the entrance between the breakwaters. No doubt there was a reason for that, and perhaps the Author would explain it. Some difficulties had been mentioned that had been encountered in the maintenance of the staging by reason of the scooping action of the water around the feet of the piles. In sand of the treacherous character which had to be dealt with in this case, he could very well perceive that difficulties of that kind would be met with, but he fancied that a little rubble judiciously placed round the piles would have overcome that difficulty. The Author had mentioned that the latter part of the gales was almost invariably more destructive than the former part, but he did not state the reason. Sir John Coode had often observed it himself, and he believed the reason was that during the height of the gale when the wind was blowing very strongly, the crest of the wave was much broken up, and the water was, so to speak, highly aërated, but when the wind sub- Sir John Coode.

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Sir John Coode. sided, the full force of the green water came in and broke upon the work, so that the shock towards the latter part of the gale was more destructive than at the former part. With regard to the bond in the breakwater, it appeared to him to be unduly small. He supposed that the vertical lines on the diagram represented the bond; if so, it was very small, and it almost looked as if the cramps had been put in to remedy that difficulty. Mr. Gregory had asked a somewhat pertinent question with regard to the maintenance of the depth of water in the North Sea harbour. He hoped that the Author would not overlook that question, and that he would state whether there was or was not any difficulty in maintaining the proper depth of water, or whether there was any tendency to silt in the channel, and if so, whether it existed to any extent. He hoped it would be clearly understood that he had asked the questions solely with a view of obtaining further particulars, because he thought that next to contributing information, it was the duty of every member of the Institution to endeavour to draw from the discussion as much interesting and useful information as the circumstances of the case admitted.

Mr. Fogerty. Mr. J. FOGERTY had been for a number of years professionally connected with Holland, and had taken considerable interest in Sir John Hawkshaw's work; and being in that country very recently, with a view of adding as far as possible to the facts so carefully collated by the Author, he had spent three days in examining all the works represented in the diagrams. He had also seen Amsterdam before any important part of the works had been constructed, and frequently during their construction, especially since the tidal water had been excluded from the harbour by the dam across Lake Y. Such works as canals in general were very little open to criticism; but this was not exactly a work of that class. It involved the introduction of what the Author had termed a "novel expedient," in the placing of a dam across Lake Y; and probably there was no harbour placed under similar conditions to those of the harbour at Ymuiden in the North Sea. It was not to be wondered at that the people of Amsterdam hesitated for a considerable time before adopting any plan which would exclude the tidal waters from their harbour. Amsterdam almost lay outside the track of trade, and had therefore great difficulty in maintaining its commerce. The efforts they had made in reference to the North Holland canal, opened in 1825, were very serious and expensive, and it was not a matter of surprise that they hesitated before adopting the present plan of connecting themselves with the North Sea by the harbour at Ymuiden. It was quite evident that if they had had means and knowledge enough at the period

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to attempt the later work, they would not have attempted the earlier one, because the Helder was a port entirely out of the ordinary run of vessels trading to the country. In examining the dam across the Lake Y, it could readily be seen why it was that the locks were placed in the position they now occupied; because the old and deepened channels were originally near the centre of the dam, at the point at which it was evident all the great subsidences had taken place. In looking at the locks themselves, there was nothing to which any serious objection could be raised, except that he thought it was desirable to ask why it was, that considering the sea gates must be maintained and carefully watched, for the sake of the safety of the vast hollow country lying beyond, that in the piers supporting those gates no provision had been made for the introduction of caissons in the event of their requiring to be repaired. At present there appeared to be no means of damming across the locks, in case of repairs being required to the external gates. No doubt it was easy to take out and repair any of the interior ones; but with regard to the sea entrance gates, it occurred to him as strange that there was no recess in the piers as usually constructed, like those at Millwall docks, for floating in a caisson for the purpose of removing or repairing the gates. In the detail diagram of the heel post to the iron gates there was shown a large piece of timber, which it was said, "took the thrust of the gates when closed;" but on looking for that in the gates themselves at the Orange locks, it appeared that the hollow quoin was not made precisely as shown, but for a considerable distance the timber did not touch the masonry at all. There had been a recess cut out behind it, and it occurred to him that that was probably introduced for the purpose of getting rid of anything which might impinge between the timber and the masonry. At the North Sea gates that recess was intermittent; one of the bonds or starts of the masonry of the hollow quoin touched the timber, and then there was a recess at the next beneath and so on in alternate courses. He presumed that was introduced for the same purpose; but as far as one could judge, looking down the angles of the gates in the Orange locks, the timber did not really touch the quoin, unless it did below water. The gates themselves had nothing peculiar about them; they were just such iron gates as were usually constructed. The crab winches which hauled them together appeared to him to be extremely light for works otherwise magnificent in construction. There was not shown in the general plan something which appeared to have been introduced at a later period in a kind of curved breakwater thrown

Mr. Fogerty.

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Mr. Fogerty.

round the side gates in the Orange locks. He presumed that that was introduced for the purpose of preventing vessels being carried through the side sluice or lock at the end, which was used for reducing the water in the Lake Y when the rainfall of the country exceeded the power of the pumps. Probably the engineers, if they had to do the work again, would provide larger pumping power than that which existed at the present time, because the very intelligent engineer in charge of the works had mentioned that, during great rainfall, those splendid centrifugal pumps, capable as they were of throwing 2,000 cubic mètres of water per minute, were frequently unable to bring to the required level Lake Y and the canal appended to it, which it was most important should be kept at a certain fixed level below the Amsterdam Peil: consequently it was necessary to discharge a considerable amount of water through the locks themselves, and it was evident that in an important structure of that kind on pile foundations it would not be desirable, in a year of great storm overflow and excessive rainfall, to make a very large use of the discharging power of those locks, or of the side sluices attached to them. Since Sir John Hawkshaw's works were completed the Dutch engineers of the municipality of Amsterdam had erected about the point marked Paardenhoek, a second large system of pumping machines, but not of the same class or efficiency as those constructed by Messrs. Easton and Amos. The most important part of the subject, as it appeared to him, was, what would be the effect of totally closing out the tidal water from Lake Y, and placing Amsterdam, which previously had some means of discharging its sewage from the canals by the ebb and flow of the tide, in a tide-locked harbour? Probably Sir John Hawkshaw had taken into consideration how he would ultimately deal with the sewage of Amsterdam, but a number of works appeared to be going on there without any particular general plan, and the result was that, at the present moment, Amsterdam, or that central portion which was indicated on the map (which did not represent one half of the city) was simply one huge cesspool. It was impossible to conceive how, in any civilised country, such a state of things could be permitted to exist. The whole of the sewage—all the flotsam and jetsam accumulating from a vast population; all the dust, detritus and rubbish of every kind—was shot into the canals, and there seemed to be no effective means of flushing them. Amsterdam was built like a series of concentric rings, with stagnant canals in every street, so that the whole town was cut up into a number of islands, of which there were over three hundred, with a population of three hundred thousand

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persons. No doubt commerce was to the Dutchmen of far more importance than any other consideration, and the desire to preserve the trade which Rotterdam, Flushing, and Antwerp would ultimately take from the people of Amsterdam, and were taking from them, induced them to construct the larger and more important work before they took the other into consideration. At the same time, he had no doubt that an English engineer did not execute that singular work of converting a harbour which had a difference of tidal level sometimes amounting to 7 feet during special winds, and so gave some means of clearing out the canals, without seriously considering the subject; and it would be interesting to learn by what means Amsterdam was to be ultimately relieved from the enormous mass of floating sewage which at present encumbered it. It was stated that fresh water could enter from the river Amstel to circulate through the city, but he had never seen anything of the kind. It was also stated, though no one seemed to be thoroughly well informed upon the subject, that sea-water could be admitted; but there was an objection to that on account of its precipitating the sewage. He believed that the remedy which had been proposed was, that the pumps or scoop-wheels erected at Paardenhoek were to keep down the level of the general canals in Amsterdam, and that the water from Lake Y was to be admitted, so as to force out the sewage and discharge it ultimately to the sea through the dam near Paardenhoek. Of course a better remedy than that would be to introduce some proper system of drainage into the city; but that was one of the most difficult problems that any engineer had yet attempted. In a portion of the town the system known as the Lieurner system had been adopted, but opinions were extremely divided about it. He did not think it would answer, but that ultimately it would be found necessary to lay cast-iron drain pipes of large dimensions in the beds of the canals so as to avoid siphons, and also that several of the worst canals such as the "Rokin" might be filled up with advantage. This would necessarily involve the construction of a low-level drain to the sea beyond the dam, and the use of considerable pumping power. In looking at the North Sea harbour and hearing the opinions of a number of Dutch engineers—not those particularly connected with North Holland, but those in the south, where there was no doubt some jealousy and a feeling of doubt as to the success of those works—one could not help forming an opinion that the existence of the harbour without a very great amount of dredging must necessarily be endangered in time. Even already there was the appearance of a moving forward of the foreshore. The sand, as far as he could judge on the

Mr. Fogerty.

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Mr. Fogerty. spot, had already formed a deposit much greater than was indicated in Plate 1. The whole of the sand of the coast had always taken a northward course; it passed the mouths of the Scheldt, and probably arose from the sea-worn rocks on the coast of Normandy, and with the south-west current it proceeded northwards, and would impinge first upon the southern pier, which he thought would act as a groyne. He believed also that sand would form rapidly behind the northern breakwater, and that it would be considerably added to by the wearing down of the large dunes adjacent. One could see the latter process going forward by a continual drift of sand blowing with the wind off the land, and it was an interesting question what time it would take for the overlapping of the harbour by the accumulation of sand behind the breakwaters. When that did arise it appeared to him that the natural result would be that the sand would be turned in and deposited in the harbour, or would form a bar at the mouth. It might be fifty or a hundred years hence, but that it would ultimately occur was a pretty general opinion amongst those best acquainted with the coast. The two moles shown at the entrance were, he presumed, supplemental works that were projected after the original design. They were shallow moles, their level being, he believed, about 1½ mètre above the level of the canal. They were simply guide moles, and at present the sand was accumulating behind them so as to be almost level with them. Dredging was being continually carried on, and it would be useful to know what would be the cost of maintaining the harbour as an effectual entrance to Amsterdam. As to the construction itself, no fault could be found with it. It had been well done, and it was apparently as substantial a work as could possibly be erected, deserving all the praise that could be given to it; but on that coast there were very exceptional conditions, and there was probably no harbour in the world situated under such trying circumstances with respect to the amount of sand or its silting up as that harbour in the North Sea, and the result of this novel experiment would always be a matter of great interest to the profession.

Mr. Redman. Mr. J. B. REDMAN observed that the Paper had brought out one remarkable fact—for all the early harbour works along our south-eastern coasts, and all our early drainage and fen works were engineered by Dutchmen, who had left their impress to the present day, as in the case of King's Lynn, which still preserved its Flemish aspect. That, however, was during the Tudor and Stuart dynasties, but in the Victorian age the Hollanders came to Great Britain for Englishmen to engineer the greatest Dutch work of modern times.

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Mr. Redman.

Amsterdam, a great centre of commerce, handling about one-tenth of the tonnage of the port of London, was situate on a tideless sea, on a morass founded upon piles like St. Petersburg, and hemmed in from the ocean by remarkable sand dunes, many of which were of great antiquity, and were undoubtedly due entirely to wind action. The same thing might be seen on our own coast. To the eastward of Bournemouth was a line of sand dunes on the summit of a cliff of great height. At Eccles, on the north side of Yarmouth, the church was standing on the seaward side of the sand dunes, showing what their movement had been. The condition of the outfall of the canal described in the Paper was remarkable, inasmuch as it was situate near the parallel of the North Sea tidal node, the central point of the North Sea, where Captain Hewitt determined that the oscillation of a spring tide was only 12 inches. The North Sea tidal wave along the English coast was to the south, and along the Dutch coast from the south to the north there was in fact a rotary motion of the tide. The oscillation of the tide was but 5 feet at the entrance of the Amsterdam canal; this in stormy weather was however sometimes nearly doubled, and the tidal oscillation at Amsterdam might be said to be nil. It would be very interesting to know what were the arguments in favour of the particular treatment of the canal as compared with an open tidal cut to connect the Zuider Zee with the North Sea. The datum A.P. was the mean tide level; the oscillation of the tides in the North Sea at the outlet was but 5 feet; assuming that the level of the Zuider Zee was the same as the mean tide level in the North Sea, the fall of water was 30 inches; the fall to the eastward from the ocean would be 30 inches; the fall to the westward would be 30 inches; that would give a gradient of something like 2 inches per mile, which was about equivalent to the fall of the water in the Thames. With north-east gales the level of the Zuider Zee was sometimes abnormally raised 5 feet; under those conditions at low water the gradients of the ebbing water through the cut would be correspondingly increased. No doubt the Author would state that there were many practical objections to such a course, the lateral banks would have to be raised higher and also the drainage, but the question arose whether an open cut would have answered the same purpose. With reference to the circular dam the Author had referred to the great leakage induced by through bolts. Those who were acquainted with the proceedings of the Institution would remember that the late Mr. Rendel originally constructed his great dam at Grimsby with three rows of sheet piles and two puddle trenches, and connected the outer and inner rows of gauge piles

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Mr. Redman. alternately with the central row of sheet piles, so that there was never a complete through bolt through the dam. He also made use of buttresses or counterforts of sheet-piles, which had likewise been used in the work described in the Paper. As to the rising of the gauge-piles, he might state from his own experience that in enlarging a dock in the Thames to take in three ships where only one ship could be taken before, the proprietor had often told him, that in the original construction referring to the nest of piles under the bridge, the platform and the gate recesses, frequently when those piles were driven down home, as it was thought, at night, that many of them would be found 12 inches higher in the morning. Great changes had been going on at Dover, but he did not think that the engineers of the work now in question need fear any great hindrance to their commerce. The particular form of entrance appeared to be admirable. It was so planned that in the event of a ship missing the entrance, she had the opportunity of wearing off, which was a great advantage. He thought the members were highly indebted to the Author for his description of a most important work forming the sea outlet to a very great centre of commerce.

Sir John Coode. Sir JOHN COODE said his remarks had had reference to the two moles at the end of the canal reach, and not to the entrance.

Sir John Hawkshaw. Sir JOHN HAWKSHAW, Past-President, remarked that as he had been professionally engaged upon the canal from its commencement to its completion, he might be expected to say a few words upon it. The Paper itself, and the drawings accompanying it, gave so many details as to leave little to be added, but there were one or two facts which it would be useful to state. The results of the canal to the trade of Amsterdam had been very important. Before the canal was opened the trade had varied little for many years. It was rather decreasing, if anything, and it amounted to about 2,000 ships and 800,000 tons annually. The canal was opened in November 1876, and in 1877 there passed along it 3,376 ships, amounting to 1,031,303 tons; in 1878, 3,242 ships, amounting to 1,136,527 tons; in 1879, 4,013 ships, amounting to 1,368,895 tons; and in the first three months of 1880, 654 ships, amounting to 273,289 tons; the corresponding period of 1879 showing 426 ships, amounting to 185,431 tons. It was well known that the last two years had been years in which no very rapid increase to trade could be expected. The peculiarities of the canal had been explained in the Paper. There was the necessity of shutting out the Zuider Zee from Amsterdam, and making locks in that dam to enable the shipping to get to and from Amsterdam; and shutting

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out the sea by locks at the sea end of the canal arose from this circumstance, that the canal had to be made through shallow lakes which previously received the drainage of Rhine land. The drainage from a large area flowed or was pumped into them, and inasmuch as the lakes had been reclaimed and replaced by land, it was necessary so to construct the canal as to make it a receptacle for the drainage water; on that account it was a stipulation with the Government that it should be maintained at a low level, namely, ½ meter under A.P.—A.P. meaning about the mean tide level. This would probably be a sufficient answer to a question by Mr. Redman, why the canal was not made open from sea to sea. Of course, if the sea flowed through the canal, the canal would have risen and fallen with the tides, and inasmuch as the time of high water in the Zuider Zee differed from that in the North Sea, there would have been a current to and fro between the two seas. That question had been considered, as well as a number of others, and the proposal referred to had been dismissed as impracticable. One or two questions had been asked which he might as well answer, and thus save the Author some trouble. In reference to the question of Sir John Coode as to the bond of the breakwater, the first portion, until it came near the wave-breaker, was made of blocks alternately 7 feet and 10 feet long, their breadth and depth being 4 feet 6 inches; but beyond that point it was thought better to make the facing blocks heavier, and from thence to the end of the breakwater, they were all made 10 feet 6 inches long. There was even then some bond, because the breakwater having a slope of 1 in 7 the blocks tailed over to a certain extent. The cramps were put in, not merely with regard to the bond, but because when a course of blocks was laid, and they became exposed to breaking waves, there was great difficulty in keeping the course in its place, and the blocks were cramped to hold them there, until a succeeding course of blocks was placed upon them. Near the top both blocks and cramps were abandoned, and the upper part was made of one mass of concrete. The position of the locks in the dam, referred to by Sir John Coode, was determined by himself. It was originally proposed to put the locks nearer the north side, because it was thought that it would be easier to construct them in that position; but it appeared to him that it would be difficult to keep a sufficiently deep water channel through the locks if they were placed so near the shore, and he consequently advised that they should be placed where they now were, and there had been no difficulty in maintaining a channel into and out of them. The angle of the

Sir John Hawkshaw.

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Sir John Hawkshaw.

canal in entering the harbour was fixed by the concession, and there were reasons for it. It led from the Wijker Meer, and went in that direction to the sea; but in designing the harbour it was thought better to put it at right angles to the coast, which led to the apparent divergence of the centre line of the canal from that of the harbour. No inconvenience had arisen from that. It could not well have been avoided unless the position of the harbour had been altered, which he did not think desirable. With reference to the objections on the subject of sewage, he did not think it necessary to allude to them further than to say that the matter had not been lost sight of. Some day Amsterdam would have to remove the sewerage further from the town. At present the whole of the sewage of Amsterdam entered the canals which passed along the centre of the streets. The sediment was annually dredged out, but that was not a very desirable state of things; it was not, however, as objectionable as might be supposed, for Amsterdam happened to be a very healthy city. At the same time some day it might be worth while to make a low-level drain from Amsterdam to carry the sewage far beyond the embankment, and to raise it by pumping into the Zuider Zee. It had been stated that the municipality of Amsterdam had made a sluice at the Paardenhoek side, at the end of the dam. That arose in this way. When the dam was completed, and the locks were constructed, the Zuider Zee, which used to flow up to Amsterdam, was shut out, and the only water that came in from it was that which had passed through the locks. Then the conclusion arrived at by the municipality was that the water was not sufficiently "refreshed," and a passage was made at Paardenhoek, with a sluice through which water was admitted into Lake Y up to Amsterdam. He mentioned that mainly because it bore on another question asked by Mr. Gregory as to whether the shutting out of the Zuider Zee from Amsterdam would not lead to silting in the deep water opposite. He did not know that he was in a condition to answer the question at present, but there was no doubt that the construction of that sluice on the shallow shore of the Zuider Zee did in the first instance bring a considerable quantity of mud into the waters of Amsterdam. The water had to flow over a shallow shore, which was wholly of mud, and it necessarily carried a considerable quantity of mud with it. It was not possible to say whether in the course of time the effect upon the deep water of Amsterdam in the way of silting might not amount to something; possibly it would, but he did not think it would amount to anything so important as to affect the trade of the town, and

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that could not be easily dealt with in the usual way by dredging. Another most important question connected with the undertaking had been asked by Mr. Gregory, whether there would not be silting in the harbour, and to what extent it would take place? There were at present disturbing elements in the consideration of that question, which rendered it impossible to give any definite reply to it. In the first place the canal had been newly formed. The berms, which were very wide through the lakes, and which were designed for the purpose of protecting the banks, though partially overgrown in many places, were not yet completely covered. When they became covered, as they would be, the denudation of the embankments and the shallow portions of the berms would be stopped. The reeds, when grown, formed a perfect protection against the wash of steamers, but they required time to grow. Then there was another disturbing element. In anticipation of the trade which the canal would bring, large works had been carried on in Amsterdam in the extension of the quays, the construction of large railway stations, and in increasing the area of the land upon which buildings were to be erected, which was done by the deposit of sand. Land could only be made in Amsterdam by taking it from the shallow surrounding seas. First sand was thrown into the shallow portions of the water, so as to convert the site into dry land. The whole of this sand was being fetched from the sides of the canal between Velsen and the locks, and the canal company had acceded to that, because the parties who fetched the sand and conveyed it to Amsterdam for the purpose of the works bound themselves greatly to increase the width of the canal between the North Sea locks and Velsen, which would be an advantage to the company; but in the meantime they dug away the slopes which had been left completely soiled above the water-level, and protected below, and those operations were going on when he was in Holland in August 1879. A considerable quantity of sand in these operations was dropped into the canal and carried out into the harbour, because at low water there was a current outward varying from 1 mile to 1¼ mile per hour. Until, therefore, the banks were properly consolidated and the slopes protected, it was impossible to say how much of the deposit in the harbour arose from that cause, or how much arose from natural causes. It had, however, always been assumed that there would be a considerable amount of dredging necessary to maintain the harbour and its approaches of the depths at which they were constructed. The principal portion of the deposit would come from the sea; but in the meantime, from the causes he had stated, some portion

Sir John Hawkshaw.

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Sir John Hawkshaw.

came from the canal. He believed that when the works to which he had referred had ceased, and the canal works were consolidated, there would not be a great amount of matter from the canal. There would always be a considerable amount from the sea, because the whole of the sand along the coast was blown sand, so remarkably fine that it was stirred up by every gale, and it was certain that a portion of it would rest in the harbour. A certain amount of dredging, therefore, would always be required.

Mr. Langley.

Mr. A. A. LANGLEY felt great interest in the subject under discussion, especially in regard to the use of sand pumps, which he had employed at Lowestoft. In pumping sand the best proportion of water to sand, according to his experience, was 5 to 1. He should be glad to know whether the sand was pumped pure, or whether it contained gravel or stones. In the dredger used at Lowestoft large stones and iron bucket pins were sucked up, in many cases over 3 lbs. weight. The dredger was 60 feet long and 20 feet broad; the suction pipe was 12 inches in diameter, 25 feet long and was composed of india-rubber, with coiled iron inside to preserve its shape. It terminated in a copper tube with a grating at the bottom, and a derrick supported the end of the flexible tube. A man stood at the end of the dredger, and lifted, or lowered it as required. If the material delivered into the hopper barge was dark he knew the dredger was lowered too much, and he raised it; if the material was light coloured he lowered the dredger, because there was too great a proportion of water. The pump was at the bottom of the dredger and forced the sand vertically into the open trough, the fan being 2 feet in diameter, and making about three hundred and fifty revolutions per minute. The fan had four blades, one of which broke, when it worked better; with two blades it worked better still. It had raised 400 tons of sand, gravel, and stones per hour, the average being 200 tons with a 10-HP. engine, and working in depths of water varying from 7 to 25 feet. Sometimes the sand was loose, and could be easily picked up, but at other times the stones interfered with the work, and the nozzle had to be carefully regulated. The total cost of this dredger complete was £2,000. Bucket dredgers were used for the inside of the harbour, and the basin dredger (a French invention) at the entrance where there was sand and gravel; it did not succeed well in silt, because the silt ran over the side of the barges without settling. Several plans had been tried to stop this, such as putting boards across the barge to prevent the water from rushing so rapidly over the sides, but so large a portion was held in suspension that it was not worth while using the dredger with mud.

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Mr. Langley.

Nor was it good for picking up solid clay; it did the best work with sand and gravel, for which it was superior to the bucket dredger. Another great advantage was its capability of working in disturbed water where the frame of the bucket dredger would be injured. With the sand pumps used at the Amsterdam works he presumed there was not much wear, because the sand was pure, but where there were stones they choked the pumps, and the fan; in fact they so blocked the pumps that the machine was at first almost a failure. An ingenious contrivance had been devised by the manager for the contractors, who made the fan small, and put india-rubber plates on it, leaving a large clearance. Since then there had been no wear to speak of, although previously the cast iron, malleable iron, and steel had all become worn. The cost of dredging was about 2*d.* per ton, including taking the material to sea, a distance of 2 miles. A total of about 200,000 tons was dredged every year at Lowestoft. The harbour was built out into the sea, and formed a groyne. The sand had gradually collected at the back until it had got to the mouth of the harbour about 1,000 feet from the original shore line. He had been instructed to take steps to prevent the sand working round the pier heads, and he proceeded to extend the jetty in an oblique line from the North Pier. This work had been attended with difficulty owing to the roughness of the sea. In the first place piles were driven 10 feet apart, then sheet piling, and counterforts which were afterwards filled up with heavy stones, chalk, and clay. The work which was now nearly completed had proved most effective.

Mr. Giles.

Mr. Alfred Giles was surprised to find that the dredging had been done at the small cost of 1½*d.* a ton. Of course, it was not to be expected that work of that kind could be carried out without some casualties, but looking at it as a whole, the work had been most successful. Some objection had been made to the angle at which the canal entered the North Sea, and to the position of the breakwaters, but he thought the angle entering the shore was of little consequence, when it was considered that the distance from the entrance between the horns of the breakwater was nearly a mile. He wished to ask a question as to the effect of those horns on the shore. The old notion was that they should act as groynes, and that there would be a deposit on the outside of each of those groynes; but he had been informed that, instead of a deposit, there was a scour on both groynes. No doubt, with a strong tide in the North Sea, there must be some difficulty in vessels shooting the piers, unless they had some little way upon them. It appeared from the Paper that it was considered

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Mr. Giles. necessary for a vessel to have a way of 6 knots an hour to enable her to get in safely, and he thought that was likely. As to the cofferdam, he could not help thinking, looking at the section of the dam, and the load it had to carry, that it was not quite equal to its work, as indeed was proved by the accidents that had happened. He did not attach the same importance to the bank of sand inside as he should do to having some additional piles with braces, to keep the top of the dam in place. He would rather criticise the shape of the dam. The difficulty of fitting piles and walings to a circle was notorious; whereas, if the dam had been made as a box dam, with straight sides, having the corners cut off, he doubted whether the expense of the greater length would have exceeded that of the round dam; and he thought there was very little strength gained by the arched form, when it was considered that the radius of the circle was 262 feet, and the thickness of the arch (viz., the piles) only about 13 inches.

Mr. Lavalley. Mr. LAVALLEY said he had had but a short time to study the Paper, and he could only say that he considered the work a remarkable one, and that the means employed in making the canal were the cheapest and the best that could be adopted. The members might perhaps be interested by some account of the method he had employed in delivering the dredgers on the Suez canal, and bringing up the soil. He was aware, when he first ordered the plant, that the soil in the lakes was very variable, not only according to the different parts, but also according to the different lengths. The surface of the soil was loose mud, which lay in some places on sand (nearly quicksand), but more generally on clay more or less hard. The short time in which he had to do the work obliged him to have plant which could be adapted to the different descriptions of soil. Of course, pumping directly from the bottom, or pumping through pipes, was the cheapest way of getting rid of the dredgings; but he was afraid at starting that he could not pump out the very stiff clay met with in very great quantities along the canal. He thought that long shoots would be available for all sorts of soil, and his expectations were not defeated. In dealing with mud, the shoots, 230 feet long, carried away the soil with hardly any inclination at all. Sand flowed away, with a sufficient quantity of water, at an inclination of about 1 in 20; but when the sand was mixed with shells, they formed a coating, and protected the sand from the action of the stream, and even with an inclination of 1 in 10, it could not be got rid of. He then adopted a pair of endless chains working down the long shoot, 230 feet. In dealing with stiff clay, the man in charge

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took care that the buckets were not choked, but whatever care was taken the clay was hard and compressed enough to fall out in lumps the exact shape of the bucket, and the shape was hardly altered by the clay falling into the shoot. To get rid of that the endless chain was quite sufficient. To facilitate the working of the chain when the shoot was almost horizontal, a very great quantity of water was pumped into the shoot. The men at the dredgers soon got clever enough to almost entirely fill up every bucket with clay, so that the quantity of water falling on the shoot was insufficient to help the chain in pushing down the clay; they had, therefore, to pump a certain quantity of water into the shoot, which had the advantage of floating the clay, and decreasing by nearly one half the weight of the large lumps on the bottom. The dredgers could turn out about 2,000 cubic yards of thick clay in fifteen hours. When the clay was not hard, they turned out 150,000 cubic yards in a month, with one dredger, for several consecutive months. He was now using pumps before the harbour of Dunkirk, pumping muddy sand from the bottom of the sea into barges. In another place he was digging out from a harbour coarse and heavy sand, and pumping it with great facility into long floating pipes (as used in making the Amsterdam canal) which did the work efficiently. The cost was about 1½*d.* per ton. Mr. Lavalley.

Mr. W. PARKES said Sir John Hawkshaw had answered the question of Mr. Gregory and Sir J. Coode, with regard to the motion of the sand, so far as it affected the probability of the silting up of the harbour; but the Author might perhaps be able to give a little more information as to the actual changes that had taken place in the sand during the progress of the works as the piers were being projected into the sea. The Admiralty chart of the harbour, published two years ago, showed considerable irregularities in the ground, which he presumed must have been caused by the works, and although there was nothing in them that was not well within the control of the dredger, it would be interesting to know what the original state of things was, and something of the changes that had taken place. He thought that the details given by the Author and Mr. Lavalley, and other facts which were coming to light every day as to the very low cost of dredging, would tend to quiet the public mind on the subject of harbours silting up. If they did silt up it only involved a little annual expense in dredging. It was curious to observe the very different idea now prevailing about dredging, from that which prevailed twenty-five years ago. He believed that one case of dredging had lately been mentioned, which was more economical than either of the cases mentioned in the course Mr. Parkes.

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Mr. Parkes. of this discussion; he referred to the dredging of the canal in Lake Fucino in Italy.[1] He was engaged twenty-five years ago, under Mr. Gregory, in preparing plans for the drainage of that lake; and Mr. Gregory was in communication with the late Mr. Brassey, with a view of his undertaking the contract. There was a large amount of dredging in the scheme, and Mr. Gregory and himself had estimated it at 6*d.* per cubic yard. Mr. Brassey accepted all the prices in their estimate with that exception, but thought the dredging ought to be put down at 1*s.* per cubic yard. Upon that the negotiations were broken off. The works were afterwards carried out under French engineers, who published an elaborate work upon the whole undertaking. The only point on which they gave any details as to the cost was the dredging, and they stated that the material of the canal was lifted from the bottom to a height of 30 feet above the water level, at a cost of 1¼*d.* per cubic yard, not including any charge for the first cost of the plant, but simply for working expenses and maintenance of plant. He imagined that if the cost of the plant were spread over the quantity of dredging done, 1*d.* or 1½*d.* would cover it; so that Mr. Brassey's shilling, and Mr. Gregory's and his own sixpence, was brought down to 2½*d.* or 3*d.* per cubic yard.

He wished to ask for some explanation with regard to the wave-breakers, to which no allusion had been made. When the section of the pier was brought forward four or five years ago, with respect to the breakwater at Kurrachee,[2] that wave-breaker did not appear, and he understood that it was an addition that had since been made. He should be glad to know what were the circumstances which led to that addition being made, especially whether there were any indications of scouring which threatened the safety of the structure, and led the engineers to apply that protection; and also whether the blocks were themselves perfectly stable in the position in which they were placed. It was rather a costly addition, amounting to one-third of the cost of the pier itself, and it was one, therefore, on which a full explanation seemed desirable.

Mr. Harrison Hayter. Mr. HARRISON HAYTER in reply, said, that Sir John Hawkshaw had answered several of the questions, and he would not go over the ground again. Mr. Gregory had inquired as to the anticipated silting at the North Sea harbour, and as to the silting at the Zuider Zee, to which Sir John Hawkshaw had replied fully; but

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[1] *Vide* "The Drainage of Lake Fucino." By Alexander Brisse and Leon de Rotrou. Rome, 1876.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xliii., Plate 2.

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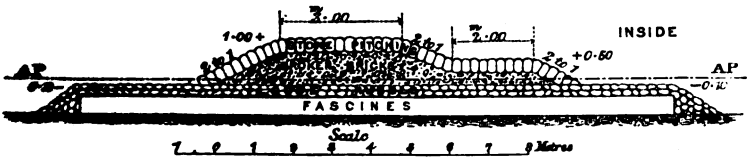
he also asked whether there was any silting in the canal itself. It was satisfactory to know that practically there was none. As regarded silting at the Zuider Zee he believed it was not such as would affect any interests, and the channel to the canal from the Zuider Zee could be well maintained, inasmuch as whenever practicable the water in the canal was lowered to the prescribed level through the sluices in the Zuider Zee system of locks, instead of by pumping, and this scoured and maintained a sufficient channel. Mr. Harrison Hayter.

In answer to Sir John Coode's question, why the locks were placed so near to the northern side of the Lake Y, he might state that their approximate position was fixed by the concession. It was desirable that the locks should, for convenience, be near the shore, and one reason why they were placed on the northern side in preference to the southern side was because the ships and craft going through them were destined, either for places on the Zuider Zee, or to pass to the North Sea through the Texel roads. This shipping would thus be clear of the vessels going to Amsterdam. Sir John Coode had also asked whether there was anything between the fascine work and the top pitching in the chambers and aprons of the locks. This pitching was of basalt, and it was laid on a layer of broken bricks, averaging about 9 inches thick, interposed between the fascine work and the top pitching. The weight of the monkey used in driving the piles of the cofferdam at the Zuider Zee locks was 1 ton, so that the difficulties encountered in connection with the recoil of the piles did not arise from the fact that the monkey was not heavy. The guide moles leading from the harbour to the canal were constructed parallel to the centre line, and this being slightly curved, the passage between the moles was well sheltered. The moles were 220 mètres apart from centre to centre, and were constructed in places on a foundation of fascine work, upon

FIG. 7.



which loose rubble stone was laid, and upon this broken bricks covered with stone pitching. Fig. 7 was a sketch of the central part of the moles.

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Mr. Harrison Hayter.

Nearer the land the moles consisted of broken bricks pitched with stone, the general sectional outline, however, being as shown on the sketch. At the land ends the moles were connected with the slopes of the sand hills, which, just there, were for a short distance covered with clay 1 mètre thick pitched with stone. In this country instead of solid moles a guide structure of timber-work, carried up above high water, would probably have been adopted; but the channel between the solid moles was well buoyed off, and there were beacons at the sea end of each mole. The aggregate length of the two moles was 670 mètres, and their cost was nearly £23,000, or at the rate of rather more than £34 per lineal mètre. No rubble stone had been tried round the piles of the staging used at the outset to construct the piers, but afterwards abandoned as described in the Paper. Mr. Hayter simply stated it as a fact, that the latter part of the gales affecting the breakwater were more destructive than the former part. The gales begun in the south-west and generally ended in the north-west, the latter part of the gale being usually more destructive than the former. It might, to some extent, be owing to the circumstance that there was a greater exposure from the north-west, but beyond this he would not venture to give an opinion as to why the gales were more destructive towards the end than at the commencement. The occurrence was not an unusual one, as Sir John Coode had observed.

The question had been asked by Mr. Fogerty why grooves were omitted in the locks for the introduction of caissons or dams for repairing the gates. These would be expensive additions to the locks in question, involving heavy foundations and coursed ashlar work. They were common in locks in this country, but were seldom brought into use in practice. It was found very easy to take out a gate and renew it by another, and this had been done in the canal. The recess behind the gate of the locks at the hollow quoins was only in the top courses above the water line. Owing to the small tidal range the lock gates were always in a state of considerable buoyancy, and there were no rollers, so that they were easily manipulated. Hence the crabs for opening and closing them were of the light construction noticed by Mr. Fogerty. The curved timber-work at the Zuider Zee locks was constructed to guide the vessels.

The canal, besides being a navigation, was a large arterial drain receiving the water from extensive lands, and united with the canals and rivers of Amsterdam. Hence the level of the water had to be kept low, and this level was fixed at ½ mètre below A.P. necessitating locks at each end. Moreover, as Sir John Hawkshaw

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had observed, in reply to observations from Mr. Redman, the time of high water in the North Sea and Zuider Zee differed materially, so that there would have been a current through the canal if there had been no locks. Mr. Harrison Hayter.

With reference to Mr. Giles' remarks there was no doubt that the full advantage of the circular form of the cofferdam for constructing the Zuider Zee locks was not obtained, but this was owing to the dam becoming crippled; had the dam been made stronger at the outset greater advantage would have resulted from the circular form. Further, the outline of the Zuider Zee locks was such that they were better enclosed by a circular than by any other regular figure. Hence both for structural and economical reasons the circular form was most desirable. The best way to make the walings in a circular dam was by planks, which could be bent to the form of the dam, and be made to break joint. In this way, also, there was but little waste of timber.

There was no doubt some scour at the extremity of the south breakwater. The flood current impinged on the south breakwater, and then ran along the outer arm or cant to a short distance seaward, creating scour near the end of the south breakwater and depositing material at the end of the north breakwater, where still water was created by the deflection of the current seaward by the cant of the south breakwater. The ebb currents, acting in the opposite direction, lessened this deposit; but as the flood current was stronger than the ebb, there was an accumulation. This might get less and would not probably cause a great expenditure for periodical dredging if such were necessary, and the scour of the south breakwater had been prevented from creating undermining by the deposit of some concrete blocks. If the outer cant had been placed more in a direction parallel to the coast, the scour might have been somewhat less. On the other hand, the direction in which it was placed created still water for a short distance in front of the entrance, which facilitated the passage of ships between the heads of the piers. The addition of the wave-breaker was, as Mr. Parkes had observed, an afterthought. The blocks, after assuming a slope of about $1\frac{1}{2}$ to 1, remained stable. The state of the coast before the breakwater works were begun would be gathered by reference to Plate 1, Fig. 3, which showed that the contour lines at the extreme north and south on either side of the piers had been unaltered. If these contour lines were joined in a direction generally parallel to the coast, the original state of the ground would be obtained with sufficient accuracy.

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Mr. Harrison Hayter.

More than one speaker had alluded to the accumulation of sand outside piers and breakwaters of the kind described in the Paper. The general proposition might be stated thus: that if piers were constructed on a sandy coast where there were littoral currents there would be a recession of the contour lines, owing to the accumulation of sand; and if this were allowed to go on, the time might come when the piers or works would be left high and dry. While assenting generally to this theory, Mr. Hayter would remark that the process would, as a rule, be a slow one, and it might be several years before mischievous results would follow, provided no remedial measures were resorted to. But piers and breakwaters, like docks, railways, and other engineering works, required to be maintained, and by the expenditure of a small periodical sum any mischief from such accumulation might be hindered. At present the North Sea piers were an exception to this theory, inasmuch as instead of the contour lines receding seaward, they, especially at the seaward end of the piers, advanced landward. Possibly the reverse action might take place in course of time, and indeed the low-water line had slightly receded at the landward end of the piers; but should this go on there need be no apprehension that it would occasion any large outlay to remove the sand, as Mr. Parkes had justly remarked.

Although not mentioned in the discussion, yet, in some quarters, at different times, the performance of the pumps at the Zuider Zee locks had been questioned, and he should like to say a word thereon. Mr. T. E. Harrison, Past-President Inst. C.E., had alluded to these pumps in his Presidential Address,[1] they being the largest of the kind ever erected, and Mr. Hayter was responsible for the figures then given. These figures were derived from a diagram prepared by Messrs. Easton and Anderson as the result of experiments. The performance being doubted, the question was inquired into, the discharge having been tested by experiments made by Mr. Dirks and Mr. Waldorp. These experiments were at lifts varying from 1·84 foot to 5·02 feet, the lift given in the Paper being 7·20 feet, and the total lift given in the diagram being 9·75 feet, and there was no reason why the laws should not apply to these higher lifts. In one experiment only was the discharge less than that given by the diagram; and in some cases the results were very close. Thus an amount of 401 tons was observed against 395 tons recorded by the diagram, and again an amount of 333 tons was

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxvii., p. 232.

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observed against 325 recorded, in both cases by one engine. Further, a Paper had been read before the Institution by Mr. Welsh in 1872, on the pumping machinery at Lade Bank on the river Witham drainage.[1] These pumps being similar to those at the Zuider Zee locks, excepting that the fan was 7 feet instead of 8 feet in diameter, Mr. Welsh found the results come very nearly to the quantity obtained from the diagram prepared by Messrs. Easton and Anderson. Under these circumstances Mr. Hayter was satisfied that the discharge he had given of the pumps at the Zuider Zee locks, viz., 670 cubic mètres or tons of water per minute by each pump, with a lift of 7·20 feet, was not overstated. The number of strokes to obtain the discharge would be 34 per minute, the length of the stroke being 2 feet 6 inches, and the pressure of steam in the boilers 50 lbs. per square inch. Mr. Harrison Hayter.

As to the expenditure on the breakwater, the piers, without the wave-breakwater, cost £64 a lineal foot, and the wave-breaker £22 a lineal foot, or together £86 a lineal foot. This was the cost freed from financial surroundings, and with an allowance for reasonable profit. This portion of the work was, comparatively, proceeded with uninterruptedly, so that the price was not seriously enhanced by delays. It was difficult to compare the cost of one breakwater with another, the conditions being generally dissimilar; but considering the average depth of water, and the difficult nature of the foundations, this price could not be considered high. The greatest progress made with the piers was about 300 lineal mètres a year at each pier.

The cost of the land reclamations had been £26 an acre, after making deductions for financial arrangements. The selling price was about £70 an acre, so that a good profit had been realized; but it must not be forgotten that some time was spent in executing the works necessary for the reclamations. The price, moreover, was exceptionally low, owing to the circumstance that the main banks of the reclamations were also the banks of the main and branch canals, and these were included in the cost of the canal earthworks. Some persons connected with the canal had recently reclaimed some land at Legmeer, not far from Amsterdam. There the cost had been £33 an acre, and this was a better example to take as to the cost of reclamations under generally like conditions, as it was not surrounded by anything abnormal. Assuming it occupied about four years to complete such reclamations, and that

[1] *Vide* Minutes of Proceedings Inst. C.E, vol. xxxiv., p. 178.

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Mr. Harrison Hayter.

the selling price was £50 an acre, this would give a sufficient profit to render it expedient to undertake the work. In the above cost of reclamations, both in the canal and at Legmeer, there was included a sum of £2 an acre for preparing the ground for seed, embracing levelling, soiling, and cutting small grips.

The dredging was in two divisions, that in the canal and that in the harbour. As regarded the canal dredging, he could give no further particulars beyond those contained in the Paper; that was that the cost by the dredgers fitted with the Woodford Pump delivery apparatus was 1½*d.* per ton of material dredged and deposited on the banks, which price included depreciation, interest, cost of plant, and repairs. It was simply the cost of the daily wages and fuel. As regarded the dredging in the harbour the only information he had given in the Paper was that it cost by the sand pumps less than 1*d.* per ton of material raised and deposited in the barges, excluding transport, depreciation, interest, cost of plant, and repairs. Now the dredging in the harbour was done in two ways, by ordinary bucket dredgers and by sand pumps. By the ordinary bucket dredger, hired from the River Tyne Commissioners, it cost 8·328*d.* per cubic yard, and by the sand pumps 7·234*d.* per cubic yard, including dredging, transport, interest, and depreciation, but excluding the prime cost of plant. It must be remarked that operations could not be carried on during stormy weather, as the material had to be conveyed two miles to sea. The number of working days in the year for this reason averaged only about one hundred and fifty. The cost of plant was 23*d.* by the bucket dredger, and 17·80*d.* by the sand pumps per cubic yard dredged per annum, so that both as regarded the cost of dredging and the cost of plant, the advantage was with the sand pumps designed and arranged by Mr. Hutton. The following Table (see next page), furnished by Mr. Hutton, gave further details of the cost of dredging in the harbour.

The material raised by the pumps was sand, with occasionally small stones. Some fine silt was met with, which was better dealt with by the bucket dredgers, inasmuch as it would not settle if pumped into the barges. The arrangement for adjusting the position of the sand pumps would be seen upon reference to Plate 3, Figs. 7, 8, 9. The suction pipe buried itself almost at once to the required depth of 3 or 4 feet from the top of the ground, and there was not any difficulty in this respect. These remarks were made in reply to Mr. Langley's observations.

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Mr. Harrison Hayter.

COST of DREDGING the HARBOUR by ORDINARY BUCKET DREDGER, and by SAND PUMPS.

Prime Cost of Plant (approximate).

	Ordinary Bucket Dredger.	Sand Pumps.
	1 bucket dredger. 3 steam hoppers. Transport 2 miles.	12 sand pumps. 28 hopper barges. 5 steam tugs. Transport 2 miles.
	£.	£.
Dredger or sand pumps	25,000	60,000
Barges and tugs	15,000	26,000
Total	40,000	86,000
	Cubic yards.	Cubic yards.
Cubic yards dredged per annum .	417,380	1,159,720
	Pence.	Pence.
Cost of plant per cubic yard dredged per annum	23·00	17·80

Working Expenses.

	Ordinary Bucket Dredger.			Sand Pumps.		
	Dredging.	Transport.	Total.	Dredging.	Transport.	Total.
	Pence per cubic yard.	Pence per cubic yard.	Pence per cubic yard.	Pence per cubic yard.	Pence per cubic yard.	Pence per cubic yard.
Wages.	1·792	1·439	3·231	1·117	1·494	2·611
Coal	0·804	0·803	1·607	0·526	0·531	1·057
Stores	0·269	0·269	0·538	0·058	0·036	0·094
Repairs	0·171	0·171	0·342	0·492	0·778	1·270
Sundries	0·155	0·155	0·310	0·211	0·211	0·422
	3·191	2·837	6·028	2·404	3·050	5·454
Interest and depreciation 10 per cent. on cost.	1·437	0·863	2·300	1·242	0·538	1·780
Total	4·628	3·700	8·328	3·646	3·588	7·234

NOTE.—The bucket dredger used approximately the same quantity of coal as the three steam hoppers. The accounts for stores, repairs, and sundries, not having been kept separate, have been equally divided between the dredging and the transport.

The above does not include general superintendence, risk, insurance, amortization of plant or profit.

In conclusion, he would express his satisfaction at the complete success of the undertaking. Sir John Hawkshaw had given some

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Mr. Harrison Hayter.

figures as to the increased trade at Amsterdam since the canal was opened in November 1876, from which it appeared that the tonnage of the shipping to Amsterdam would be doubled before the end of the year 1880, whilst the number of ships had already more than doubled. It was always a matter of congratulation to be associated with a work that had resulted in success, and this effect upon the trade of Amsterdam, and that during a period marked by extreme commercial depression, demonstrated the great utility of the canal to Holland in general, and to Amsterdam in particular.

Correspondence.

Mr. Russel Aitken.

Mr. Russel Aitken had always considered it a mistake to expect that the upright walls of the North and South breakwater could be maintained on sand such as that which was known to exist at the entrance to the Amsterdam Sea canal. The thickness of the breakwaters was, he thought, ample to meet the force of any waves which they would have to encounter in a position such as this, where the sea in front of the harbour was so shallow, and where, of course, large waves could not reach the breakwaters. When at Dover breakwater, he had carefully noted the action of waves on an upright wall, starting at once from the bed of the sea; and he had observed that the force they exerted was small compared with what was exerted by them when they meet a wall built on the top of a sloping bank of stone, as at Alderney or Tynemouth. If the sand underneath the foundations of the Amsterdam Sea canal breakwaters could have been maintained in position, the breakwaters were amply strong enough. What caused the breaches in the works during progress was not, in his opinion, the insufficient thickness of the breakwaters, but the action of the back lash of the waves undermining the insufficient rubble base, and so the foundations of the breakwaters.

To show how little force the sea exerted on a vertical wall raised from the bottom of the sea, he would instance the case of the parapet of the breakwater at Dover, which, although it was 11 feet high, was but 4 feet 6 inches thick. In 1862 he proposed to strengthen this parapet where it faced the south-west by 3 feet more of masonry, but his views were not adopted, and the parapet remained only 4 feet 6 inches thick. Notwithstanding that this parapet was so high and so slight, it withstood the storms of fifteen years, and was only overthrown by a violent storm, accompanied by a high tide, which brought a greater weight of water against it than it could withstand.

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Mr. Imrie Bell.

Mr. IMRIE BELL could quite appreciate the obstacles which the Author stated had to be encountered in regard to financial arrangements, along with the limiting of the rate of expenditure from time to time; such difficulties being often harder to surmount than the engineering ones. He presumed they had in a great measure prevented the Author from going into minute details of expenditure. In the heads of total expenditure it would, however, have been more satisfactory had the Author given, 1st. The actual cost of dredging and excavation per cubic yard; 2nd. The cost of cofferdam per lineal yard; 3rd. The price per cubic yard of concrete blocks set in place; 4th. The cost per lineal yard of the dam across Lake Y. It would also be valuable to have a description of the plant used in the construction of the work. In describing the use of the overhanging cranes, called Titans, the Author stated that several designs were tried, and that the one employed on the South breakwater (of which he gives no description) answered throughout very well; but that the North breakwater, being more exposed, it was decided, after the works had been considerably advanced, and two Titans had been swept away, to employ a steam travelling crane, which was run out to its work by a locomotive engine, and brought back every evening for security in case of storms. He thought these Titans might have been constructed so as to traverse backwards and forwards by their own machinery. He now came to a paragraph of the Paper which required some explanation; it was stated: "When the piers were originally designed, the information supplied as to the rise of the tides was inaccurate, the tidal range being much greater than was then assumed. Partly in consequence of this, the design proved too near the margin of safety for a sea work, and when the breakwaters were considerably advanced seawards, the wave-breaker on the sea side was added." He should like to ask the Author to state the amount of difference between the inaccurate assumed level and the actual levels of the tidal range, also when it was discovered, and the reason for adopting such an expensive structure as the "wave-breaker." It was stated in a former part of the Paper that the rubble deposit was allowed to lie for twelve months before being built upon, which made it appear that ample time had been afforded for the purpose of ascertaining the true range of tide, and to allow of such modification in the design being made as might be necessary. It seemed strange that, in place of modifying the design to suit the necessities of the situation, an additional work of such magnitude, costing nearly a third of the whole cost of the main work of the breakwaters themselves, should be substituted.

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Mr. Dyce Cay. Mr. W. DYCE CAY thought the North Sea piers enclosing Ymuiden harbour would have cost less if a section similar to that of the New South breakwater [1] at Aberdeen had been adopted. For that work the original design had been similar to that for these piers, but on commencing operations he had seen the economy and increase of strength to be gained by substituting liquid concrete building *en masse*, in place of concrete blockwork, in the whole work from about low-water level upwards, and he had devised a system of timber framework, lined and floored with jute cloth, by which this was easily accomplished. This plan made the part of the work, where the shock of the waves was most severe, so solid that a "wavebreaker" such as that described in the Paper was not required. Also, he considered that the apron, which would in that case have been necessary to protect the rubble foundation from the scour of the waves along the toe of the work, might have been advantageously constructed of concrete in bags, a description of work which was less liable to be disturbed by the waves than that formed by prismatic concrete blocks. With reference to the form of the harbour, he observed in the Paper that the littoral current of the flood-tide running from the south was caught by the north pier, and flowed along it into the harbour, and with greater force, he supposed, than would be due to the current caused by the rise of the tide in Ymuiden harbour. This, he thought, was to be regretted, as, being a sand-bearing current, it would deposit sand in the harbour, and form sand banks, and possibly a bar, an annoyance from which otherwise the entrance might have been nearly exempt. This interception of the littoral current might, however, have been unavoidable, owing to the heaviest seas coming to the harbour from the north-west.

Mr. Doherty. Mr. WILLIAM J. DOHERTY observed that the Paper would probably be consulted by many young engineers, as giving a clear and concise view of one of the gigantic undertakings of modern engineering. The "mattresses of fascines," used for the purpose of preventing sinkage in the dam, or embankments, might be judiciously copied by railway engineers in passing through estuaries, or over other doubtful foundations. In one instance which had come under his notice, if such had been adopted, much time, labour and cost would have been saved. In making the embankment through the Rosse's Bay, on the Derry and Coleraine railway, the sinkage there was estimated at about 80 feet. The cofferdam used for constructing the locks, situated in Lake Y, and its mode of

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxix., p. 126.

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Mr. Doherty.

construction, was highly interesting to every one engaged in carrying out submarine works. It was easier to criticise a work after it had been executed, and when the weak points had been pointed out, than to originate a design of such magnitude and to carry it into execution. In theory nothing could be better designed than a circular dam of such dimensions; but in practice, he was of opinion that a dam having six straight sides, each of 300 feet, would have been an improvement, supported on the inside by two rows of piles driven 30 feet apart, and bound together by wales, into which struts calculated to receive the whole weight of the dam would be placed. By these means less trouble would have been caused in setting out correctly the line of the dam, the piles could have been more carefully driven, and the resistance throughout would have been uniform. The only danger to be dreaded in a dam of great magnitude, was impounding a quantity of water higher than the level of the tidal water outside at low water. If the pressure from without could always be kept as a constant quantity, which might largely be done by the adoption of the method explained by himself, of placing earthwork on the outside of the dam, reaching up to half-tide level, then sufficient struts and supporting piles inside would be all that was required to carry the whole superstructure in safety. A sufficient number of ordinary valves (such as were used for water mains) to enable the tidal waters to flow in and out until the pumping of the dam was commenced, was a great safeguard against the pressure of water inside ever being allowed to get higher than on the outside. Indeed, no dam should be constructed without having such a provision. Circular dams, except under special circumstances, should be avoided, for the further reason that the walings were more easily applied to a straight line than to a curved one. The sluices should always be placed about 2 feet above low-water level, so as never to allow the head of water inside to exceed 2 feet. Pump wells should, if possible, be always placed a good distance away from, and out of immediate contact with, the cofferdam, as no doubt the vibration of the pumping engines, as alluded to by the Author, and the continuous drawing of sand, should any be in the vicinity, created vacuities that continually increased unnoticed, until an abrupt "blow" occurred. On the whole he believed that as little weight as possible should be placed inside and adjacent to a cofferdam constructed of piles, and that an extensive toe of earth should be placed against the outside of the dam, sloping up at least to a level above low water. The Author had very properly alluded to

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Mr. Doherty. the leakage occasioned by through bolts; and as the use of through bolts was merely for the purpose of holding the dam together and preventing the puddle from spreading it open, then the quantity of puddle being reduced to the lowest minimum, the tie bolts might be also reduced to a degree just sufficient to carry the weight of the puddle. One of the most successful cofferdams that he had dealt with was the one surrounding the central pier; and also the north abutment of the new swing bridge over the Liffey, which had just been completed, under the specification of Mr. B. B. Stoney, M. Inst. C.E. Here, although completely surrounded with a head of water of from 23 to 25 feet, at high water, the use of puddle and through bolts had been dispensed with. The dam consisted of a single row of 12-inch piles driven closely together in sets of three, dowelled to each other, and the joints caulked with oakum. As the excavations inside the dam reached the rock into which the toes of the piles were driven, the whole interior face of the piles was exposed, when the excavations were taken out, yet the driving, caulking, and strutting was so secure, that not a single "blow" occurred, although the foundations were taken down to 20 feet below low water. He thought that two rows of piles driven down to the same level, at distances apart of either 4 or 6 feet, tended to break up, cut, and crack the substratum through which they were driven, and frequently caused fissures to be more easily acted upon by water from outside finding its way through to the pump well, especially in ground so treacherous as that described by the Author, upon which the cofferdam of the Zuider Zee had been constructed.

Mr. Messent. Mr. PHILIP J. MESSENT stated, in reference to the Tyne dredger, that three steam hopper barges were hired with the dredger, and were included in the first cost of £40,000. These were let to the Amsterdam Canal Company in May 1877, at a rental of £154 per week, being £100 for the dredger and £18 for each of the barges, exclusive of the wages of the crew, insurance, fuel, and cost of maintenance and repairs. Although originally only hired for six months, the plant was retained for two years; half rent being paid during the winter months, when it was not in use. As the above arrangement was made and continued by the canal company after experience with the pump dredgers, it did not seem to justify the remark, that the cost of raising material with the bucket dredgers, or at all events with that from the Tyne, was more than with the sand pumps. Mr. Messent had been informed that during eight months in 1878 the work done gave an average of 679 cubic mètres for each of the pump dredgers, of 699 cubic mètres for each of the

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local bucket dredgers, and of 1,994 cubic mètres for the Tyne dredger. He also understood that the pump dredgers were not fit for finishing work; they made a deep hole, but for completing the bottom and slopes it had been found necessary gradually to discontinue the use of the pump dredgers, and to increase the number of bucket dredgers. Mr. Messent.

Mr. G. H. PHIPPS observed, that in his remarks[1] upon Mr. Blandy's Paper the Author had expressed his preference for wooden gates over iron ones, especially near the sea. In the present Paper it was stated[2] that iron was considered by the Dutch authorities to be more trustworthy than wood. The reason for the adoption of that material was, therefore, out of deference to the Dutch opinions. The hollow quoins referred to, so common in Holland, no doubt admitted of easier workmanship in preparing the flat surfaces instead of the circular ones usual in this country; but it appeared to involve the rather serious mechanical difficulty of making those surfaces come into contact with the sill and the other two surfaces at the same time. With reference to a proposition formerly made by him, to allow a certain play, or freedom of vertical motion, to the rollers of lock gates, to which the Author of the present Paper objected, that "such a contrivance would seldom be brought into operation, and the joints would not be kept oiled," Mr. Phipps thought the apparatus so simple and self-acting that it could not fail of coming into operation when required, and that the oiling would be easy. Mr. Phipps.

Mr. VERNON-HARCOURT observed that he had visited the cofferdam in Lake Y, in company with Mr. Watson, shortly after the mishap referred to in the Paper. It appeared to him that the cofferdam had been considerably shaken by the unexpected pressure from the inside, and he thought that the difficulty subsequently experienced in keeping the cofferdam watertight was partly due to this cause. He could not agree with Mr. Watson in thinking that the circular form was a mistake. The segmental cofferdam erected across the Blackwall entrance to the south dock of the West India Docks had stood remarkably well,[3] and the circular form appeared specially suitable in Lake Y. Through bolts were a necessity in that form of cofferdam, but probably the leakage along them was increased by the settlement of the clay inside on the very soft bottom, in addition to the shrinkage which always occurred. A peculiarity in the locks was the employment of a paving of fascinage and basalt, instead of an invert, between the gates; but this Mr. Vernon-Harcourt.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lix., p. 75.
[2] *Ibid.*, p. 13. [3] *Ibid.*, vol. xxxiv., p. 164.

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Mr. Vernon-Harcourt.

was rendered practicable in consequence of the small rise of tide, and by the enclosure of the space by sheet piling. The plan adopted for the hollow quoins, referred to by the Author, saved a great deal of expense in dressing them; but the danger of rubbish getting in between the heelpost and the hollow quoins, thereby tending to prevent the tight closing of the gates, was an objection. The dispensing with rollers for the gates was a great advantage; but the small rise of tide rendered this easier in Holland than in this country.

The winds appeared to veer round on the shore of the North Sea just as he had observed them do at Alderney,[1] the greatest force being attained from the north-west, the waves also increasing with the length of duration of the gale; and consequently the greatest damage occurring towards the close of a storm, and to works exposed to that quarter. The Author had attributed the necessity of protecting the outer portions of the piers partly to the tidal range having proved greater than had been assumed; it would be interesting to know what that rise was. He gathered, however, from an account of the works by M. Croizette Desnoyers[2] that the storms on that coast were more vehement than had been anticipated, as it was stated that the works were damaged considerably several times during construction, and that the blocks had to be made much larger and tied together, and the proportion of cement increased. It would be interesting if the Author could state whether these accidents occurred merely to the exposed end of the unfinished structure, or whether the finished portions were also injured; also where the injuries occurred, whether below low water where the blocks were not cemented together, or above that level. If the lower blocks were forced out, a mound of protecting blocks was evidently an indispensable necessity; whilst, had the force of the storms been known at the outset, injury above might have been prevented by wider piers and the continuous masses of concrete finally adopted. The position of the piers resembled somewhat those of Kingstown harbour, which, though situated in a sandy estuary, had not suffered from any progression of the foreshore; and at Kingstown the depth of the harbour at the entrance and inside had been easily maintained. He imagined that the strong tidal current across the ends of the North Sea piers would tend to produce a scour at that part; that the depth inside

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxvii., p. 75.

[2] "Notice sur les Travaux Publics en Holland." By M. Croizette Desnoyers, p. 31.

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the piers would be maintained without difficulty by dredging, and that the only danger to the maintenance of the harbour would be a progression of the foreshore. From the advance of the low-water mark at Calais, Dunkirk, and Ostend, in proportion to the extension of the jetties, it might be feared that the North Sea piers, jutting out into the sea on a sandy coast, would cause an accumulation of sand to form outside them; the sand being either brought along by the strong flood tide from the south, or blown in against the north pier by the north-westerly winds. As there appeared to be some divergence of opinion in this respect between Mr. Fogerty, who stated that the sand was accumulating rapidly on both sides, and Mr. Giles, who said he understood the shore was somewhat receding, he thought that a statement from the Author as to the alterations in the line of the shore and in the depths, as far out as the end of the piers, outside the harbour since the commencement of the piers would be valuable. Mr. Vernon-Harcourt.

He had read, with much surprise, in a French periodical[1] that M. de Lesseps, in the course of answering some questions recently put to him in America with reference to the proposed Panama canal, stated he had heard that Sir John Hawkshaw had raised objections to the Amsterdam canal. He was in a position to know that the statement was entirely devoid of foundation, and he trusted that Mr. Hayter would take this opportunity of giving it an authoritative contradiction.

Mr. HARRISON HAYTER, in reply to the correspondence, remarked that he agreed with Mr. Russel Aitken that the action of waves on an upright wall was small compared with the force exerted on a wall built on the top of a sloping bank of stone. This applied more especially to cases where the range of tide was considerable. A sea slope like that at Alderney and at Holyhead (a construction it was often desirable to follow) converted a wave of oscillation into a wave of translation, and introduced a new force. In the Amsterdam piers, however, the wave-breaker had a steep and broken slope, and was carried to within a few feet of the top of the wall, and prevented the wave forming and striking with undue force. Mr. Harrison Hayter.

In the course of the discussion he had furnished particulars of the actual cost of the dredging. Prices that had not been given, either in the Paper or in the discussion, could not be arrived at with accuracy owing to circumstances that had been referred to. He would have illustrated more of the contractor's plant had not

[1] "Bulletin du Canal Interocéanique." May 2, 1880.

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Mr. Harrison Hayter.

the limit properly allotted for illustrations to one Paper been reached. When the Paper was read, much of the contractor's plant —especially the Titan and travelling cranes—was shown either by drawings or by photographs. The difference between the inaccurate assumed level and the actual level of the tidal range was under extraordinary conditions as much as 7 or 8 feet. It was true time was afforded for discovering to some extent that the range of tides originally furnished was not correct; but it took considerable time to prove that a wave-breaker was desirable, and to obtain the necessary sanction for such a work. The wave-breaker had added to the security of the work, and with it the breakwater had not cost a large sum of money, as he had mentioned in the discussion.

In the opinion of Mr. Dyce Cay the piers might have cost less had the design and system followed at Aberdeen been adopted, an account of which had been given to the Institution.[1] Without, however, entering into the comparative cost, Mr. Hayter would venture to say that the saving, if any, would not have been material. He had always regarded with favour Mr. Dyce Cay's method of building with concrete in large masses, but although generally applicable, it would not be so for foundation courses on fine sand subjected to the scour described in the Paper.

As regarded the use of mattresses of fascines, he concurred with Mr. Doherty that they might be judiciously copied by railway engineers in passing over doubtful foundations. He might mention that on the Great Northern railway, in the construction of which he had been engaged, the late Mr. Joseph Cubitt adopted fascine work under a long embankment which carried the railway across fens in Huntingdonshire at that time undrained. The peat was in places 20 feet deep, and a layer of fascines, or rather loose underwood, was first carefully laid and then a layer of peat was added, and afterwards a second layer of loose underwood, and then another layer of peat, and on this the embankment, which was about 7 feet above the ground, was constructed. As might have been, and was, anticipated, the embankment sank a good deal, but the plan answered perfectly. He might observe that the bridges across the fen drains were, in one or two instances, laid on a platform of timberwork placed directly on the peat. The brick abutments were built on the platform and were weighted with rails before the girders were put on. The fen had since been drained, but no difficulty had been experienced by the settlement

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxix., p. 126.

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either of the embankment or of the bridges. Mr. Doherty had also alluded to the circular form of the cofferdam. He could not concur in the remark that a dam having six straight sides would have been better than a circular dam. To this and to other points connected with the dam he had alluded in the discussion. Mr. Harrison Hayter.

There could be no doubt that bucket dredgers, as remarked by Mr. Messent, were better adapted than sand pumps for completing work to precise levels and forms, but, for ordinary dredging in the harbour, experience proved that advantage was derived by the use of sand pumps.

With reference to the lock gates, the adoption of iron in the gates pointing seaward was out of deference to the Dutch views, as remarked by Mr. Phipps. No doubt the introduction of flat-shutting surfaces at the hollow quoins involved the difficulty of making a close contact with the sill and with the vertical face at the same time. In Holland, however, there was not any great head of water, as the rise of tide was small, and in practice no difficulty was experienced in making the gates tight. Accurate fitting was of course essential.

The accidents to the piers occurred, for the most part, either at or near the exposed ends of the unfinished structures, but finished portions elsewhere were often much shaken. The injuries were generally at and above low water. The ordinary tidal range was given in the Paper, but strong northerly and north-westerly winds caused the tide to rise 7 or 8 feet higher. Like Mr. Vernon-Harcourt, he had learnt with surprise that M. de Lesseps had stated that Sir John Hawkshaw had raised objections to the Amsterdam ship canal. It was hardly necessary to say that the reverse was the case. M. de Lesseps could only have made such a statement under an entire misconception of the facts, and he trusted that this Paper would put an end to such an erroneous, but without doubt unintentional, misrepresentation.

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4 May, 1880.

WILLIAM HENRY BARLOW, F.R.S., President, in the Chair.

The following Associate Members have been transferred by the Council to the class of

Members.

JAMES CLEMINSON.
LAVINGTON EVANS FLETCHER.
GEORGE HENRY LIST, Junr.
PATRICK WALTER MEIK.
OSCAR REICHENBACH.
JOHN WILLIAM MITTON WATSON.

The following Candidates have been admitted by the Council as

Students.

JOHN GORELL STANYAN BIGG.
GEORGE FREDRICK BLACKMORE.
EVELYN GEORGE CAREY.
WALTER CLEEVE EDWARDS.
JOHN HALL.
WILLIAM KIDD.
RANALD MACINTOSH MACDONALD.
RICHARD ROBERT MENNEER.
ROBERT ANTHONY SYNGE, B.A.
LOUIS EDWARD TYLOR.
THEODORE ISAAC VACHELL.
HARRY ERNEST WALTERS.

The following Candidates were balloted for and duly elected as :—

Honorary Member.—Count FERDINAND DE LESSEPS, G.C.S.I.

Members.

PATRICK KENNEDY HYNDMAN.
HENRY JOHN PAULING.
CARL PIHL.
GEORGE SEATON.

Associate Members.

JOE BURMAN ABBEY.
EDWIN SYDNEY BARLOW.
JAMES GILLESPIE HENRY CLOW, Stud. Inst. C.E.
WILLIAM PALLISER COSTOBADIE, Stud. Inst. C.E.
JOHN CRAIG, B A.
JOHN GEORGE GRIFFIN.
MATTHEW WILSON HERVEY, Stud. Inst. C.E.
EVERARD HESKETH, Stud. Inst. C.E.
PHILIP HARRISON HOLMES, Stud. Inst. C.E.
FRANK HUDSON.
HERBERT DENT JOHNSTON, Stud. Inst. C.E.
JOHN LYONS.
JOHN CHARLES MACKAY, Stud. Inst. C.E.
THEOPHILUS MICHELL, Stud. Inst. C.E.
MARMADUKE JOHN MONCKTON, Stud. Inst. C.E.
ROBERT ORMISTON PATERSON.
JAMES COURTHOPE PEACHE.
GERVAISE PURCELL, B.A.
FREDERICK SHARP, Stud. Inst. C.E.
JAMES DONNITHORNE THOMAS.
LEWIS GORDON TYRRELL, Stud. Inst. C.E.
ERNEST FREDERICK WELCH, Stud. Inst. C.E.
ROBERT STODART WYLD, Jun., Stud. Inst. C.E.

The discussion upon Mr. Harrison Hayter's Paper on "The Amsterdam Ship Canal" occupied the whole evening.

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11 May, 1880.

WILLIAM HENRY BARLOW, F.R.S., President,
in the Chair.

(*Paper No. 1649.*)

"The Manufacture and Testing of Portland Cement."[1]

By Major-General HENRY YOUNG DARRACOTT SCOTT, C.B., R.E., F.R.S., Assoc. Inst. C.E., and GILBERT RICHARD REDGRAVE, Assoc. Inst. C.E.

NOTWITHSTANDING that much has been written concerning Portland cement, the history of its early manufacture is involved in considerable obscurity. The investigations of Smeaton and Pasley in England, of Fuchs and John in Germany, and of Vicat in France, into the nature and causes of the hydraulicity of limes, are well known; but the discovery of the exact conditions of the manufacture of the cement now recognised as Portland seems to have been only gradually arrived at.

The first mention of a cement named, in consequence of its fancied resemblance to Portland stone, "Portland cement," occurs in the specification of a patent, No. 5,022, granted to Joseph Aspdin, a bricklayer of Leeds, dated October 21st, 1824. The cement originally made by Aspdin does not, however, appear to have been a true Portland, nor was his process identical with that which has since been generally adopted in the production of this material. He used, in fact, a double system of calcination, as he employed a hard limestone in lieu of a soft and friable chalk. He specified, first burning the limestone to lime, so as to obtain a readily pulverised quicklime; this lime he mixed with a suitable, or, as he terms it, "a specific quantity, of argillaceous earth or clay," and then he directed that the mixture should be calcined "in a furnace similar to a limekiln, till the carbonic acid is entirely expelled." This process of double calcination is perhaps,

[1] The discussion upon this Paper was taken together with that upon the two following ones.

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in the absence of chalk, and where fuel is cheap, a readier way of preparing a cement than is that of grinding the limestone to a fine powder. Moreover, by this means the lime is obtained in the finest possible state of subdivision; and its particles can thus be brought into a more favourable condition for chemical action with the minute particles of clay, than is the case with the carbonate of lime mechanically reduced to powder by grinding or crushing. It may be noted here that Aspdin, the inventor, as he has been called, of Portland cement, fails to indicate in his specification the requisite proportions of the two ingredients, and that his omission of the fact, that incipient vitrification must be reached in the process of calcination, would seem to throw serious doubts upon the authenticity of his discovery, at the date of his patent, of the material now known as Portland cement.

There is reason to believe, however, that he was certainly the first to insist upon the importance of partial vitrification, for his son, William Aspdin (who established a manufactory at Northfleet, on the Thames, where he traded, a few years after the date of his father's discovery, as Maude, Jones, and Aspdin) was one of the earliest makers of true Portland. A little later young Aspdin is found in partnership with Robins, trading as Robins, Aspdin, and Co.; and this firm, together with that of J. Bazley White and Co., may be considered to have been the founders of the Portland cement manufacture in the London district.

It is singular that Pasley, when writing the preface to the second edition of his work on cement, in August 1847, states, on page xiii., "At present there are three manufactories of artificial cement in England, which have all been used more or less extensively in works of importance, and have given satisfaction." He then enumerates them as follows:—First, that of Messrs. J. B. White and Sons, of Swanscombe, the successors to Mr. Frost (who attempted to make Portland), and who founded in 1825 the first factory on the Thames; secondly, that of Messrs. Evans and Nicholson, of Manchester; thirdly, that of Mr. Richard Greaves, of Stratford-upon-Avon. Now all this time, as Pasley himself explained subsequently in a letter to Dr. Garthe, of Cologne, dated March 1852,[1] Messrs. Robins, Aspdin, and Co. had been making Portland cement within 10 miles of where Pasley had been living at Chatham; and yet he had never heard of what they were doing, nor of the inventor's manufactory at Wakefield (established in 1825), until he accidentally met Mr. Aspdin at the Exhibition of 1851.

[1] *Vide* "Dingler's Polytechnisches Journal," vol. cxxiv., p. 27.

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In spite of the gradual growth of the new cement in public favour—due in all probability partly to the great estimation in which the cement patented by Messrs. Wyatt, Parker, and Co., in 1796, and known as "Roman cement," was held; and partly also to imperfections in its quality arising from defective manufacture—Portland cement in time outlived all opposition, and as early as 1849 had come to be considered a better cement than Parker's. As is too often the case with inventions of a practical nature in this country, scientific men paid very little attention to the new cement; and even now the bulk of what is known respecting the chemistry of Portland cement is derived from German sources. The researches of Pettenkofer in its early days, and more recently those of Knapp, Schott, and Kuhlmann, have afforded a long series of patient and well-considered investigations concerning the action of cements, which may be sought for in vain among the annals of English laboratories.

The first impulse to the more extended use of Portland cement may be traced back, undoubtedly, to the period when English engineers began to institute careful and accurate tests of the quality of the cement supplied for works of importance. Thus it was not until Messrs. Rendel and Druce, and more especially Mr. Grant, had established the fact that Portland cement of a specified weight and density could be depended upon to undergo certain definite tests, that reliance began to be placed in the new material, and that confidence in the merits of Portland cement as a building material became fairly established. The admirable series of experiments upon the cement supplied for the Main Drainage Works of London, carried out for the Metropolitan Board of Works by Mr. John Grant, M. Inst. C.E., between the years 1859–1871, and communicated to the Institution of Civil Engineers in 1865 and 1871,[1] constitute the basis of an accurate knowledge of the behaviour of Portland cement; and since Mr. Grant's observations the records of Messrs. Colson,[2] Mann,[3] and numerous other observers, have increased the store of information concerning the strength and characteristics of Portland cement. To Mr. Henry Reid, also, who has written a work[4] upon this cement, the acknowledgments of the profession are due for the facts and statistics he has brought together. It is impossible to doubt that the adoption of certain

[1] *Vide* Minutes of Proceedings Inst. C.E., vols. xxv., p. 66, and xxxii., p. 266.
[2] *Ibid.*, vol. xli., p. 125.
[3] *Ibid.*, vol. xlvii., p. 248.
[4] "The science and art of the manufacture of Portland cement."

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rigidly imposed tests of quality has been of the utmost advantage in improving the manufacture, and in ensuring the uniform excellence of Portland cement.

The Authors, after having briefly considered the history of Portland cement, next examine the main features of its manufacture, and at the same time treat of the chemistry involved in the different processes. The plan of manufacture employed by the earlier makers in the Thames district has been followed, with but trifling modifications, by all manufacturers up to within a few years of the present time. Recently, however, several important changes have been effected; and the introduction of these processes by some of the leading firms has, so to speak, revolutionised the manufacture. In order to explain these alterations in the preparation of the cement, it will be necessary to refer briefly to the plan of manufacture formerly pursued.

Concerning the materials, the Authors need say but little. Some have thought that the upper and lower chalk formations and the alluvial clay of the Medway afford the *ne plus ultra* of the ingredients for Portland cement making. The fact is, however, that the proper mixture of carbonate of lime together with silica, alumina, iron, and the alkalies, such as shall ensure, when calcined and ground, a slow-setting, hydraulic cement of the Portland type, exists naturally compounded in numerous forms, and the clays and carbonate of lime suitable for the purposes of the cement maker may be obtained in nearly every part of the world. The danger in using a naturally compounded material, such, for instance, as the clayey limestones of the lias formation, consists mainly in the wide and frequent fluctuations which, almost without exception, characterise such beds, and expose the manufacturer to serious failures, unless more than ordinary care and watchfulness are exercised in their selection. Examples of the extensive use of such natural cement compounds are furnished by the important manufactories at Boulogne-sur-Mer, in France, where the lower chalk is made use of, and by the employment of the lias beds at Rugby for the manufacture of Portland cement.

It is useless to conceal the fact that the exact percentage of clay which is added to the lime is far less accurately determined than most manufacturers are willing to admit; and, within certain not very clearly defined limits, all mixtures which contain say between 74 and 77 per cent. of carbonate of lime, when sufficiently calcined, will yield a good sample of Portland cement. With too large a portion of clay—that is, when the carbonate of lime in the raw state (after drying at 100° centigrade) falls below

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74 per cent.—a cement is produced which is technically termed "over-clayed." Such compounds are liable to "run" or fuse in the kilns, in which case they yield a wholly inert substance: they cannot therefore be calcined at so high a temperature as those mixtures in which the ingredients are properly proportioned. They produce a cement light in weight, brown in colour, rather quick-setting than otherwise, but which never becomes thoroughly indurated, and which is liable to crumble on exposure to the weather. Cement mixtures, on the other hand, deficient in clay, and known as "under-clayed," will stand the highest temperature in the kiln during the firing. When well burned they are extremely hard, and difficult to grind; they produce, however, a heavy, dense Portland, of a treacherous description—one which, unless it has been properly "purged," as it is termed, or exposed in thin layers to the atmosphere, in order to air-slake the particles in which the lime is in excess, is liable to "blow," or swell in the work.

Passing on to the manufacture: in the course originally pursued the clay and the chalk were first incorporated together, and pulverised by attrition in a wash mill with a large volume of water. A general plan of the arrangement of a cement works of the old type is shown by Fig. 1 (Plate 4). The wash mill (Fig. 3, Plate 4, which illustrates a mill of the most ordinary type) consists of a stone- or brick-lined pit, circular in plan, in the centre of which is a pier carrying a shaft, which latter should make from twelve to twenty revolutions per minute. The shaft is furnished with arms, to which are attached knives or cutters, reaching nearly to the bottom of the pit and serving to break up and disintegrate the clay and chalk. Some manufacturers prefer an arrangement of cross-bars and cutters, suspended from chains, on the principle of the harrow; and it is obvious that many different methods of fitting up the mill can be devised. In certain districts the wet "slip" is caused to pass from the wash mill, by overflow, to the pan of a heavy edge-runner, similar in every way to a mortar mill, where any small lumps are further reduced; and from this mill the slip escapes through brass wire gratings to sumps, from which it is pumped or raised into shoots, for conveyance to the different reservoirs or "backs" (Fig. 1, Plate 4). In this condition the mixture of chalk and clay is technically known as "wet slip." Various devices are employed to arrest hard particles in the chalk which have failed to be reduced to the requisite degree of fineness in the wash mill. Small traps or catch pits in the shoots, gratings, and other contrivances, have been proposed. These particles are the

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bane of the cement maker, and are among the most frequent causes of imperfections in the quality of the cement.

One of the most important of the modifications recently introduced into the manufacture of Portland cement, is the principle of grinding with the smallest possible quantity of water, under the patent granted to Mr. W. Goreham, No. 1963, in July 1870. The clay and chalk are ground in a wash mill with revolving cutters, and the mixture is subsequently passed between French burr stones running horizontally, similar, in fact, to the mill employed for grinding the clinker. The amount of water need not, with care, exceed 40 per cent. of the total weight of the dense wet slip or "slurry," as the creamy paste produced in this way is termed; and the action of the mill-stones is very efficacious in destroying hard particles, and rendering the mixture uniform in texture, and impalpable when tested with the thumb and finger. In lieu of passing the mixture from the wash mill into backs, or settling tanks, it becomes now possible to pass it at once on to the drying floors, allowing it, therefore, no time to settle. Apart from the great economy of space and the vast saving of time thus effected, the power of entirely dispensing with backs is of considerable importance, when it is remembered that the difference in the specific gravities of the chalk and the clay implies a tendency to a separation of these ingredients in the backs, and involves the necessity of constant lutings, a process too apt to be neglected or to be insufficiently performed. An intermediate step to the total abolition of backs was the plan, proposed by Mr. Johnson, of employing cylindrical reservoirs or settling-towers, into which the wet slip was pumped, and from the top of which the supernatant water was from time to time drawn off, leaving the dense slurry in a fit state to be removed to the drying floors.

The most recent improvement in the wash mill is, it is believed, that of Mr. V. de Michele, Assoc. M. Inst. C.E. (Fig. 4, Plate 4). The mill is of the usual form, from which the materials escape by overflow round the edges; but there are introduced grinding surfaces of iron, forming a species of broad rim, over which all the small particles as they pass are reduced by attrition to the finest state of subdivision. From an examination of the slip thus produced, and that passed through mill stones, the Authors are of the opinion that the former was the better sample.

Whatever be the method adopted, the aim of the manufacturer is to produce a uniform and intimate mixture of the correct proportions of chalk and clay. When the process is continuous throughout the day, as is generally the case, entire accuracy in the results

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cannot be relied upon. A more reliable plan would be to fill up a mill with weighed quantities of the ingredients, and to run it off when the mixture is completed; or to wash the chalk and clay, as is sometimes done, in separate mills, subsequently incorporating them in measured volumes in a third mill. The proportioning of the ingredients, which is by far the most important step in the whole manufacture, is too often a matter of guess-work, and is, as a rule, entrusted to a steady experienced workman, who, from long practice, has learned the exact mode of feeding the wash mill—the Authors must, however, concede that the cement usually justifies the confidence placed in him by his employers.

By means of improved modern grinding machinery it is possible, at a moderate rate, to reduce the chalk and clay (after drying them), or even hard limestones and shales, to the finest powder. This plan of reduction is practised at some of the continental manufactories and at several cement works in England. The plan pursued is thoroughly to mix the pulverized ingredients, and to moisten them sufficiently to render them capable of being moulded into bricks or cakes, which are then dried and calcined. Perhaps, by hydraulic pressure the nearly dry powder might be stamped into slabs of great density, which when thoroughly calcined ought, theoretically, to yield a first-rate cement. Machines are used in the Staffordshire potteries to produce tiles from dry powder, by stamping it in a screw press; and it would be interesting to try some experiments in making Portland cement in this way.

In most English manufactories the wet slip has until lately been dried by artificial heat, applied to hot plates or drying floors by flues passing under them. The drying floors may thus be heated by the surplus heat from coke ovens placed beneath them, or by the waste heat from the kilns, or by special furnaces for the purpose. One of the most important changes recently introduced consists, in so utilizing the surplus heat from the kilns as practically to abolish the old-fashioned drying floor. In kilns of the usual construction, the products of combustion escape by the brick cone (Fig. 6, Plate 5); but in order to utilize the surplus heat, the orifice at the summit of the cone is fitted with a damper, which can be closed when the kiln is fairly alight and a good draught has been established. The heat is then conducted by down-draught flues to the points where it has to be utilized. The methods of applying the waste heat from the kilns may be classified under three heads: 1. Those in which the heat passes beneath the wet slip by flues. 2. Those in which the heat passes over the surface of the material to be dried. 3. Combinations of the two

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systems. The plan of passing the gases from the kiln under a drying floor of the usual construction has been frequently employed. It is open, however, to several objections; the first of which is, that the amount of heat thus obtained has to be supplemented by the heat from furnaces (except, of course, when the kilns are worked as draw-kilns or continuous kilns), as for many hours after they are lighted the heat is not available for the hot floors. The same objections apply also in this case that may be urged against all drying floors with flues beneath them—the great wear and tear of plates or flue covers, the liability of the flues to become obstructed, and the expense of repairs and maintenance. Another objection is that, owing to the closing up of the kilns, the evolution of the carbonic acid and the fusion of the clinker takes place more slowly, and in some cases an inferior quality of cement is produced.

To the second class belongs the recent important invention of Mr. I. C. Johnson (Fig. 5, Plate 5). Here, at the level of the top of the kiln, a chamber is constructed by means of an arched vault, which incloses an area of 1,300 square feet, sufficient to dry the wet slip necessary to charge the kiln. The heat issuing from the kiln passes over the surface of the slip, which has been pumped on to the floor direct from the wash mill, and gradually dries it from the top downwards, so that by the time the kiln has burnt out, a new charge of dried material is ready for use. The bottom of the drying chamber falls towards the kiln 1 foot in 100 feet, and the average thickness of dried slip is 8 inches. Apart from the great facilities afforded by this plan, and the important saving of fuel which it effects, the Authors believe that the dense compact slip dried on a floor with surface heat is preferable to the spongy, porous compound produced by bottom heat on a hot floor. Mr. de Michele has proposed a modification of the Johnson kiln (Fig. 8, Plate 5). He constructs the arches as thin as possible, and uses the upper surface of the vault as well as the floor beneath. By this means he is enabled to reduce considerably the length of the chamber, but he is compelled to roof in the arch; and he obtains slip dried by both top and bottom heat, which brings his method under the third head. To this class belong also the plan which has been long employed by Messrs. J. B. White, and the recent invention of Mr. R. A. Gibbons (Fig. 7, Plate 5). Messrs. White conduct the surplus heat from their kilns, which are not continuous but intermittent, into long chambers covered with removable iron plates, and so constructed that the gases pass first under the slip to be dried, and then return over it into the shaft, in their passage

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to which they heat an additional coating of slip placed on the iron plates. The total thickness of dried slip thus obtained is 15 to 16 inches for every square foot of heating area, and the total weight of fuel for drying and calcining the slip is about 35 per cent. by weight of the finished cement. Mr. Gibbons employs a running kiln, in connection with which are two or more chambers. These chambers he uses alternately, and passes the heat both under and over the material to be dried. All the above systems aim at utilizing to the best advantage the waste heat from the kilns; and there can be no question that one of the chief features of the recent improvements in the manufacture of Portland cement is the attention which has been directed to this subject.

The Authors may here observe, that slip which has been dried on plates or floors with bottom heat, presents a different appearance to that obtained when the heat is applied above it; and though the former porous quality can perhaps be calcined into a dense Portland at a smaller expenditure of fuel than the more solid variety of slip made on the latter plan, preference should be given theoretically to the surface-dried slip, as all its particles are more favourably situated for chemical action than they can possibly be in the more open-grained variety. Glancing at the plan of preparing Portland cement by washing with a minimum amount of water, and the use of chambers attached to the kiln, which would be the characteristics of works of the modern type (Fig. 2, Plate 4), as opposed to the system of backs, drying floors, and coke ovens, which are typical of the works of the old-fashioned kind (Fig. 1, Plate 4), and enumerating briefly the advantages of the modern system: In lieu of the slow and tedious process of passing the wet slip into backs from which the water is gradually drawn from the surface, an operation lasting from four to seven weeks, and the digging out and wheeling of the slurry from the backs to the drying floor, the new process enables the slip to be pumped from the wash mill to the drying floor direct. This implies a saving of all the manual labour formerly required, and an enormous diminution in the area necessary for the works; in the cost of repairs to coke ovens, backs, drying floors, &c.; and in the expense of buildings and plant. When coke ovens were employed to dry the slurry, the production of coke was so wastefully conducted that 1 ton of coal seldom yielded more than ½ ton of coke, and it was necessary to make or buy additional coke for the kilns. It is safe to say that the cost of buying gas coke at the present time does not exceed half the cost of the coke made under the drying flats. The Authors are indebted to Mr. Johnson for the following statistics of the relative cost

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of his system as compared with the original process of manufacture: —

Fuel per ton of cement, old system	20¼ bushels.
„ „ „ Johnson's process	18 „

Cost of cement on old system, on actual experiment, for burning only:—

For 133 tons of cement 75 chaldrons of coke (costing 16*s.* 10*d.* per chaldron including labour) are required, of which two-thirds would be made in coke ovens and one-third would be gas coke; thus:—

	£.	s.	d.
By ⅔ of 75 chaldrons of coke = 50 chaldrons, at 16*s.* 10*d.* =	42	1	8
⅓ „ „ „ = 25 „ „ 10*s.* 6*d.* =	13	2	6
	55	4	2
New system:—			
By 65 chaldrons of coke, at 10*s.* 6*d.* . . . . . =	34	2	6
Difference	21	1	8

Saving on 133 tons by new system, £21 1*s.* 8*d.*, or 3*s.* 2*d.* per ton.

Mr. Johnson sets down the cost of fuel for drying and calcining the slip at 5*s.* 3*d.* per ton of the finished cement, the price of coke being 10*s.* 6*d.* per chaldron.

The most important consideration to the cement maker of the future will undoubtedly be the saving of fuel, which is the most expensive item in the cost of production; probably next in importance will rank the extent to which the outlay upon buildings and plant, and repairs and maintenance, can be reduced. The wear and tear of kilns is very heavy; and as the continuous or running kiln is much more economical, both as respects fuel and repairs, than the ordinary draw-kiln, attention should be directed to improvements in the application of this system of burning. There can be no question that the annular kiln introduced by Messrs. Hoffmann, of which numerous modifications have at various times been proposed, is theoretically far superior to the present form of cement kiln. The Authors believe that, in spite of the fair measure of success which has attended this plan of calcination abroad, no annular kiln has been found in this country to produce satisfactory Portland cement clinker, and the plan, though nearly perfect theoretically, has failed in practice. The calcination of cement requires the utmost degree of care and attention, and unless the manufacturer thoroughly understands the nature of the changes he has to bring about in the kiln, he is more likely to

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fail at this stage in the preparation of the cement than at any other.

It seems necessary, having arrived at this point, to allude briefly to the chemistry of Portland cement, for the explanation of which, as here given, the Authors must express their obligations to Professor Pettenkofer, who published, in conjunction with Dr. Hopfgärtner, in 1849,[1] the first accurate analysis of the cement, and whose able investigations supplemented those of Fuchs. The analysis is interesting as indicating the nature of the cement then being manufactured:—

Lime	54·11	Brought forward	70·67
Magnesia	0·75	Silica	22 23
Potash	1·10	Carbonic acid	2·15
Soda	1·66	Phosphoric acid	0·75
Alumina	7·75	Sulphuric acid	1·00
Oxide of iron with traces of oxide of manganese	5·30	Water	1·00
		Insoluble residue	2·20
Carried forward	70·67		100·00

The researches of Fuchs, published during the years 1829–32, form the basis of the existing knowledge of the causes of hydraulicity in limes and cements. Professor Pettenkofer was undoubtedly the first to direct attention to the chemical reasons for the superiority of Portland over the rival material Roman cement; and the Authors believe that the accuracy of his surmises, published thirty years ago, has never been disproved.

Professor Pettenkofer asserts that the objects to be effected in the calcination of a cement compound are twofold: 1st, the conversion of the carbonate of lime into an oxide of calcium at a dull red heat; and 2ndly, the production, at a temperature approaching fusion, of a chemical combination of silicic acid with alumina, iron, and the alkalies, the silica being by this means protected from at once combining with the lime, but made available for future chemical action under changed conditions brought about on the addition of water. The due formation of these silicates must greatly depend upon the physical condition of the mixture of lime and clay, and upon the presence, in sufficient quantities, of bases for which silicic acid has at a red heat a more powerful affinity than it has for lime. Among such bases are prominently the alkalies, potash and soda, and, in a less degree, alumina and the oxides of iron. It is not, however, alone imperative that such silicates should be produced in the calcination; but in order that

[1] *Vide* "Dingler's Polytechnisches Journal," vol. cxiii., p. 355.

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the hydraulic properties of the cement should be exerted to the utmost, the compound, when treated with water, must contain these partly soluble and partly insoluble silicates, in a form capable of permitting the substitution of the hydrate of lime for certain of the bases previously in combination with the silica. Instances are by no means uncommon in chemistry, in which the affinities as they exist at a red heat are reversed when cold and in the presence of water; and the property of hydraulicity undoubtedly belongs to this class of phenomena. When Portland cement is thoroughly well made hardly any causticity can be detected by the taste, owing to the silicates which have been formed round the particles of quicklime. On treating the powdered cement with water a chemical change immediately takes place; the silicic acid previously combined with the alkalies in the form of soluble compounds goes to the recently-formed hydrate of lime, leaving the alkalies with which it was first in combination free to be washed out of the compound. The newly-formed silicate of lime partially decomposes the other silicates of alumina and iron in the act of hydration, forming double hydrated silicates, which are practically insoluble. This, according to Pettenkofer, is the chemistry of true Portland cement.

Knapp, in his work on Technology,[1] puts the case somewhat differently; and, in the absence of conclusive experiments respecting the chemistry of Portland cement, it is as well to record his observations on the subject. He states of hydraulic limes that lime rendered caustic by calcination "reacts upon the siliceous clay, converting it into a compound that is easily decomposed by acids. The excess of caustic lime, as well as the compound into which the siliceous clay has been converted, then react upon each other, when mortar is prepared from the ground burnt lime, in such a manner, that a solid stone-like silicate is produced in the humid way. The water here obviously has a double action. Dry substances, like lime and the silicate of alumina, act very little, or, under certain circumstances, not at all, upon each other, unless the solvent power of water is employed to bring them into intimate contact. During solidification, the water will constantly transfer the lime which it has dissolved, to the siliceous particles; it will then dissolve fresh lime, which is again employed in the production of the silicate, and so on." He maintains, further, that the setting of hydraulic mortars is in nowise due to the formation of simple hydrates, but states that "the process of solidification is, on the contrary, not so much the conversion of

[1] *Vide* "Technology," vol. ii., p. 407.

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a ready formed silicate into a hydrate, as the formation of a hydrated silicate in one and the same operation." Knapp shows, from the researches of Fuchs, Kuhlmann, and others, that iron and alumina are only negatively useful constituents of hydraulic limes, serving, in fact, only as components of double silicates, and assisting as such the formation of silicates of lime. The alkalies, on the other hand, play an important part in the cement compound, and act as transferers of silicic acid to the lime. Owing to their great solubility they are readily carried by the water to the caustic lime, to which they part with their silica, leaving them free to be washed out of the cement. It is not improbable that the cement theory, as given by Pettenkofer and Knapp, may be in part correct, and that the complicated changes which occur in the kiln, and subsequently on hydration, partake of the character ascribed to them.

German writers, moreover, affirm that if the oxides of iron and alumina are present in too great an abundance for the proportion of lime and silica, and the calcination is effected at a moderate heat, a cement is obtained of the quick-setting Roman type, in which the set is chiefly due, when water is added, to the formation of hydrated silicates of iron and alumina. Mixtures of this type result more readily upon increase of temperature in the kiln in a species of glass, which consists of wholly insoluble double silicates, quite worthless as cements. If the silicic acid is entirely combined with the right proportions of bases to neutralise it, a cement is obtained of the slow-setting, dense Portland type, in which the compound silicates are only formed after long intervals of time as compared with that required for the simple hydration of ready-formed silicates. Even in those compounds of iron and alumina with silicic acid in which an excess of these oxides is present, lime is capable of abstracting from them a portion of the silica which had combined with them at high temperatures in the kiln; for it must be remembered that silica always combines more freely with several bases than with one, and has a tendency, when several bases are present, to leave one with which it is already saturated, in order to combine with new ones.

It will be manifest from these observations that the nature of the clay employed to mix with the chalk is a matter of considerable importance. Clays rich in iron generally contain much of it in an uncombined form, and their silica is therefore not so apt after burning to gelatinise when treated with acids. The tendency to gelatinise may be regarded as a ready test of suitability for the Portland cement maker. Clays deficient in alumina and iron, and

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in which the silica is present in the condition of finely divided quartz, are apt to form insoluble silicates of lime at a high temperature, owing to the want of suitable bases to combine with the silica, which also renders them unfit for Portland cement making. Such clays, moreover, when calcined at too low a temperature, yield hardly any soluble silicates, form therefore no protection to, and serve in no way to prevent the hydration of, the lime, and produce consequently a material devoid of hydraulic properties. Fuchs pointed out in connection with the above the imperative necessity of a very fine state of subdivision in the silica, in order to form compounds with lime; and he proved, from numerous ingenious experiments, that by no known mechanical subdivision could a substance fine enough for the purpose be obtained. He demonstrated, in the same series of experiments, a fact to which sufficient attention has not been paid, namely, that under certain conditions carbonic acid is capable of decomposing silicate of lime; to which cause is perhaps attributable the frequent failure of imperfectly burned, over-clayed Portland cement.

Before quitting the subject of manufacture, the Authors may remark that, in the state in which it is placed in the kiln, the dried slip rarely contains less than 10 per cent of moisture, and that during the early stages of the calcination a vast quantity of steam is evolved. The presence of vapour throughout the whole period of calcination is not by any means to be deprecated, as it has been shown by Gay Lussac that carbonic acid is more readily expelled in an atmosphere of steam than in dry air. This must not be used as an argument for filling the kiln with insufficiently dried slip, for, long before the temperature is reached at which the carbonic acid is driven off, the whole of the water will have been expelled from the slip. Steam may, however, it is believed, be introduced into the kiln during the later stages of the calcination with advantage.

The manufacture of Portland cement from sewage sludge rendered it necessary to devise means for absorbing or destroying the offensive fumes emitted by the organic matter during the process of calcination. For this purpose the Authors have used successfully a down-draught kiln, in which the whole of the products of combustion are conducted by means of specially contrived flues, formed in the walls of the kiln (Fig. 11, Plate 5), to a collecting flue at its base. From this flue the fumes are passed into a furnace, and consumed previous to entering the chimney.

It has been observed that when the products of combustion passing from the kiln are employed, as on Mr. Johnson's plan, for

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drying the slip spread in a thin layer upon a floor above which the heated gases are conducted, a film of whitish dust is frequently found covering the surface of the dried slip. This film may be in part due to a bleaching action caused by the sulphurous acid of the coke fuel, or it may be owing to the formation of a sulphite of lime, which subsequently passes to a sulphate. The Authors are not aware that this matter has been chemically investigated. German manufacturers attach great importance to the freedom of the Portland cement from sulphate of lime, though as far as the Authors' experience goes a small quantity of sulphuric acid is beneficial rather than otherwise in its action upon the cement. This acid has a marked effect in controlling the slaking action of the uncombined lime, as manifested in its employment in the production of selenitic cement.

It now only remains to glance at the subsequent treatment of the clinker after it is withdrawn from the kiln. It must be carefully picked over, to exclude the glassy slag due to overburning, and the yellow or pink insufficiently-calcined slip. Some manufacturers employ rollers to break up the clinker; others pass it under heavy edge runners; and the different forms of Blake's stone breaker have also been used with advantage. There can be no question that it is a matter of doubtful economy to pass anything larger than a hazel nut into the eye of the burr stones; and consequently care should be taken to reduce the clinker to the smallest possible size before putting it through the mill. Certain varieties of over-clayed cements yield a deep bronze-coloured clinker, which, as it cools on coming from the kiln, disintegrates spontaneously into a fine flakey greyish powder. Such clinker is said to be "slippy," and the powder, when employed as a cement, is wholly inert, and should, along with the clinker which gives rise to it, be excluded from the finished cement. The above action of disintegration, which is extremely curious to witness, is a purely physical one, and is due, doubtless, to the difference in tension between the particles of the compound in the hot and cold state, the action being similar to the bursting of the little glass beads known as Prince Rupert's drops.

On issuing from the mill the cement should be carefully sifted, though this operation is frequently neglected. That it can be done efficiently and well is unquestionable; indeed the whole of the cement at the extensive manufactory of Messrs. Robins and Co., of Northfleet, has been sifted for some considerable time, the mesh employed being (excepting in certain special cases) $40 \times 40 = 1{,}600$ to the square inch. After leaving the sieves, the final

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process is to distribute the cement in thin layers on the floor of the warehouse. Each day's make is spread over the layer placed the day before; and after a bed some feet in depth has been accumulated, it is filled into casks or sacks by working vertically down through the numerous layers, which may represent the work of a week or even longer. This spreading, which tends to air-slake the free lime, is most beneficial to the cement, and is practised by all the principal users of Portland cement. The exposure is generally too short at the manufactory to effect the total hydration of the dangerous particles, and it is therefore important in specifications to enforce on the contractor the provision of covered floors adjacent to the works, suitable for the spreading of the cement for some days previous to its use.

Having thus followed the cement through the various stages of its manufacture to the time of its delivery to the consumer, the subject of testing the cement will be briefly dealt with. The machines employed for breaking sample briquettes have been greatly improved in recent years. In the early days of cement-testing, the steel-yard, with contrivances for gradually moving forward the suspended weight, was in general use. Mr. V. de Michele has introduced a simple apparatus, in which the increment of weight is slowly obtained by altering the position of a lever arm by the action of an endless screw. An excellent method of adding gradually to the strain on the sample briquette is that proposed by Messrs. W. H. Bailey and Co., of Salford, who employ water for the purpose, which is passed into a vessel suspended at the end of a lever-arm, through which the strain is imparted to the sample under test (Fig. 9, Plate 4). A similar machine, but more roughly and cheaply constructed, is manufactured by Messrs. Frühling and Michaëlis, of Berlin. The societies interested in the manufacture and use of cement throughout Germany met in 1877 in Berlin, and mutually agreed upon a system of uniform tests in a standard machine of improved construction. The abstract of the resolutions which were then passed, and the rules drawn up for the guidance of those undertaking the testing of cement, are admirable in their way; and the Authors feel convinced that the time has arrived when the authorities in this country should agree upon some similar uniform plan of testing cements.

Strange and anomalous as it may seem, although, except in rare cases, Portland cement is never used neat, or subjected to a direct tensile strain, experimenters have hitherto almost invariably followed the plan of testing the neat cement, and of employing tension instead of compression for the purpose. The German

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authorities point to the difficulty of testing cements in compression, owing to the costliness of the requisite apparatus. They have therefore adopted the old system of fracturing briquettes by a gradually applied tensile strain.[1] The cement is mixed with 3 parts of specially prepared sand (normal sand) to 1 part of cement. The tests are applied twenty-eight days after the making of the sample, during twenty-seven of which it has been placed in water. The machine used is shown in Fig. 10. The weight is applied through a double lever by means of shot gradually run into a vessel at the extremity of the longer arm. Though this plan has not the advantage of Messrs. Bailey's machine, of being absolutely self-recording, the breaking weight as indicated by the vessel filled with shot can be readily ascertained by a simple change in the apparatus. The shot bucket is unhooked from A and suspended at B, and as the decimal system is employed, one-tenth of the actual weight placed in the scale pan at C will counterpoise the weight of the vessel and its contents. The employment of the double lever has many advantages, the chief of which is that the line of tension is much less altered in its direction than with a single lever. The section of the test briquette at the point to be fractured is only, in the German machine, 5 square centimètres (0·775 square inch), or, as compared with the section generally employed in this country, of 2¼ inches, as 1 is to 2·9. This the Authors think small for a test block made up with 3 parts of sand; the section has, however, been carefully considered in Germany. It is one which no doubt reduces to a minimum the chances of flaws and imperfections in the sample, and it gives uniform and excellent results in the tests. The German regulations comprise standard weights for casks and packages — specified periods within which the cement, either quick setting or slow setting, must set— grinding to such a degree of fineness that when passed through a sieve having 5,806 meshes to the square inch, it shall leave a residue not exceeding 25 per cent. The cement is to be made up with 3 parts of sand, prepared by sifting washed sand through sieves of 387 meshes per square inch to remove the coarse grains, and removing from it all the fine particles which pass through a sieve of 774 meshes per square inch. After remaining one day in the open air, and twenty-seven days in water, the briquettes must bear a strain of not less than 113·8 lbs. per square inch. Quick-setting cement must not be expected to stand this test, and, as a check, an eight-day test of neat cement is specified. This uniform plan of

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lv., p. 336.

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testing cement has so much to commend it, that the Authors venture to propose the adoption of this pattern of machine, and the plan of employing a mixture with sand in lieu of the neat cement as practised in this country. After examining the various arguments in favour of and against a sand test, they feel that it is by this means that the best knowledge of the behaviour of a cement in the actual work is obtained; and even the departure from the recognised area of $2\frac{1}{4}$ square inches has much to recommend it. The following might be the general tests for English cements:—

1. The whole of the cement to be ground fine enough to pass through a sieve of $40 \times 40 = 1{,}600$ meshes per square inch without residue.

2. The cement to weigh not less than 85 lbs. per cubic foot filled from an inclined plane (at an angle of, say, 45°).

3. The cement tested with 3 parts of standard sand must have a minimum strength of 112 lbs. per square inch in twenty-eight days, during one day of which it has been in air and twenty-seven days in water.

There appears to be no reason for adopting a standard machine made by one sole maker, but it might be advisable to specify the class of machine to be employed. The samples to be moulded to a standard size, giving 1 square inch of sectional area for fracture. The German regulations respecting the method of mixing the cement and sand, adding the water, and filling the compound into the moulds, should all be added as notes to the regulations.

With reference to the first of the above rules, the Authors would observe that the presence of coarse unground particles, though it may even prove beneficial to the neat cement, is extremely prejudicial when the mixtures with sand are made. To the manufacturer's objection that if all the coarse particles are to be excluded the price of cement must be raised, a German writer, who has carefully examined this subject recently, replies:—"Better to remove the coarse particles and add an equivalent proportion of coarse sand than retain the small lumps of unground cement, which may, and undoubtedly do in certain cases, prove sources of danger." An analysis is given in an article in "Dingler's Polytechnisches Journal," which shows how similar in composition are the coarse and the fine parts of the cement. To determine this, a sample of first-class cement, as received from the manufacturer, was stirred up with petroleum spirit. By pouring off the spirit, and allowing the fine suspended particles to subside, a perfect separation was effected between the coarse and the finely-ground portions of the cement.

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On careful analysis, a sample of each yielded the following results:—

	Fine Cement.	Coarse Particles of Cement.
Oxide of iron	4·276	4·352
Alumina	4·519	6·527
Lime	60·075	59·749
Magnesia	1·376	1·394
Potash	1·082	1·447
Soda	0·307	0·294
Sulphuric acid	0·797	0·774
Silica	22·750	22·749
Carbonic acid	2·831	0·731
Water	0·867	
Insoluble residue	1·347	2·125
Totals	100·227	100·142

The coarse particles which, as will be seen from the above figures, were almost identical in composition with the fine ones, when made up into a paste with water showed no signs of setting, and after a month still remained in the form of a gritty, crumbling powder; whereas the fine particles had acquired the consistency of stone. When the coarse particles were crushed to a fine powder in a mortar, and made up with water, they behaved, however, precisely in the same way as the fine particles which had been previously separated from them, and proved a first-class cement. The coarse portions were in fact wholly inert, and their presence was no more beneficial to the cement than so much sand. Of the value of fine grinding, when the cement is intended to be used with sand, the experiments of Mr. Colson,[1] furnish conclusive evidence.

Concerning the test by weight, as applied to Portland cement, though this has been dispensed with by the German authorities, the Authors think that when checked by means of the sieve it is a valuable one, and worthy of being retained. They consider, however, that in lieu of the bushel as a measure of capacity, the contents of a cubic foot would be a more suitable standard. A fixed angle for the filling board is also important.

With respect to the third regulation, and the employment of a mixture of cement and sand as adopted in Germany, in lieu of the neat cement, the Authors think it will be generally conceded that, although it would appear that the behaviour of the neat cement affords a reliable estimate of its action when gauged with sand, there are really few good arguments in favour of testing

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. liv., p. 264.

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the cement in a form in which it is rarely used in practice. Probably the chief advantage obtained by the employment of neat cement, is the gain in time, as shown by a seven-day in lieu of a twenty-eight day period under experiment. There is reason to believe, however, that for the best class of dense, slow-setting cements now manufactured, the seven days allowed to elapse between the moulding and testing of the briquette are insufficient; and it must be remembered that even the German authorities propose to check the cement and sand test by means of one conducted with neat cement, after an interval of eight days. The numerous experiments of Grant, Mann, and Colson, must be carefully studied in connection with this point, upon which, no doubt, there are many differences of opinion. Generally, however, the Authors trust that engineers will agree in declaring that the time has now arrived when a uniform scheme for the testing of Portland cement can be drawn up, and a standard scale of tests can be adopted throughout the country.

The communication is accompanied by several drawings, from which Plates 4 and 5 have been engraved.

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(*Paper No. 1689.*)

"Portland Cement Concrete, and some of its Applications." [1]

By EDWIN ARTHUR BERNAYS, M. Inst. C.E.

IN this Paper it is proposed to give the results of the experience acquired by the Author, chiefly in carrying out the great works in connection with the extension of the Royal Dockyard at Chatham. Less than twenty years ago, before the use of Portland cement concrete had become general, the Author was of opinion that he knew nearly as much as there was to be learnt, or at least as much as it was necessary for him to know on the matter; but, after long practical acquaintance with the value of Portland cement as a material for the manufacture of concrete, he is compelled to admit that he knows, after all, extremely little on a highly important subject; and that he constantly has reason to welcome further information on the behaviour of a material which he believes to be fast revolutionising the practice of the civil engineer.

In one form or another concrete has been used in various ways for ages; but, until recent times, it has been treated as quite subordinate to brickwork and masonry, and has been hidden away in foundations, as backing, or in "pockets" of brickwork or masonry to give dead weight, at small cost, to retaining walls.

Since it has become possible to obtain Portland cement at moderate cost and of uniformly good quality, engineers have learned to appreciate more highly the intrinsic value of concrete; and, for some years past, it has been steadily finding favour as a valuable material of construction, fit for independent existence, and for many purposes able to compete, on equal terms as to usefulness, and on superior terms as to cost, with brickwork or masonry.

The first attempt, in the recollection of the Author, to construct engineering works wholly of concrete was by a contractor named Ranger, who, about the year 1835, built a graving dock at Woolwich dockyard, and sea-walls at Woolwich, Chatham and elsewhere, entirely of that material. The concrete was made of greystone, or of hydraulic lime, and of Thames or beach gravel, and was mixed with hot water. It is believed that a patent was taken out by the inventor for the use of hot water for mixing concrete.

[1] The discussion upon this Paper was taken together with that upon the preceding and following ones.

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The floor of the dock blew up from weakness of construction, or from defective material, but the sea-wall at Woolwich is standing to this day, and was, a few years ago, in remarkably good condition. It is needless to say that hot water had little effect, for good or evil, on the concrete; but there is reason to believe that unusual care was taken in securing good proportions of lime and gravel, and especially in the combination of these materials.

As recently as the year 1867, when the first contract for the works for the extension of Chatham dockyard was put out for competition, so little confidence was placed by the Admiralty authorities in Portland cement, that the material is not even mentioned in the specification. Grey-stone and blue lias limes were prescribed for ordinary mortar and for all concrete; and pozzolano and Roman cement for use as mortar in all work below high-water mark. While blue lias lime was to be brought from Warwickshire, and pozzolano from Italy, for use as hydraulic cement, Portland cement, the most valuable of all, in the central district of its manufacture, and with two excellent manufactories within a few hundred yards of the works, was wholly ignored. For more than ten years past, however, Portland cement has superseded every other description of mortar for brickwork and masonry, as well as for all varieties of concrete.

Shortly after the commencement of the works, it was found difficult to secure steady and continuous supplies of freshly-burnt blue lias lime; still more difficult to secure its thoroughly fine grinding in sufficient quantities, and to preserve it, when ground, in good condition till required for use. It was also found that blue lias lime concrete, even when the lime was thoroughly good, and, as far as was known, properly ground and mixed in the best manner, did not always set well under water.

After much consideration and experiment it was determined to substitute Portland cement for blue lias lime, in the preparation of concrete; and, in order not to interfere with the contract, it was decided, if possible, to use the cement in such proportions as to admit of the contractor's providing the concrete at the same price as he had agreed to when using blue lias lime. The contract required the concrete to be made of 1 part of blue lias lime to 6 parts of river ballast. At the price allowed, it was found that, in order to supply Portland cement concrete at the same rate, it would be necessary to use the cement in the proportion of 1 part of cement to 12 parts of ballast. Comparative experiments were tried with the materials in these respective proportions; and it was found, beyond all question, that concrete made of 1 part of

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Portland cement to 12 parts of ballast was in all respects better and more uniformly trustworthy than the lias concrete of the original specification.

From that time Portland cement concrete has been used for all ordinary purposes at Chatham, in the proportions named, with a most satisfactory result.

The Author believes that concrete, in large quantities, has rarely been used by civil engineers with so small a proportion of Portland cement; but he is satisfied that, where the cement and gravel are of good quality, the mixing properly executed, and the work carried up carefully, without hurry, this proportion is ample for all ordinary purposes.

When it is remembered that where all the interstices between the aggregate of pebbles or broken stone, &c., are filled, the matrix amounts to only about one-third of the bulk of concrete, the aggregate becomes merely so many individual pieces of stone bedded in a mortar of about 1 part of cement to 4 parts of sand. Mortar of this combination is suitable for setting the very best kinds of brickwork or masonry; and the Author believes that it is therefore good enough to serve as a matrix to concrete for most purposes.

The Portland cement used at Chatham is supplied to the following specification:—

"The cement must be of uniformly good quality, finely ground, and weighing not less than 112 lbs. to the imperial (striked) bushel. At the time of delivery samples will be taken from about one sack in ten, and gauged in moulds. As soon as the test blocks are set they will be placed in water, and at the expiration of seven clear days, broken at the superintending civil engineer's office in the apparatus provided for that purpose.

"All cement that does not bear, without breaking, a weight of 650 lbs. upon the test blocks, of 1½ inch by 1½ inch in section, will be rejected, and must be at once removed from the works by, and at the expense of, the contractor."

It will be seen that the requirements of this specification are extremely moderate; and that, in the matters of weight per bushel, fineness of grinding, and tensile strength, it is far below the requirements of many civil engineers.

No importance can be attached to fine grinding except when the cement is of great weight; and when this is so, the cost becomes, in the opinion of the Author, greater than the fine grinding is worth, in comparison with the advantages of ordinary Portland cement if it can be obtained at a moderate price. In foreign

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countries, where the price of cement is enormously increased by the expenses of freight or transport, it may probably be well worth while to pay the cost of any increase of the initial value of cement that will make it go farther in combination with other materials for mortar or concrete. The value of a cement evidently depends upon its power of giving the greatest strength when combined with the largest proportion of sand, and the day is probably at hand when all engineers (as some do now) will test cement in combination with sand, instead of neat, as at present.

It may be worth mentioning that nearly 50,000 tons of cement have been supplied under the specification mentioned above; that the average weight per bushel has been 116½ lbs.; that the mean breaking strain of the briquettes has been 773½ lbs.; and that about 75 per cent., by weight, of the cement will pass through a sieve of 50 meshes to the lineal inch. The cement, with these characteristics, has been delivered at prices ranging from 27*s.* 6*d.* to 39*s.* per ton. The highest price was in 1873, when coals and labour were very dear. The lowest prices were in 1875 and 1879.

The cement is delivered in the contractor's sacks, and is stored in them until the testing is complete. If, as has very rarely happened, the tests are unsatisfactory, the cement is returned to the contractor in the same sacks. If the testing proves satisfactory, the cement is at once turned out on to the concrete floor of a shed with closed sides, where it can be stowed in bulk to a height not exceeding 4 feet. Each cargo is kept separate from all others.

No cement is allowed to be used until it has been stored, in bulk, for a minimum period of three weeks. This interval gives time for the air-slacking of all free lime in the cement; and in the Author's opinion it is unsafe to use any cement until this process has been effected. He believes that many of the so-called failures of cement are attributable to the neglect of this precaution. His experience is that fresh cement, on exposure to air, increases in bulk, without increase of weight, about 5 per cent.; and it must be, assuredly, safer to allow this expansion to take place in the store shed rather than in the work. Where, as is generally the case, the cement is used by measure instead of by weight, this increase of bulk will amply repay a contractor for the expense of turning the cement out of the sacks, and re-bagging it for issue when wanted. In re-bagging the cement the Author requires each bag to contain a definite bulk, bearing a direct ratio to the size of the gauge-box for the shingle, and to the proportion in which the cement is to be used. By this means considerable security is obtained against carelessness or fraud in mixing the

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concrete. On the Chatham works the shingle gauge-boxes are made of one uniform size, of such dimensions that each filling shall yield a cubic yard of concrete when mixed. Cement of exactly $\frac{1}{17}$ of the cubic contents of this gauge-box is placed in bags, each of which contains the quantity of cement required for each gauge-box. It is found in practice more easy to supervise the measurement of the cement in the shed than on the works.

The mixing of the concrete is at Chatham always done by hand. Several descriptions of mixing machines have been tried, and though some of them do the actual mixing to perfection, the concrete cannot be so advantageously, or even economically, brought from the machine to the place of deposit as when mixed by hand. If this is attempted by "shoots," there is an invariable tendency to a separation between the aggregate and the matrix, and it becomes necessary, at the place of deposit, again to mix them by hand. If the mixed concrete is dropped from the machine on to a platform beneath, and thence placed into barrows and wheeled to the place of deposit, little advantage is gained by machinery in mixing. It is practically impossible on a large work to be constantly shifting the machine, so as in all cases to bring it to the exact spot where the concrete is to be deposited.

The practice of the Author is to have the dry materials turned over twice, and then to apply water through the rose of a watering-can, turning over the materials twice in the process of wetting. Some engineers are particular in applying water in the smallest quantity that will suffice for wetting the concrete; but the Author is satisfied that an excess of water is beneficial rather than injurious to the concrete. In getting concrete into position much water passes away by absorption, by evaporation, or by actual leakage, so that in many cases the concrete is left too dry to allow of its setting perfectly. When concrete is made thoroughly wet it can bear to part with some of the surplus water by absorption, &c.; all the rest rises to the surface without bringing with it any portion of the cement. When got in wet the concrete admits of being made thoroughly solid against the sides of a trench, or against wood framing, by treading or working with a shovel, while the matrix never fills in the interstices in the aggregate so thoroughly as when water is freely used in mixing. No cement sets better than such as is covered by the tide almost immediately after it is put into place. It is needless to say that, in frosty weather, excess of water in mixing concrete is to be avoided.

In many cases engineers have found that large masses of concrete show horizontal and vertical shrinkage cracks on the exposed

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surfaces. Various explanations have been suggested as to the causes of those cracks. In the concrete works executed at Chatham such cracks have rarely, if ever, occurred. The Author is inclined to attribute immunity from this defect, partly, perhaps, to the free use of water in the mixing, but chiefly to the practice of thoroughly aërating the cement before it is used, and to the fact that the layers of concrete got in each day are never allowed to exceed 18 inches in thickness. It is far safer in carrying up a concrete wall to get in a length of 200 feet to a height of 18 inches daily, than to carry up half that length twice the height. It is the interest of contractors, in order to avoid extra wheeling or frequent shifting of staging, to carry up the work in short lengths of considerable height; but no engineer who values a good result will allow of this being done. It is always desirable, in order to ensure the solidity of walls, to leave the top surface of concrete as rough as possible, and to follow up the layers steadily from day to day.

At Chatham, if the top of a layer has been exposed for several days, the surface is always thoroughly swept clean of dust, or loose stones, and well watered before a fresh layer of concrete is put on it; if the surface has been exposed for some time, it is dusted over with neat cement after it has been watered. If, as will sometimes happen, the surface has been exposed for a considerable time, a chase is cut in the upper layer of the concrete, about 1 foot wide and 9 inches deep, in addition to the other precautions named, in order to secure a good key between the new concrete and the old.

For many purposes it is not absolutely necessary to fill in the concrete solid, but, in all concrete used in retaining walls, it is desirable that this should be done; while, when it is required to exclude water, it is absolutely indispensable. This result can be effected only where there is an ample quantity of sand (or cement) to fill the interstices; and to do this effectually it is necessary that the matrix, of whatever material composed, should be of a bulk of at least one-half of the aggregate. In beach shingle this proportion is very rarely exceeded; but it is not an uncommon practice on the part of contractors, and a practice much to be deprecated, to screen out some of the sand from the shingle for use with brickwork. It is more frequently necessary to add sand to the shingle than to remove it.

The shingle used at Chatham is dredged from the bed of the River Medway. The gravelly portions are coarse and more angular than the pebbles of Thames ballast, while the sand is always more or less loamy. When the quantity of loam is small, 12 parts

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of this gravel to 1 part of cement make, not only a good hard, but a very tough concrete; but an excess of loam is injurious, and, as the workmen say, "kills" the cement. In winter the slightest excess of loam in the gravel renders the concrete liable to injury from frost for a long time after it is made. Concrete made with Thames gravel will set, so as to be impervious to damage from frost, in much less time than when made from loamy gravel.

Over a large portion of the Chatham works concrete was used only for the foundations of masonry or brickwork, for backing to walls, and for similar purposes. The retaining walls generally consisted of a veneering of brickwork 3 feet thick, on a backing of concrete, with bond-courses of brickwork 21 inches thick (and with hoop-iron bond between the courses), passing horizontally through the wall at intervals of 6 feet, for the purpose of tying together the brick facing and concrete backing. Over, perhaps, three-fourths of the works a good foundation for the walls, of chalk, gravel, or loam, was found at depths varying from 48 to 52 feet below the coping; while, above this foundation, a deep deposit of hard silt lay immediately under the marsh mud. It was possible, therefore, by free use of timbering, to take out the wall trenches in such a manner as not to expose the walls, when finished, to the pressure of an excessive amount of backing, while the backing available was, generally, of fairly good quality.

On the eastern portion of the works, however, these conditions ceased to prevail; and the average depth at which good foundations were procurable was only attained at 60 feet. At the same time the hard silt was replaced by upwards of 35 feet of soft, recently deposited mud, necessitating the exposure of the retaining walls, when carried up, to enormous lateral pressure from the backing to be placed against them.

It became necessary, under these circumstances, to add materially to the strength and thickness of the retaining walls; while it was desirable, if possible, to avoid increasing the cost of the work. As the cost of the brickwork in the walls was, foot for foot, at least three times as great as that of the concrete, it was evidently possible to construct a much thicker and stronger wall, wholly of concrete, without increased cost. As a mere retaining wall, it was clear, from previous experience, that a concrete wall composed of 1 part of Portland cement to 12 parts of gravel, would be as good as one of similar concrete faced with brickwork; but it would not present so neat an appearance, nor would its face withstand so well as good hard brickwork, the rubbing of floating fenders, and the bumping of boats or larger vessels. It occurred to the Author

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that these objections would be overcome, if the common concrete could be protected by a thin facing of superior concrete, carried up simultaneously with the rest of the wall, and forming a homogeneous portion of it. A single experiment, made early in the year 1874, was sufficient to prove that this desideratum could be easily attained in practice; and all the retaining walls, as well as the walls of two locks and a graving dock, have since been built, most satisfactorily, on this plan.

A simple and inexpensive system of timber framing was devised, by which the form to be taken by the wall was outlined by planking, or shuttering, and kept in position to receive the concrete, against it; the liquid concrete was wheeled in barrows from the banker to the site of the wall, and filled in carefully against the shutters. The whole of the wall was composed of ordinary concrete, except a facing of from 9 to 10 inches thick on the side exposed to the water, which was formed of superior concrete.

This special concrete is composed of 4 parts by measure of slag, from the dockyard furnaces used in the re-manufacture of wrought iron, broken by one of Marsden's "Blake's stone crushers" into pieces of about $\frac{3}{4}$ inch cube. To this quantity of slag (which includes the dust arising in the crushing) is added 2 parts by measure, of coarse, sharp river sand, and 1 part of Portland cement. These component parts are mixed in the usual way, and put in position by a simple contrivance. A plank, $1\frac{1}{2}$ inch thick, 10 feet long, and 11 inches wide, is furnished with rope handles attached to one edge at each end of the plank. Two distance-pieces, from 9 to 10 inches long, are inserted loosely between the face shutter and this plank, which is placed on edge, to keep the proper distance for the facing. The common concrete is then put in from the back of the plank to the back face of the wall, while the slag concrete is filled in between the face of the wall and the face of the plank. The face concrete is then thoroughly worked by a shovel against the facing shutter, until all air has been expelled from it, when the plank is lifted and the two concretes well trodden together. The result is, first, that the two concretes become thoroughly incorporated at their line of junction; and, secondly, that a very hard facing, much stronger than brickwork, and as smooth and fair on the face as if it had been plastered, is put upon the common concrete wall, and is quite inseparable from it. The specific gravity of the face-concrete so made is nearly the same as that of Cornish granite. The appearance of this wall, when constructed with ordinary care, is far from unpleasing, either in texture or in colour; while it is needless to say it is much

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less expensive than any plan of composite construction with brickwork or masonry. This facing of superior concrete being very thin, in proportion to the bulk of material in the wall, adds little to the cost of a wall otherwise composed wholly of common concrete. Though good furnace-slag makes an admirable aggregate for facing concrete, a material nearly, if not quite as good, is found in granite, limestone, or other stone chips, or even in large gravel flints broken in a stone crusher to a gauge of $\frac{1}{2}$ to $\frac{3}{4}$ inch cube, as is done in the case of the slag. Face-concrete, formed of any of these materials in the proportion of 4 parts of the aggregate, 2 parts of sand, and 1 part of Portland cement, becomes so hard that it may be cut into for receiving bolts of any kind for fixing machinery just as if it were stone. For face-concrete of culverts, drains, penstock shafts, and other places not much exposed, ordinary Thames ballast or Medway ballast, washed and with the large stones raked out, with the addition of 1 part instead of 2 parts of sand, is used in combination with 1 part of Portland cement. Great care is taken to secure, while the material is fluid, the best possible surface to the face concrete, as defects cannot be made good afterwards without leaving a patch. The surface is invariably left with all imperfections, as it appears on the removal of the shuttering; no attempt is made to disguise the fact that the wall is of concrete.

Since a concrete wall, constructed as has been described, is practically a single homogeneous mass, it is advisable, wherever it can be done, to avoid the use of concrete blocks set like masonry. Where the concrete is deposited in a liquid state, *in situ*, a few planks, barrows, and tressel-staging will supersede the costly plant of gantries, travellers, staging and cranes necessary for making, storing, transporting and setting ponderous blocks of concrete.

The success attending the attempt to form a solid, united structure of two qualities and descriptions of concrete placed vertically, has led to its employment in a similar manner, horizontally, as well as vertically, for a variety of uses. It has been successfully employed for water-tanks without plastering, for crane-pits, and pump wells for engine-houses, and in the construction of foundations of steam engines, hydraulic capstans, and other machinery, at a moderate cost in all cases; while in foundations for machinery it presents great advantages in solidity of construction over foundations of brickwork or masonry. The principle has been applied to the vertical and horizontal faces of concrete copings, of river and basin walls, to flights of steps, and to curbs and surfaces of street paving, to areas and yards of dwelling-houses,

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floors of kitchens, sculleries, and blocks for house building, &c. For copings and steps, granite, broken into very small cubes, is generally used for the facing; while for paving, the small stones from river gravel, passed through a $\frac{1}{4}$-inch mesh sieve, is found to answer best. In the earlier part of this Paper the Author has insisted on the necessity of using an ample quantity of sand, for forming, with the cement, the matrix for the aggregate; but he has found that, for face-concrete, in steps and paving, and for surfaces exposed to heavy foot traffic, it is necessary to eliminate all sand, and to form the matrix of neat Portland cement. The composition used in all these cases is 2 parts of the aggregate, of whatever material, and 1 part of Portland cement. The durability of paving and steps so made is greater than that of Yorkshire or Portland stone, while its cost is much less.

In the case of copings, &c., the face-concrete is about 2 inches thick; while in surface paving it is not more than $\frac{3}{4}$ inch thick. It is needless to say that, in using horizontal face-concrete, it is as necessary as in vertical face concrete that the two materials, in order to ensure thorough union, should be put in as nearly as may be simultaneously. When the face-concrete of granite is used for copings to dock or river walls, curbs to capstans, &c., it is found that, if dressed over with a diamond-pointed hammer, the foot hold is much improved, and it is then difficult to distinguish the concrete from real granite.

It is the practice at Chatham to let in ring-bolts, fairleads and bollards, into the liquid concrete as the walls are carried up. The ironwork gets as good a hold on the wall as if set in granite, while, in the case of fairleads, the cost is considerably less than $\frac{1}{10}$ of that of letting them into granite.

The sections of basin, lock, and dock walls, &c. (Plate 6), show a variety of applications of facing-concrete to engineering purposes. These uses might easily have been multiplied, but enough has been given to show the numerous applications of which the principle is capable. It will be observed that the upper arch of one of the subways and of one of the culverts is shown as formed of a single ring of brickwork. This part of the work may just as well be executed in concrete; but if brickwork be used, the centering can be struck sooner, and the work carried on more rapidly.

This Paper is only intended to indicate a few among the numerous uses to which concrete has been put for engineering or architectural purposes. The object has been rather to draw attention to its use for independent and complete works, and to show

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that, by the employment of such a cheap and good material, many engineering works that would be otherwise impossible of execution on the score of expense, may be rendered practicable, and may be carried out cheaply and in a durable manner.

Most of the work at Chatham has been executed by convict labour, and with material dredged, at small cost, on the spot. Any account, therefore, of the actual cost in money would be of little value to others working under ordinary conditions.

In the annexed Table the net cost of a cubic yard of concrete, formed of 12 parts of shingle to 1 part of Portland cement, is calculated carefully in detail at about the ordinary London rates for material and labour.

The cost so estimated of 1 cubic yard of concrete is 7*s.* 2*d.* Calculated on the same basis a yard of 9 parts of shingle to 1 part of cement will cost 8*s.* 2½*d.*, and of 6 parts of shingle to 1 part of cement, 10*s.* 3*d.* The framing for the basin wall (Fig. 1) adds from 4*d.* to 6*d.* per cubic yard, according to circumstances, to the cost; and is of course the same in all cases, whatever description of concrete is used. A cubic yard of slag concrete (6 to 1) used in facing will cost about 12*s.* 2*d.* per yard; of flint-face concrete about 14*s.* 2*d.*

The proportion of slag concrete at 12*s.* 2*d.* required for facing a wall of the section shown in Fig. 1 is so small that the whole cost of the concrete, on a lineal foot of the wall, is only increased by about 2½*d.* per cubic yard; thus making the entire cost of the wall including staging and framing, about 7*s.* 10*d.* per cubic yard.

NET COST of 1 CUBIC YARD of PORTLAND CEMENT CONCRETE, 12 PARTS of GRAVEL to 1 PART of CEMENT.

	s.	*d.*
1¼ cubic yard gravel alongside wharf (the quantity includes 16 per cent. for shrinkage, and 4 per cent. for waste), per cubic yard 2*s.*	2	5
2 1/16 cwt. Portland cement alongside wharf, including allowance for waste and use of bags, per cwt. 1*s.* 6*d.*	3	1
50 gallons water, including allowance for waste and use of service pipes, per 1,000 gallons 10*d.*		½
1 cubic yard mixing concrete and depositing in work, per cubic yard 1*s.* 1*d.*	1	1
1¼ cubic yard landing gravel, including use of crane and depositing in trucks, per cubic yard 3*d.*		3¼
2 1/16 cwt. unloading cement and placing in store, loading cement at store for transport to work, unloading at work, use of store shed, &c., per cwt. ¾*d.*		1½
1¼ cubic yard transport of cement and gravel to work, including use of trucks, roads, banking, &c., per cubic yard 1*d.*		1½
Total	7	2

The communication is illustrated by a series of diagrams, from which Plate 6 has been prepared.

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(*Paper No. 1700.*)

"Portland Cement; its Nature, Tests, and Uses."[1]

By JOHN GRANT, M. Inst. C.E.

1. DURING the last twenty years the use of Portland cement has greatly extended, improvements have been made in its manufacture, and much attention given to the best methods of testing and using it. In England, Germany, France, America and elsewhere, increasing interest has been taken by engineers, manufacturers and technical chemists, in investigating its nature and the conditions which affect its strength and adaptability to works of different kinds. In two Papers, read before this Institution in 1865 and 1871,[2] the Author gave the results of a number of tests and experiments commenced in 1858; but even since 1871 enough has been added to the general knowledge of the subject to make it seem worth while to review a few of the more important points, especially those which relate to more perfect modes of testing the qualities of cement.

The testing of this material is by no means so simple or so easy as the testing of iron, steel, stones, &c.; because the cement, being supplied in the form of a fine powder, has to be formed into briquettes and pass through a great variety of operations demanding the utmost care, and attention to the minutest points of detail. The slightest want of uniformity in the smallest appreciable condition will affect the results to an extent which will make them worthless for comparison, and which only those who have had considerable experience could believe.

Within the last three years certain rules for supplying and testing cement have been agreed upon by the engineers and manufacturers of Germany and Austria, in which countries most of the public works are carried on under the auspices of Government engineers. In this country every engineer specifies that which he considers best adapted for the work he designs. By drawing attention to what has been done on the continent, an opportunity will be given for forming a judgment of the merits of the foreign system. At Berlin, Munich, and other chief cities on the continent, there are official establishments where cement and

[1] The discussion upon this Paper was taken together with that upon the two preceding ones.

[2] *Vide* Minutes of Proceedings Inst. C.E., vols. xxv., p. 66, and xxxii., p. 266.

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other building materials may be tested under the supervision of scientific men, and by means of very ingenious and complete apparatus. Useful as these establishments are for the promotion of scientific knowledge, and for obtaining accurate and impartial reports, there is nothing to prevent them from being employed for trade purposes, by sending specially prepared samples for the purpose of getting certificates, to be afterwards extensively published in trade circulars as trustworthy and indisputable proofs of the high character of the general produce, to which, however, they may be utterly inapplicable. There may be some security in having a guarantee of quality from a manufacturer, and for small quantities this may be sufficient; but for large works, extending over a long time, the safest and most convenient course is to thoroughly test every delivery.

Nothing has done so much to raise the quality of cement in Germany as the adoption of the system of testing its strength when mixed with three times its weight of sand of a standard gauge and quality, and made into briquettes which are tested when twenty-eight days old. To give a clue to any cause of discrepancy or disappointment which may arise, and for experimental purposes, it is desirable to ascertain its weight, degree of fineness, time of setting, and, where there are facilities for it, the chemical character and other features of cement. But if it give the required strength when mixed with sand after four weeks it may be accepted without fear, and the specification be much simplified.

The discovery of the influence of fine grinding on the strength of cement thus tested, and the adoption of this test of cement with sand throughout Germany and Austria, have led the manufacturers in those countries to pay special attention to the production of finely ground cement, as otherwise it could not come up to the accepted standard. The principal makers, however, produce, and in some cases guarantee, a much higher quality; and there is reason to believe that the standard of strength, which has already been raised 25 per cent., will by general consent be raised still higher.

The Author has for several years past used the test of cement with sand, and would have adopted it long before he did, but for the occasional and temporary difficulty it involves at the commencement of works carried on in public thoroughfares, of waiting a month to know the results. This can, however, in most cases be got over either by making early arrangements for getting the cement, by a tentative test at seven or fourteen days, or by other methods approximately ascertaining the quality of

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that which has to be first used; but no cement should be rejected before the test at twenty-eight days has been made.

Numerous experiments, by a great number of observers in different countries, have shown beyond dispute that heavy, well burnt cements, which when tested neat have given high results, have notwithstanding, when mixed with sand, turned out disproportionately weak. Even when the important test of fineness is coupled with that of weight, the strength of cement if tested neat does not always correspond with its strength when mixed with sand. The only thing wanting to make this (sand with cement) test perfect is time, *i.e.*, to be able to wait for the results months, instead of weeks. In four weeks, however, a fair and practically accurate judgment may be formed; though if for experimental purposes a number of different cements be tested simultaneously every month for, say, a year, those which were but second or third at the end of a month may overtake and surpass the first. Further remarks on this part of the subject will be found under the head of "Time of Setting."

The chief object of this Paper is not to describe the best or different ways of making cement, but the best known methods of ascertaining its strength, that it may be used to the greatest advantage, its quality be accurately ascertained, disputes avoided, and results compared with those of other observers at home and abroad. The subject has many features, and is almost inexhaustible. For its clearer elucidation it will be necessary to some extent to refer briefly to some points already discussed by various writers.

2. *Manufacture.*—The strength of Portland cement depends on the thorough amalgamation of the raw materials mixed in proper proportions, the extent and degree to which they are burnt, and the greater or less approximation to an impalpable powder attained in grinding the clinker.

3. *Materials.*—Chalk and clay are the materials used on the Thames and Medway, at Boulogne, at Stettin in North Germany, and elsewhere; limestone and clay at Rugby and Stockton in Warwickshire, Bridgwater in Somerset, Poole and Wareham in Dorset. At Biebrich on the Rhine, and at some other places in the neighbourhood of Mayence, at Bonn, &c., the marl and hard limestone of the tertiary basin of Mayence are used. The chalk and clay in proper proportions are reduced to a milky state, with more or less of water either in shallow ponds, called "backs," or by Goreham's process, with about a third or fourth of the water used in the former case, pugged, ground and pumped, or otherwise passed on to the drying

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flues. The limestones are mixed with clay in proper proportions, and ground to a fine powder; a minimum quantity of water is added, and the whole passed through pug mills, and either formed into bricks or cut up into pieces fit for the kilns. In one manufactory, the works at Biebrich, the wet and dry processes are combined.

4. *Proportion of chalk or lime and clay for cement.*—The strength of cement depends, in great measure, upon the right proportion between the chief constituents being observed in the manufacture. If the lime be in excess, the cement has a tendency to crack and blow, especially if not sufficiently burnt, or finely ground. If the clay be in excess, the cement will be permanently weak, will have a buff colour when made up neat and exposed to the air, and to some extent have the character of Roman cement.

5. *Burning.*—The burning is in kilns of different forms, the best combining thorough and uniform calcination with economy. Many of the kilns are of the simplest kind, and waste much heat. With others a series of heating flues is combined, through which the air passes, on its way to the chimney, over or under the slurry from the "backs" or the pug mills; or else through the chambers in which the "bricks" are stacked on "hacks" or shelves. In some cases the heat is generated specially and separately for this purpose. Both coal and coke are used as fuel. In Germany the Hoffman kiln, or Ringofen, is much used, and though expensive in the first instance, appears to combine economy with great uniformity in the burning. It has in one or two instances been tried for cement in this country, and abandoned or modified. Whether this was due to inattention to some details in constructing or using it, is difficult to say. It gives perfect satisfaction to those who have it in Germany, and its use is constantly extending. The Pluckley Brick Company, Kent, has one of fourteen compartments, each holding twenty-five thousand bricks, in which blue bricks are satisfactorily burnt to the point of vitrifaction. Its cost was about £3,000. To produce clinker of uniform character burnt to a point short of vitrifaction, is perfect burning.

6. *Grinding.*—The clinker, broken into small pieces, is ground like flour between millstones. It is ground finer in Germany than in this country. The standard of fineness, recognised throughout Germany and Austria, is that the residue must not exceed 20 per cent. on a sieve of 900 meshes per square centimètre = 5,806 per square inch, or 76·2 meshes per lineal inch. In practice the principal manufacturers supply cement so fine that the residue does not exceed 10 per cent. The reason for this is that they have found

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by experience that they can thus best bring out, and prove the high quality and economy of, their cement when mixed with sand and subjected to the test for tensile strength. In England the residue would be from 15 per cent. to 27 per cent. with a sieve of 400 meshes to the square centimètre = 2,580 per square inch, or 50·8 meshes per lineal inch. The coarser part, which is generally the hardest and most highly burnt, when not finely ground has hardly any cementitious value, and may be left out without much, if any, diminution of strength, and the waste is therefore enormous; but if finely ground this coarse part becomes the best. The practical importance of this quality of fineness will be best understood by examining the Tables in the Appendix.

It is a question for the manufacturers whether it would not be economical to use two sets of millstones, and to combine a system of blowers or fans to separate the fine from the coarse cement, and thereby reduce the quantity requiring to be ground a second time. Bovill's patents are an application of this principle to the grinding of flour. Because cement when lightly burnt is more easily ground fine, some advocate a light but fine cement, which is a mistake. Lightly burnt cement at seven, or even twenty-eight days, may appear to be superior to heavy, which is with difficulty ground as fine as the lightly burnt; but in the long run, the heavy, if not too coarsely ground, will surpass the lightly burnt, and if the heavily burnt were as finely ground as the light, it would be a great deal stronger from the beginning, the time of setting being of course the same. Fine cement, as it takes more sand, goes further than coarse. It is also much safer, where it verges on the blowing point from an excess of lime.

7. *Sifting.*—In some manufactories, where grinding is carried to perfection, there is no after-sifting, only the test sifting by the miller during the process of grinding; but in some cases, both at home and abroad, the cement is passed from the mill through sieves of one kind or another. By whatever process fineness is secured, the effective quality of the cement is improved; but the coarse, and generally stronger part, should be re-ground and mixed with the finer. Heavy clinker ground fine will, when tested, give higher results than lighter cement of equal fineness obtained by sifting. The difference in strength of coarse and fine cements is not ascertained by testing them neat, for of the two the coarse would generally appear to be the stronger. It is only when mixed with sand that this can be seen. For illustration of this point, see Tables in the Appendix, Nos. XXVII.–XXXI., XXXVIII., XXXIX., XLI., XLII., XLV.–XLVII.

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8. *Weight of cement.*—Though the test of tensile strength with 3 parts of sand to 1 part of cement after twenty-eight days is sufficient, and makes any other test of minor importance, it is desirable, as a means of approximately comparing the fineness and quality of cements made of the same raw materials, to ascertain their weight; but before doing so they should be sifted; then, by means of one or other of the funnels or fillers shown on Figs. 32 and 33, put into a measure, which may be an imperial bushel, or one-tenth of a bushel, or a litre, of which there are 36·3477 in a bushel. Coarse cement, being less in bulk than finer, renders it necessary to ascertain the degree of fineness. The larger the measure, the more is the cement compressed. Thus it will be found that it takes about $10\frac{3}{4}$ of the tenth of a bushel, or about 40 litres of cement, to fill a bushel measure. For this reason the same size of measure must be used, and be filled in the same way, in comparing the weights of different cements. To judge of the quality of cement by its weight alone, without regard to the raw materials of which it is made, or to its fineness, is impossible; but having regard to these it is, within certain limits, one characteristic of strong cement, and it is desirable that it should be ascertained as nearly as possible. Mr. Colson, Mr. Maclay, and Mr. Mann, all dispute the theory that the weight and strength of cement have any relation to each other; and to prove this refer to experiments made by themselves and the Author with briquettes of neat cement seven days old. But long experience has shown that no sound conclusions can be drawn from tests made with neat cement, especially after an interval of only seven days, and with cements that vary in their composition, age, time of setting and fineness, as well as in the quantity of water used and density obtained in making the briquettes. If the relative strength of two or more cements has to be ascertained, not only must all the conditions be uniformly observed, but for accuracy many months must be allowed to elapse between making the briquettes and testing them. It is frequently found, as has been already stated, that those which at the earlier stages were apparently the weaker, afterwards overtake the stronger. On the whole, the relative strength and economical value of different cements can be better ascertained by mixing them with sand, than by making the briquettes of neat cement. The proportion of water to the combined weight of cement and sand can be kept uniform, or nearly so.

9. *Specific gravity.*—In the discussion upon the Author's first Paper (1865), Mr. Bramwell suggested that it would be better to ascertain the specific gravity than the weight of cement. Mr.

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Mann, in a recent Paper,[1] described a simple means of doing this by a small glass vessel and a graduated glass pipette. The Author still ascertains the weight of cements in the manner which has been described, and he has for a long time for experimental purposes, but without practical benefit, taken their specific gravity by means of a bottle suggested by Mr. T. W. Keates, F.C.S., for this purpose, described in an Appendix, page 66. On this subject, some remarks which appeared in "Thonindustrie Zeitung," 1877, from the Chemical Laboratory for Ceramics, are also given.

10. *Time that cement takes to set.*—It is of great importance to note, every time that briquettes are being made, the number of minutes that the cement takes to set when made into a thin cake neat. If it take the impression of a finger-nail after two hours, when kept in air, it may be considered slow setting. A quick-setting, not to be confounded with lightly-burnt, cement, may, as a rule, at seven and twenty-eight days, show less apparent strength than slow-setting, and yet, at a later period, grow stronger, and overtake and surpass the latter. Slow-setting cements (not heavy) show high strength in the early stage of hardening; but the strength does not increase in the same high degree as quicker-setting cement after twenty-eight or more days. Heavily-burnt cement, ground as fine as lightly-burnt cement, will always attain to higher strength than lightly-burnt. Coarsely-ground cement will, as a rule, give somewhat higher results when tested neat than finely-ground; but when mixed with sand, say, in the proportion of 1 to 3, the superiority of the finely-ground cement becomes apparent.

The heaviest and strongest cements are generally, though not uniformly, the slowest. A higher test may be applied to and required of slow-setting cement. Thus it has been proposed in Germany to make the tensile strain:—

1. 10 kilogrammes per square centimètre for cement setting in from thirty minutes to two hours.

2. 12 kilogrammes for cement setting in from two to five hours.

3. 14 kilogrammes for cement taking more than five hours to set, being equal to 142·23, 170·68, and 199·12 lbs. per square inch respectively, for 1 part of cement with 3 parts of standard sand at twenty-eight days.

In illustration of the fact that if the time of setting is prolonged, either by storing or otherwise, the initial strength will

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlvii., p. 248.

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increase in proportion, the following results have been communicated by Messrs. Dyckerhoff:—

Time of Setting.	Tensile Strength per Square Centimètre. At 28 Days. Kilogrammes.	At 12 Months. Kilogrammes.	
30 minutes	14·7	28·6	
10 hours	14·4	25·5	
10 minutes	10·5	25·7	
1 hour	12·7	22·1	
20 minutes	13·9	32·1	The same cement made
7 hours	17·3	32·3	slow by storing.
5 „	19·6	32·4	
30 minutes	14·7	28·6	
10 hours	17·1	28·3	
45 minutes	10·8	25·3	
11 hours	16·5	27·2	

From these facts, it may fairly be concluded that a cement capable of enduring a tensile strain of 10 kilogrammes per square centimètre (142 lbs. per square inch), setting in thirty minutes, is not inferior in quality, or worth less, than another of 14 kilogrammes per square centimètre (about 200 lbs. per square inch) which takes five hours to set. If, however, a cement which sets in from thirty minutes to two hours shows 14 kilogrammes per square centimètre (200 lbs. per square inch), it is superior in quality to one that shows the same strength setting in five hours, because the former will increase in strength if brought to set in the same time. Still further, the superiority of the quicker setting cement of 14 kilogrammes at twenty-eight days, is proved at later periods by its surpassing the slow-setting of 14 kilogrammes at twenty-eight days.

11. *Hardening.*—After "setting," the process of hardening commences and goes on for years. There is no reason to fear that good cement ever deteriorates: for though the result of a series extending over ten years, seven of which were given in Table XVIII. of the Author's first Paper in 1865, appeared to fall off in the eighth, ninth, and tenth years, this was in all probability due to the fact that, from the person who had charge of them having died, the briquettes were shifted from place to place, neglected, and were eventually tested by another person.

12. *Effect of storing cement.*—It is one of the valuable qualities of Portland cement that, at least within considerable limits, the time it is kept before being used does not injure, but, on the contrary, improves it if kept dry. Cement should be delivered fit for

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immediate use, but if not, should be spread out and cooled before it is used. It will then, if good, give higher results than it would when new or hot. Sometimes cement, that if tested new would have a tendency to crack or blow, will, if kept in store for a fortnight, lose this tendency. It is to the advantage of the manufacturer to keep a stock of cement in clinker, that it may cool and mellow, and be more easily ground.

13. *Effect of temperature of air and water.*—The water used in making mortar or concrete is best when of moderate temperature. During the process of setting and hardening, especially in the earlier stages, the abstraction of moisture by external heat, or a draught, is most prejudicial, and should be counteracted, by keeping the brickwork or concrete wet. This explains the apparent anomaly that, although concrete made with just sufficient water is stronger than that in which there is an excess, many engineers prefer the latter, especially if the work is above ground and exposed to the action of the sun and wind. But concrete made with water in just sufficient proportion, which is well rammed, and if above ground, kept wet during the first two or three weeks, becomes the hardest. For this reason concrete blocks kept in water become exceedingly strong. Some interesting experiments by Mr. W. M. Maclay, on the effect upon cement of air and water of extremely low temperatures, were published in December 1877, in the sixth volume of the Transactions of the American Society of Engineers. These form a substantial addition to the information accumulated on the general subject, and their value will be greatly enhanced if a greater number of them be made with briquettes at least a month old, with and without sand. The Author has for some years attached very little value to experiments with neat cement made at the end of a week, and would only use them for marking a stage in the growth of strength, or where, from unavoidable circumstances, it was necessary to ascertain approximately the quality of a cement.

14. *Effect of heat.*—Dry heat, by abstracting the necessary moisture, is, as already stated, prejudicial to the strength of cement whilst setting or hardening. It ceases to be hurtful when the latter process has attained to a certain point. For this reason cement testing should be conducted in a room of moderate temperature; and to prevent the abstraction of the moisture required whilst setting, the briquettes should either be covered with a wet cloth, or be put into a box with a lid, lined with damp woollen or linen cloth, and kept thus until they are put into water. Briquettes of neat cement, after being kept in water, if taken out of water and exposed to heat or dry air, seem for a time to lose part of their

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strength. But after the hardening process has gone on for some time the difference is not so perceptible. This does not apply to briquettes made with a mixture of sand, which, on the contrary, bear a higher strain. Dry heat stimulates the tendency to crack or blow, where such tendency exists either from an excess of lime or imperfect burning. For this reason some make a very thin cake of cement on an iron plate, and heat it under a gas jet to develop this tendency, if it exist. Others expose a cake of cement before a fire. In the application of either of these tests there is considerable risk of making a mistake and rejecting some of the best cement, for which reason the Author does not recommend them. Warm water should not be used in mixing cement, unless on occasion to make it set quickly. Salt water is as well adapted for mixing mortar or concrete as fresh; except for walls of houses or plaster.

15. *Effect of sulphuric acid.*—There is generally 0·5 to 1·5 per cent. of sulphuric acid in Portland cement. Its effect is to prolong the time of setting, but in excess it is injurious. It has sometimes been added to quick-setting cements to give at first, though but temporarily, an appearance of greater strength. This is supposed to be due to its retarding the setting, and thereby giving time for the particles to cohere more closely. It has not this effect upon cements already slow-setting and well made. Here it may be observed that the time which cement takes to set is more dependent on the nature, proportion, and comminution of the raw materials than on the burning; though, as a rule, the more highly a cement is burnt the more slowly it sets. Some quick-setting cements are highly, and some slow-setting lightly, burnt.

16. *Selenitic process.*—The effect of using a small quantity of plaster of Paris, or its equivalent of sulphuric acid, is partly shown by the experiments in Tables XXXII.–XXXV. and XLIII. A series of tests made with samples kept in water is required, and of others tested by tensile strain.

17. *Testing lime.*—In Appendix XLIII. will be found a few experiments made with Aberthaw, lias, and other hydraulic limes as ordinarily used, and as treated by the Selenitic process. Had circumstances allowed, these would have been greatly extended, so as to give a much more complete view of the value of these limes compared with cement. From their generally lower strength and slower action it is much more tedious to test limes than cement; and it would take some years to get a sufficient number of results to form the basis for a sound judgment.

18. *Expansion of cement.*—From a Table, Appendix XLVIII., which

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gives the results of a series of experiments by Messrs. Dyckerhoff, on the expansion of various cements, extending over twelve months, it may be inferred:—1. That all cements expand more or less when hardening in water; 2. That the expansion of good cements is so very slight that in practice it need hardly be taken into consideration; 3. That it is greatest when the increase of strength is most active; 4. That it diminishes in proportion to the addition of sand; 5. That it is greatest with new cement, and least with that which has been kept in stock; 6. That it is increased by the addition of gypsum; 7. Further experiments prove that it is greatest with over-limed or lightly-burnt cements, and that all cements contract when drying, and expand on being put into water. Similar experiments on different kinds of brick and stone show that these also expand when wet, and contract as they dry, and it would be interesting to pursue this investigation further.

19. *Testing by compression.*—To test the strength of cement or concrete by compression is not so delicate or accurate an operation as to test by tensile strain. The results vary with the size, form, and proportions adopted. Thus cubes, prisms, columns, cylinders, bars, &c., all differ from each other as their dimensions and proportions differ. Elaborate experiments have been made on this point by Professor Bauschinger, of the Polytechnic School, Munich, Dr. Michaëlis, of Berlin, Messrs. Dyckerhoff, of Biebrich, and others. Some of these results are given in the Appendix. Dr. Michaëlis has expressed the opinion that after some years cement ceases to grow in tensile strength, and becomes like a piece of pottery, after which it should be tested by compression. Messrs. Dyckerhoff, with the view of ascertaining the relation between tensile and compressive strength, after trying cubes of 10 × 10 × 10 centimètres (= about 4 inches) and of other sizes, tried a circular mould of 7·15 centimètres diameter, having an area of 40 square centimètres, and a depth of 2·236 centimètres. This they filled with cement and sand in the same proportion as for the briquettes of 5 square centimètres, used for testing by tensile strain, and made them in the same way and at the same time. The conditions were thus all alike, and the general result was that the compressive was found to be about twenty times that of the tensile strength.

20. *Adhesion.*—In his earlier Papers the Author gave a number of experiments on the adhesion of different kinds of stone and brick cemented together with various cements and mortars. Professor Bauschinger, Dr. Michaëlis, and others, have pursued this in-

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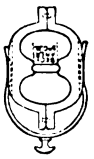
quiry; and for this purpose Dr. Michaëlis has adopted the form of briquette used for tensile strain (area 5 square centimètres), in which he inserts a thin lamina of brick or stone, cemented with the mortar of which he desires to test the adhesive strength. Whether the small area of the breaking section will give trustworthy results remains to be seen.



In some which the Author has recently made with bricks, having an area of 40 square inches, cemented together with mortar made of 1 part of cement to 2 parts of sand, the adhesion after twenty-eight days was found to vary from 15 to 30 lbs. per square inch. But adhesion must vary with the qualities of the bricks, their rough or smooth surface, porosity and degree of saturation; the strength of the cement, quality of the sand, and time that the mortar has had to set.

21. *Effect of the proportion of water used in making mortar or concrete.*—An excess of water weakens either cement mortar or concrete, and no more should be used than is necessary to work up either and make it fit for use. More than this produces porousness and retards the process of hardening. The extent to which even a small additional quantity of water, beyond what is required to thoroughly mix the materials, diminishes the strength, may be seen by studying the Tables in the Appendix. In testing cement the proportion of water used should be ascertained by weight with relation to the cement and sand. Briquettes of neat cement may be made upon plates of plaster of Paris much denser, so as to take more cement, and be apparently much stronger than those made on a marble or slate slab. With hot or quick-setting cement more water will be required in making tests of neat cement than with cool and slow-setting cement. For tests made with cement and sand the proportion of water may be kept nearly uniform with all cements which take more than thirty minutes to set, which is an advantage in making comparative tests. With those that set in less than thirty minutes from 11 to 12 per cent. of water may be required.

22. *Effect of sand.*—Sand mixed with cement dilutes its strength. In other words, neat cement is stronger than any mixture that can be made of it with sand, gravel, or broken stone. Sand should be perfectly clean, sharp, hard, and angular. Cement will go farther with coarse sand of large grain than with fine. For the same reason in walls that are thick enough there is economy in using stone, broken bricks, and coarse gravel, care being taken that the cement and sand are sufficient to fill the interstices. The stone or bricks for such purpose should all be wet. Some old Roman work might

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indifferently be called rubble-stone or coarse concrete. For mortar in brickwork, where the proportion of sand is greater than 2 to 1, or the sand is coarse and sharp, a small quantity of lime or chalk will make the mortar fat and mellow to work with, better than fine loamy sand. Mr. Bernays, of Chatham dockyard, makes a strong cement mortar cheaper than lime, with 8 parts of sand, 1 part being foundry loam. This is for an economical mortar; but for strength there is nothing superior to cement without lime. In Germany many interesting experiments have been made on this subject by various observers. Some by Messrs. Dyckerhoff are given in the Appendix. One effect of sand is to retard the process of hardening, which should not be lost sight of when using concrete for arches or floors supported on centres or timber. From what has been already said, it will be understood that by using the minimum proportion of water and compressing the concrete, the time required for hardening is reduced. As in testing with briquettes of sand and cement the process of hardening goes on at a slower rate than with neat, twenty-eight days has, by pretty general consent, been adopted as the earliest time for ascertaining their strength when made with 3 parts of sand to 1 part of cement. Where experiments with larger proportions of sand, or comparative tests are made of different cements, or under different conditions, a longer time is desirable, as it will often be found that those which at an earlier stage led the way, fall off at a later.

23. *Mixing concrete.*—Cement concrete may either be made by hand or by one or other of several machines. If by hand, the materials should be turned over at least three times dry; the water in fixed proportion being then added through a "rose," and turned over three or four times wet. In proportioning the quantity of cement to gravel it would be advisable to specify a given weight to a yard, rather than a given quantity in bulk, as it would favour the supply of strong heavy cement. The measure for the gravel should, for the sake of accuracy, be as nearly as possible a cube, whose height is equal to either of its other dimensions. So with the cement if measured. The machines used for mixing are the pug-mill, or a horizontal trough, with a screw turning the materials over and working them forward; or for large quantities, Messent's machine. There is one advantage in using a shovel or barrow for filling in concrete, that the larger stones are not so apt to separate from the finer gravel, as when shot in a continuous stream out of a trough.

24. *Compression.*—It is perhaps needless to say that compression adds to the strength of concrete. For blocks, thin walls, sewers,

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arches, floors, or paving, concrete may be punned in layers with advantage. The concrete for flagging, or artificial stone paving, made at Messrs. Hodges and Butler's works, is shaken in a machine invented for this purpose. In making concrete tubes and sewers in segments, and junction and invert blocks, considerable force is used, either by hand or a tamping machine. Such tubes, blocks, &c., are exceedingly dense, strong and true in form. They are largely used both in Germany and in England, and supply a want where either brickwork or stoneware is expensive. Objection has been taken that they are subject to the action of acids, and therefore unfit for the conveyance of sewage; but, as a matter of fact, the amount of acid to be found in ordinary sewage is not enough to have this effect; and if it were, it would act equally upon the joints of brickwork or pipes made with either cement or lime mortar, and involve the use of pitch. Even iron pipes and gratings would be acted upon.

25. *Concrete in blocks and in a soft state.*—For various purposes concrete is made in blocks, sometimes of very large size. This is of course more costly than when the concrete can be put in place in a soft state. Blocks can be made in a variety of shapes, and be splayed, bevelled, chamfered, or curved like worked stones. They afford facilities for compressing the material to any required degree of density, and for keeping them any length of time to harden before being put into the work. If any defect show itself the defective block can be kept out. As before mentioned, wherever possible, they should be kept under water, or be regularly watered for some weeks, to keep them damp. Concrete is well adapted for making every variety of culverts, openings, junctions, copings, kerbs, and channels. As a rule, it saves in the cost of labour at least a third to use concrete in a soft state. At Chatham Dockyard Mr. Bernays has made copings to the dock walls *in situ* that can scarcely be distinguished from granite, the sand being washed and used with one-third of cement. Lewis-bolt holes, mooring-rings, bollards, &c., are fixed in the concrete as the work proceeds at trifling expense.

Walls of concrete should be carried up uniformly in layers of moderate height, the bed of each fresh layer being watered with thin grout. By this means vertical cracks proceeding from unequal setting will be prevented.

For concrete, as for mortars, cement cannot be ground too fine. In mixing cement with sand it is to be observed that its bulk is affected by its weight and degree of fineness. A cement of 100 lbs. to the bushel will of course be larger in bulk than one of 120 or

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125 lbs., and still more so if ground much finer. As cement is mostly sold by weight it is by weight, combined with fineness and tensile strength when mixed with sand, that the relative economical value of different cements for the purpose to which they are to be applied is to be ascertained. Being sold by weight, it should be brought in bags of a given weight, adapted to the proportion of the cement to gravel that is to be used. Assuming the cement to weigh 112 lbs. to the bushel, and the gravel 2,900 lbs. per cubic yard of 21 net bushels—

2 bushels, or cwt., per cube yard, will be equal to 1 to 10½ by bulk, or 1 to 13 by weight.
2⅔ bushels, or cwt., per cube yard, will be equal to 1 to 8 by bulk, or 1 to 10⅓ by weight.
3 bushels, or cwt., per cube yard, will be equal to 1 to 7 by bulk, or 1 to 8¾ by weight.
3½ bushels, or cwt., per cube yard, will be equal to 1 to 6 by bulk, or 1 to 7·4 by weight.

26. *Effect of acids on cement.*—Some prejudice has been felt against Portland cement because of the possibility of its being affected by muriatic, nitric, or sulphuric acid. In only two cases, after an experience of thirty years, has the Author observed the effect of diluted muriatic acid on cement. In one case where the sewer received the drainage of a number of chemical works at Battersea, the acid very slightly affected the concrete under the mouth of a drain connected with the sewer; but there was no perceptible effect elsewhere. In the other the invert of a sewer in Church Street, Lambeth, built of gault clay bricks, was injured for several hundred feet, but the cement in the joints withstood the action of the acids better than the bricks. The invert was repaired with cement concrete. In exceptional cases where a drain or sewer takes the waste acid of the works in which it is used, and more especially where the quantity of water flowing through the sewer is under ordinary circumstances small, it may be desirable to use vitrified bricks or pipes, and make the joints with asphalt or some other material. But the need for such exceptional materials is very rare; and it would be as unwise to give up the use of cement and of a great variety of bricks adapted for sewers, as to abandon iron for penstocks and sewer gratings because it will not resist the action of certain acids.

27. *Conditions affecting the strength of cement, and the accuracy of the tests applied to it.*—From what has been stated it may be concluded that, to ascertain the tensile strength of cement with some approximation to accuracy, it is necessary to pay attention to a good many

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minute points, and, in the case of comparative experiments, to adhere strictly to the uniformity of conditions. The results will be affected by the age and temperature of the cement, and its degree of fineness; the nature of the sand with which it may be mixed—as to whether it is clean, sharp, coarse, or fine; its mineral and more or less hard or absorbent character; the proportion of sand used; the proportion of water, which should be between 50° and 70° Fahrenheit; the temperature, or rather the hygrometric condition of the air in which the briquettes are kept previous to their being put into water; the time they are thus kept in air; the time they are kept in water; the time that elapses between their being taken out of water and being broken; the size, shape and proportions of the briquettes; their greater or less density, *i.e.*, their freedom from air-holes (see paragraph as to different modes of filling moulds); the form of the breaking-clips, and freedom from indirect strain; the greater or less time occupied in applying the strain. The proportions of sand and water used with a given quantity of cement should be weighed, not measured. Careful manipulation, and dexterity only to be acquired by practice, are required at every stage. To reduce the risk of error to a minimum, the average of ten tests should, if possible, be taken. The testing room should be either of brick or double boarding, well protected against extremes of temperature, and be fitted with a firm bench, the top of which should be a smooth slab of slate, marble, or close-grained stone resting on brickwork.

28. *The apparatus and appliances* which it is necessary or desirable to have for making tests and experiments are: a number of boxes about 4 inches deep lined with lead or zinc, having loose covers and a tap for drawing off the water; a similar box, which need not be lined, but the lid of which should be covered inside with several layers of coarse linen, woollen, or cotton cloth, to be kept always damp, and made to fit closely over the box; a number of pieces of plate-glass or slates about 12 inches by 6 inches, or 15 inches by 8 inches; an imperial bushel measure; a measure of one-tenth of a bushel, either 6 inches square by 6·16 inches deep; or, if cylindrical, 6·5 inches in diameter by 6·684 inches deep; scales for weighing a bushel or smaller quantities of cement, sand or water; weights of various denominations, including a pound and decimal parts of a pound; 10,000 grains and decimal parts; funnels or fillers for the bushel and smaller measures (see Figs. 32 and 33); brass wire sieves of 400, 900, 2,580, 5,806, and 32,256 per square inch (the first two are used for sand, the last three for cement, and correspond with the sieves used in Germany of 400,

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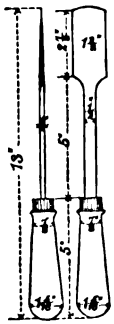
900, and 5,000 per square centimètre); ten or more gun-metal moulds for making briquettes of 1 square inch sectional area (Fig. 22), and, if required, as many of (Fig. 21), 1½ inch × 1½ inch = 2·25 square inches; machine for ascertaining tensile strain; a spatula (Fig. 1), with thin edges to the blade, weighing 7¼ ozs., to be used for beating the cement and sand in the moulds; straight-edges for striking off the measures; a straight-bladed knife for cutting off surplus cement in making briquettes; one or two small trowels; two strong basins or mortars; maximum and minimum thermometers; blotting paper; a graduated glass for water; sand, washed, dried, and sifted through a 20, and caught on a 30 meshes to the inch sieve, = 400 and 900 per square inch; forms for tabulating and registering results. For experiments on compression a hydraulic press is required. Also moulds for blocks of different sizes and shapes—as cakes of 3 inches or 4 inches diameter and 1 inch thick, or cubes of 4 or 6 inches. For experiments on expansion or contraction an instrument of great delicacy has been constructed by Professor Bauschinger (Plate 7, Fig. 5), and observations made on bars of cement 10 centimètres, or 3·933 inches, in length, and of 5 square centimètres sectional area.

FIG. 1.



German Spatula. Weight 7¼ ozs.

29. *Adie's large machine for tensile strain* (Plate 7, Fig. 1).—The instrument for measuring the tensile strain of briquettes of 2·25 square inches, made in 1859 by Mr. Adie, was described in the Author's first Paper. It is convertible at pleasure into a simple lever of 20 to 1, with water as a weight. By changing the clips it can be used for the 1 inch or the German standard briquette of 5 square centimètres. It can also be used for testing the adhesive strength of various mortars with bricks or blocks of moderate area (Plate 7, Fig. 2). A larger machine on the same principle was used for making the experiments on adhesion described in the Author's previous Papers; but it was found to be unnecessarily and inconveniently strong and heavy, and to lack delicacy.

30. *Adie's smaller machine for tensile strain* (Plate 7, Fig. 3).—For the briquettes of 1 square inch sectional area Mr. Adie has, at the Author's request, made a convenient instrument which is a modification of that first mentioned, and being only half the price supplies a want much felt. It shows strains of from 1 lb. to 800 lbs., and by extra weights to 1,150 lbs. It is thus adapted for testing lime or cement mortars of low strength as well as the strongest neat cement. For weighing up to 130 lbs. the bottom row of

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figures is used, the weight F being hung in the notch at the head or left end of the beam. For weights between 85 and 215 lbs. the second row of figures is used, the weight F having previously been removed. From 160 to 800 lbs. the top row of figures is read, the weight F having been hung in the notch at G. For weights above 800 lbs. extra weights are suspended at the notch on the right hand extremity of the bar marked I. When the briquette is put into the clips B and C, it is advisable, before winding up the machine by the screw D, so to dispose the transferable weight G, that a part of the expected strain may be brought to bear when the lever is put to zero on the fork E. In using either this or the larger machine, the graduated lever and moving vernier should be kept perfectly clean, free from dust, and properly oiled. The vernier weight must be moved along with a slow, steady and uniform motion. To facilitate this, the Author in 1878 added a wheel and pinion, and would recommend that the operator should acquire a habit of moving the weight at a measured rate, and note the number of seconds occupied.[1] For testing, some engineers specify that when a certain strain has been attained, the weight shall be left to rest for one minute. For experimental purposes a variety of other arrangements may be tried.

31. *Experiments on the effect of the time occupied in applying weight.*—Some experiments will be found in the Appendix on the influence which the time occupied in moving or increasing the weight has upon the results. If moved rapidly the results are higher than when moved slowly. This affects the results with every form of machine devised for testing tensile strains; and in comparing the experiments of different observers, it is necessary in this and many other respects to know that they have followed exactly the same system. This of course applies to instruments in which, as in Adie's, the weight is moved along a graduated lever, or those, whether simple or compound levers, in which the weight consists of shot or water. (*See* Note to last paragraph).

32. *Machine used in Germany* (Plate 7, Fig. 4).—The instrument adopted in Germany by the Associations of Engineers, Architects, and Cement Manufacturers is a compound lever, the weight being small shot. The leverage is 50 to 1, and the operation is usually very rapidly performed.

For ten years another instrument had been used there by some

[1] Since writing this Mr. Adie has added a simple automatic arrangement for moving the weight with perfect uniformity.

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observers, viz., a simple lever of about 20 or 30 to 1, and a cistern of water with a graduated tube attached to show the weight.

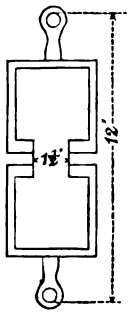
33. *Quillot's machine for tensile strain.*—An ingenious modification of this was invented by M. Quillot, and exhibited at the French Exposition of 1878. The object was to avoid the necessity for filling and emptying the vessel which holds the water. This is effected by raising or lowering it above or below the feeder; the difference between the surface of the water on the two vessels, shown by a graduated scale, giving the quantity or weight of water at the moment of breaking.

34. *Studt's machine.*—Another instrument, on the principle of the hydraulic press, has been invented by Herr Studt.

All the Author's experiments have been made with either the large or small instrument, (Plate 7, Figs. 1 and 3), by Mr. Adie. By long practice and care in regulating the rate of motion great accuracy may be attained with it, and the instrument is very convenient. Either these, or the same instruments used as simple levers of 20 or 25 to 1, with water as a weight, seem to combine accuracy, simplicity and convenience.

35. *Forms of briquettes.*—For testing cement perhaps no point is of greater importance than the size and shape of the briquettes, and the kind of clips used in breaking them. As stated in his first Paper, the Author, in January 1859, adopted the form (Fig. 2) which had been in use for some years in France and England; but it was soon found to be capable of improvement, as the briquettes of this form broke with much irregularity. This was due partly to the imperfect shape, with sharp angles, and partly to the fact that the briquettes had to be pressed out of the moulds, which were in one piece, by a press devised and made by Mr. Adie. In the process of removing them from the moulds, the briquettes occasionally got strained and cracked at the angles, these imperfections not being always perceptible at the moment. Various shapes were tried, the experiments with which, in 1866, were given in Table 1 of the Author's second Paper. (See p. 53.) The moulds were afterwards made to open in the middle, and the small press was dispensed with. The form still seemed capable of improvement, and further experiments were made, which will be best understood by reference to the following figures, which also show various arrangements of the moulds intended to ensure accuracy, facility in use and economy of material. (See p. 54.) All tests have been

FIG. 2.



Original briquette clips.

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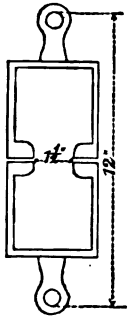
made since 1876–77 with briquettes of one or other of the two forms shown by Figs. 21 and 22. (See p. 55.) The fiddle-shaped form

Fig. 3.

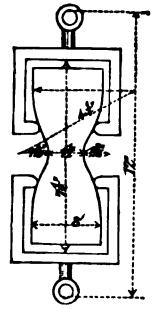


First modification of original mould with close fitting clips.

Fig. 4.

Improved briquette and mould.

Fig. 5.



The last with improved clips, which, however, were liable to slip. Compare with Figs. 21 and 25.

Fig. 9.

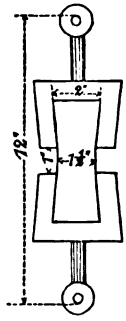


Fig. 6.

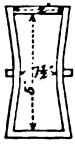


Fig. 7.

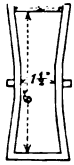
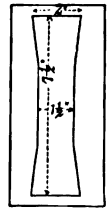


Fig. 8.



Briquettes of 1½ inch × 1½ inch of different lengths with their moulds. These clips slipped.

Fig. 10.

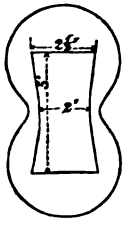


Fig. 11.

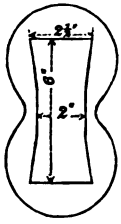


Fig. 12.

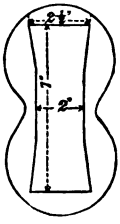
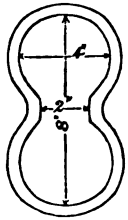


Fig. 13.



Briquettes of 2 inches × 2 inches with their moulds. These clips slipped like the last.

2 inches × 2 inches briquette and mould.

of briquette shown by Fig. 23 (see p. 55) is that which has been adopted as the standard form in Germany. Its breaking area is

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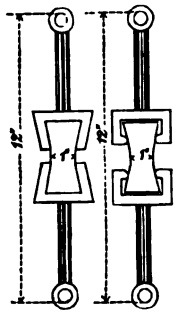
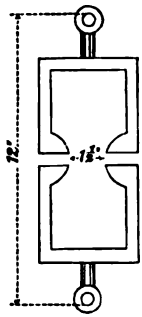
5 square centimètres (2·25 × 2·22 centimètres). Being small it is well adapted for making briquettes of great density with very little trouble; but the shoulders seem too wide for the waist, and the little nick in the latter must have a tendency to produce cracks and to make the briquettes break prematurely. A briquette of 10 square centimètres area would be equal to 1·55 square inch. Since the Author has used the small machine (Plate 7, Fig. 3), and the

FIG. 14. FIG. 15.



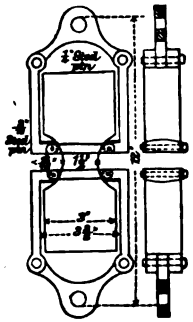
One inch briquettes with wedge-shaped ends, close fitting and with improved clips.

FIG. 16.



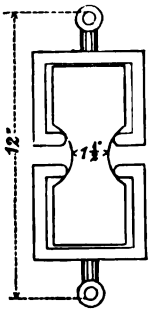
Modified form of waist, but with close fitting clips.

FIG. 17.



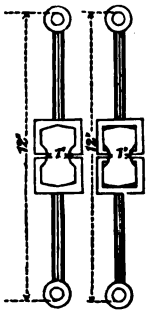
The same, but with jointed clips.

FIG. 18.



The same, with improved clips clear of briquette excepting where pinched.

FIG. 19. FIG. 20.



One inch briquettes with close and with loose fitting clips.

briquette of 1 square inch (Fig. 22), his confidence in the accuracy of both, even for experimental purposes, has increased. Some comparative experiments made with it and the larger briquettes of 1½ inch × 1½ inch (Fig. 21) are given in the Appendix. For testing cement the 1-inch briquette is as accurate as the other. The cement required to make one briquette of neat cement of the larger size (1½ inch × 1½ inch, Fig. 21) will make five of the small (1 inch × by 1 inch, Fig. 22).

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36. *Moulds.*—Some of the different kinds of moulds which have been used are shown by the above Figures. Those now used are

FIG. 21.

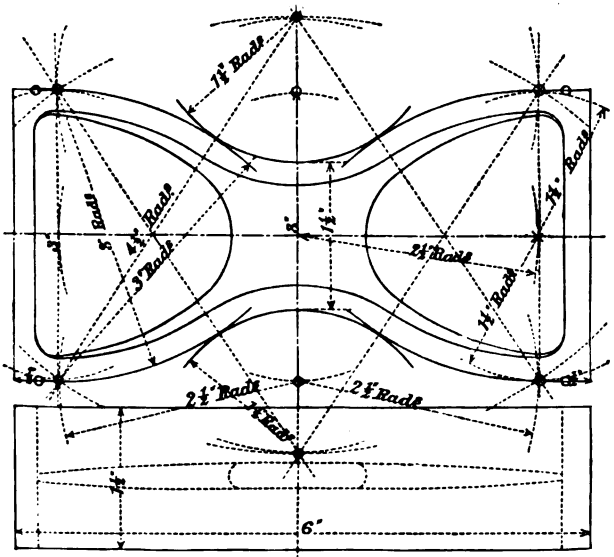

Diagram of centres for template.
(Compare radii and dimensions with Fig. 5.)

FIG. 22.

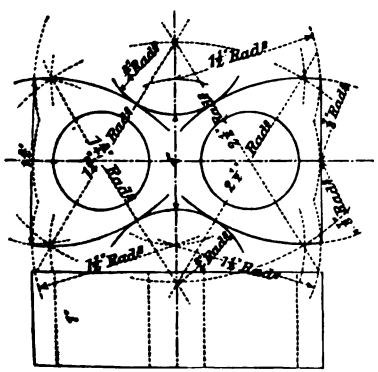

Diagram of centres for template.

FIG. 23.

shown by Figs. 26, 27, and 29. Comparative tests or experiments should be made with briquettes of the same size, shape and proportions.

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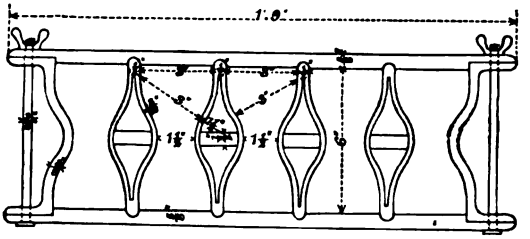
37. *Clips.*—Intimately connected with the shape of the briquette was the form of the clips by which they were held when being broken. For many years every attempt to improve them was in

FIG. 24.



Mould for making five briquettes 92·25 square inches.

FIG. 25.

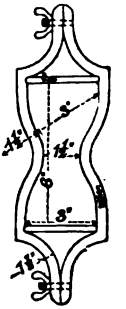


FIG. 26.

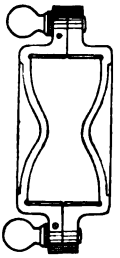


FIG. 27.

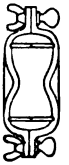


FIG. 28.

FIG. 29.

the direction of making them fit more exactly to the shape of the briquette, and, by means of knife edges, ball-and-socket joints and other contrivances, to get rid of all tendency to distortion

FIG. 30.

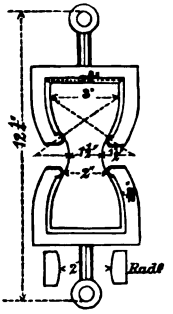
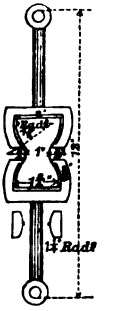


FIG. 31.



(shown full size, Plate 7, Fig. 6); after numberless experiments the form shown on Figs. 30 and 31 was found to be as nearly as

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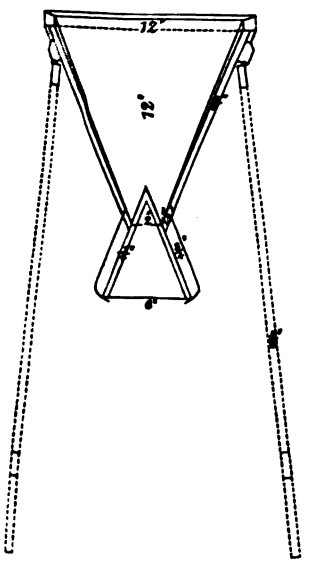
possible free from error. The clips touch the briquette only at the lips, which are curved in both directions, and are in fact blunt rounded points which allow of perfect freedom of action when the strain is applied. This form of clips has been used in every case with briquettes of the forms shown by Figs. 21 and 22.

38. *Effect of improved form of briquette, clip, &c.*—The effect of the improvements in the mode of filling the moulds, in the form of briquette in the clips, and in the mode of testing, has been materially to increase the apparent strength of the cement tested. No doubt great improvement has been made in the manufacture of cement of late years. Still greater is certain yet to be effected; but allowance must be made for the higher results now obtained by more accurate testing, when comparing the later with the earlier tests and requirements of engineers.

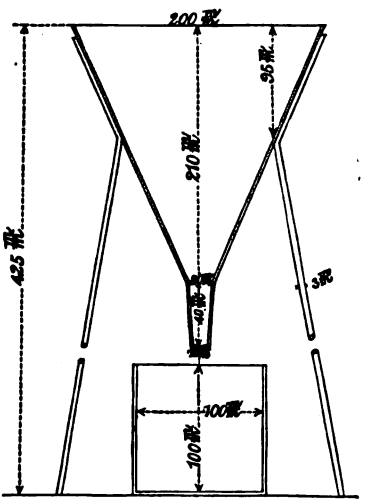
39. *Measures.*—Cements and limes were, and still are, frequently sold by the bushel, though when in large quantities by the ton and

FIG. 32.



Section of
Filler for bushel measure $\frac{1}{10}$ full size.

FIG. 33.



Filler for $\frac{1}{10}$ of a bushel measure, or for a litre.

cwt. in this country, and in sacks or casks of a fixed number of kilogrammes in Germany and Austria. For this reason it is convenient to use the bushel measure, or tenth of a bushel, in ascertaining the weight; there being 21 net bushels in the cubic yard. On the

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continent the measure used is the litre, of which there are 36·3477 in a bushel. The fillers or funnels used in filling these are shown by Figs. 32 and 33. For weighing cement, the small machine (Plate 7, Fig. 3) can be used by removing the sliding block carrying D and C, taking out the upper clip B, and hanging on the scale-pan. For this purpose a tenth of a bushel measure, with a hook to pass through a hole in the stand, is supplied. It will, however, save much trouble to use separate scales.

Testing Cement.

40. Having referred to the chief points that characterise cement, and to the apparatus used for testing and making experiments with it, the following description of the mode of procedure may be useful:—Take enough cement to make as many briquettes of either neat cement or of cement with sand, as may be required. For neat, about 3·20 lbs. of cement will be required to make ten briquettes of the smaller size (Fig. 22) of 1 inch sectional area, and 16 lbs. for ten of the larger size (Fig. 21) of 2·25 square inches area. About 1 lb. of cement and 3 lbs. of sand will make ten of the 1-inch briquettes. 500 grammes of cement, 1,500 grammes of sand, and 200 grammes of water, will make ten of the German normal briquettes and allow for waste. For testing the cement in different sacks, casks, or bins, a sample may be taken from each and numbered. For experiments, or to get averages, the samples may be taken in equal quantities from each and mixed. The cement, unless it is going to be used at once, ought to be spread in a thin layer on a slate or piece of wood, and exposed to cool dry air as long as may be necessary. With newly-ground and quick-setting cements it is important to ascertain they are fit for immediate use. Two cakes of neat cement 2 or 3 inches in diameter, about $\frac{1}{2}$ inch thick with thin edges, should be made, and the time noted in minutes that they take to set sufficiently to resist an impression of the finger-nail. One of these cakes, when hard enough, to be put into water and examined from day to day to see if it shows any tendency to "fly" by cracks of the slightest kind, beginning, and being widest, at the edges. With slow-setting cement, however, cracks on the surface, beginning at the centre, are merely the result of the surface drying too rapidly from exposure to a draught or to external heat. The other cake to be kept in air and its colour observed. A small quantity, which may be 1 lb., 5, or 10 lbs., or 10,000 grains = $1\frac{3}{7}$ lb., to be sifted through the three sieves of 2,580, 5,806, and 32,257 meshes to the square inch, and the proportion by weight that will not pass through each sieve tested,

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The cement to be weighed, using a filler of one of the forms, Figs. 32 and 33, either, 1st. in an imperial bushel measure, or, 2nd, in a box = $\frac{1}{10}$ of a bushel, which may be a cube of 6 inches by 6 inches by 6·16, or a cylinder of 6½ inches diameter and 6·684 inches in depth. The weight to be taken in lbs. and decimal parts. Ten briquettes to be made with three times the weight of the cement of sand which has been washed, dried, and passed through a sieve of 20 and caught on a sieve of 30 to the lineal inch. Twenty more briquettes may be made of neat cement, to be tested as to strength after seven and twenty-eight days. The proportion of water (as of sand) to be to the cement by weight, viz., for neat cement from 20 to 25 per cent. (or more) according to the fineness, the age or other conditions of the cement and the temperature of the air. With 3 parts of sand to 1 part of cement, 10 per cent. of the weight of the united cement and sand will, as a rule, serve. Sufficient water must be used to make a stiff paste, but no more. When cement is new or hot, lightly burnt, finely ground, or made up in hot weather, it takes more water, but a very little more than is sufficient to make it into a stiff paste will sensibly diminish the strength. With 3 parts of sand to 1 part of cement the quantity of water required hardly varies from 10 per cent. A number of pieces of wet blotting-paper, a little larger than the mould, one for each mould, may be laid on the slate or marble bench, and the moulds put upon them. The moulds are filled with a small trowel, and the briquettes made with the spatula already described, the mortar being beaten till all the air has been driven out and the mortar has become elastic. The surplus is cut off level, and the surface left smooth. Dr. Michaëlis, of Berlin, recommends another system of making briquettes of neat cement, which, however, is not adapted for very quick-setting cements, nor for briquettes made with a mixture of sand. It is known as the gypsum-plate process. The cement is mixed with from 30 to 35 per cent. of water, and poured into moulds resting on sheets of wet blotting-paper laid upon plates of plaster of Paris. The moulds are tapped or shaken. About 50 per cent. of the water is quickly absorbed, and, if necessary, more of the cement is added. The surface having been smoothed with a trowel or knife, the briquettes are dexterously dropped out of the mould. This process is a very quick one, and Dr. Michaëlis claims for it that it leaves only the amount of water which is required by the cement for setting properly, and that greater uniformity is attained than by any other process. The briquettes can thus be made denser, taking more cement, and

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breaking frequently under a strain about 50 per cent. higher, or even more. The absorbent slab he compares to the brick or stone with which mortar is in practice used. But to make strong work with cement it is necessary to soak with water bricks or stone before using them. No doubt by long practice any one may attain to great uniformity by following this or any other process; but the Author has not succeeded in getting greater uniformity by this than he has by the process first described. When the moulds have been filled the briquettes are numbered, laid aside, and covered with a damp cloth till they have set sufficiently to be taken out of the moulds. The briquettes are then put on sheets of glass, or on slates, and laid in a flat box, having a cover lined with several layers of linen, woollen or cotton cloth, kept damp. In this box they are kept until they have hardened sufficiently to be put into water. This will vary from one or two hours to a day or more; but for uniformity, unless in cases of specially slow-setting cement, briquettes of neat cement may be kept for twenty-four hours, and those with sand for forty-eight hours, before being transferred from this box to the shallow tanks in which they are to remain till the moment of testing. The numbers on the neat cement briquettes may be made with a sharp point or with a strong pencil. For the sand and cement briquettes numbers previously written or stamped on small pieces of zinc will be found more convenient. The water and the testing room should be kept at a temperature as nearly uniform as possible, say, from 60° to 70° Fahrenheit; but if the box and tanks in which the briquettes are kept be covered, moderate changes of temperature will not materially affect the results. It may be useful, especially at certain seasons, or in countries in which the temperature varies very much, to note the readings of the maximum and minimum thermometers. Seven, twenty-eight, or more days after the briquettes have been made, their tensile strength can be ascertained. In doing this as much uniformity as possible is to be observed in applying the weight slowly and gradually, avoiding all sudden jerks. The result for each briquette being recorded, the average is ascertained. See forms of register attached. In the column of remarks any feature that is worthy of observation may be noted, and especially anything that is exceptional, such as the existence of any flaw in a briquette that has broken below the general average strain. The test with neat cement at the end of seven days is of little more use than to show approximately, by comparison with the tests made at a later date, whether the cement has increased in strength. The later tests are of most value, and especially those made with sand.

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41. As to the uses to which Portland cement has hitherto been applied, very little more need be said. Every year increases their number. For breakwaters, piers, retaining walls, docks, and other works of magnitude, it has for many years been used in all parts of the world. The piers extending a mile out into the North Sea at Ymuiden, near Velsen, on the "North Sea and Amsterdam Canal"; the Victoria Docks, North Woolwich; and the docks at Chatham, are recent examples. Others have been described in Papers read before the Institution. For dwelling-houses, paving, and sewers of all sizes it is well adapted. It will be more and more used, both for concrete and for mortar, as a substitute for, and in combination with, lime. Its essential strength and portability afford facilities for its being transported to great distances. Combined with broken stones, bricks, slag, sand, gravel, &c., it may be applied to an infinite variety of useful purposes, and form an economical substitute for stone and brickwork requiring skilled labour. Many thousands of pounds have been saved of late years in the metropolis by its use as concrete in the construction of sewers and embankments. The improvements which have taken place in its manufacture in this country, but still more in Germany, especially in respect of more uniform burning and better grinding, have rendered it possible to make a given quantity go much further. The more thoroughly its nature and the means of testing its quality and strength are understood the further will this economy extend. The Author is indebted to Messrs. Dyckerhoff for several Tables given in the Appendix, which not only confirm by independent observations the results given in his own; but, as in that which relates to the expansion or contraction of cement, specially illustrate certain points on which they have made an extensive series of experiments. The rules and investigations already alluded to of the German Associations of Engineers, Architects, and Cement Manufacturers, have done more than anything else to improve the quality of cement made in Germany. The Author hopes that the references he has made to these, and his suggestions and experiments extending over many years, may be of some assistance to those who take an interest in this subject.

The communication is accompanied by numerous illustrations, from which Plate 7 and the woodcuts have been engraved.

[APPENDICES.

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APPENDIX I.

FORM OF SPECIFICATION FOR PORTLAND CEMENT.

Cement-Mortar and Concrete.

Portland cement.—The whole of the cement for these works, and herein referred to, is to be Portland cement of the best quality,[1] ground so fine that the residue on a sieve of [2] meshes to the square inch shall not be more than [3] per cent. by weight. Should the residue be greater, a quantity of cement proportionate to such excess must be added. When brought upon the works it is to be put into a dry shed or store which the contractor to provide for the purpose, having a wooden floor and all necessary subdivisions. The cement is to be emptied out upon the floor, every [ ] bushels being kept separate, and is not to be used until it has been tested by samples taken from different sacks.

Testing.—The cement is to be gauged with three times its weight of dry sand, which has passed through a sieve of 400, and been retained upon one of 900 meshes to the square inch. The cement and sand having been well mixed dry, about 10 per cent. of their weight of water is to be added, and briquettes formed in moulds of 1 inch sectional area at the weakest part. The briquettes having in the meantime been kept in a damp atmosphere are to be put into water twenty-four hours after they have been made, and remain in water until their tensile strength is tested by means of apparatus belonging to the Board, and by their officers. All cement that, when neat, sets in less than two hours, must bear without breaking, when subjected to this test, a weight of [4] lbs., and if it take from two to five hours to set neat, it must bear a breaking weight of [170] lbs. per square inch twenty-eight days after the briquettes have been made. If not, it will be rejected, and must be forthwith removed from the works.[5]

Cement-mortar.—The cement hereinbefore described, excepting as herein otherwise specified, shall for mortar be mixed in the proportion of 1 bushel or 112 lbs.[6] of cement to [two] bushels of sand.

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[1] Here, if desired, the words may be inserted "weighing not less than 112 lbs. to the bushel."

[2] Either 6,400 meshes to the square = 80 to the lineal inch, or 5,806 per square inch = 76·2 to the lineal inch, which corresponds with 900 per square centimètre.

[3] The residue may be either 20 per cent. as in the German rules, or 10 per cent. as in their practice.

[4] Here insert either 142 lbs. = the German minimum of 10 kilogrammes per square centimètre, or a higher number, especially if the cement, neat, takes more than two hours to set.

[5] If a test for neat cement is inserted, the following words may be added here —"tested neat, the cement must bear a tensile strain of at least 400 lbs. per square inch, after seven days, six of them in water; and 550 or 600 lbs. per square inch after twenty-eight days, twenty-seven of them in water."

[6] The contractor may either measure or weigh the cement.

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Cement concrete.—The whole of the concrete to be used throughout the works is to be formed of Imperial bushels or cwts. of 112 lbs. of Portland cement to 1 cubic yard of ballast. The materials to be turned over three times in a dry state; the water then to be added, and the mass turned over three or four times more and thoroughly intermixed.

APPENDIX II.

M. QUILLOT'S APPARATUS.

This apparatus consists of a piece of wood of 0·15 mètre by 0·02 mètre, which stands about 1·50 mètre above the level of the table on which the breaking machine is placed, and which goes down to the floor. It has to be well fastened to the leg of the table, or to the wall, so as to avoid any shock.

This piece of wood has a dovetailed slide-groove in which another piece of wood slides, hanging from a string. This piece, in length 1·20 mètre, has at the upper part a collar of two halves to be joined together by means of screws, and at the lower end a console with a hole of 0·01 mètre diameter.

The piece bears at the top a guide-pulley, fixed in such a manner that the string comes down vertically to the middle of the movable piece to which it is fastened. Behind, at the height of the table, a windlass with disengaging apparatus is fixed.

On the movable piece the glass tube of 1·20 mètre in height, 0·065 mètre internal diameter is placed; the lower end of it is closed by a brass socket having in the middle an orifice of 0·01 mètre internal diameter, which goes through the console. This communicates with the bottle hanging on the lever of the breaking machine by a caoutchouc tube in which a cock is inserted, traversing the large piece of wood. The second part of the caoutchouc tube is now placed behind, and is again fixed by a ring, so as to make the floating part of the tube, between the plank and the neck at the bottom of the bottle, not to vary in length, but to give a constant weight which has not to be taken into account.

The bottle, holding about 3 litres, is provided with two necks, the one at the top, which remains open, the other horizontal, at the bottom, to which the caoutchouc tube at the movable water-basin is fixed.

This bottle is hung at the lever of the machine in a brass bow ending in a ring at the top; it is moulded to the neck of the bottle, to which it is fixed by a screw and nut.

The two branches traverse two brass plates, of the thickness of 2 millimètres, placed at a distance of 0·07 mètre. The upper one carries the bottle, the lower one serves to put weight upon when it is presumed that the strength of the briquette will be greater than the weight of the water contained in the bottle.

APPENDIX III.

(From the "Thonindustrie Zeitung" of 23rd June, 1877.)

ON THE SPECIFIC GRAVITY OF PORTLAND CEMENT.

(From the Chemical Laboratory for Ceramics.)

Experiments were made by us as to the specific gravity of different cements with a **Mann's** apparatus, and to our surprise we arrived at the results given below.

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Although the apparatus is but little applicable for accurate scientific experiments, yet it is very serviceable for comparative experiments which require despatch.

We first took pulverised quartz and determined its specific gravity by means of distilled water. Fifty grammes were used for this experiment. Three trials gave identical results, the specific gravity being 2·59. As we thought that air might perhaps be retained by the powder, we inclined the flask containing the powdered substance covered with liquid in such a manner that any air-bubbles rising would collect in one spot. The flask remained in this position for twenty-four hours without any air collecting, even when the flask was carefully shaken. The volume of the few air-bubbles that appeared in one or two cases was so small as not to be equal to the error which is unavoidable in reading off the results. If the cement is used in the form of a sandy powder there is no fear of inaccuracy from this source. In estimating the specific gravity of cement, petroleum was used instead of water, as the latter decomposed cement. The air escaped without difficulty when petroleum was used. The following specific gravities were obtained:—

Cement from	Groschowitz.	3·03
„	Wildau	3·01
„	Höxter	3·08
„	Stern	3·08
„	Lüneburg	3·03
„	Beckum	3·04
„	Offenbach	2·99

The differences in the figures are so slight that they may almost be considered as identical, especially if we take into account that slight experimental errors are inevitable. It is evident that these figures afford no data for the valuation of cement.

We thought that lightly-burnt cement, or, in other words, a hydraulic lime of the same composition as Portland cement, would have a different specific gravity.

Dr. Heintzel had the kindness to send us lightly-burnt Lüneburg cement. It was burnt till all carbonic acid had been expelled, but it was still quite porous. Two experiments which coincided in every respect showed its specific gravity to be 3·04, the same as well burnt Portland cement.

It follows that cement acquires its high specific gravity before it is completely burnt; before, therefore, the clinkering or incipient fusion has reduced it to a dense slag-like product. We may conclude that that which we call Portland cement at a later stage is already produced before clinkering takes place; the object of burning it still more is only to bring the particles closer to destroy the pores. It is evident that this destruction of the pores must be of the greatest importance as regards the action of water on cement, as well as the manner of setting. The nearer the particles of cement are brought, the less is the exposed surface, the slower and more regular, consequently the deposition of the cementitious products of decomposition.

From the results obtained, so far as a general conclusion may be drawn from them, we must infer that the specific gravity neither indicates the quality of Portland cement, nor whether one and the same cement is lightly or heavily burnt. It may appear strange that cements made from such very different raw materials as the above, namely, freshwater limestone, chalk, or compact limestone, should show no difference in specific gravity; but we must bear in mind that the ultimate composition of normal Portland cement only varies within very narrow

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limits; there is, therefore, no reason for any very considerable variation in the specific gravity. If variations occur they must be attributed to the greater or less proportion of iron, magnesia, &c. But as these substances occur in very small quantities as compared with the lime and silica which form the chief mass of the cement in nearly constant proportions, it follows that variations cannot be considerable. If Mr. Mann found differences from 2·77 to 3·03, he may have experimented on Roman cements as well, the chemical composition of which differs materially from that of Portland cements.

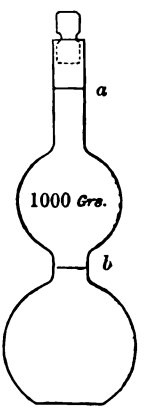
APPENDIX IV.

Mr. Keates's Double Bulb Bottle for ascertaining the Specific Gravity of Cement.

This bottle consists of two bulbs, the lower somewhat exceeding the upper in capacity. The exact capacity of the lower bulb is of no importance. On the neck between the bulbs is a file-mark *b*, on the neck of the upper bulb is a similar mark *a*.

The capacity of the upper bulb between the marks *a* and *b* must be accurately determined, and may conveniently be either 500 or 1,000 grains in water measure at 60°.

In ascertaining the specific gravity of a solid in small fragments, small shot, for example, the following is the mode of procedure: Fill the bottle with distilled water up to the mark *b*, accurately counterpoise the bottle so filled in a balance, drop the substance (of which the specific gravity is to be taken) carefully and gradually into the bottle until the water rises from *b* to *a*, ascertain exactly the weight of the material so added; if the capacity of the upper bulb be 1,000 grains of water, the weight of the material required to raise the water from *b* to *a* is its specific gravity; if the capacity of the bulb be 500 grains of water, the weight of the substance added must be multiplied by 2, which will give the specific gravity.



Keates' specific gravity bottle.

The principle of the apparatus is very simple; the capacity of the upper bulb is an exact measure of distilled water, and when the water is raised from *b* to *a* by dropping a solid into the bottle, the bulk of that solid equivalent to the given volume of distilled water is ascertained, and the relation between the weights of the two is given by the weight of the substance added, which is either the specific gravity direct, if the capacity of the bulb be 1,000 grains, or it can be ascertained by multiplying the weight of the solid by the number which represents the part of 1,000 represented by the capacity of the bulb, &c.

If the solid be soluble in water, any convenient liquid can be used in the place of water in making the experiment, the only thing necessary being to carefully counterpoise the bottle filled with the liquid up to *b* in this manner. Petroleum, oil, turpentine, or any liquid suitable to the nature of the material to be tested may be used, all other things remaining the same.

The only precautions to be observed are, that the air, which is apt to cling somewhat to the solid matter when dropped into the liquid, is carefully removed; and that, if a very volatile liquid be used in the place of water, the bottle should be stopped or corked to prevent evaporation.

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APPENDIX V.

WEIGHT and SPECIFIC GRAVITY of DIFFERENT CEMENTS.

Sort of Cement.	Weight of 1 litre.	Specific Gravity.
	Grammes.	
B, light burnt	1,001	3·130
„ hard „	1,344	3·134
„ medium burnt	1,301	3·131
R	1,428	3·130
S	1,235	3·130
H	1,328	3·130
V	1,332	3·054

APPENDIX VI.

ANALYSES of DIFFERENT GERMAN and ENGLISH CEMENTS.

Marks.	1 Lime.	2 Silica.	3 Alumina.	4 Oxide of Iron.	5 Magnesia.	6 Sulphuric Acid.	7 Potash.	8 Soda.	9 Carbonic Acid and Water.	10 Insoluble Residue.
					German.					
L D. .	62·68	23·29	5·43	2·47	1·10	1·03	0·36	0·49	1·42	1·17
S D. .	63·21	22·82	2·69	3·52	3·00	1·12	1·26		1·12	0·67
H B. .	62·02	22·58	6·52	2·82	1·13	1·15	..	1·70	1·71	0·57
D . .	63·27	19·80	6·73	3·22	2·02	1·08	1·22	0·26	1·00	1·38
					English.				Carbonic Acid.	Moisture and Organic Matter.
N . .	58·29	20·56	6·20	6·76	0·32	1·62	1·23		1·60	2·96
W . .	60·76	21·52	4·76	4·24	0·61	2·50	2·80		0·80	1·08
H . .	60·71	21·48	6·10	6·66	1·08	0·79	1·15		0·58	0·62
G . .	58·35	22·40	7·56	6·56	0·72	0·83	1·60		0·66	0·94
H . .	58·02	23·38	8·42	5·10	0·90	0·84	0·64		1·38	0·86

APPENDIX VII.

PROPORTION of WATER, by WEIGHT, USED for DIFFERENT MIXTURES of CEMENT and SAND in GERMANY.

Mixture.	Cement in Grammes.	Sand in Grammes.	Water in Grammes.	—
Cement to Sand.				
..	..	..	275 for	Quick setting.
1 to 0	1,000	..	250 „	Slow „
1 „ 1	500	500	120	
1 „ 3	250	750	100	
1 „ 4	200	800	100	
1 „ 5	200	1,000	120	

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EXPERIMENTS with DIFFERENT FORMS of MACHINES for ASCERTAINING TENSILE STRENGTH of CEMENT BRIQUETTES.

Mark. Cement. Sand.	Initial Weight.										Average Breaking Weight on Section of 5 Square Centimètres.	Average Time in Seconds.	Average Tensile Strain per Square Centimètre.	
	Kilos.										Kilos.	"	Kilos. per Sq. Centimètre.	
1 : 0	100	Time in seconds . .	43	45	54	14	..	..	..	..	..	39	..	By direct weight of water.
	„	Tensile strain in kilos.	155	138	160	114	..	..	..	..	142	..	28·4	
1 : 0	100	Time in seconds . .	39	58	72	56	62	..	..	..	..	57·4	..	By Adie's small machine without the slow motion.
	„	Tensile strain in kilos.	154	159	171	158	162	..	..	..	160·8	..	32·16	
1 : 0	100	Time in seconds . .	24	51	34	52	38	..	..	..	..	39·8	..	By the German normal machine.
	„	Tensile strain in kilos.	197·5	190	197·5	210	197·5	..	..	..	198·5	..	39·7	
1 : 0	100	Time in seconds . .	43	37	30	39	52	..	..	..	..	40·2	..	By Herr Studt's machine.
	„	Tensile strain in kilos.	185	160	160	175	185	..	..	..	173	..	34·6	
Cement. Sand.														
1 : 3	35	Time in seconds . .	42	41	39	57	58	56	47	47	..	47	..	By direct weight of water.
	„	Tensile strain in kilos.	82	79	77	88	99	87	85	88	83·7	..	16·47	
1 : 3	35	Time in seconds . .	32	35	27	32	34	14	19	24	..	27·12	..	By Adie's small machine.
	„	Tensile strain in kilos.	87	93	92	101	97	80	84	88	90·25	..	18·05	
1 : 3	35	Time in seconds . .	27	14	19	16	22	20	18	..	..	19·43	..	By the German normal machine.
	„	Tensile strain in kilos.	102·5	100	97·5	102·5	107·5	120	107·5	..	105·36	..	21·07	
1 : 3	35	Time in seconds . .	33	32	27	27	23	22	24	26	..	26·75	..	By Herr Studt's machine.
	„	Tensile strain in kilos.	120	115	120	110	125	105	115	177	117·2	..	23·44	
1 : 3	35	Time in seconds . .	52	48	28	37	30	27	30	40	..	36·5	..	By Michaëlis' original lever 30 to 1.
	„	Tensile strain in kilos.	110	110	87·5	95	87·5	80	85	97·5	94·06	..	18·81	

NOTE.—All the briquettes were made on the same day, by the same person, and in every respect under the same conditions.

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APPENDIX IX.

EXPERIMENTS with DIFFERENT TESTING MACHINES to ASCERTAIN the EFFECT of COMMENCING with DIFFERENT INITIAL WEIGHTS, and of the TIME OCCUPIED in MAKING the TEST.

Four sets of ten each, of 1 inch briquettes, Fig. 22, made of neat cement, and kept seventy-six weeks.

	Lbs.
1. With small machine and rolling weight, Plate 7, Fig. 3, commencing with 400 lbs., and moving at the rate of 200 lbs. per minute—occupied one minute, and broke at	602·00
2. With large machine and water for a weight, Plate 7, Fig. 2, as a lever of 20 to 1, commencing with 127 lbs.—occupied three minutes one second, and broke at	622·42
3. With last machine and rolling weight, Plate 7, Fig. 1, commencing with 150 lbs.—occupied three minutes, and broke at . . .	658·00
4. With large machine and water, as in No. 2, commencing with 400 lbs.—occupied one minute forty-seven seconds, and broke at	674·36

Four sets of 1-inch briquettes, Fig. 22, made with 3 of standard sand (20–30). Cement set neat in six hundred minutes, 4 per cent. residue on sieve A 2,580 per square inch, and 12 per cent. on sieve B 5,806 per square inch.

5. With large machine and water as a weight, Plate 7, Fig. 2, commencing with a weight of 170 lbs.—occupied fourteen seconds and a half, and broke at	214·72
Briquettes being eighty-one days old.	
6. Large machine and water, as with last, commencing with a weight of 43 lbs.—occupied fifty-five seconds, and broke at .	217·16
Briquettes eighty-one days old.	
7. Large machine and rolling weight, Plate 7, Fig. 7, commencing with 170 lbs., weight added at rate of 223 lbs. per minute—occupied sixteen seconds, and broke at	223·50
Briquettes eighty-seven days old.	
8. Small machine and rolling weight, Plate 7, Fig. 3, commencing with 170 lbs., additional weight at rate of 200 lbs. per minute—occupied 17 seconds and a half, and broke at	228·50
Briquettes eighty days old.	

See Note at Paragraph 30 as to an automatic arrangement for moving the weight at a uniform rate.

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APPENDIX X.

PORTLAND CEMENT TESTS at NINE MONTHS. JULY 1879.

Neat cement. Moulds 1½ inch by 1½ inch. Figs. 21 and 30.

Tested by the following methods.

Nos. 1 to 10.	Nos. 11 to 20.		Nos. 21 to 30.	Nos. 31 to 40.		Nos. 41 to 50.	Nos. 51 to 60.	
Initial Weight 1,160 lbs. Additional Weight 400 lbs. per Minute.	The Weight fixed at the Average of First Test, and allowed to remain till broken, keeping account of the Time.		Initial Weight 1,160 lbs. Additional Weight 100 lbs. per Minute.	The Weight fixed at 1,160 lbs., and allowed to remain until broken, taking account of the Time.		The Weight fixed at 1,000 lbs. for Fifteen Minutes, then moved at the rate of 400 lbs. per Minute.	The Weight fixed at 1,100 lbs., and allowed to remain for the Time marked.	
Lbs.	Lbs.	′ ″	Lbs.	Lbs.	′ ″	Lbs.	Lbs.	′ ″
1,460	1,321	2·30	1,355	1,160	4·00	1,450	1,450	90·0
1,320	1,321	0·00	1,225	1,160	8·00	1,440	1,360	90·0
1,290	1,321	1·30	1,305	1,160	12·00	1,405	1,100	1·0
1,275	1,321	0·15	1,215	1,160	16·00	1,375	1,100	34·0
1,195	1,321	0·30	1,340	1,160	2·00	1,000	1,100	2·0
1,365	1,321	0·25	1,330	1,160	17·30	1,315	1,315	102·0
1,400	1,321	1·40	1,330	1,160	3·00	1,365	1,100	10·0
1,360	1,321	0·30	1,350	1,160	3·00	1,215	1,100	5·0
1,325	1,321	0·15	1,255	1,160	13·00	1,320	1,100	65·0
1,220	1,321	0·30	1,320	1,160	6·00	1,350	1,100	20·0
1,321	1,321	0·48	1,302·5	1,160	8·24	1,323·5	1,182·5	42·0

APPENDIX XI.

RESULTS of an EXPERIMENT MADE WITH THREE SETS of BRIQUETTES MOULDED by THREE DIFFERENT PERSONS on the 13th of MARCH, and TESTED on the 10th of APRIL, 1880. Cement delivered 24th of February.

Three of sand 20–30. Water 10 per cent. Briquettes (Figs. 22 and 31).

No. 1.	No. 2.	No. 3.
195	200	198
200	195	201
204	197	195
193	194	190
190	199	192
192	190	197
198	203	194
197	193	200
199	196	193
200	199	197
196·8	196·6	195·7

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APPENDIX XII.

1876.

EXPERIMENTS on the RELATIVE VALUE of DIFFERENT FORMS of BRIQUETTES and CLIPS. EACH NUMBER the AVERAGE of 10.

At seven days.

Fig. 2.	Fig. 3.	Fig. 4.	Fig. 17.	Fig. 5.	Figs. 21 and 30.	Figs. 22 and 31.	
1¼ In. Sq. Original Clips. Broke at	1¼ In. Sq. Original Clips. Broke at	1¼ In. Sq. Jointed Clips. Broke at	1¼ In. Sq. Jointed Clips. Broke at	1¼ In. Sq. Improved Clips. Broke at	1¼ In. Sq. New Design. Broke at	1 In. Sq. New Design. Broke at	Cement 118 lbs. per Bushel.
Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
577·0	678·0	690·5	702·5	863·5	873·5	377·5	

The same at per inch.

256·44 | 301·33 | 306·89 | 312·22 | 383·77 | 388·22 | 377·5 | Sifted.

At each gauging the seven moulds were filled once.

APPENDIX XIII.

1876.

EXPERIMENTS on the RELATIVE VALUE of DIFFERENT FORMS of BRIQUETTES and CLIPS. EACH NUMBER the AVERAGE of 10.

At twenty-eight days.

Fig. 2.	Fig. 3.	Fig. 4.	Fig. 17.	Fig. 5.	Figs. 21 and 30.	Figs. 22 and 31.	
1¼ In. Sq. Original Clips. Broke at	1¼ In. Sq. Original Clips. Broke at	1¼ In. Sq. Jointed Clips. Broke at	1¼ In. Sq. Jointed Clips. Broke at	1¼ In. Sq. Improved Clips. Broke at	1¼ In. Sq. New Design. Broke at	1 In. Sq. New Design. Broke at	Cement 118 lbs. per Bushel.
Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
744·5	889·5	984·5	1,047·5	1,126·5	1,149·0	496·5	..

The same at per inch.

330·89 | 395·33 | 437·55 | 465·55 | 500·66 | 510·67 | 496·5 | ..

At each gauging the seven moulds were filled once.

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APPENDIX XIV.—EXPERIMENTS ON DIFFERENT FORMS of BRIQUETTES and CLIPS Portland cement weighing 120 lbs. per bushel. 1877.

When Moulded.	When Tested.	Days in Moulds.	1½ In.Sq. Fig. 2. Broke at in lbs.	1½ In. Sq. Fig. 9. Broke at in lbs.	1½ In.Sq. Fig. 3. Broke at in lbs.	1½ In. Sq. Fig. 21. Broke at in lbs.	1 In. Sq. Fig. 22. Broke at in lbs.	No.	The Original Clips to Figs. 2, 3 & 9. New Clips to Figs. 21 & 22. See Figs. 30 & 31.
1877	1877								
May 25	July 12	48	900					51	
				1,055				52	
					770			53	Each mould filled once at each gauging—
						1,315	640	54	
								55	
			890					56	Cement 6·50
				1,170				57	Water. 1·50
					1,030			58	
						1,225	630	59	= 23 per cent.
								60	
			760					61	
				1,040				62	
					1,090			63	
						1,410		64	
							690	65	
„ 26	„ 12	47	875					66	
				1,050				67	
					1,260			68	
						1,415		69	
							610	70	
„ 28	„ 12	45	720					71	
				1,100				72	
					1,235			73	
						1,300		74	
							640	75	
			915					76	
				1,205				77	
					1,180			78	
						1,465		79	
							670	80	
„ 29	„ 12	44	730					81	
				1,015				82	
					1,215			83	
						1,425		84	
							650	85	
			880					86	
				1,165				87	
					1,165			88	
						1,460		89	
							675	90	
			840					91	
				1,005				92	
					1,065			93	
						1,310		94	
							625	95	
			800					96	
				1,030				97	
					900			98	
						1,270		99	
							610	100	
			831	1,083·5	1,091	1,359·5	..		
	Per inch .		369·3	481·5	485	604·2	644		

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APPENDIX XV. *November* 1877.

EXPERIMENTS with BRIQUETTES and CLIPS of DIFFERENT FORMS.

Portland Cement weighing 117 lbs. per bushel. Broken at seven days. Kept in water. Original Clips to Figs. 2, 3, 9 and 16.

Broken at in lbs.

1¼ Inch Sq. Fig. 2.	1¼ Inch Sq. Fig. 9.	1¼ Inch Sq. Fig. 3.	1¼ Inch Sq. Fig. 16.	1¼ Inch Sq. Figs. 21 & 30.	1 Inch Sq. Figs. 22 & 31.	The German Briquette. Fig. 23.
660	845	890	860	960	475	280
605	790	890	845	955	455	215
605	805	885	800	955	460	230
605	765	900	895	970	480	250
600	725	880	905	1,010	485	240
615	720	875	900	1,005	455	260
625	760	915	880	1,000	425	260
600	715	865	860	960	420	240
660	765	855	860	950	470	320
675	815	860	885	1,025	470	265
625	770·5	881·5	869	979	459·5	256
277·7	342·4	391·7	386·2	435·1	459·5	330·5 per inch.

Delivered October 4th. One gauging filled each mould. Water 24 per cent. 71·73 per cent. passed 50 sieve.

APPENDIX XVI. *November* 1877.

EXPERIMENTS with BRIQUETTES and CLIPS of DIFFERENT FORMS.

Portland Cement weighing 118 lbs. per bushel. Broken at sixty days. Kept in water.

Broken at in lbs.

1¼ Inch Square. Fig. 2.	1¼ Inch Square. Fig. 9.	1¼ Inch Square. Fig. 3.	1¼ Inch Square. Figs. 21 & 30.	1 Inch Square. Fig. 22 & 31.	The German normal mould. Fig. 23.
860	905	1,015	1,150	475	315
830	840	960	1,160	505	290
810	865	975	1,090	510	285
660	825	835	1,160	515	290
785	790	960	1,150	500	320
840	880	910	1,125	525	340
830	845	980	1,125	515	335
820	855	1,025	1,145	490	315
845	845	1,010	1,105	530	370
815	875	1,040	1,135	515	355
809·5	852·5	971	1,134·5	..	321·5
359·7	378·8	431·5	504·2	508	415·1 per inch.

Cement delivered September 8th. One gauging filled each mould. Water 25 per cent. 78 per cent. of the Cement passed 50 sieve.

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APPENDIX XVII.

November 1877.

EXPERIMENTS with BRIQUETTES and CLIPS of DIFFERENT FORMS.

Portland Cement weighing 117 lbs. per bushel.
Broken at seven days. Kept in water.
Original Clips to all.

Broken at in lbs.							Numbers.
First Mould with Square Shoulders 1¼ In. Sq. Fig. 2.	1¼ In. Sq. Fig. 9.	1¼ In. Sq. Fig. 3.	1¼ In. Sq. Fig. 16.	1¼ In. Sq. Figs. 21 and 30.	1 In. Sq. Fig. 22 and 31.	The German Normal Mould. Fig. 23.	
730	815	905	930	1,110	480	310	2,611 to 2,617
715	855	990	960	1,140	520	315	2,618 „ 2,624
675	780	940	970	1,120	495	340	2,625 „ 2,631
750	930	910	950	1,070	470	270	2,632 „ 2,638
790	870	895	920	1,110	460	275	2,639 „ 2,645
685	825	925	980	1,080	475	240	2,646 „ 2,652
720	925	965	965	1,145	495	295	2,653 „ 2,659
650	915	975	985	1,025	495	250	2,660 „ 2,666
735	890	830	990	1,130	480	245	2,667 „ 2,673
780	920	910	945	1,145	515	240	2,674 „ 2,680
723	872·5	924·5	959·5	1,107·5	488·5	278	
321·3	387·7	410·7	426·4	492·2	488·5	359	per inch.

Delivered October 11th. One gauging filled each mould.
Water 25 per cent. 76·2 per cent. of the Cement passed 50 sieve.

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APPENDIX

EXPERIMENTS with BRIQUETTES of DIFFERENT FORMS

When Moulded.	When Tested.	Days in Water.	Fig. 17.		Fig. 5.		Figs. 21 and 30.		Figs. 22 and 36.	No. of Test.
			Broken at in lbs.	At per Inch.	Broken at in lbs.	At per Inch.	Broken at in lbs.	At per Inch.	Broken at in lbs. per Square Inch.	
1876 Oct. 10	1876 Nov. 22	43	1,130	502·2						191
					1,110	493·3				192
							1,255	557·7		193
									520	194
„ 12	„	41	1,140	506·6						201
					1,065	473·3				202
							910	404·4		203
									410	204
			910	404·4						211
					910	404·4				212
							1,015	451·1		213
									410	214
„ 13	„	40	925	411·1						215
					910	404·4				216
							930	413·3		217
									410	218
			900	400·0						224
					900	400·0				225
							945	420·0		226
									395	227
„ 14	„	39	955	424·4						233
					975	433·3				234
							1,025	455·0		235
									425	236
			960	426·6						242
					1,040	462·2				243
							1,000	444·4		244
									445	245
„ 16	„	37	1,060	471·1						246
					1,090	484·4				247
							1,045	464·4		248
									460	249
			1,045	464·4						225
					1,070	475·5				226
							1,065	473·3		227
									490	228
			1,025	455·5	990	440·0				264
										265
							945	420·0		266
									475	267
			1,005	446·6	1,006	447·0	1,013·5	450·4	444	

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XVIII.

and with IMPROVED CLIPS, FIG. 5, and JOINTED CLIPS to Fig. 16.

When Moulded.	When Tested.	Days in Water.	Fig. 17.		Fig. 5.		Figs. 21 and 30.		Figs. 22 and 31.	No. of Test.
			Broken at in lbs.	At per Inch.	Broken at in lbs.	At per Inch.	Broken at in lbs.	At per Inch.	Broken at in lbs. per Square Inch.	
1876 Oct. 17	1876 Nov. 23	37	1,040	462·2						268
					1,050	466·6				269
							1,110	493·3		270
									485	271
			1,020	453·3						277
					1,100	488·8				278
							1,095	486·6		279
									500	280
			995	442·2						281
					1,070	475·5				282
							1,065	473·3		283
									445	284
„ 19	„	35	980	435·5						285
					1,080	480·0				286
							1,090	484·4		287
									445	288
			950	422·2						295
					1,000	444·4				296
							1,110	493·3		297
									480	298
			1,010	448·8						299
					935	415·5				300
							1,155	513·3		301
									465	302
„ 20	„	34	1,075	477·7						303
					950	422·2				304
							1,090	484·4		305
									475	306
			975	433·3						307
					910	404·4				308
							1,100	488·8		309
									465	310
			1,065	473·3						317
					945	420·0				318
							1,065	473·3		319
									430	320
			990	440·0						321
					945	420·0				322
							1,065	473·3		323
									480	324
			1,010	448·8	998·5	443·7	1,094·5	486·4	467	

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APPENDIX XIX.

EXPERIMENTS WITH BRIQUETTES of DIFFERENT FORMS. 1 of CEMENT to 3 of GERMAN STANDARD SAND.

The briquettes were all tested by Mr. Adie's small machine.

Briquettes 1 inch by 1 inch. Fig. 22, by Messrs. Dyckerhoff.

Seven days.

54·2 kilogrammes per square inch.
50·0 " "
51·0 " "
52·0 " "
50·0 " "
54·0 " "

311·2 "

Average 51·87 kilogrammes = 114·35 lbs. per square inch, or 8·04 kilogrammes per square centimètre.

Twenty-eight days.

94 kilogrammes per square inch.
92 " "
90 " "
95 " "
92 " "

463 "

Average 92·6 kilogrammes = 204 lbs. per square inch, or 14·354 kilogrammes per square centimètre.

GERMAN MOULD, FIG. 23, of 5 SQUARE CENTIMÈTRES BREAKING AREA.

Seven days.

37·5 kilos. per square centimètre.
39·0 " "
37·0 " "
40·0 " "
38·0 " "

191·5 "

Average 38·3 kilogrammes per 5 square centimètres, or 7·65 kilogrammes per square centimètre = 109 lbs. per square inch.

Twenty-eight days.

70·0 kilogrammes.
69·5 "
70·0 "
72·0 "
72·0 "
74·0 "
70·0 "
73·0 "
75·0 "
73·0 "

718·5 "

Average 71·85 per 5 square centimètres, or 14·37 kilogrammes 31·6 lbs. per square centimètre = 204·4 lbs. per square inch.

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APPENDIX XX.

The WEIGHT and TENSILE STRENGTH of BRIQUETTES MADE on a MARBLE SLAB as COMPARED WITH BRIQUETTES MADE on a GYPSUM SLAB.

(Experiments made in 1876 by Messrs. Dyckerhoff.)

Portland Cement.	Time of Setting.	Method of making the Sample Briquette.	Average Weight.				Increase of Weight in Per Cent.	Increase of Strength in Per Cent.
			One Briquette Weighs Wet.	When Dried at 100° Celsius = 212° Fahr.	Dried by Red Heat.	Breaking Weight at Seven Days in Kilogrammes per Square Centimètres. Fig. .		
	Minutes.		Grammes.					
A. Weighing 1,312 grammes per litre.	30	Marble slab (600 cubic centimètres cement to 220 cubic centimètres water).	154·4	127·8	119·9	15·8	12·3	57·0
		Gypsum slab (600 cubic centimètres cement to 260 cubic centimètres water).	163·2	141·9	134·7	24·8		
B. Weighing 1,295 grammes per litre.	420	Marble slab (600 cubic centimètres cement to 200 cubic centimètres water).	156·7	130·5	123·6	18·1	15·5	84·0
		Gypsum slab (600 cubic centimètres cement to 240 cubic centimètres water).	168·3	149·5	142·8	33·3		

Both cements—the one quick, the other slow setting—were from the same manufactory, and their analyses show exactly the same ingredients.

Eighteen briquettes were made for each experiment, ten of them were broken, and eight of each were used to ascertain the quantity of water contained in the briquettes.

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APPENDIX XXI.

26th March, 1878.

CEMENT (R. KENT).

Proportions by weight. All kept in water. The weight per bushel: Cement, 111 lbs.; sand, 120 lbs. All cement sifted through 2,580 per square inch. Moulded between the 15th and 30th August, 1878. Mould (Fig. 22), 1 inch by 1 inch. German mould, 5 square centimètres.

NEAT TESTS. TENSILE STRAIN in LBS.

German Mould, Fig. 23. Water 22·5 per cent.			1 Square Inch Mould. Figs. 22 and 31. Water 22·5 per cent.			1 Square Inch Mould. Figs. 22 and 31. Water 33 per cent. On Gypsum Plates.		
Weight of Ten Briquettes.		Average of Ten Samples.	Weight of Ten Briquettes.		Average of Ten Samples.	Weight of Ten Briquettes.		Average of Ten Samples.
When Tested.	Seven Days after.		When Tested.	Seven Days after.		When Tested.	Seven Days after.	
Lbs.	Lbs.	5 square centi-mètres. Square inch.	Lbs.	Lbs.		Lbs.	Lbs.	Lbs.
			Seven days.					
3·52	3·48	298·0=384·5	3·54	3·48	449·0	3·23	3·00	256·6
			Twenty-eight days.					
3·54	3·50	460·0=593·4	3·65	3·55	687·5	3·34	3·20	454·5
			Sixty days.					
3·58	3·52	437·5=564·5	3·64	3·60	765·0	3·43	3·35	634·5
			Ninety-one days.					
3·60	3·55	561·0=724·9	3·70	3·65	808·5	3·40	3·34	626·5
			Twenty-six weeks.					
3·60	3·45	482·0=622·0	3·68	3·61	731·0	3·44	3·38	620·0
			Thirty-nine weeks.					
3·63	3·60	494·0=637·4	3·72	3·66	746·0	3·42	3·35	655·5
			Fifty-two weeks.					
3·60	3·56	464·5=598·7	3·70	3·65	718·0	3·43	3·37	608·5

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CEMENT (R. KENT) SIFTED THROUGH SIEVE A = 2,580 PER SQUARE INCH.

All kept in water. Proportions by weight. Moulded from 15th to 30th August, 1878. SAND TESTS.

Standard sand sifted from 20 to 30 per lineal inch. Note, in last column, the great increase of strength by using coarser sand.

German Mould, Fig. 23, 5 Square Centimètres. Iron Spatula. Standard (20–30) Sand.			German Mould, Fig. 23. 5 Square Centimètres. Made by ordinary Pressure. Standard (20–30) Sand.			1 Sq. In. Mould. Figs. 22 & 31. Wooden Spatula. Standard (20–30) Sand.			1 Sq. In. Mould. Figs. 22 & 31. Made by ordinary Pressure. Standard (20–30) Sand.			1 Sq. In. Mould. Figs. 22 & 31. Wooden Spatula. Sand Sifted from 10 to 20.		
Weight of Ten Briquettes,		Average of Ten Tests.	Weight of Ten Briquettes,		Average of Ten Tests.	Weight of Ten Briquettes,		Average of Ten Tests.	Weight of Ten Briquettes,		Average of Ten Tests.	Weight of Ten Briquettes,		Average of Ten Tests.
When Tested.	Seven Days after.		When Tested.	Seven Days after.		When Tested.	Seven Days after.		When Tested.	Seven Days after.		When Tested.	Seven Days after.	
Lbs.	Lbs.	5 square centimètres. Square inch.	Lbs.	Lbs.	5 square centimètres. Square inch.	Lbs.	Lbs.	Lbs. per Sq. inch.	Lbs.	Lbs.	Lbs. per Sq. inch.	Lbs.	Lbs.	Lbs. per Sq. inch.
						Four weeks.								
3·56	3·47	88·2=113·8	3·50	3·29	81·2=104·8	3·64	3·45	117·2	3·58	3·42	115·6	3·65	3·52	212·0
						Sixty days.								
3·56	3·43	83·8=108·1	3·52	3·42	101·3=130·7	3·57	3·41	134·5	3·57	3·40	126·2	3·66	3·53	236·5
						Ninety-one days.								
3·57	3·49	104·5=134·8	3·56	3·45	86·0=111·0	3·67	3·46	145·0	3·60	3·48	123·5	3·60	3·55	206·0
						Twenty-six weeks.								
3·60	3·50	122·2=157·7	3·59	3·45	110·6=142·7	3·66	3·52	156·0	3·64	3·50	135·1	3·60	3·55	253·0
						Thirty-nine weeks.								
3·58	3·10	128·6=166·0	3·57	3·43	130·0=167·7	3·60	3·48	157·8	3·65	3·48	160·2	3·65	3·55	267·5
						Fifty-two weeks.								
3·60	3·45	144·3=186·2	3·58	3·41	133·5=172·2	3·57	3·46	213·0	3·62	3·55	181·5	3·70	3·60	273·5

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APPENDIX XXIII.

26*th March*, 1878.

Cement. Sifted through 2,580 per Square Inch.

Seven Days.			Twenty-eight Days.			Sixty Days.			Thirteen Weeks.			Twenty-six Weeks.			Thirty-nine Weeks.			Fifty-two Weeks.			Remarks.
Weight when Tested.	Weight Seven Days after.	Average of Ten Samples per Square Inch.	Weight when Tested.	Weight Seven Days after.	Average of Ten Samples per Square Inch.	Weight when Tested.	Weight Seven Days after.	Average of Ten Samples per Square Inch.	Weight when Tested.	Weight Seven Days after.	Average of Ten Samples per Square Inch.	Weight when Tested.	Weight Seven Days after.	Average of Ten Samples per Square Inch.	Weight when Tested.	Weight Seven Days after.	Average of Ten Samples per Square Inch.	Weight when Tested.	Weight Seven Days after.	Average of Ten Samples per Square Inch.	
Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
3·62	3·51	491·5	3·62	3·50	605·0	3·66	3·58	713·0	3·66	3·63	784·5	3·71	3·67	700·0	3·71	3·65	708·0	3·65	3·63	670·5	Clips, Fig. 31. Mould (Fig. 22), 1 inch by 1 inch. Neat cement. Water 22·5 per cent.
..	..	..	3·56	3·47	78·5	3·60	3·45	113·9	3·65	3·52	116·9	3·67	3·54	142·3	3·65	3·51	178·0	3·68	3·57	205·5	Mould (Fig. 22), 1 inch by 1 inch. 1 of cement to 3 of standard sand (20-30). Water 10 per cent. Made by ordinary pressure.
..	..	..	3·68	3·53	137·1	3·72	3·59	239·5	3·70	3·57	223·0	3·74	3·63	231·5	3·71	3·57	254·5	3·75	3·65	251·5	Mould (Fig. 22), 1 inch by 1 inch. 1 of cement to 3 of sand, sifted from 10–20. Water 10 per cent. Note the greater strength with coarser sand.

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APPENDIX XXIV.

26th March, 1878.

Cement (Warwickshire).

Sifted through 2,580 per square inch; leaving 14·5 per cent. residue. All kept in water until tested. Proportions by weight. Tensile strain in lbs. Made between April 8th and July 26th, 1878. Specific gravity: cement, 3·06; sand, 2·683; sifted from 20 to 30. Weight per bushel: cement, 115 lbs.: sand 120 lbs. Mould, 1 inch × 1 inch, Figs. 22 and 31, and German standard mould of 5 square centimètres.

Neat Tests.

German Mould, Fig. 23. Water 22·5 per cent.			Mould (Figs. 22 and 31). Water 22·5 per cent.			Mould (Figs. 22 and 31). On Gypsum Slabs. Water 33 per cent.		
Weight when Tested.	Weight Seven Days after.	Tensile Strength in lbs. Average of Ten Tests.	Weight of Ten Briquettes, When Tested.	Weight of Ten Briquettes, Seven Days after.	Tensile Strength in lbs. per Sq. inch. Average of Ten Tests.	Weight of Ten Briquettes, When Tested.	Weight of Ten Briquettes, Seven Days after.	Tensile Strength in lbs. per Sq. inch. Average of Ten Tests.
Lbs.	Lbs.	5 square centimetres. Square Inch.	Lbs.	Lbs.		Lbs.	Lbs.	
			One week.					
3·50	3·37	312·0=402·5	3·48	3·34	492·5	3·03	2·88	250·0
			Four weeks.					
3·53	3·37	445·0=574·0	3·52	3·36	626·5	3·30	3·20	507·0
			Sixty days.					
3·56	3·39	537·5=693·5	3·59	3·50	803·5	3·40	3·28	749·5
			Thirteen weeks.					
3·52	3·44	489·0=631·0	3·60	3·50	851·1	3·35	3·26	759·0
			Twenty-six weeks.					
3·69	3·57	598·0=771·6	3·74	3·60	845·5	3·32	3·28	793·5
			Thirty-nine weeks.					
3·60	3·57	530·0=684·8	3·74	3·69	798·0	3·43	3·40	745·0
			Fifty-two weeks.					
3·66	3·62	549·0=708·3	3·80	3·76	784·0	3·68	3·65	739·5

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APPENDIX XXV.

26th March, 1878.

SAME CEMENT AS LAST; SIFTED THROUGH SIEVE A = 2580 PER SQUARE INCH, LEAVING 14·5 PER CENT. RESIDUE.
One of cement to three of sand. Water 10 per cent. SAND TESTS.

German Mould. Fig. 23. Iron Spatula. Standard (20–30) Sand.				German Mould. Fig. 23. Made by ordinary Pressure. Standard (20–30) Sand.			Mould (Figs. 22 & 31), 1″ × 1″. Wooden Spatula. Standard (20–30) Sand.			Mould. Figs. 22 and 31. Made by ordinary Pressure. Standard (20–30) Sand.			Mould. Fig. 22. Wooden Spatula. Sand Sifted from 10 to 20.		
Weight of Ten Briquettes,		Tensile Strength in lbs. Average of Ten Tests.		Weight of Ten Briquettes,		Tensile Strength in lbs. Average of Ten Tests.	Weight of Ten Briquettes,		Tensile Strength per Sq. Inch. Average of Ten Tests.	Weight of Ten Briquettes,		Tensile Strength per Sq. Inch. Average of Ten Tests.	Weight of Ten Briquettes,		Tensile Strength per Sq. Inch. Average of Ten Tests.
When Tested.	Seven Days after.			When Tested.	Seven Days after.		When Tested.	Seven Days after.		When Tested.	Seven Days after.		When Tested.	Seven Days after.	
Lbs.	Lbs.	5 square centimètres.	Square Inch.	Lbs.	Lbs.	5 square centimètres.	Square Inch.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
							Four weeks.								
3·45	3·26	129·7	167·3	3·45	3·24	143·5	185·1	3·58	3·41	198·5	3·56	3·31	162·9	3·70	3·57	222·0
							Sixty days.								
3·55	3·40	169·0	218·0	3·53	3·38	178·8	231·0	3·55	3·36	224·5	3·54	3·34	219·5	3·62	3·50	248·5
							Thirteen weeks.								
3·52	3·33	154·9	200·0	3·50	3·35	165·5	213·5	3·58	3·40	265·0	3·58	3·42	245·0	3·74	3·61	263·0
							Twenty-six weeks.								
3·54	3·46	195·8	252·6	3·50	3·41	187·0	241·3	3·60	3·45	256·0	3·57	3·51	294·0	3·76	3·65	263·0
							Thirty-nine weeks.								
3·52	3·44	144·8	186·8	3·50	3·42	180·0	232·2	3·60	3·52	232·0	3·62	3·51	242·5	3·80	3·66	246·5
							Fifty-two weeks.								
3·60	3·50	210·0	271·0	3·53	3·43	192·0	247·7	3·66	3·56	280·5	3·70	3·58	269·5	3·67	3·57	270·0

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APPENDIX XXVI. 1876–7.

B. Portland Cement gauged neat.

Moulded in pattern Fig. 15, 1 inch by 1 inch. Half moulded on glass and half on plaster of Paris slab. Cement 119 lbs. coarsely ground. Delivered quite fresh on the 1st October, 1876. Compare with Appendix XXXII.

When Moulded.	When Tested.	Days in Mould.	On Glass. Broken at in lbs.	Remarks.	When Moulded.	When Tested.	Days in Mould.	On Plaster. Broken at in lbs.	Remarks.
			Each No. the Average of 5.	Proportions for each 5 moulds of cement 1·32, and water 0·33. Weight of 5 briquettes when tested 1·50.				Each No. the Average of 5.	Weight when tested 1·53
Oct. 19	Oct. 26	7	313·0		Oct. 20	Oct. 27	7	302·0	
„ 25	Nov. 24	30	500·0	Weight when tested 1·52.	„ 27	Nov. 27	31	608·0	Ditto 1·51.
„ 20	Dec. 19 1877	60	536·0	Ditto 1·51.	„ 24	Dec. 23 1877	60	660·0	Ditto 1·53.
„ 25	Jan. 23	90	605·4	Ditto 1·51.	„ 24	Jan. 22	90	678·0	Ditto 1·52.

APPENDIX XXVII.

Table showing the measure of Strength when Cement is sifted fine.

(Messrs. Dyckerhoff.)

—	Weight per Litre.	Time of Setting.	Residue upon Sieves of		Seven Days.	Four Weeks.	Twelve Weeks.	Twenty-five Weeks.	One Year.	Nos.
			400 Sq. Centimètres.	900 Sq. Centimètres.						
	Grammes.	Hours.	In per cent.		Kilog. per Square Centimètre.					
A. Neat .	1,428	10	10·2	18·8	24·8	37·5	51·4	49·3	50·6	1
Do. with 3 of standard sand . .	..	..	..	..	5·3	12·0	17·9	19·8	24·3	2
Do. A sifted all through 5,000 meshes to square centimètre. Neat . .	1,126	Minutes. 135	..	..	24·3	26·7	..	34·8	..	3
Do. with 3 of sand . .	..	..	..	..	17·7	23·2	..	27·9	..	4
B. Neat .	1,307	90	1·8	5·3	20·4	26·5	34·8	40·5	45·2	5
Three of sand	..	..	..	..	7·6	13·2	19·4	21·1	25·8	6

At twenty-five weeks the sifted cement, No. 3, is only 70 per cent. of the strength neat of No. 1; but with 3 of sand is 41 per cent. stronger—27·9 to 19·8. At the end of a year the cement B, though 10 per cent. weaker than A, (No. 1), is stronger with sand—compare No. 6 = 25·8 with No. 2 = 24·3.—J. G.

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APPENDIX XXVIII.

NEAT CEMENT, WEIGHING 122 lbs. per BUSHEL, DELIVERED 16th FEBRUARY.

Result of testing. Sifted and not sifted.

When Moulded.	When Tested.	Days in Mould.	Broken at in lbs. 1¼"×1¼" Fig. 5.	At per Inch.	Broken at in lbs. 1½"×1½" Fig. 17.	At per Inch.	Broken at in lbs. 1½"×1½" Fig. 4. With Jointed Clips.	At per Inch.	Remarks.
1877 Feb. 21	1877 Mar. 24	31	905	402·2	855	380			Not Sifted.
							975	433·3	Cement 5·8, water 1·27 = 22 per cent.
			900	400·0	915	406·6			
							900	400·0	Cement 5·8, water 1·22 = 21 per cent.
			905	402·2	895	397·7			
							925	411·1	„ „
			870	386·6	975	433·3			
							935	411·5	„ „
„ 22	„	30	930	413·3					
					965	428·8			
							900	400·0	„ „
			902	400·8	921	409·3	927	412·0	Average.
„ 23	„ 26	31	1,080	480·0					Sifted through 48 × 48 leaving 39·84 per cent. residue.
					1,125	500·0			
							770	342·2	Cement 5·6, water 1·34 = 24 per cent.
			940	417·7					
					965	428·8			
							960	426·6	„ „
			1,035	460·0					
					1,015	451·1			
							1,050	466·6	„ „
			1,060	471·1					
					1,150	511·1			
							1,050	466·6	„ „
			1,095	486·6					
					1,195	531·1			Passed 36 × 36 leaving 20·93 per cent. residue.
							1,045	464·4	Cement 5·1, water 1·31 = 23 per cent.
			1,042	463·1	1,090	484·4	975	433·3	Average.

Figs. 17 and 4 broken with the jointed clips. One gauging filled three moulds.

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APPENDIX XXIX. *May 12th*, 1877.

EIGHT VARIETIES OF PORTLAND CEMENT.

The weight per tenth of a bushel sifted and not sifted.
The percentage of coarse caught on 48 × 48 = per square inch 2,304.
The tensile strength of neat cement at sixty days, sifted and not sifted.
The average of 10 briquettes to each test kept in water.
Mould pattern 1 inch by 1 inch, Fig. 22.

	Weight in lbs.			Percentage.		Broke at in lbs. per Square Inch.	
	Per Bushel.	Per Tenth of a Bushel.	Per Tenth of a Bushel after Sifting.	Of Coarse Residue on 2,304 per Square Inch.	Of Water used.	Unsifted.	Sifted.
a	..	11·58	10·63	19·70	20·60 22·50	770	828
b	..	10·68	9·80	24·96	22·88 25·77	627	688
c	119	10·97	9·61	24·06	20·40 25·00	774	774
d	..	10·67	9·03	28·03	22·52 25·00	646	677
e	..	10·78	..	15·79	20·68 22·50	625	632
f	..	10·73	9·37	23·84	21·57 26·00	816	779
g	120	11·27	9·72	24·96	21·00 21·00	614	681
h	122	11·37	9·62	28·46	21·00	656	661

APPENDIX XXX.

TABLE SHOWING the SAME CEMENT COARSELY GROUND and SIFTED THROUGH a FINE SIEVE NEAT and MIXED with SAND. The GERMAN MOULD USED = 5 square centimètres. Fig. 23.

Breaking weight converted into lbs. per square inch.

Cement R. (Messrs. Dyckerhoff.)

	Neat		Three of Sand.		Five of Sand.	
Age of Briquettes.	10·2 per cent. Residue on a Sieve of 400 Meshes per Sq. Centimètre = 2,580 per Square Inch.	Sifted so to pass all through 5,000 per Square Centimètre = 32,257 per Square Inch.	10·2 per cent. on 400 per Square Centimètre = 2,580 per Square Inch.	All through 5,000 per Square Centimètre = 32,257 per Square Inch.	10·2 per cent. on 400 per Square Centimètre = 2,580 per Square Inch.	All through 5,000 per Square Centimètre = 32,257 per Square Inch.
Weeks.	Lbs. per Square Inch.	Lbs. per Square Inch.	Lbs. per Square Inch.	Lbs. per Square Inch.	Lbs. per Square Inch.	Lbs. per Square Inch.
1	353	346	75	252	31	136
4	533	380	171	330	97	208
8	585	469	206	358	118	223
25	701	495	282	397	166	272

REMARKS.—This Table shows—(1.) That the coarsely-ground cement broke at a higher point when tested neat than when finely ground or sifted; but at a much lower point when mixed with sand. (2.) That at twenty-five weeks, with three of sand, the gain was equal to 41 per cent., and with five of sand equal to 64 per cent. (3.) That the strength of the fine cement, with five of sand, was equal to a greater strain than that of coarse with three of sand, especially at the earlier stages. The proportion remaining on a sieve of 5,000 per square centimètre was 49·5 per cent.—J. G.

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APPENDIX XXXI.—On Strength by Tensile Strain.

Experiments with various Portland Cements as delivered unsifted, and sifted through sieve of 50 to lineal inch, 2,500 to square inch.
Neat and mixed with Sand in the proportion of 1 to 1 by weight. Sizes 1″ × 1″ and, 1½″ × 1½″ = 2¼ square inches.
Sand passed 30 sieve—900 to square inch.

Broken at in lbs. per sq. in. Weight of Sand $\frac{1}{10}$ bushel 11·90 lbs. Briquettes marked S, Fig. 22, Clips 31. Briquettes marked L, Fig. 21, Clips 30.

Cement Delivered.	Mark of Cement.	Seven Days Neat.			At Twenty-eight Days.					At Thirty Days.					At Sixty Days.					Specific Gravity.	Weight.		Percentage Caught on Sieve 50.
		Not Sifted.		Sifted.	Neat.			With Sand 1 to 1.		Neat.			With Sand 1 to 1.		Neat.			With Sand 1 to 1.			Bush.	$\frac{1}{10}$.	
					Not Sifted.		Sifted.	Not Sifted.	Sifted.	Not Sifted.		Sifted.	Not Sifted.	Sifted.	Not Sifted.		Sifted.	Not Sifted.	Sifted.				
		S.	L.	S.	S.	L.	S.	S.	S.	S.	L.	S.	S.	S.	S.	L.	S.	S.	S.				
1877																							
June 7	L.	449·0	..	..	..	..	..	..	..	571·5	..	582·0	249·5	249·5	596·5	..	632·5	260·5	336·0	..	118	10·80	20·75
,, 8	W.	..	202·0	326·0	..	..	..	..	..	431·0	401·3	425·5	152·5	196·0	..	..	524·5	248·0	266·5	..	112	10·07	19·75
,, 13	W.	294·0	258·5	..	..	..	..	..	..	466·0	453·0	..	176·0	228·0	..	..	..	..	..	..	116	10·55	18·80
..	..	280·0	274·6	..	..	..	..	..	..	496·5	455·5	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	269·7	..	..	470·0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	308·2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 23	L.	429·0	445·3	..	..	525·8	..	..	..	549·5	..	540·0	231·0	286·5	583·5	..	616·5	268·5	333·5	3·098	122	11·06	24·00
..	..	498·5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 30	L.	404·0	..	..	..	..	..	..	..	456·5	..	..	213·5	..	553·0	..	..	..	313·0	3·068	..	10·10	15·84
..	..	..	..	..	..	..	..	..	..	..	..	..	207·5	257·5	..	..	..	..	..	..	..	..	..
July 27	L.	364·5	370·4	407·5	482·5	448·3	501·0	190·0	249·5	..	..	..	..	..	582·5	..	577·0	238·5	281·5	3·096	116	10·04	16·00
..	..	390·0	355·0	..	478·5	491·3	..	232·5	..	..	..	..	..	..	585·0	..	..	309·5	..	..	..	..	..
..	..	480·5	431·7	..	530·0	572·2	..	237·5	..	..	..	..	..	..	..	..	..	304·0	..	..	..	..	..
..	..	..	..	..	506·5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 31	H.	454·5	..	..	563·0	..	424·0	197·0	217·5	..	..	..	..	..	..	..	..	218·0	246·0	3·070	..	10·30	11·20
Sept. 8	L.	389·0	392·6	453·5	534·0	..	528·0	193·0	242·0	..	..	..	..	..	577·0	..	596·0	234·5	284·5	3·070	118	10·52	22·00
..	..	447·5	..	..	543·5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 11	W. K.	495·5	..	511·0	573·0	..	584·0	178·5	271·0	..	..	..	..	..	..	..	..	..	..	3·082	120	11·10	27·50
..	..	..	..	..	..	..	..	210·0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 13	L.	551·0	..	563·5	548·0	..	651·5	214·5	254·0	..	..	..	..	..	648·5	..	609·0	222·0	279·0	3·090	119	10·53	21·60
..	..	521·0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 25	L.	503·5	561·5	492·0	592·5	589·5	585·0	215·0	297·2	..	..	..	..	..	624·5	..	597·5	281·5	379·0	3·091	123	11·30	26·80
..	..	493·0	513·0	..	619·5	..	..	209·5	232·0	..	..	..	..	..	..	..	..	280·0	..	..	..	..	..
Oct. 4	W. K.	406·5	..	413·0	518·5	..	524·0	183·5	250·0	..	..	..	..	..	619·5	..	592·0	226·5	313·0	3·060	117	10·64	28·27
..	..	412·0	..	..	532·5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	432·0	..	..	573·5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,, 8	L.	544·0	..	..	594·5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	124	11·00	..
,, 11	L.	465·5	501·3	438·5	565·5	552·6	595·5	210·0	259·0	..	..	..	..	..	714·0	..	664·5	290·0	372·0	3·109	117	10·40	23·80
..	..	..	..	..	..	..	..	234·0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

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APPENDIX XXXII.

PORTLAND CEMENT GAUGED NEAT. 1876-7.

Half per cent. of sulphuric acid mixed with the water. Fig. 15, 1″ × 1″. Half moulded on glass and half on plaster of Paris slab. Cement 119 lbs. coarsely ground. Delivered quite fresh on the 1st October, 1876. Compare with Appendix XXVI.

When Moulded.	When Tested.	Days in Mould.	On Glass. Broken at in lbs.	Remarks.	When Moulded.	When Tested.	Days in Mould.	On Plaster. Broken at in lbs.	Remarks.
			Each No. the Average of 5.					Each No. the Average of 5.	
Oct. 17	Oct. 24	7	305	For each 5 moulds, cement 1·32, water, 0·33 = 25 per cent. Weight of 5 briquettes when tested 1·52.	Oct. 16	Oct. 23	7	387	Weight when tested 1·53.
„ 12	Nov. 11	30	503	Weight when tested 1·50.	„ 12	Nov. 11	30	621	Weight when tested 1·52.
„ 13	Dec. 12	60	567	Weight when tested 1·51.	„ 13	Dec. 12	60	575	Weight when tested 1·51.
„ 14	1877 Jan. 12	90	618	Weight when tested 1·52.	„ 16	1877 Jan. 14	90	633	Weight when tested 1·50.

NOTE.—A bushel of the cement was sifted with a sieve 48 × 48; 119 lbs. per bushel; caught on a sieve 35·20, or 29½ per cent. of coarse. The cement used for these experiments was not sifted.

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APPENDIX

With Sulphuric

Sample of Portland Cement gauged half Cement and half Sand. Half per Fig. 15, 1″ × 1″. Half moulded on Plaster of Paris slab and half on 2nd Nov. 1876. Cement and Sand passed 36 × 36. Only the fine used. sifting, weighed 1·50 per measure—Sand 1·80 the same measure. The

When Moulded.	When Tested.	Days in Mould.	Broken at in lbs. on Glass.	Number of Test.	Remarks.
					For each.
1876 Nov. 2					
„ 15	1876 Nov. 22	7	130	500	Five moulds.
			150	501	Cement 0·66
			123	502	Sand 0·80
			121	503	Water 0·25
			122	504	Weight when tested 1·40.
			5) 646		
			129·2		
„ 10	Dec. 11	31	231	470	
			230	471	
			225	472	Weight when tested 1·43.
			222	473	
			225	474	
			5) 1,133		
			226·6		
	1877				
„ 13	Jan. 12	60	286	480	
			257	481	
			237	482	Weight when tested 1·45.
			252	483	
			266	484	
			5) 1,298		
			259·6		
„ 14	Feb. 12	90	258	485	
			247	486	
			250	487	Weight when tested 1·44.
			256	488	
			265	489	
			5) 1,276		
			255·2		

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XXXIII. 1876–77.

ACID.

cent. Sulphuric Acid, mixed with the Water. Briquettes and Clips, Glass. Cement 118 lbs. per bushel before sifted, delivered quite fresh on Sand clean and sharp, and mixed with the Cement dry. Cement, after mixture of Cement, Sand, and Water taken by weight.

When Moulded.	When Tested.	Days in Mould.	Broken at in lbs. on Plaster.	Number of Test.	Remarks.
1876 Nov. 17	1876 Nov. 24	7	178	505	Weight when tested 1·43.
			199	506	
			183	507	
			195	508	
			195	509	
			5) 950		
			190		
„ 9	Dec. 9	30	191	460	Weight when tested 1·39.
			202	461	
			203	462	
			207	463	
			190	464	
			5) 993		
			198·6		
„ 13	1877 Jan. 12	60	234	465	Weight when tested 1·41.
			231	466	
			242	467	
			207	468	
			252	469	
			5) 1,166		
			233·2		
„ 14	Feb. 12	90	315	495	Weight when tested 1·44.
			302	496	
			352	497	
			336	498	
			292	499	
			5) 1,597		
			319·4		

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APPENDIX

WITHOUT SULPHURIC

Sample of Portland Cement gauged half Cement and half Sand.
Sulphuric Acid

When Moulded.	When Tested.	Days in Mould.	Broken at in lbs. on Glass.	Number of Test.	Remarks.
1876 Nov. 8	1876 Nov. 15	7	105 105 102 115 107	445 446 447 448 449	Weight when tested 1·41.
			5) 534		
			106·8		
„ 2	Dec. 2	30	165 163 147 172 149	365 366 367 368 369	Weight when tested 1·42.
			5) 796		
			159·2		
„ 3	1877 Jan. 2	60	218 170 168 170 216	375 376 377 358 379	Weight when tested 1·42.
			5) 942		
			188·4		
„ 6	Feb. 4	90	263 264 271 271 265	400 401 402 403 404	
			5) 1,334		
			266·8		

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XXXIV. 1876–77.

ACID.

Exactly the same in every respect except that there was not any in the Water. Briquettes and Clips, Fig. 15.

When Moulded.	When Tested.	Days in Mould.	Broken at in lbs. on Plaster.	Number of Test.	Remarks.
1876 Nov. 9	1876 Nov. 16	7	155	450	Weight when tested 1·42.
			137	451	
			152	452	
			155	453	
			145	454	
			5) 744		
			148·8		
„ 7	Dec. 7	30	235	405	Weight when tested 1·44.
			222	406	
			221	407	
			241	408	
			240	409	
			5) 1,159		
			231·8		
„ 8	1877 Jan. 7	60	200	430	Weight when tested 1·42.
			225	431	
			260	432	
			210	433	
			257	434	
			5) 1,152		
			230·4		
„ „	Feb. 6	90	226	435	Weight when tested 1·44.
			250	436	
			294	437	
			260	438	
			294	439	
			5) 1,324		
			264·8		

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APPENDIX XXXV.

TABLE SHOWING the INCREASE in STRENGTH WHICH RESULTS from an INCREASE in the TIME OCCUPIED in SETTING.

Kilogrammes per square centimètre (by Messrs. Dyckerhoff).

No.	One Sort of Cement.	Time of setting. Neat.	Neat Cement. 275 Grammes of Water to 1,000 Grammes of Cement.					One of Cement to Three of Sand. Standard Test.				
			One Week.	Four Weeks.	Twelve Weeks.	Twenty-five Weeks.	Fifty-two Weeks.	One Week.	Four Weeks.	Twelve Weeks.	Twenty-six Weeks.	Fifty-two Weeks.
1		20 minutes	22·7	28·5	36·4	43·7	49·3	8·1	11·8	16·7	21·2	25·3
2	The same cement with ½ per cent. of gypsum	210 „	22·2	32·1	40·3	43·9	45·8	10·0	14·9	23·8	24·8	27·4
3	The same cement with 1 per cent. of gypsum	600 „	26·4	35·7	39·9	49·0	54·9	11·2	16·7	21·9	25·9	27·0
4	The same cement with 2 per cent. of gypsum	840 „	29·9	38·2	48·4	50·5	56·7	12·7	18·5	21·4	26·3	28·8
5	The same cement without gypsum, but kept in store for some months	630 „	22·3	31·6	38·7	41·7	43·5	11·8	15·4	22·4	25·3	30·3

REMARKS.—The strength of No. 5, kept in store, is less when neat; but with three of sand, exceeds that of No. 1 at fifty-two weeks by 20 per cent., and of No. 3 by 12½ per cent.—J. G.

The weight of No. 1 per litre was 1,256 grammes; of No. 5, 1,201 = 4·4 per cent. loss.

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APPENDIX XXXVI.

Two Freights of Portland Cement, delivered on the 31st January and the 16th February, 1877.

Remarkably different in tensile strength at seven days.

These were made for the purpose of comparing results at a later period.

Days in Moulds.	Broken in lbs.	Delivered 31st January. Weight per bushel, 120 lbs.	Days in Moulds.	Broken in lbs.	Delivered 16th February. Weight per bushel, 122 lbs.
	Moulds 1″ × 1″ Figs. 22 and 31.			Moulds 1″ × 1″ Figs. 22 and 31.	
7	486·0	Average of 5. Per cent. Water 20	7	232	Per cent.
			7	285	Average of 5. Water 21
			14	485	„ 5 „ 20
			21	541	„ 5 „ 20
			28	648	„ 5 „ 20
			35	500	„ 5 „ 20
30	811·5	„ 10 each „ 20	42	592	
			49	638	Average of 5 each test.
			56	662	Water 20 per cent.
90	726·0	„ 5 „ „ 20	63	600	
			70	625	The whole of these
			77	609	are from the second
			84	648	bushel of cement.
120	780·0	„ 5 „ „ 20	91	676	Same freight.
			98	585	
			105	672	
			112	728	
150	791·0	„ 5 „ „ 20	119	711	
			126	756	
			133	704	
			140	745	
			147	750	
180	846·0	„ 5 „ „ 20	154	803	
			161	766	
			168	731	
			175	800	
210	821·0		182	848	
			189	752	
			196	841	
			203	820	
240	803·0		210	817	
270	895·0		210	821	
			217	864	
			224	856	
			231	849	
			238	817	
			7	397	Made after the cement had lain in bushel measure three weeks.

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APPENDIX XXXVII.—Result of testing Portland

Water 25 per cent. Delivery on 31 st January, 1877.

When Moulded.	When Tested.	Days in Mould.	Fig. 5.		Figs. 21 and 30.		Figs. 22 and 31.	Remarks.
			Broken at in lbs. $1\frac{1}{4}''\times1\frac{1}{4}''$	At per Inch.	Broken at in lbs. $1\frac{1}{4}''\times1\frac{1}{4}''$	At per Inch.	Broken at in lbs. $1''\times1''$	
Feb. 2	Mar. 5	31	1,200	533·3	1,160	515·5	410	For this section the quantity of water used with the cement is 25 per cent.
			900	400·0	910	404·4	480	For each gauging to fill 3 moulds.
„ 6	„ 8	30	1,145	508·5	1,070	475·5	640	Cement 3·60 Water 0·90
			1,100	488·8	1,115	495·5	465	With this quantity of water the cement made a stiff grout (sloppy).
„ 7	„ 9	30	1,110	493·3	1,065	473·3	480	
			1,015	451·1	1,130	502·2	505	
			1,030	457·7	1,085	482·2	515	
„ 8	„ 10	30	1,270	564·4	1,210	537·7	535	
„ 9	„ 11	30	910	404·4	1,095	486·6	505	
„ 13	„ 15	30	1,300	577·7	1,155	513·3	585	
			1,098	488·0	1,099·5	488·6	512	

488·0 is to 512 as 1 to 1·05
488·6 „ 512 „ 1 „ 1·048

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CEMENT with DIFFERENT PROPORTIONS of WATER.

Weight per bushel 120 lbs. Water 19 per cent.

When Moulded.	When Tested.	Days in Mould.	Fig. 5. Broken at in lbs. 1½"×1½"	Fig. 5. At per Inch.	Figs. 21 and 30. Broken at in lbs.	Figs. 21 and 30. At per Inch.	Figs. 22 and 31. Broken at in lbs. 1"×1"	Remarks.
Feb. 2	Mar. 5	31	1,545	686·6	1,675	744·4	660	For this section the quantity of water used with the cement is 19 per cent.
			1,570	697·7	1,815	806·6	750	For each gauging to fill 3 moulds.
			1,825	811·1	1,700	755·5	680	Cement 4·0 lbs. Water 0·76 „
			1,565	695·5	1,340	595·5	625	With this quantity of water the cement made a stiff paste.
			1,450	644·4	1,420	631·1	675	
			1,710	760·0	1,495	664·4	600	
			1,670	742·2	1,400	622·2	635	
			1,395	620·0	1,370	608·8	625	
			1,335	593·3	13,75	611·1	615	
			1,785	793·3	1,785	793·3	656	
			1,585	704·4	1,537·5	683·3	656	

1098 is to 1585·0 as 1 to 1·443
1099 „ 1537·5 „ 1 „ 1·40
512 „ 656·0 „ 1 „ 1·28

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APPENDIX XXXVIII.

REGISTER of PORTLAND CEMENT. 1877.

Specific gravity.	Broke at in lbs.	Remarks.
	Averages of ten.	Moulds 1″ × 1″. Figs. 22 and 31.
		A.
3·0412	592	The cement as delivered— Cement 3·30 / Water ·69 } 21 per cent.
		B.
3·0368	573	Passed 50 × 50 sieve— Cement 3·00 / Water ·75 } 25 per cent.
		C.
3·1010	534·5	The coarse caught on sieve. Ground fine enough to pass through 50 × 50 sieve— Cement 3·20 / Water ·67 } 21 per cent.
		D.
2·9648	..	The coarse caught on 50 × 50 sieve. No results for this. The uniting powers of these particles are so feeble that they crumble or separate again between the fingers.

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APPENDIX XXXIX.

Result of testing Portland Cement, Sifted and not Sifted, and with different proportions of Water.

Delivered on 31st January, 1877. Weight per bushel, 120 lbs. Weight per $\frac{1}{10}$th bushel, 11·27. After passing sieve 48 × 48, 9·72 lbs. Sample 14·10. Caught on 48 × 48, 3·52, or 25 per cent.

Fig. 17.		Remarks.	Fig. 17.		Remarks.	Figs. 22 and 31.	Remarks.	Figs. 22 and 31.	Remarks.
Broken at in lbs. $1\frac{1}{4}'' \times 1\frac{1}{4}''$.	At per Inch.		Broken at in lbs. $1\frac{1}{4}'' \times 1\frac{1}{4}''$.	At per Inch.		Broken at in lbs. $1'' \times 1''$.		Broken at in lbs. $1'' \times 1''$	
Averages of ten.			Averages of ten.			Averages of ten.		Averages of ten.	
1037·5 7 days.	461·1	Cement 21 lbs. Water 4·40 „ 21 per cent.	1544·0 30 days.	686·2	Cement 21 lbs. Water 3·99 „ 19 per cent.	544·8 7 days.	Passed 48 × 48 Cement 3 lbs. Water 0·72 „ 24 per cent.	486·5 7 days.	Not sifted. Cement 1·60 lb. Water 0·32 „ 20 per cent.
995·5 7 days.	442·4	Cement 21 lbs. Water 4·83 „ 23 per cent. With this quantity of water the cement is quite soft.	1274·0 30 days.	566·2	Cement 21·5 lbs. Water 4·73 „ 22 per cent.	482·0 7 days.	Passed 36 × 36 Cement 1·60 lb. Water 0·38 „ 24 per cent.	803·5 30 days.	Passed 36 × 36 Cement 1·60 lb. Water 0·32 „ 20 per cent.
			1400·5 30 days.	622·4	Passed 48 × 48 Cement 19 lbs. Water 4·56 „ 24 per cent.	561·5 7 days.	Passed 36 × 36 Cement 1·60 lb. Water 0·32 „ 20 per cent.	811·5 30 days.	Not sifted. Cement 1·60 lb. Water 0·32 „ 20 per cent.

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APPENDIX XL.

CEMENT DELIVERED 20TH MARCH, 1877.

Weight per bushel, 120 lbs. Weight per $\frac{1}{10}$th bushel, 11·20.
Result of testing (seven and eight days) with different proportions of water.
Part spread out in air seventeen hours, and the other part moulded as soon as taken from the sacks.

Moulded as soon as taken from the Sacks.

When moulded.	When tested.	Fig. 17. 1½″ × 1½″ with Jointed Clips. Broken at in lbs.	Fig. 17. 1½″ × 1½″ with Jointed Clips. At per Inch.	Remarks.	When moulded.	When tested.	Figs. 22 and 31. 1″ × 1″ Broken at in lbs.	Remarks.
		Averages of five.					Averages of five.	
Mar. 22	Mar. 29	772	343·1	Cement 2 lbs. Water 0·40 lb. 20 per cent. Set in twenty minutes.	Mar. 22	Mar. 29	354	Cement 1·6 lb. Water 0·32 lb. 20 per cent. Set in twenty minutes.
..	..	675	300·0	Cement 2 lbs. Water 0·46 lb. 23 per cent. Set in thirty minutes.	..	..	304	Cement 1·6 lb. Water 0·36 lb. 23 per cent. Set in thirty minutes.

Spread out in Air Seventeen Hours.

Mar. 23	Mar. 31	888	394·6	Cement 2 lbs. Water 0·40 lb. 20 per cent. Set in thirty minutes.	Mar. 23	Mar. 31	412	Cement 1·6 lb. Water 0·32 lb. 20 per cent. Set in thirty minutes.
..	..	737	327·5	Cement 2 lbs. Water 0·46 lb. 23 per cent. Set in thirty-five minutes.	..	..	347	Cement 1·6 lb. Water 0·36 lb. 23 per cent. Set in thirty-five minutes.

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TENSILE STRENGTH of THIRTY-TWO DIFFERENT CEMENTS, NEAT and with an EQUAL PROPORTION of SAND. Clips for 1½" Fig. 30, and for 1" Fig. 31.

Mark of Cement.	Moulds 1"×1" Fig. 22. Standard Sand, 3. Weight. Per Bushel.	Weight. ¹/₁₀th.	Per Cent. on 400 pr. Square Centimetre=2,540 pr. Square Inch.	Days. Twenty-eight.	Days. Sixty.	Days. Ninety.	Fig. 21 1½"×1½", and Fig. 22 1"×1". Sand 1, passed 30. Days, Thirty. 1"×1" Fig. 22.	Days, Thirty. 1½"×1½" Fig. 21. At per Square Inch.	Days, Sixty. 1"×1" Fig. 22.	Days, Sixty. 1½"×1½" Fig. 21. At per Square Inch.	Days, Ninety. 1"×1" Fig. 22.	Days, Ninety. 1½"×1½" Fig. 21. At per Square Inch.	Neat. Days, Seven. 1"×1" Fig. 22.	Days, Seven. 1½"×1½" Fig. 21. At per Square Inch.	Days, Thirty. 1"×1" Fig. 22.	Days, Thirty. 1½"×1½" Fig. 21. At per Square Inch.	Days, Sixty. 1"×1" Fig. 22.	Days, Sixty. 1½"×1½" Fig. 21. At per Square Inch.	Days, Ninety. 1"×1" Fig. 22.	Days, Ninety. 1½"×1½" Fig. 21. At per Square Inch.
L.	118	10·8	20·75	..	..	..	249	..	260	..	..	..	449	..	571	..	596·0	..	..	..
W.	112	10·07	19·75	..	..	..	152	..	248	..	..	..	..	202	431	401	..	..	..	..
W.	116	10·55	18·8	..	..	..	176	..	..	..	..	..	287	277	481	454	..	..	..	..
L.	122	11·06	14·0	..	..	..	231	..	268	..	..	..	498	445	549	..	583·0	..	..	..
L.	..	10·10	16·0	..	..	..	210	..	..	..	..	..	406	..	456	..	553·0	..	..	..
H.	..	10·3	11·2	..	..	..	197	..	218	..	..	..	454	..	..	..	..	..	..	..
							Days, 28.								Days, 28.					
L.	116	10·04	16·0	..	..	..	223	..	238	..	..	..	378	385	497	503	583·0	..	..	..
L.	118	10·52	22·0	..	..	..	193	..	234	..	..	..	447	392	538	523	542·0	504	..	..
W.K.	120	11·10	27·5	..	..	..	189	..	..	..	..	..	495	..	573	..	..	..	..	..
L.	119	10·53	21·6	..	..	..	214	..	222	..	..	..	536	..	548	..	648·0	..	..	..
L.	123	11·30	16·8	..	..	..	212	..	280	..	..	..	498	537	606	589	624·0	..	..	..
W. K.	117	10·64	28·7	110	..	..	183	..	226	..	..	..	416	..	541	..	619·0	..	..	..
L.	117	10·4	23·8	..	..	..	222	..	290	..	..	..	465	501	565	..	714·0	..	..	..
H.	103	9·58	16·7	133	147·0	..	192	..	232	..	..	..	323	359	492	522	567·0	520	..	..
R.	118	11·57	6·7	62	97·0	132·0	..	..	..	..	..	..	470	458	728	671	678·0	..	815	..
B.R.	..	10·57	22·5	113	150·0	..	..	..	..	..	..	..	444	..	615	..	..	..	..	..
R.	108	9·64	12·5	23	..	..	..	..	..	..	..	..	291	312	413	391	459·0	..	..	..
R.	109	..	3·0	96	..	..	..	..	..	..	..	..	502	456	587	544	669·0	..	..	..
L.	118	10·59	19·0	132	153·0	165·0	..	..	..	..	..	..	422	..	662	..	741·0	..	793·0	..
L.	121	..	25·3	..	..	..	..	227	..	..	..	..	435	476	569	592	..	..	..	..
R.	129	12·3	16·5	..	..	..	..	69	..	..	..	..	474	263	533	623	..	..	..	..
R.	119	11·65	14·5	..	..	..	..	166	..	201·0	..	..	546	452	669	662	..	672	..	..
R.	125	12·10	13·7	..	..	..	..	172	..	248·0	..	229·0	..	514	..	662	..	739	..	623
L.	..	10·8	24·6	120	142·0	179·0	..	..	..	..	..	..	551	..	718	..	751·0	..	825·0	..
L.	108	10·28	20·5	112	112·0	198·0 / [1]237·0	..	211	..	260·0	..	270·0	599	542	700	608	723·0	694	747·0	660
R.	116	11·35	8·2	106	109·0	147·8	..	134	..	190·0	..	232·4	487	386	603	484	703·0	..	685·5	..
R.	118	11·29	8·3	158	200·0	..	..	165	..	..	..	..	502	421	558	566	706·0	..	..	716
L.	112	10·7	24·0	128	241·0	..	..	..	..	..	..	..	528	498	688	636	753·0	745	..	..
R.	112	10·78	9·0	163	198·0	222	..	208	..	246·0	..	..	580	474	532	564	805·5	..	..	..
R.	118	11·12	9·9	..	..	..	..	174	..	201·7	..	..	..	462	..	645	..	..	..	..
L.	112	10·28	20·6	103	120·4 / 136·13		..	..	..	..	..	..	422	..	535	..	591·5	..	..	..
B.	..	10·3	18·0	120	..	..	..	..	..	..	..	..	488	487	561	570	..	..	..	..

In some cases the sand passed 30, and in others it passed 30 and was caught on 50, but the difference in grain was hardly perceptible.

[1] This (237) was with different sand (20–30).

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APPENDIX XLII.

TENSILE STRENGTH of FOUR CEMENTS of DIFFERENT DEGREES of FINENESS, NEAT and with SAND. (Messrs. Dyckerhoff.)

No.	Kind of Cement.	Time of Setting.	Weight of 1 Litre.	Percentage.		Per-centage of Water.	Tested after Weeks.	Kilo. per square Centimètre.			
				900 Meshes per square Centi-mètre.	400 Meshes per square Centi-mètre.			Neat Cement.	One of Sand.	Three of Sand.	Five of Sand.
		Minutes.	Grammes.								
666	Hard burnt D.	30	1,303	2·3	0·3	27·5	1	21·3	19·8	10·5	
..	..	..	..	..	..	..	4	37·9	24·5	14·7	11·1
..	..	..	..	..	..	..	8	33·2	29·9	18·5	12·4
..	..	..	..	..	..	..	12	*33·3	31·6	22·4	13·1
..	..	..	..	..	..	..	25	*34·5	40·4	25·1	17·3
760	D.	90	1,307	5·3	1·8	25·0	1	20·4	15·0	7 6	2·7
..	..	..	..	..	..	..	4	26·5	23·1	13·2	7·3
..	..	..	..	..	..	..	8	29·6	28·4	16·2	10·0
..	..	..	..	..	..	..	12	34·8	30·1	19·4	11·4
750	S.	600	1,235	10·3	5·5	25·0	1	24·6	21·4	9·4	4·6
..	..	..	..	..	..	..	4	40·8	31·0	14·4	6·9
..	..	..	..	..	..	..	8	43·1	33·5	18·2	9·8
..	..	..	..	..	..	..	12	41·5	41·8	23·3	11·9
755	R.	600	1,428	18·8	10·2	25·0	1	24·8	18·9	5·3	2·2
..	..	..	..	..	..	..	4	37·5	26·9	12·0	6·8
..	..	..	..	..	..	..	8	41·4	31·0	14·5	8·3
..	..	..	..	..	..	..	12	51·4	35·3	17·9	9·9

NOTE.—The figures marked * in the column for neat cement, No. 666, are the results actually found, but show some want of uniformity in making the briquettes of neat cement. The cement marked 755 gives the highest result at 12 months, neat; but the lowest with three and five of sand. It is heavier but coarser.—J. G.

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APPENDIX XLIII.

TABLE SHOWING THE TENSILE STRENGTH of various Limes, Selenitic Limes and Portland Cements, with different proportions of Sand at the end of twelve months. Five of the Briquettes kept dry and five in water. Size 1·5" × 1·5" = 2·25 square inches.

Fig. 16. Sand, 96 lbs. per Bushel.

Neat proportion by volume.	Gray Lime. L.		Selenitic Gray Lime. L.		Lias Lime. N.		Selenitic Lias Lime. N.		Lias Lime. W. P. S.		Selenitic Lime. C.		Selenitic Rugby Lias.		Selenitic Aberthaw Lime.		Rugby Lias Cement No. 3, Weight 74 lbs.		Portland Cement 114 lbs. per Bushel. R.		W. P. S. Portland Cement 120 lbs.		Neat proportion by volume.
	Dry.	Wet	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	
	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1,059	1,050	1,243	1,460	..
1 to 1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	762	751	804	913	1 to 1
2 – 1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	536	583	479	551	2 – 1
3 – 1	113	154	288	318	108	215	178	296	91	182	278	334	206	340	289	459	176	319	445	486	405	439	3 – 1
4 – 1	99	129	147	314	110	134	141	222	62	138	179	290	133	230	188	330	141	248	370	384	362	315	4 – 1
5 – 1	68	102	123	195	73	105	99	162	48	100	163	188	74	174	161	276	91	168	323	321	295	280	5 – 1
6 – 1	47	62	90	146	52	61	117	180	41	76	130	167	65	148	..	171	45	103	254	278	222	225	6 – 1
8 – 1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	119	229	157	141	8 – 1
10 – 1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	101	138	116	127	10 – 1
12 – 1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	73	129	93	96	12 – 1

TABLE SHOWING THE COMPRESSIVE STRENGTH of the same Limes and Cements mixed with different proportions of Gravel and Sand weighing 137 lbs. to the bushel. All kept dry. Size 6" cubes. Each number the average of ten cubes.

	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
6 to 1	5,712	10,393	6,417	9,654	12,913	14,918	20,787	19,107	9,676	56,425	48,384	6 to 1
8 – 1	2,576	4,278	6,204	10,988	6,014	8,579	19,196	12,208	5,980	42,806	51,363	8 – 1
10 – 1	2,912	4,569	6,451	5,745	4,793	7,571	11,849	8,624	3,248	29,971	29,232	10 – 1
12 – 1	..	..	..	..	..	..	..	..	..	20,809	16,329	12 – 1

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APPENDIX XLIV.—CEMENT A.

Mixture in Proportions of Weight.			Tensile Strength, Kilogrammes per Square Centimètre.										Compressive Resistance, Kilogrammes per Square Centimètre.				
			Three of Sand.		Five of Sand.		Six of Sand.		Seven of Sand.		Eight of Sand.		Three of Sand.	Five of Sand.	Six of Sand.	Seven of Sand.	Eight of Sand.
Cement.	Sand.	Lime in Dry State.	One Week.	Four Weeks.	One Week.	Four Weeks.	One Week.	Four Weeks.	One Week.	Four Weeks.	One Week.	Four Weeks.	Four Weeks.	Four Weeks.	Four Weeks.	Four Weeks.	Four Weeks.
1	3, 5, 6	..	11·0	15·8	5·7	9·7	3·9	6·4	..	..	..	..	338·9	164·5	108·9	..	..
1	3, 5	½	11·9	16·6	7·7	11·2	..	..	..	..	..	..	387·2	213·4	..	..	..
1	3, 5, 6	½	12·8	18·2	7·2	10·6	6·0	10·2	..	..	..	..	442·2	224·4	176·0	..	..
1	5, 6, 7	½	..	..	6·7	9·8	5·9	9·3	4·4	8·4	..	..	..	254·1	174·4	145·2	..
1	5, 6, 7, 8	½	..	..	5·5	9·0	5·6	9·4	5·0	7·0	3·2	6·1	..	239·8	190·9	136·4	115·5
1	6, 7,	½	..	..	..	..	5·3	8·1	4·2	6·4	2·7	5·2	..	..	247·5	178·2	129·8
1	8	½	..	..	..	..	..	..	..	..	2·5	5·4	..	..	..	..	131·5

All these tests were made with normal sand (60 per square centimètre to 120 per beaten into the moulds until it became elastic. The briquettes, containing half or

Same CEMENT A, being now so much

1	3, 5	..	10·8	17·5	6·4	11·4	..	..	..	..	..	..	..	..	..	..	..
1	3, 5	½	12·0	18·6	7·8	12·1	..	..	..	..	..	..	..	..	..	..	..
1	3, 5, 7	½	11·5	17·5	7·4	11·4	..	..	4·7	8·2	..	..	..	..	..	..	..
1	5, 7, 8	½	..	..	8·6	11·5	..	..	3·3	7·5	2·7	6·7	..	..	..	..	..
1	7, 8	½	..	..	..	..	..	..	2·8	6·8	2·2	6·3	..	..	..	..	..
1	8	½	..	..	..	..	..	..	..	..	1·7	5·8	..	..	..	..	..

This series of tests was made with ordinary sand of the Rhine, such as is used for with standard sand 19·7 kilogrammes, whilst by the above test, when it took but

CEMENT B, of one

1	3, 5	..	9·4	15·1	5·0	8·2	..	..	..	..	..	..	273·9	143·6	..	..	..
1	3, 5	½	10·1	15·4	5·7	8·9	..	..	..	..	..	..	..	..	..	..	..
1	3, 5	½	11·3	16·4	6·2	9·9	..	..	..	..	..	..	312·4	193·1	..	..	..
1	3, 5, 7	½	9·0	14·3	6·1	8·8	..	..	3·7	6·3	..	..	..	..	..	132·0	..
1	5, 7, 8	½	..	..	5·3	8·5	..	..	3·4	7·4	2·3	5·6	..	..	..	..	..
1	7, 8	½	..	..	..	..	..	..	3·0	6·6	2·5	5·4	..	..	..	..	..
1	8	½	..	..	..	..	..	..	..	..	2·5	4·8	..	..	..	..	..

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Time of setting, four and a half hours (by Messrs. Dyckerhoff).

Weight of Ten Briquettes for Tensile Strain, in Grammes.					Weight of Ten Briquettes for Compressive Strength, in Grammes.					—
Three of Sand.	Five of Sand.	Six of Sand.	Seven of Sand.	Eight of Sand.	Three of Sand.	Five of Sand.	Six of Sand.	Seven of Sand.	Eight of Sand.	
1,510	1,445	1,400	..	..	1,972	1,880	1,849	..	..	Standard sand.
1,540	1,455	..	..	..	2,004	1,940	..	..	..	
1,570	1,490	1,460	..	..	2,030	1,960	1,937	..	..	
..	1,532	1,490	1,450	..	..	1,986	1,950	1,925	..	
..	1,522	1,512	1,475	1,450	..	2,000	1,976	1,936	1,870	
..	..	1,535	1,523	1,490	..	..	2,000	1,974	1,930	
..	..	..	..	1,505	..	..	..	..	1,936	

square centimètre), the mortar being in every case of the same consistency, and more lime, were kept in the air.

older, it set only in ten hours.

1,488	1,460	..	..	..	..	..	..	..	..	Common sand.
1,527	1,475	..	..	..	..	..	..	..	..	
1,532	1,500	..	1,475	..	..	..	..	..	..	
..	1,500	..	1,465	1,460	..	..	..	..	..	
..	..	..	1,485	1,492	..	..	..	..	..	
..	..	..	..	1,485	..	..	..	..	..	

masonry. The cement now taking ten hours to set, showed by the normal test four and a half hours to set, it showed but 15·8 kilogrammes.

hour's time of setting.

1,502	1,465	..	..	..	2,012	1,950	..	..	..	Common sand.
1,515	1,470	..	..	..	..	..	..	..	..	
1,542	1,490	..	..	..	2,020	1,970	..	..	..	
1,525	1,500	..	1,420	..	..	..	..	1,966	..	
..	1,496	..	1,458	1,435	..	..	..	..	..	
..	..	..	1,488	1,493	..	..	..	..	..	
..	..	..	..	1,460	..	..	..	..	..	

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APPENDIX XLV.

TABLE to ILLUSTRATE the RELATION to STRENGTH of "THE TIME OF SETTING" and the FINENESS of GRINDING.

Nineteen varieties of cement, tested in 1877–78, since the settlement of the Normal Rules in January 1877.

Tensile strength given in kilogrammes per square centimètre. (Messrs. Dyckerhoff.)

I. Cements setting in from half an hour to two hours.				II. Cements setting in from two to five hours.				III. Cements setting in five or more hours.			
Kind of Cement.	Set in Minutes.	Residue on a Sieve of 900 meshes.	Tensile Strength with three parts of Sand after twenty-eight days.	Kind of Cement.	Set in Minutes.	Residue on a Sieve of 900 meshes.	Tensile Strength with three parts of Sand after twenty-eight days.	Kind of Cement.	Set in Minutes.	Residue on a Sieve of 900 meshes.	Tensile Strength with three parts of Sand after twenty-eight days.
1	40	9·0	11·3	8	120	8·5	13·3	15	420	12·0	9·9
2	30	3·0	12·5	9	180	7·5	9·9	16	540	26·8	14·7
3	35	10·7	10·4	10	180	21·8	8·0	17	600	7·7	16·3
4	35	5·2	10·2	11	180	8·5	12·6	18	600	10·0	15·7
5	60	26·8	10·0	12	200	7·0	14·2	19	600	18·8	12·0
6	60	31·0	5·5	13	270	22·5	8·5				
7	90	8·6	13·2	14	270	9·7	11·4				

APPENDIX XLVI.

TABLE SHOWING the DIFFERENCE in STRENGTH of DIFFERENT DEGREES of FINENESS.

N.B.—1. The difference of times of setting neat 600′–135′, and 600′–30′. 2. The percentage of water: 1. 25 per cent. (900 centimètres) to 30 per cent. (500 square centimètres); and 2. 25 per cent. to 32 per cent. ditto. (Messrs. Dyckerhoff.)

Kind of Cement.	Tested after received. Weeks.	As received.				Ground fine through a Sieve 5,000 meshes per square centimetre.			Quantity of water to 1,000 grammes of Cement.		Remarks.
		Set in Minutes.	Residue on Sieve of	Neat Cement.	Three of Sand.	Set in minutes.	Neat Cement.	Three of Sand.	Cement as received.	Cement ground fine.	
				Kilogrames per square centimètre.			Kilogrammes per square centimètre.				
									Grs.	Grs.	
I.	1	600	18·8	24·8	5·3	135	24·3	17·7	250	300	All briquettes of sand and cement, whether formed of fine or coarse cement, were made with the same per cent. of water, viz., 10 per cent.
	4	..	..	37·5	12 0	..	26·7	23·2	..	..	
	8	..	..	41·1	14·5	..	33·0	25·2	..	..	
	12	..	..	51·4	17·9	..	..	..	..	Water used for neat cement testing.	
	25	..	..	49·3	19·8	..	34·8	27·9	..		
	52	..	..	50·6	24·3	..	..	..	..		
II.	1	600	10·3	24·6	9·4	30	25·0	18·4	250	320	
	4	..	..	40·8	14·4	..	30·9	23·2	..	..	
	8	..	..	43·1	18·2	..	34·4	27·6	..	..	
	25	..	..	47·0	24·2	..	31·6	33·3	..	..	

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APPENDIX XLVII.

TABLE showing the SPECIFIC GRAVITY, WEIGHT, FINENESS, and TENSILE STRENGTH of FORTY DIFFERENT CEMENTS tested neat and with three times their weight of Standard Sand (20–30, except where otherwise noted), showing the importance of fineness when the cement is mixed with sand.

Average of Ten to each Test. Proportions by Weight.
Tests of Cement with sand in black figures.

Numbers.	Specific Gravity.	Weight of 1 Bushel	Weight of ¼ Bushel	Residue on Sieves. Sq. In. 2,580; L. In. 50·8; Sq. C.M. 400	Residue on Sieves. Sq. In. 5,806; L. In. 76·2; Sq. C.M. 900.	Residue on Sieves. Sq. In. 32,257; L. In. 180; Sq. C.M. 5,000.	Water by Weight per cent.	Neat Cement set in Minutes.	Tensile Strain in lbs. per Square Inch, in Weeks. 1	4	13	26	39	52
				A Per cent.	B Per cent.	C Per cent.	Per cent.							
1	3·193	118	11·57	6·7	..	..	18·5	Slow	558	674	815	..	..	825
									1 c. to 3 s.	62·3	132·7	127·5	130·4	161·7
2	3·188	125	12·10	13·7	..	..	24·0	..	479	621				
							22·5	..	550	703	623			
									1 sand	172	230			
3	3·173	119	11·65	14·5	..	..	22·5	..	546	669				
							15·0	..	1 c. to 1 s.	166				
4	3·160	118	11·29	8·3	..	..	22·5	..	502	558	716			
							10·0	..	3 sand	158	212			
5	3·160	118	11·12	9·9	..	..	22·5	..	473	681				
							25·0	..	451	610				
							10·0	..	3 sand	158	212			
							15·0	..	1 sand	174	303	278	273	
6	3·160	..	11·83	14·0	27	..	20·0	..	542	735				
							10·0	..	3 sand	77				
							10·0	..	3 road grit	120				
							11·11	..	3 „	98				
	Cement sifted through				B		10·55	..	3 sand	143				
	„		„		..	C	..	..	3 „	218	241			
7	3·160	116	11·10	6·0	18	..	21·25	..	480	665	761			
							10·0	..	3 st. sand	164	194	230		
							10·55	..	3 „	176	206			
	Cement sifted thro' A						10·0	..	3 „	200	243	260		
	„	„			B		10·0	..	3 „	261	259	294		
	„	„			6,400		10·0	..	3 „	243	287			
	„	„				C	10·55	..	3 „	285	360	354		
	„	„				C	8·63	..	5 sand	155	216			
	„	„			6,400		12·18 and 12·75	..	2 „	310	366	2 of s.		10–20
	„	„			6,400		12·75	..	2 „	283	380	2 „		20–30
	„	„			6,400		13·33	..	2 „	261	354	2 „		30–40
	„	„			6,400		13·91	..	2 „	256	318	2 „		40–50
	„	„			6,400		14·7	..	1 „	417	536	1 „		10–20
	„	„			6,400		14·7	..	1 „	381	508	1 „		20–30
	„	„			6,400		15·0	..	1 „	..	425	484		1 s. 30–40
	„	„			6,400		16·89	..	1 „	321	447	..		40–50

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APPENDIX XLVII.—*continued.*

Numbers.	Specific Gravity.	Weight of 1 Bushel.	Weight of $\frac{1}{10}$ Bushel.	Residue on Sieves. Sq. In. 2,580; L. In. 50·8; Sq. C.M. 400. A Per cent.	Residue on Sieves. Sq. In. 5,806; L. In. 76·2; Sq. C.M. 900. B Per cent.	Residue on Sieves. Sq. In. 32,257; L. In. 180; Sq. C.M. 5,000. C Per cent.	Water by Weight per cent.	Neat Cement set in Minutes.	Tensile Strain in lbs. per Square Inch, in Weeks. 1	4	13	26	39	52
8	3·153	116	11·35	8·2	..	..	Per cent. 22·5	Slow	487	603	685			
							10·0	3 s.	..	106	148			
							15·0	1 „	..	134	232	1 of sand 30–50		
9	3·149	..	10·7	11·0	..	..	21·25	Slow	628	700	At 65° F.			
							21·25	..	527	730	„ 37° F.			
							10·0	..	..	54	(68 at 8 weeks)			
10	3·148	129	12·3	16·5	..	..	22·5	Slow	474	533				
							15·0	..	1 sand	70	..	268	208	Sand 30–50
11	3·147	113	10·3	8·0	19	..	22·5	..	336	449	531	675		
							10·0	..	3 sand	82	122	149	179	
12	3·145	123	10·3	17·8	..	..	22·5	15 m.	422	558	744	742	702	694
	3·165	..	9·87	Sifted thro' A			10·0	3 s.	..	108	89	113	109	125
	3·095	..	..	Residue on A				m.						
13	3·140	126	12·1	6·0	29	..	20·0	600	614	731	846	848	844	813
							21·25	,,	610	730	840	799	846	779
							22·5	,,	520	678	783	791	820	772
							,,	,,	574	717	Out of water.			
							10·0	..	3 sand	71	90	89	107	123
							8·9	..	3 „	72	77	89	102	126
							10·0	..	3 „	138	171	193	Sand	10–20
				Sifted thro' B			10·0	..	3 „	139	112	187	170	210
				„	„	C	10·55	..	3 „	..	371	473		
14	3·130	..	9·52	None	10	25	28·16	..	551	649	700	514		
							..	..	600	..	..	502		
							25·0	..	558	740	645	702		
							10·88	..	3 st.sand	288	291	294		
							10·0	..	..	287	323	335		
15	3·127	118	11·4	3	17	..	20·0	480	626	660	824	761	809	718
							21·25	..	625	790	818	820	868	738
							22·5	..	576	817	833	854	823	785
							8·9	..	3 st.sand	85	92	111	112	113
							10·0	..	3 „	84	81	96	112	139
							10·0	..	3 sand	124	154	204	Sand	10–20
	Cement sifted through				B		10·0	..	..	110	141	195	182	221
	„		„		..	C	10·55	..	..	371	354	389		
16	3·122	..	..	14	24	..	22·5	..	448	478	650			
									3 sand	94	114			
17	3·120	112	10·78	9	..	..	22·5	..	509	548	808	..	765	755
							10·0	..	..	163	222	225	273	247

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APPENDIX XLVII.—*continued.*

Numbers.	Specific Gravity.	Weight of 1 / ¼ Bushel.		Residue on Sieves. A: Sq. In. 2,580; L. In. 50·8; Sq. C.M. 400.	Residue on Sieves. B: Sq. In. 5,806; L. In. 76·2; Sq. C.M. 900.	Residue on Sieves. C: Sq. In. 32,257; L. In. 180; Sq. C.M. 5,000.	Water by Weight per cent.	Neat Cement set in Minutes.	Tensile Strain in lbs. per Square Inch, in Weeks. 1	4	13	26	39	52
				A Per cent.	B Per cent.	C Per cent.	Per cent.							
18	3·116	117¾	10·48	10	18	..	22·5	..	383	648	763			
							10·0	..	..	115	117			
19	3·11	118	10·59	19	..	..	22·5	..	422	728	793	783	796	747
							10·0	..	..	133	165	260	212	203
20	3·11	112	10·5	20	..	(Quick setting)	23·75	..	400	502	474			
							11·31	3 s.	..	129	147			
	Sifted through			A	..	..	11·31	20–30	..	217	239			
	,,			..	B	..	11·9	,,	..	248	277			
	,,			..	..	C	12·5	,,	..	275	334			
								30–40	..	93	146			
	,,			A	..	..	..	,,	..	157	259			
	,,			..	B	..	..	,,	..	202	241			
	,,			..	..	C	..	,,	..	228	260			
										258	317	With 2·6 gypsum.		
21	3·109	117	10·4	23·8	..	..	22·66	..	465	565				
	All sifted thro'			A	..	..	..	..	438	595				
							17·0	1 s.	..	222				
	,,	,,		A	..	..	12·92	1 ,,	..	315				
22	3·107	109	10·56	10	20	..	22·5	..	365	..	..	780		
							21·25	..	422	548				
							10	3 st. s.	..	..	211	250		
	All sifted thro'				B	..	10·55	..	..	226	271	317		
23	3·102	109	10·9	9	..	..	23·75	..	536	638				
							24·4	..	439	617				
							10·55	3 st. s.	..	115				
24	3·102	110	10·13	12	23	..	23·75	..	451	601	607	655		
								With 2·6 gypsum	525	830	756	738		
							10·55	3 s.	..	214	211	233		
	All sifted thro'			..	B	..	10·55	3 ,,	..	261	314	328		
	,,	,,		..	B	..	16·26	1 ,,	..	324	356	443	1 s.	10–20
	,,	,,		..	B	..	16·26	1 ,,	..	376	434	495	1 ,,	20–30
	,,	,,		..	B	..	17·0	1 ,,	..	375	469	536	1 ,,	30–40
							18·14	1 ,,	..	329	406	461	1 ,,	40–50
							19·37	1 ,,	..	337	416	465	1 ,,	50–76
							11·74	2 ,,	..	298	325	358	2 ,,	10–20
							13·66	2 ,,	..	317	352	383	2 ,,	20–30
							14·85	2 ,,	..	305	323	391	2 ,,	30–40
							16·2	..	..	283	313	348	2 ,,	40–50
							18·14	..	..	222	260	352	2 ,,	50–76

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APPENDIX XLVII.—*continued.*

Numbers.	Specific Gravity.	Weight of 1 Bushel.	Weight of 1/16 Bushel.	Residue on Sieves. Sq. In. 2,580; L. In. 50·8; Sq. C.M. 400.	Residue on Sieves. Sq. In. 5,806; L. In. 76·2; Sq. C.M. 900.	Residue on Sieves. Sq. In. 32,257; L. In. 180; Sq. C.M. 5,000.	Water by Weight.	Neat Cement set in Minutes.	Tensile Strain in lbs. per Square Inch, in Weeks. 1	4	13	26	39	52
				Per cent.	Per cent.	Per cent.	Per cent.							
25	3·101	109	10·0	10·0	19·0	42·0	23·75	Quick	456·0	526·5	527·5			
							22·5	20	586·5	632·0	641·0			
							23·75	..	641·0	777·0	701·0	Selenitic, 2·6 per cent. gypsum.		
	1 of cement to 3 of standard sand			..			11·9	..	..	182·5	217·0			
							„	..	..	227·5	248·5	Cement sifted thro' 2,580 sq. in.		
							„	..	..	227·0	285·0	C. sifted through 5,806 sq. in.		
	1 of cement to 3 of sand			Sand sifted from 30 to 40			„	Very quick	..	149·7	..			
							„	..	..	160·0	213·5			
							„	..	..	173·0	227·5			
							„	..	..	179·4	241·0	C. sifted through 2 580 sq. in.		
							„	..	..	210·0	257·0			
							„	..	..	227·5	274·0	C. sifted through 5,806 sq. in.		
							„	..	..	220·0	261·0			
				Sand sifted from 40 to 50			„	..	..	203·5	250·5	C. sifted through 2,580 sq. in.		
							„	..	..	..	289·5	C. sifted through 5,806 sq. in.		
				Sand sifted from 30 to 40			10·55	..	..	146·0	209·5			
							10·0							
				Sand sifted from 40 to 50			12·5	..	..	196·0	262·0	C. sifted through 2,580 sq. in.		
							„	..	..	225·0	257·0	C. sifted through 5,806 sq. in.		
26	3·072	107	9·88	13·0	21·0	41·0	23·75	15	543·5	571·0	..			
							„	..	538·0	590·0	636·0			
							10·0	..	..	172·0	202·5			
							10·88	..	..	177·5	203·0			
				Sand sifted from 20 to 30			11·48	..	..	226·5	254·0	C. sifted through 2,580 sq. in.		
							„	..	..	238·5	291·5	C. sifted through 5,806 sq. in.		
	1 of cement to 3 of sand						„	..	..	241·0	301·5	C. sifted through 32,257 sq. in.		
							10·88	..	..	157·4	195·5			
							11·48	..	..	159·1	175·5			
				Sand sifted from 30 to 40			„	..	..	191·0	247·5	C. sifted through 2,580 sq. in.		
							„	..	..	227·5	278·0	C. sifted through 5,806 sq. in.		
							„	..	..	229·0	278·0	C. sifted through 32,257 sq. in.		

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APPENDIX XLVII.—*continued.*

Numbers.	Specific Gravity.	Weight of 1 Bushel.	Weight of $\frac{1}{10}$ Bushel.	Residue on Sieves. Sq. In. 2,580; L. In. 50·8; Sq. C.M. 400.	Residue on Sieves. Sq. In. 5,806; L. In. 76·2; Sq. C.M. 9·0.	Residue on Sieves. Sq. In. 32,257; L. In. 180; Sq. C.M. 5,000.	Water by Weight.	Neat Cement set in Minutes.	Tensile Strain in lbs. per Square Inch, in Weeks. 1	4	13	26	39	52
				Per cent.	Per cent.	Per cent.	Per cent.							
26	3·072	107	9·88	13·0	21·0	41·0		15	538·0					
	1 of cement to 3 of sand			Sand sifted from 40 to 50			11·48	..	..	147·1	183·5			
							„	..	..	187·0	247·5	C. sifted through 2,580 sq. in.		
							„	..	..	211·0	280·0	C. sifted through 5,806 sq. in.		
							„	..	..	234·0	271·0	C. sifted through 32,257 sq. in.		
	1 of cement to 5 of sand			Sand sifted from 30 to 40			10·0	..	..	105·5	140·3	C. sifted through 2,580 sq. in.		
							„	..	..	113·2	155·7	C. sifted through 5,806 sq. in.		
							„	..	..	119·0	148·5	C. sifted through 32,257 sq. in.		
				Sand sifted from 40 to 50			„	..	..	114·1	154·6	C. sifted through 5,806 sq. in.		
							„	..	..	134·0	174·0	C. sifted through 32,257 sq. in.		
27	3·07	111	10·45	13·0	24·0	..	23·75	15 30	445·0	..	582·0	In water 24 hours.		
							„	15 30	379·5	..	595·0	„ 2 „		
							22·5	20	..	..	574·0	„ 24 „		
	1 of cement to 3 of standard sand			Sand.			11·11 10·55	..	..	187·0	249·0			
				Cement sifted through 180			11·89	..	..	293·0	305·0			
				Cement sifted through 76			11·31	..	..	..	276·5			
	1 of cement to 1 of sand			Sand sifted from 10 to 20			14·7	..	..	347·0	333·0			
				„ 20 „ 30			15·29	..	..	356·0	374·0			
				„ 30 „ 40			15·77	..	..	303·0	364·5			
				„ 40 „ 50			16·66	..	..	281·5	311·5			
	1 of cement to 2 of sand			„ 40 „ 50			13·94	..	..	195·0	231·5			
				„ 30 „ 40			„	..	..	202·0	266·5			
				„ 20 „ 30			12·18	..	..	245·5	287·5			
				„ 10 „ 20			11·58	..	..	261·5	292·0			
	1 of cement to 3 of sand			„ 10 „ 20			10·0	..	..	..	222·0			
				„ 30 „ 40			11·48	..	..	..	214·0			
				„ 40 „ 50			12·65	..	..	..	203·5			

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APPENDIX XLVII.—*continued.*

Numbers.	Specific Gravity.	Weight of Bushel. 1	Weight of Bushel. $\frac{1}{10}$	Weight of Bushel. $\frac{1}{100}$	Residue on Sieves. Sq. In. 2,580; L. In. 50·8; Sq. C.M. 400.	Residue on Sieves. Sq. In 5,806; L. In. 76·2; Sq. C.M. 900.	Residue on Sieves. Sq. In. 32,257; L. In. 180; Sq. C.M. 5,000.	Water by Weight.	Neat Cement set in Minutes.	Tensile Strain in lbs. per Square Inch, in Weeks. 1	4	13	26	39	52	
					Per cent.	Per cent.	Per cent.	Per cent.								
27	3·07	111	10·45	..	13·0	24·0	..									
	1 of cement to 1 of sand				Sand sifted from 10	„ 20		16·66	..	..	301·5	359·5				
					„	20 „ 30		16·97	..	..	310·0	431·0				
					„	30 „ 40		17·51	..	..	306·5	448·0				
					„	40 „ 50		18·76	..	..	295·5	382·5				
	1 of cement to 2 of sand				„	40 „ 50		15·31	..	..	261·0	314·5				C. sifted through 5,806 sq. in.
					„	30 „ 40		13·94	..	..	270·0	328·0				
					„	20 „ 30		13·4	..	..	281·5	333·0				
					„	10 „ 20		12·8	..	..	270·0	325·0				
	1 of cement to 3 of sand				„	40 „ 50		13·73	..	..	155·5	229·5				
					„	30 „ 40		12·5	..	..	..	259·5				
					„	20 „ 30		11·31	..	..	..	276·5				
					„	10 „ 20		10·72	..	..	..	247·5				
												8 wks.				
28	3·064	113	10·55	0·97	18·0	36·0	46·0	23·75	Quick	396·0	437·5	538·5				
	1 of cement to 3 of sand							11·48	..	..	122·9	145·6				
								„	..	..	180·0	..				C. sifted through 2,580 sq. in.
					Standard sand (20–30)			„	..	..	185·5	..				
								„	..	..	207·5	259·5				C. sifted through 5,806 sq. in.
								„	..	..	..	259·0				C. sifted through 32,257 sq. in.
								„	..	..	111·3	128·5				
								„	..	..	..	199·0				C. sifted through 2,580 sq. in.
					Sand sifted from 30–40			„	..	..	222·0	235·0				C. sifted through 5,806 sq. in.
								12·35	..	..	..	252·0				C. sifted through 32,257 sq. in.
											2 wks.					
								11·48	..	..	96·0	..				C. sifted through 2,580 sq. in.
					Standard sand (20–30)			„	..	..	189·0	..				C. sifted through 5,806 sq. in.
								12·35	..	..	201·0	..				C. sifted through 32,257 sq. in.
								11·48	..	..	104·8	Unsifted, as delivered.				
								„	..	..	130·0	..				C. sifted through 2,580 sq. in.
					Sand sifted from 30–40			„	..	..	155·7	..				C. sifted through 5,806 sq. in.
								12·35	..	..	189·0	..				C. sifted through 32,257 sq. in.

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APPENDIX XLVII.—*continued.*

Numbers.	Specific Gravity.	Weight of Bushel. 1	Weight of Bushel. $\frac{1}{10}$	Weight of Bushel. $\frac{1}{100}$	Residue on Sieves. Sq. In. 2,580; L. In. 50·8; Sq. C.M. 400. A Per cent.	Residue on Sieves. Sq. In. 5,806; L. In. 76·2; Sq. C.M. 900. B Per cent.	Residue on Sieves. Sq. In. 32,257; L. In. 180; Sq. C.M. 5,000. C Per cent.	Water by Weight. Per cent.	Neat Cement set in Minutes.	Tensile Strain in lbs. per Square Inch, in Weeks. 1	4	13	26	39	52	
29	3·057	108	10·15	0·95	14·0	33·0	..	23·75	30–40	543·0	568·0	584·0				
		1 of cement to 3 of sand			Sand sifted from 20 to 40			11·18	..	..	133·2	133·1				
					„ 30 „ 40			„	..	..	146·7	152·7				
					„ 20 „ 40			11·76	..	..	129·0	148·2				
					„ 30 „ 40			„	..	..	116·9	109·7				
					„ 20 „ 40			10·0	..	..	116·7	107·5				
					„ 20 „ 40			11·18	..	..	163·3	282·5				
					„ 30 „ 40			„	..	..	163·6	202·5				C. sifted through 5,806 sq. in.
					„ 20 „ 40			11·76	..	..	213·5	193·5				
					„ 30 „ 40			„	..	..	204·5	252·0				
					„ 30 „ 40			11·18	..	..	237·5	246·0				C. sifted through 14,400 sq. in.
								11·76	..	..	..	248·0				
					Less 33 % for cement. Sand sifted from 30 to 40			11·18	..	..	116·2	144·4				C. sifted through 5,806 sq. in.
		All tests of No. 29 at thirteen weeks were frozen.														
30	3·049	107	10·07	0·94	12·0	31·0	41·0	23·75	240·0	536·0	672·0	730·0				
		1 of cement to 3 of sand			Standard sand (20–30)			10·6	..	..	142·9	213·5				
								„	..	..	203·0	254·5				C. sifted through 2,580 sq. in.
								„	..	..	194·5	247·5				
					Sand sifted from 30 to 40			„	..	..	196·5	212·0				
								11·76	..	..	166·5	221·0				
								„	..	..	207·0	234·5				C. sifted through 2,580 sq. in.
					Sand sifted from 20 to 40			10·6	..	..	212·0	248·5				C. sifted through 5,806 sq. in.
					Sand sifted from 30 to 40			„	..	..	239·0	270·0				C. sifted through 32,257 sq. in.
31	3·04	..	10·8	..	24·6	..	..	22·5	20–60	551·0	718·0	825·0				
								10·0	3 s.	..	121·0	179·0				
32	..	..	10·5	..	4	11	..	23·75	1,500	566·0	661·0	678·0				
								10·0	3 of s.	..	177·0	202·0				
		Sifted through			..	B	..	10·55	„	..	189·0	333·3				
		„			..	B	..	11·18	„	..	200·0	..				
33	..	..	10·45	..	3	10	..	23·75	1,080	362·0	477·0	..				
								10·0	..	..	169·0	..				
		Sifted through			A	..	..	..	..	..	179·0	231·0	279·0			
		„			..	B	..	..	..	..	204·0	240·0				

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APPENDIX XLVII.—*continued.*

Tests of Cement with 3 of Sand, unless otherwise expressed, in black figures.

Numbers.	Specific Gravity.	Weight of Bushel. 1	Weight of Bushel. ⅛	Weight of Bushel. 1/156	Residue on Sieves. Sq. In. 2,500; L. In. 50·8; Sq. C.M. 400. A Per cent.	Residue on Sieves. Sq. In. 5,806; L. In. 76·2; Sq. C.M. 900. B Per cent.	Residue on Sieves. Sq. In. 32,257; L. In. 180; Sq. C.M. 5,000. C Per cent.	Water by Weight. Per cent.	Neat Cement set in Minutes.	Tensile Strain in lbs. per Square Inch, in Weeks. 1	4	13	26	39	52	
34	3·08	..	10·85	0·96	4	12	..	23·75	50	341	..	..				
					3	..	..	„	..	310	507	..				
								10·0	..	..	203	217	276			
		Sifted through			A entirely			10·0	..	..	192	239	298			
		„			..	B	..	10·0	..	..	221	241	321			
35	3·09	..	10·45	0·97	3	10	..	23·75	600	410	562	..				
								..	..	..	177	190				
		Sifted through			A entirely			..	..	..	196	203				
		„			..	B	..	..	..	..	202	226				
36	..	..	10·65	..	4	12	..	23·75	450	423	549	..				
								10·0	..	..	188	201				
		Sifted through A, 4 per cent. left out						10·0	..	..	196	208				The 4 % residue left out.
		Sifted through .. B, 12 per cent. left out						10·0	..	..	205	212				The 12 % residue left out.
37	..	..	10·5	..	3	10	..	23·75	480	416	583					
								10·0	..	..	183	205				
		Sifted through A, 3 per cent. residue left out						10·0	..	..	200	214				
		Sifted through .. B, 10 per cent. residue left out						..	..	..	211	212				
38	..	..	10·4	..	3	10	..	23·75	270	406	536					
								„	285	407	..	With water at 46° F.				
								„	110	350	..	„ 97° F.				
								10·0	290	..	157	182				
		Sifted through A, 3 per cent. residue left out						10·0	295	..	183	211				
		Sifted through .. B, 10 per cent. left out						..	284	..	195	235				
39	..	..	11·10	..	6	15	..	23·75	375	409	..	..				
								10·0	..	..	115	189				
		Sifted through A, 6 per cent. residue left out						10·0	345	..	122	215				
		Sifted through .. B, 15 per cent. left out						10·0	..	..	130	229				
40	..	..	..	..	..	5	..	23·75	18	..	512	215				
								10·0	..	..	163	With 3 of standard sand.				
		Sifted through .. B, 5 per cent. residue left out						..	..	..	175	271				

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APPENDIX XLVIII.

TABLE SHOWING the AMOUNT of EXPANSION in TWELVE VARIETIES of CEMENT NEAT and MIXED with 3 PARTS of SAND.
(Messrs. Dyckerhoff.)

Sort of Cement.	Residue on Sieve of 900 Meshes Square Centimetres = 5,806 per Square Inch.	Time of setting. Minutes.	A Prism of 10 Centimètres = 3·9708 Inches in Length and 5 Centimètres Square lying in Water Expands Millimètres:—														Remarks.
			Neat Cement.							Three of Standard Sand.							
			One Week.	From One to Four Weeks.	From One to Three Months	From Three to Six Months.	From Six to Nine Months.	From Nine to Twelve Months.	Total.	One Week.	From One to Four Weeks.	From One to Three Months.	From Three to Six Months.	From Six to Nine Months.	From Nine to Twelve Months.	Total.	
A	5·0	240	0·0254	0·0228	0·0233	0·0067	0·0184	0·0100	0·1066	..	..	..	..	..	..	..	
B	8·5	30	0·0471	0·0198	0·0140	0·0135	0·0186	0·0097	0·1227	0·0134	0·0040	0·0003	0·0050	0·0033	0·0057	0·0317	
C	7·5	660	0·0141	0·0148	0·0081	0·0177	0·0107	0·0048	0·0702	0·0073	0·0013	0·0007	0·0000	0·0007	0·0000	0·0100	
D	10·7	35	0·0467	0·0450	0·0217	0·0341	0·0260	0·0132	0·1867	0·0172	0·0023	0·0006	0·0038	0·0033	0·0044	0·0316	
E	12·5	540	0·1217	0·0322	0·0173	0·0195	0·0080	0·0037	0·2024	0·0392	0·0047	0·0048	0·0020	0·0030	0·0037	0·0574	
F	0·7	600	0 0230	0·0177	0·0170	0·0170	0·0030	0·0130	0·0907	..	..	..	..	..	..	..	
G	5·2	35	0·0439	0·0415	0·0245	0·0226	0·0212	0·0115	0·1652	0·0094	0·0025	0,0000	0·0011	0·0087	0·0000	0·0217	
H	9·8	600	0·0140	0·0121	0·0041	0·0108	0·0089	0·0093	0·0592	0·0044	0·0040	0·0000	0·0000	0·0005	0·0028	0·0117	
I	8·5	480	0·0240	0·0229	0·0118	0·0120	0·0055	0·0080	0·0842	..	..	..	..	..	..	..	
K	9·8	20	0·0694	0·0437	0·0386	0·0278	0·0187	0·0150	0·2132	0·0164	0·0092	0·0061	0·0053	0·0019	0·0043	0·0432	
K^1	9·8	210	0·0317	0·0299	0·0262	0·0229	0·0110	0·0055	0·1272	0·0117	0·0074	0·0037	0·0079	0·0035	0·0005	0·0347	Same cement, but 2 months older.
K^2	9·8	360	0·0897	0·0679	0·0406	0·0247	0·0248	0·0105	0·2582	..	..	..	..	..	..	..	The same cement with 1 per cent. of gypsum.
K^3	9·8	600	0·0966	0·6625	0·0335	0·0247	0·0154	0·0193	0·2457	0·0266	0·0150	0·0000	0·0034	0·0029	0·0018	0·0497	Do. 2 % of gypsum.
K^4	9·8	810	0·4131	1·0335	0·3122	0·0202	0·0100	0·0139	1·8029	0·1396	0·3035	0·0200	0·0024	0·0025	0·0039	0·4719	Do. 5 % „
L	7·3	120	0·0428	0·0449	0·0313	0·0207	0·0080	0·0030	0·1507	0·0178	0·0124	0·0097	0·0048	0·0000	0·0010	0·0457	L. cement.
L^1	7·3	420	0·0543	0·0499	0·0322	0·0198	0·0080	0·0030	0·1672	0·0168	0·0124	0 0027	0·0043	0·0030	0·0000	0·0392	Do. 1 % gypsum.
L^2	7·3	600	0·1013	0·0424	0·0228	0·0267	0·0080	0·0030	0·2042	0·0259	0·0078	0·0062	0·0033	0·0030	0·0005	0·0467	Do. 2 % „
M	9·3	30	0·0530	0·0272	0·0167	0·0098	0·0072	0·0058	0·1197	..	..	..	..	..	..	..	M. cement.
M^1	9·3	300	0·0599	0·0353	0·0167	0·0148	0·0047	0·0083	0·1397	..	..	..	..	..	..	..	Do. 1 % „

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APPENDIX XLIX.—Form A for Daily Record.

Portland Cement Tests.

Bushels, for Work at . Delivered 188 . Manufactured by .

Weight per Bushel lbs. Specific Gravity = 3.			Neat Cement Set in Minutes.			Residue on Sieves of			
						A 2,580 Sq. In = 50·8 L. In. 400 Sq. C.M. = 20 L. C.M.		B 5,806 Sq. In.= 76·2 L. In. 900 Sq. C.M. =30 L. C.M.	C 32,257 Sq. In. =180 L. In. 5,000 Sq. C.M. =70·7 L. C.M.
Numbers of Tests.	Per Cent. of Water by Weight.	Moulded.	Put into Water after Hours.	Tested.	Age of the Briquettes, in Weeks.	Broken by Tensile Strain, in lbs.		Remarks.	
						Moulds. Fig. 21. 1¼"×1¼"	Fig. 22. 1" × 1".		

APPENDIX L.—Form of Abstract B.

Register of Portland Cement Tests.

Bushels, for Work at . Manufactured by . Delivered 188 .

Average of Ten to each Test. Proportions by Weight. Tests of Cement with Sand in Red.

Nos.	Specific Gravity	Weight of 1 Bushel.	Weight of 1/10 Bushel.	Weight of 1/100 Bushel.	Residue on Sieves Sq. In. 2,580, L. In. 50·8, Sq. C.M. 400. A	Residue on Sieves Sq. In. 5,806, L. In. 76·2, Sq. C.M. 900. B	Residue on Sieves Sq. In. 32,257, L. In. 180, Sq. C.M. 5,000. C	Water by Weight Per Cent.	Neat Cement Set in Minutes.	Tensile Strain in lbs. per Square Inch, in Weeks. 1	4	13	26	39	52

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APPENDIX LI.

Memoranda.

1 square inch = 6·45137 square centimètres.
2¼ „ „ = 16·12842 „
1 lineal „ = 25·39954 millimètres.
= 2·539954 centimètres.
39·37079 lineal inches = 1 mètre.
400 per square centimètre (400 sq. c. m.) = 2,580 per square inch.
900 „ „ (900 sq. c. m.) = 5,806 „ „
5,000 „ „ (5,000 sq. c. m.) = 32,257 „ „
1 gramme = 15·43235 grains.
1 kilogramme = 2·20462125 lbs., or 15,432·3487 grains.
1 lb. = 16 ounces or 7,000 grains = 453·59265 grammes.
1 cwt. (112 lbs.) = 50·80238 kilogrammes, or 0·50802 quintal.
1 ton (20 cwt.) = 1·01605 millier or tonne.
1 hectolitre = 2·75121 bushels, or 22·01 gallons.
1248 grammes per litre = 100 lbs. per bushel.
12·48 „ „ = 1 lb. „
1 litre = $\frac{1}{1000}$ of cubic mètre = 1,000 grammes.
1 „ = 61·02705 cubic inches.
1 „ = $\frac{1}{38{\cdot}3477}$ of a bushel.
1 kilogramme per square centimètre = 14·228 lbs. per square inch.
7 „ „ „ = 99·596 „ „ „
10 „ „ „ = 142·228 „ „ „
15 „ „ „ = 213·342 „ „ „
20 „ „ „ = 284·456 „ „ „

To convert lbs. per square inch into lbs. per area of 5 square centimètres multiply by ·775.

To convert lbs. per area of 5 square centimètres into lbs. per square inch multiply by 1·29.

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Discussion.

Mr. White.

Mr. G. F. WHITE said that the three Papers which had been read so completely covered the whole subject, and were so exhaustive in their character, as to leave little room for saying anything new on the question. They seemed to be replete with information and accurate research into the matters on which they treated. The Paper by Mr. Bernays in particular was valuable in pointing out the numberless uses to which Portland cement could be put, and in showing that as a concrete it could be dosed with as large a proportion of foreign material as 12 of ballast to 1 of cement, and yet be trustworthy as a building material for the important dock works which Mr. Bernays had had under his charge. It was within his knowledge that many users of concrete *en masse* still continued to specify the old proportions of 6 parts of ballast to 1 part of cement, which, though suitable enough for lime, involved a waste of good material as applied to Portland cement, and meant a price of 12*s.* to 15*s.* per cubic yard, instead of 7*s.* 6*d.* to 10*s.* per cubic yard, as stated by Mr. Bernays. Without attempting to follow the Authors into all the points of interest contained in their Papers, he wished to make one or two observations, from a manufacturer's point of view, on the Paper of General Scott and Mr. Redgrave; and 1st, as to overclayed cements. It was stated in the Paper that it was not advisable to use in the confection of cement a less proportion of lime than 74 per cent., and consequently a larger proportion of clay than 26 per cent.; that any mixture short of these proportions would 'run' or fuse in the kilns, and would yield a cement light in weight, brown in colour, that would never thoroughly indurate, and would crumble on exposure to the weather.

He was unable to concur with the statement in the Paper, as it was beyond all doubt that with a proportion of even 70 per cent., but preferably 72 per cent., of lime, it was easy to make cement of a high class, which, so far from being unsafe in use, was especially sought after by a large class of users for stuccoing purposes, owing to the fineness of its grinding, its comparative quickness of setting, and its growing induration after use. This, however, was said without prejudice to the denser cements used for engineering purposes, which, being prepared with a larger portion of lime, would bear a higher degree of calcination, and be more resistant in quality, though not free from the danger of crumbling and disintegrating in the work, if any portion of the lime was left

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in a free state, and attackable by the action of the weather—a risk to which cements dosed with more clay were not exposed. It was felt right to notice this point, lest amongst other tests it should even be prescribed that cements must be found on analysis to have been made with not more than 26 per cent. of clay. Mr. White.

The next point he wished to notice was the important change in the mode of washing, or mixing, the chalk and the clay. This process, known as the "Goreham" plan, he considered to have worked a revolution in the manufacture of Portland cement, in rendering its production more uniform and constant. It had been first employed at his works when Mr. Goreham was manager there. He deemed it necessary to draw special attention to this process, because some manufacturers still contended for the superiority of extreme dilution in the mixing. The old plan consisted in mixing the chalk and clay with about three times their volume of water, which reduced the whole to a thin consistency, but left a considerable number of particles of chalk in a coarse and unground condition. These particles were either trapped by sieves in their exit from the mill, or, being allowed to flow into the backs, or reservoirs, sank to the bottom by the action of gravity, and so in either case disturbed the homogeneity of the compound. The means resorted to of restoring this homogeneity, by mixing the top of one back with the bottom of another; or, worse still, of washing into the back a new proportion to rectify the first, were at best but makeshifts, uncertain in their action, and involving trouble and needless expense in the operation. In all the principal factories the thick mode of washing was now used, which consisted in the employment of about 35 per cent. of water, or just sufficient to allow the mixture to flow, and to be reduced by millstones, or other means of trituration, to an impalpable paste. It was then distributed at once through pipes to the drying floors or chambers, instead of lying for weeks and months in the reservoirs, out of which it was dug by hand labour, as soon as evaporation or the draining off of the water allowed this to be done. Not only, it was remarked, was there a considerable saving of labour and of capital by the "stiff" process, but, what was even more important, there was no alteration or disturbance of the proportions in which the ingredients were originally mixed.

The next point discussed was the mode of drying the "slip," and afterwards burning it. In some factories, it was remarked, that coke ovens under drying floors were even now used to dry the slip, though that process could be much more economically effected by the waste gases from the kilns. It was, perhaps,

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Mr. White. hardly fair to say, as stated in the Paper, that this practice was a recent one, or in any way the invention of Mr. Johnson, who was at one time foreman to Messrs. White, and had gained all his experience in cement making in their service. So far from its being a new idea, it had been used by his firm under a patent taken out by Mr. R. O. White five-and-twenty years ago, in closed chambers traversed by surplus heat from the kilns, which sufficed to dry 1½ cubic foot of material for every square foot of area employed. These chambers had been originally connected with running, or continuous kilns, which being vertical in shape and drawn from the bottom, were exposed to the disadvantage of allowing portions of imperfectly burned cement to pass out with that which was properly calcined. Moreover, the heat was abstracted from the kiln before it had done its duty there, which involved loss of fuel in burning.

This state of things had led, in Messrs. White's works, to the adoption of the Hoffman kiln, which seemed to combine the desired properties of a continuous kiln with a horizontal instead of a vertical discharge. In the Hoffman kiln, as was well known, the surplus heat travelled from cell to cell, and was used for the progressive calcination of the material which lay in advance of the point where the incandescence was at the highest pitch. The economy in fuel realised by this means was great; but inasmuch as no portion of the waste heat was applied to the desiccation of the slip, other and independent means of effecting this object, either by converting the "pug" into bricks, or by drying it by separate artificial heat, had to be resorted to.

But in adopting this plan in a country like England, where fuel was comparatively cheap and labour dear (the converse of which held good on the Continent where Hoffman kilns were used), the first economy realised in the burning was to a great extent nullified, to say nothing of other inconveniences which seemed to attend the use of the Hoffman kiln for cement burning, though for the burning of bricks it left nothing to be desired. These circumstances had led to the adoption at Messrs. White's works of a plan, which in preserving the highly advantageous arrangement of the Hoffman kiln in its gathering flues and shafts, would combine with it the advantage of applying the waste heat to the desiccation of the slip. This plan was shown in Plate 8, which indicated a series of vertical kilns of small size grouped together in blocks of twenty-five or thirty, each one of which had its separate drying chamber, calculated to dry stuff enough for its own kiln, and something over. The whole were connected with a central flue and

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common shaft, into which the gases were passed at a temperature not exceeding 200° Fahrenheit, and escaped into the atmosphere at an elevation which rendered them harmless to the surrounding neighbourhood. The wear and tear of these kilns was stated to be inconsiderable, and though they were not continuous but intermittent, the rapidity with which they could be loaded, burnt off, and discharged, together with their close proximity to one another, which prevented radiation and loss of heat, gave them all the advantage of continuous kilns without the attending disadvantage of incomplete calcination. Mr. White.

The economy of fuel by this process was all that could be wished, the fuel used being not more than 35 per cent. in weight of the finished material, for all purposes of drying and burning; while the output from a given cubical kiln space was nearly double that of the Hoffman or any other kiln, as was evidenced by the fact that the structure, which was calculated on the Hoffman principle to produce 350 tons of cement weekly, in its altered state turned out double that quantity. It had been remarked in the course of the discussion, as he thought somewhat illogically, that these modes of economical washing and utilization of the gases were only expedients for producing cheap cement, whereas in truth they were arrangements on scientific principles for producing the best cement in the cheapest way, which was a widely different thing. On the whole he was prepared to regard the kiln and drying chambers in use at his works as the *ne plus ultra* of economy and compactness, combined with a nearly entire suppression of vapours and smoke which had proved offensive, and had been the cause of litigation in certain neighbourhoods.

Reference was made in the Paper of General Scott and Mr. Redgrave to the superiority of the solid slip obtained by passing the heat only over the chamber containing the material to be dried (as in Mr. Johnson's plan), instead of passing it both over and under, as in the plan pursued at his works. It was impossible to understand in what the superiority consisted. The solid slip, retaining as it did a certain amount of moisture not entirely drawn off, was liable to break up and disintegrate when cast into the kiln; whereas the slip which had been dried by over and under heat, and had become honeycombed in the process, was provided with interstices which allowed the gases in the kiln more easily to attack it and accomplish the work of vitrification more quickly. Practically the quality of cement produced from either slip was identical, as had been proved by numerous and careful experiments at his works. It was necessary to resist this notion about the solid slip, because

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Mr. White.

considerable stress had been placed on it in the Paper, and because it had been stated by a manufacturer that the average tensile force at seven days of neat cement made from it had in a given year been 1,160 lbs. on a sectional area of 2·25 inches, to which it might be answered that the average tensile strength of cement made from the other sort of slip during the two past years had been 1,130 to 1,180 lbs. on the same sectional area at seven days.

In the matter of testing the cement after it had been ground and prepared for use, it was remarked that manufacturers would probably endorse the opinion expressed by the Authors of the several Papers, that it would be desirable if the engineers of this country could agree on some uniform conditions of testing cement. As things stood at present scarcely any two engineers made the same requirements. One authority relied almost entirely on fineness of pulverization. Another exacted a certain tensile strength without regard to other conditions; while a third considered a high specific gravity the essential condition of a good cement, though no one of them agreed with the other as to what should be the limit in each direction. Neither was it decided whether tests should be made of neat cement, or of cement mixed with sand, in the condition in which it would be used as mortar. A good deal was no doubt to be said for doing it in the latter way, if only due allowance were made for the varying conditions of temperature between summer and winter, and if uniformity in the character and quality of the sand could be relied on equally with that of the cement. In the difficulty of securing this, it was open to question whether the sand that had to be used on the work was not that with which the tests should be made, which would then vary according to circumstances. The great objection to sand tests, as admitted in all the Papers, was the difficulty in small works of giving the time and the space needed for the trials. A great deal of Portland cement, for instance, went abroad; but whether for export, or for use in distant parts of England, manufacturers increasingly objected to submit to tests at the place of use, and so possibly to rejection after freight and other expenses had been incurred upon it. Testing was, therefore, now chiefly done at the makers' works. But how to deal with parcels of 1,000 tons, which should have to be stored twenty-eight days? Who could find space for it? A seven-day test was therefore, it was submitted, after all, the most advisable, as the obligatory test, though *facultatif* tests could, as with the French engineers, be resorted to at twenty-eight or thirty days if the behaviour of the cement at an earlier stage should seem to render it necessary. In no case should rejection take place without

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a second performance of the obligatory or first tests, and afterwards of the *facultatif* or ultimate ones. The section on which the tests should be made had also been latterly made matter of question. The recognised one of $1\frac{1}{2}$ inch × $1\frac{1}{2}$ inch = 2·25 inches had been copied from the French, as the nearest approximation to their dimension of 4 × 4 centimètres = 16 centimètres square, which had been transformed by the Germans, without apparent reason, into 14·51 centimètres square. The area of $2\frac{1}{4}$ inches had this convenience, that as in round figures $2\frac{1}{4}$ lbs. went to 1 kilogramme, a steelyard graduated for the $2\frac{1}{4}$ inches section in lbs. on one side, and for kilogrammes on the other side, would give on the kilogramme side the number of lbs. per square inch as well as of kilogrammes on the $2\frac{1}{4}$ inches section. Mr. White.

The tests proposed by General Scott and Mr. Redgrave, though less severe than those exacted in some quarters, would doubtless be amply sufficient to secure the best quality of cement without needlessly harassing the manufacturer, and interfering with his legitimate profit. As the result of an experience which was now rather considerable, and dated from the earliest introduction of Portland cement, Mr. White would say that a mixture composed of 72 per cent. of carbonate of lime and 28 per cent. of clay, when burnt with 35 to 40 lbs. of fuel, should produce a cement of which the average density would be 90 lbs. per cubic foot, or 115 lbs. per striked bushel, of which the analysis would be as nearly as possible that given in General Scott's and Mr. Redgrave's Paper, and the tensile force, when tried neat at seven days, be not less than 400 lbs. on the square inch.

In conclusion, while asking for moderation in the imposition of tests, he would readily avow his conviction that the researches of Mr. Grant and others had been very useful to the cement interests, in greatly improving the quality of the material produced, and as a consequence, largely increasing its consumption.

Mr. H. Faija observed that General Scott and Mr. Redgrave had in their Paper so accurately and fully described the mode of manufacture, as carried out on the Thames and Medway, that there remained little to say on that head. With respect to the wet grinding, Mr. Faija did not think anybody, about to make cement from chalk and clay, would at the present day put down backs. Mr. Michele's wash mill was the latest application of this principle, but it seemed to him that a large wheel 14 feet or 16 feet diameter must be very accurately balanced to ensure the grinding being even and regular on all sides. That was merely a mechanical difficulty which seemed to present itself, but no Mr. Faija.

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Mr. Faija. doubt it had been duly considered and overcome. As to the utilisation of heat from the kiln, he felt some diffidence in taking the estimate of cost of fuel given in General Scott's and Mr. Redgrave's Paper, which seemed to be very low, but that was a point for manufacturers to decide. Mr. Bernays had advocated the use of an excess of water, of which Mr. Faija could not see the advantage. The setting of cement was a purely chemical action, and it only required a certain amount of water, and when that amount was exceeded it simply meant a porous cement or concrete. No doubt in some instances an excess of water was better than a deficiency, because a good deal drained away; but that better results were generally obtained from an excess of water he could not admit. The accuracy required in testing was undoubtedly a matter of great importance. From the very commencement of a test different persons would obtain varying results; even in weighing cement they would make the same cement seem of different weights per bushel through having different appliances and practice for weighing it, and so on throughout the remainder of the test. A uniform method should be adopted, but at present every experimenter had to rely on his own comparative experiments for the opinion he might form, and hence the conflicting results presented by different experimenters. He was surprised that when Mr. Grant alluded to specific gravity, he did not take it in combination with the weight per bushel. The two together afforded a fairly accurate measure of the value of cement. A heavy specific gravity and a heavy weight per bushel would indicate a finely ground cement; whereas a light specific gravity and a heavy weight per bushel was almost sure to be a coarse one. Mr. White had alluded to the sand test, and, like himself, was not quite sure that it was a wise one to adopt, but Mr. Faija's reasons for objecting to it were not quite the same. It was difficult to obtain sand of uniform quality that might be used by engineers whenever they had to test cement. Even river sand washed as clean as possible contained particles that would be detrimental to the cement with which it was used. He had obtained a sample from the Thames at Sunbury and washed it carefully, and even then, when a little acid was applied to it, there was found a large amount of carbonate of lime in small nodules, about the same size as the sand, which could not be got rid of by washing. He was sure Mr. Grant would allow that they would be detrimental to the quality of the concrete. In order therefore to obtain satisfactory results it would be necessary to adopt a plan of testing the sand before testing the cement. In the face of this difficulty he would prefer that the cement should be tested as usual, and that if a

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sand test was required the sand employed for the purpose should be the sand used in the actual works, and not any standard sand. As to the seven days' test, they were all agreed that that was of no value without further tests. He was glad to find that Mr. Grant advocated the 1-inch section instead of the 1½-inch, which was an awkward section to use. Engineers specified that the cement should carry so many pounds to the square inch, so that there was really no object in using the 1½-inch; besides which, by using the 1-inch, five or ten briquettes could be made at one gauging, and thus one great cause of error could be eliminated. As Mr. Grant had stated, different forms of briquettes would give different results. He alluded to the point because he had quite unintentionally pirated Mr. Grant's form of briquette. When he saw it, it appeared to him so good that he tried it. He had used it now for more than a year, and had obtained better results from it than from any other section. He agreed with Mr. Grant that testing cement by compression was valueless. It seemed to him that cement or mortar in practice was actually strained by a partially shearing, and partially tensile strain; never by a crushing strain, because it would carry more weight than could be put upon it. A tensile test was easily applied, and gave fairly accurate results, while a crushing strain was not an accurate one; he therefore saw no reason why the tensile test should be abandoned for any other. Mr. Grant had stated that salt water might be used with as good results as fresh water. Mr. Faija had lately made some experiments on that point, and the results with the two kinds of water were certainly not the same. A cement which, when gauged with fresh water, and placed, when set, in fresh water, and which at seven days broke at 411 lbs. per square inch, and at twenty-eight days at 655 lbs., when gauged with salt water and placed, when set, in salt water, at seven days broke at 355 lbs., and at twenty-eight days at 551 lbs.; while, when gauged with fresh water and placed, when set, in salt water, at twenty-eight days it broke at 717 lbs. These results were in each case the average of experiments on five briquettes. This was only the beginning of a series of experiments, so that he was not able to state anything very definite. As to the different testing machines exhibited, they were only so many weighing machines, and if different results were obtained from them, some of them must be wrong. It seemed to him wisest to adopt the one that was most convenient and least liable to get out of order; the particular one being of little consequence so long as the machine was accurately scaled.

Mr. Faija.

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Mr. Grawitz.

Mr. GUSTAV GRAWITZ had followed with great interest the progress lately made in England in the manufacture and testing of Portland cement, and in its applications for concrete. In his opinion three important questions were:—(1.) The uniform system of testing Portland cement; (2.) The establishment of official and independent testing rooms; (3.) The valuation of Portland cement according to quality. With regard to uniform regulations for testing, as introduced in Germany, Austria, Sweden, and Russia, General Scott and Mr. Redgrave proposed that the whole of the cement should be ground fine enough to pass through a sieve of 1,600 meshes per square inch without residue. As an illustration of this proposal, he might say that the principal authorities on the subject in Germany now agreed, that all residue left on a sieve of 900 meshes per square centimètre, or 5,806 meshes per square inch, was entirely worthless, had no cementitious power whatever, and might—and undoubtedy did in certain cases —prove a source of danger. Some cements were now so finely prepared in Germany, that the residue left on a sieve of 32,000 meshes per square inch was between 10 and 3 per cent., and sometimes even less. The minimum tensile strength proposed by General Scott and Mr. Redgrave was 112 lbs. per square inch for 1 part of cement and 3 parts of standard sand after twenty-eight days. Now, he believed many persons would agree with him, that this was an extremely low test, especially for a country like England, where the best raw materials were at the disposal of most cement manufacturers, and where it was easy to produce Portland cement having fully three times the value demanded by General Scott and Mr. Redgrave.

The German rules had been referred to by Mr. Grant, who, in his new specification, proposed an average tensile strength of 170 lbs. per square inch for such a test. In Germany, opinions as to the requisite strength of cement were divided, and this was natural, for, owing to a greater variety of raw materials from which Portland cement must be made in Germany, not every manufacturer could procure chalk and clay of a quality equal to the materials found in the north of Germany, and on the Thames and Medway. Some German manufacturers who could easily produce high-class Portland cements, asked for higher tests, whilst others were satisfied with 10 kilogrammes per square centimètre, or 142 lbs. per square inch, as prescribed by the established rules. Amongst those who demanded higher tests were: the Vorwohler Portland Cement Works of Messrs. Pruessing, Planck, and Co., at Holzminden, on the Weser, and the Silesian Portland Cement

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Works at Groschowitz, near Oppeln, both guaranteeing a minimum strength of 16 kilogrammes per square centimètre; over 227 lbs. per square inch for 1 part of cement mixed with 3 parts of standard sand after twenty-eight days; also the Portland Cement Works "Stern," of Messrs. Toepffer, Grawitz, and Co., at Stettin, who could supply cement bearing a breaking weight of from 300 to 350 lbs. per square inch. Mr. Grawitz.

A recognized authority on cement, Dr. W. Michaëlis, of Berlin, was an ardent advocate for higher tests than proposed by Mr. Grant, and, in a letter to Mr. Grawitz, stated that he should be sorry were England, which country ought always to have the lead in Portland cement matters, to sympathise with those German manufacturers who, for the reasons he had mentioned, would never be capable of producing high-class Portland cements, and therefore were so strongly opposed to higher tests, which were synonymous with progress. The German rules recommended that the twenty-eight days' test, with 1 part of cement to 3 parts of sand, should be checked by the seven days' test with neat cement. This, in his opinion, was not sufficient, and the latter test ought to be obligatory also. Dr. L. Erdmenger, Manager of the Cement Works at Goessnitz, had arrived at the conclusion that—"Although the twenty-eight days' test, with 3 parts of standard sand, ought to be considered as the principal base for ascertaining the value of a cement, it should always be checked by the seven days' test with neat cement." The opponents of high tests in Germany were anxious to abolish the seven days' test with neat cement, because finely prepared quick-setting cements might give low results, if tested neat after seven days, and comparatively high results after twenty-eight days, if mixed with sand. Nobody, however, could deny that those cements were the best which showed the greatest strength in both tests.

With regard to the time that cement took to set, Mr. Grant had given results of experiments with slow- and quick-setting cements after twenty-eight days and twelve months, and from these figures had made deductions highly prejudicial to slow-setting cements. Supposing even these figures were reliable they would simply prove that good quick-setting cements might surpass ordinary and inferior slow-setting cements, but the best slow-setting cements had never been surpassed by the best quick-setting cements; on the contrary, the best quick-setting cements had always proved inferior except perhaps for the first three days of hardening. Little attention had yet been paid to the "hardening process" in Portland cements, it would not otherwise have been

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Mr. Grawitz. possible to have enunciated the theory that: "A good Portland cement, if tested neat, should show an increase in strength of 25 per cent. between the seven days' and twenty-eight days' tests." Now, the most prominent feature of a good cement was decidedly "great energy of hardening," and a cement which attained on the seventh day 90 per cent. of its strength at twenty-eight days was certainly superior to another cement showing only 50 per cent. under equal circumstances. Besides, it was obvious that a cement would not increase in strength in the same proportion after having reached a very high degree of strength at seven days already, whilst cement possessed of less energy of hardening in the beginning might easily gain the above mentioned 25 per cent. within twenty-eight days. High class slow-setting cements might safely be used without being distributed in thin layers on the floor. At the Stern works at Stettin, for instance, casks were filled with the cement when still hot and coming from the sifting machinery, and there was no necessity for cooling or seasoning Stern Portland cement. The advantages that could be realised from the employment of slow-setting cements were such that in nine cases out of ten slow-setting cements should be used. As to the advantages afforded by public testing rooms, he thought that Mr. Grant underestimated their importance and usefulness for the general public, if, as he considered, they were useful only for the promotion of scientific knowledge, because there was nothing to prevent them from being employed for trade purposes by sending specially-prepared samples for the purpose of getting certificates to be afterwards extensively published in trade circulars. Against this he might state that the testing department for building materials at the Royal Industrial Academy in Berlin worked admirably, and that each certificate mentioned the name of the person who sent the sample and described the bulk from which it was taken. Although he strongly recommended the establishment of public testing rooms, he was by no means opposed to private testing; on the contrary, every facility ought to be given to users and shippers of cements who should themselves test every delivery. The double-lever cement-testing apparatus designed by Messrs. Fruehling and Michaëlis of Berlin had many points in its favour, and he agreed with General Scott and Mr. Redgrave, that the line of tension was much less altered in direction than with a single lever. The weakest briquette of 1 part of cement and 10 parts of sand could be tested, and even the strength of a hair could be accurately ascertained. For this purpose the small brass shot bucket was used instead of the large zinc bucket,

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and the levers were brought into equilibrium by the counter-weight on the upper lever. The outflow of the shot was stopped by a self-acting apparatus when the briquette broke. He trusted that a commission would soon be appointed for the purpose of drawing up a uniform scheme for testing Portland cement. To induce manufacturers to make further improvements the regulations should prescribe higher prices for cements which surpassed the requirements of the specification, for there was no reason why Portland cement should not be valued, like every other merchandise, according to quality. The German rules contained the following recommendation:—"Cement of higher tensile strength than 10 kilogrammes per square centimètre, in most instances permits of a larger addition of sand. From this point of view, and often even on account of its greater strength, if mixed with equal proportions of sand, it is entitled to a higher price in proportion." This recommendation should be enforced. The War Department in Berlin had made a step in the right direction. They bought high-class cements only, and paid for overstrength, thus saving cartage and freight, which could not be avoided where large bulks of inferior Portland cement were used. Mr. Grawitz.

Mr. Henry Reid thought English cement manufacturers had nothing to fear from German competition; but, undoubtedly, at the Stern works a cement was made much superior to any that could be obtained in England. He had gone over the works, and could testify that great attention was paid to the minutest detail, and the result was that an unvarying quality was produced equal to the guaranteed tests. Some German cement, however, that he had tested in England had not come up to the mark. He had recently broken some in Scotland, and had found a difference of 30 per cent. between the guaranteed tests and the results of his experiments. He did not think it would be well for engineers either to manufacture or to dictate to manufacturers the modes they should adopt in testing cement. Mr. Grant was regarded by some as an authority in testing, and had doubtless assisted in the attainment of a good cement. The improvements, represented by the new kilns and washing apparatus, indicated a desire to cheapen cement; but with engineers he believed the object was to obtain, not so much a cheap as a good cement. It was difficult to understand why there was so great a desire for the utilization of waste heat; this appeared to him to be a conservation of dangerous gaseous products, which in some of the new inventions were in a great measure re-absorbed by the material that heat had previously been used to purify. Portland cement Mr. H. Reid.

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Mr. H. Reid. was derived from chalk, which could be obtained in abundance all over England, and clay of the finest character. It was only a mechanical combination ultimately improved by chemical action. The first process was the exact proportionate mixture of the two materials—a matter of no difficulty; but in the improvements described (except in Mr. Michele's mill) there was no exact mixture, and without it no good cement could be obtained. The burning and the drying might be accurate and true, but the product from the millstones was what the engineer had to look to. It was of no consequence whether the cement had been obtained by the utilization of waste heat, or by any other process, as long as it was true and good. Mr. Johnson's kiln had worked successfully, and produced a good cement, and so did that of Messrs. White. Messrs. White were amongst the most experienced manufacturers in England, and if they would direct their attention to a more reliable measure of quantities and a better admixture, he believed that better results would be obtained. At Stern the materials used were inferior to English, but they were mixed in the most accurate way and no dust was allowed to enter the kiln from which pure clinker alone came forth, and this, when ground, required no warehousing in order to be seasoned; in fact, the cement might be used the next morning, or the very day it was made. Why could not that be done in England, where the materials were plentiful and capital abundant? Mr. Grawitz, who did not know what Portland cement was eighteen months ago, had now actually read a lecture on the subject to Englishmen, who surely might acquire the necessary knowledge in the same space of time. With regard to modern testing, he never thought that such eccentricity of moulds and tests would have led to no better results, and have obliged English engineers to go to Germany for assistance. The double wedge mould was what he proposed sixteen years ago to Mr. Grant, and it appeared to be an illustration of "the survival of the fittest." He thought it was time for the members seriously to consider whether some uniform test could not be adopted, so that there should be one common standard.

Mr. Vernon-Harcourt. Mr. L. F. VERNON-HARCOURT said he would confine his remarks to Mr. Bernays' Paper. With regard to the construction of dock walls entirely of Portland cement, he could recollect the time when it was considered necessary to make them with a facing of brickwork. Fifteen years ago, both at the West India docks and the Millwall docks, concrete was used for backing, and the face and cross walls were made of brickwork, which considerably increased the cost of the walls; but at the present time, at the Victoria

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docks and at Chatham, the whole of the dock wall was made of Portland cement concrete. In former times the concrete was made with greystone lime, and for the lower parts blue lias lime concrete was employed; but he had no doubt that if the works were done in the present day, they would be made merely of Portland cement concrete, owing to the increased confidence in, and improved quality of, Portland cement, and would be done at a cheaper rate. In a Paper on the West India docks, which was read eight years ago,[1] he mentioned that the dock wall was cheap, and so he thought at the time. The price was 12*s.* 6*d.* per cubic yard, but Mr. Bernays had stated that he could make a dock wall at 7*s.* 6*d.* per cubic yard. That was a great reduction, and he thought that in the Thames the price of dock walls might be still further reduced. At the West India docks the price of the lias lime concrete was 5*s.* 6*d.* per cubic yard, but owing to the use of the facing of brickwork, the cost of the wall was enormously increased. With gravel so close to the works (a great part of the excavation was gravel), he thought it would be possible to make a dock wall even cheaper than Mr. Bernays had described. It would be interesting to know what was the proportion of Portland cement in the concrete at the Victoria docks. It seemed very similar to that used by Mr. Bernays in the walls. The facing was perhaps not quite so neat, but it seemed to answer all practical purposes. The only defect he had observed in the dock walls was that there were transverse cracks here and there, though not, he imagined, of any importance. He noticed also at the Victoria docks that the facing of the lock wall was not composed of concrete. Blue bricks were used, and for the hollow quoins granite was employed. He should like to ask Mr. Bernays whether he had used the material, consisting of coarse gravel and Portland cement for sills, hollow quoins, and square quoins. If hollow quoins could be moulded out of this material, instead of being dressed out of granite, there would be a great saving in labour and material. He had been surprised to observe in his Paper that he did not object to having loam with the gravel. Having since seen it he confessed it was not a kind of gravel that he should very much like to use, but there was no doubt that a certain amount of loam in concrete was not objected to by some persons, for looking through some of the old Minutes of Proceedings, he observed that Mr. Giles stated, in the course of a

Mr. Vernon-Harcourt.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxiv., p. 157.

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Mr. Vernon-Harcourt.

discussion, that he approved of it.[1] He might mention that some bridges had been made in Switzerland purely of Portland cement concrete, the proportion being about 1 to 7. One of them was built in 1874, of 60 feet span.[2]

Mr. Johnson.

Mr. I. C. JOHNSON said it was singular that Mr. Reid should have objected to manufacturers utilizing waste heat, and should at the same time have said that the Germans were sending cement into the English market, and selling it at a very low price. As a manufacturer of cement he found it necessary to utilize to the greatest possible extent all the advantages of which he could avail himself. He might be permitted to make a few remarks upon the subject, as he believed he was the oldest cement manufacturer in the country. He had had the run of cement manufactories nearly seventy years, and had been actively engaged in the manufacture fifty-five years. The method represented in Fig. 5, and of which he was the inventor, had for its object the utilization of waste heat, and he could state from experience that slurry or slip dried with heat passing over its surface and not underneath, was very superior to that dried by any other method. The slip was not honeycombed by the bubbling up of the material from the bottom; but as the heated air had a great affinity for moisture, it licked it up, so to speak, in passing over the surface, and with a tolerable draught the vapour was carried away effectually, so that there was no re-absorption of the gases, as intimated by Mr. Reid. It was true the surface of the slip was whitened (as if it had been lime-whitened) with some of the sulphur that came from the coke, and passed over the surface, producing a white powder, of which he had an analysis. He thought the plan superior to others, because he had a plain floor where there were no flues, and consequently there were no iron plates to remove every time the kiln was charged; there was no wear and tear either of iron plates or fire tiles. The plan had been in operation at Gateshead, at Cliffe, and at Greenhithe. The floors had been down for several years without costing 10*s.* for repair. He would ask any manufacturer whether the same result had been produced by any other system. Another point in its favour was the uniformity of the results obtained. In connection with Goreham's process, the slip was conveyed to the chambers without a hand touching it; everything was done by the steam engine, and the consequence was that there was a great economy in labour as well

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvii., p. 545.

[2] *Ibid.*, vol. lviii., p. 310.

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as an economy of fuel by utilizing the waste heat. His tests during the year 1879 had averaged 1,160 lbs. upon the 2¼ square inch briquette as tested by de Michele's machine. As a proof that the method was worth the notice of manufacturers, he might state that the license fees, since the plan had been in existence, amounted to some thousands of pounds, which was perhaps the best argument that he could adduce. It had been stated that the origin of Portland cement was involved in obscurity. Had time permitted he might have removed some of the clouds causing that obscurity. He was contemporary with Mr. Aspdin, and he believed he was the first to produce true Portland cement. At the time when Aspdin's Portland cement was the only Portland sold in the open market, he had seen, at Pimlico, heavy cornices tumbled over into the areas below, and chimneys forming different angles in various directions, showing that the art of making true Portland cement was not then understood. Mr. White could bear witness that Mr. Johnson had had some experience in cement making, inasmuch as he had had the privilege of first introducing it into the manufactory of that firm in 1844. Mr. Johnson.

Mr. DARNTON HUTTON observed that some of the Tables were not in accordance with his own experience. In Appendix XLII. it was stated that when the cement was mixed with 1 part of sand the breaking weight was 40 kilogrammes per square centimètre, whereas with the neat cement it was 34 kilogrammes. In Appendix XXX. it was stated that after twenty-five weeks neat cement gave a breaking weight of 701 lbs. per square inch, but with 3 of sand 282 lbs. per square inch, a difference that rather surprised him. He had prepared a Table of some experiments made at Plymouth Breakwater Fort, showing the following results:— Mr Hutton.

Parts.		Broken at.
		lbs. per Sq. In.
Cement 1	Sand 0	224
„ 1	„ 1	284
„ 1	„ 2	250
„ 1	„ 3	215
„ 1	„ 4	132
„ 1	„ 5	118
„ 1	„ 6	97
„ 1	„ 7	92
All the above were seven months old.		

In other words there was a depreciation of from 20 to 10 per cent. for every proportionate part of sand added. He thought

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Mr. Hutton.

that in making experiments engineers were apt to forget that there was nearly as much variation in the quality of sand as there was in the quality of cement. The object of testing cement was to know what sort of concrete it would make, and he should incline to believe in the testing of concrete if possible by transverse strains, not by any means as the sole test, but in addition to the neat cement tests. Some curious results were produced at the Amsterdam canal and harbour works upon which he had been engaged, showing that where the sand was very fine, the less sand that was used the better. When work was begun it was found that the blocks were not as hard and strong as they ought to be. It was suspected that that arose from the fineness of the sea sand used, and some experiments were made to ascertain the fact. The following Table gave the results:—

AMSTERDAM CANAL HARBOUR WORKS.

Experiments on transverse strength of concrete blocks, 4 feet long by 1 foot wide by 1 foot deep, broken by weights suspended from the centre.

Made November 23rd, 1872, broken February 26th, 1873.						Made December 31st, 1872, broken May 19th, 1873.			
Number.	Composition.	Proportion.	Average Weight of Test Blocks.	Average breaking weights. With Supports 3 feet apart.	Average breaking weights. With Supports 1 foot 6 ins. apart.	Number.	Proportion.	Weight of Test Block.	Breaking Weights. Supports 3 feet apart.
			lbs.	lbs.	lbs.			lbs.	lbs.
1	Portland cement / Shingle / Sand	1 / 5 / 4	529	Broken by being loaded too heavily at first	2,267 / 3,313	6	1 / 5 / 4	506	2,656
2	Portland cement / Shingle / Sand	1 / 6 / 3	557	2,215	3,392	7	1 / 5 / 3	526	3,023
3	Portland cement / Shingle / Sand	1 / 7 / 2	561	3,377	6,290	8	1 / 5 / 2	550	4,884
4	Portland cement / Shingle / Sand	1 / 8 / 1	550[1]	4,296	7,973	9[3]	1 / 5 / 1	572	7,699
5	Portland cement / Shingle / Sand	1 / 9 / 0	459[2]	4,296	9,323	10[4]	1 / 5 / 0	530	9,590

[1] Full of holes outside, but tolerably solid within.

[2] Very rough and full of holes; outside worse than inside; beams rather stronger than ([1]); although broken by the same weight it carried it for some minutes.

[3] Slightly honeycombed outside from want of sand, but more solid within.

[4] Much honeycombed outside, but more solid within, though not so good as ([3]).

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In the fourth experiment, with only 1 part of sand, the block was full of holes, and the shingle was so rough that it appeared at first sight to be impossible that the block could be as sound as it turned out to be; and in the fifth experiment with 1 part of Portland cement, 9 parts of shingle, and no sand, the block was exceedingly rough, but it broke at 9,300 lbs. He did not mean to state that the shingle was absolutely free from sand; there was a certain amount of sand in it, but the interstices of the concrete were not full of sand, there being a vacancy of at least 12 or 14 per cent. in the block. Mr. Hutton.

Mr. CARLETON BAYNES observed that in comparing the modern plan of pumping from the wash-mill on to the drying floor with the old-fashioned system of pumping into the backs, one point of great importance had been overlooked—a point affecting the uniformity of the cement—namely, the correction of the irregularities of the mixing of chalk and clay. Considering that chalk contained clay in various proportions in different levels of the pit, and that the clay contained foreign matter owing to accidental circumstances, and that in dealing with those bulky materials all had to be used in one continuous course of washing, it was inevitable that certain irregularities must occur, and the question arose how they could be compensated. In the old system the compensations were made in the back by washing with a certain excess of chalk or clay, and then, if necessary, luting, and if the mixture was not as complete as it might be, it was again mixed on the dry floor, again mixed in the kiln, again when it came to the crackers, and again in the cement mill; but in the new system all those irregularities must be corrected in the cement store. The mixing of two bins of cement was most tedious. It was very difficult to get the men to work in such dust, and it was impossible to get any one to stand over them to see that they did their work properly. He once had a mask for a workman to wear, by which he could inhale the air from the outside, the exhalations passing off by a valve into the bin; but the workman was in the habit of spitting, and although he did not make light of the great nuisance of the dust, he would not use the mask. Two large parcels of ground cement could not be completely mixed at any ordinary cost, and if the inevitable irregularities of the washing were only to be corrected in that way, how could the cement be supplied so uniformly by the new system as by the old? Mr. Baynes.

Mr. A. GILES said his remarks with reference to the use of loam in concrete (referred to by Mr. Vernon-Harcourt) did not apply to concrete made of Portland cement. He agreed that Portland Mr. Giles.

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Mr. Giles. cement concrete could not be too clean, but it was true that many years ago he made large masses of concrete with gravel, which had a considerable quantity of loam in it, and having cut into it years afterwards, he found it perfectly sound and hard.

Mr. Gibbons. Mr. R. A. GIBBONS was sure that if Mr. Baynes had had a month's experience in the use of Goreham's process, he would not have made the remarks he had with regard to irregularities in washing. In one respect it certainly required an amount of care, which had not been given under the old system; it was necessary with Goreham's process to weigh in accurately the raw materials. That had been done formerly by a rule of thumb; a wagon of chalk was a wagon of chalk, and a wagon of clay a wagon of clay; but by Goreham's process it was necessary that the materials should be accurately weighed. After three years' experience of the process, he could state distinctly that the cement made by it was from 15 to 20 per cent. stronger than that made by the old-fashioned system. The desirability of producing a good uniform cement was a matter that concerned all manufacturers, and he was sure they would be happy to produce it; but, unfortunately, the prices offered were such that in many instances people could not afford to lay the cement by for a month or six weeks without some increase in the price. Their desire, however, was to go forward, and, if they could improve the quality, he believed the demand would be increased.

Mr. de Michele. Mr. V. DE MICHELE said, with regard to the test of fineness, perhaps the cost of grinding might be so great that ordinary cement would be cheaper in the long run, although a larger quantity were used. With reference to Mr. Faija's objection to the Michele mills on the ground that the rim might not work truly, being 14 feet in diameter, he could only say that they had been in use for the last two or three years, and had answered perfectly. He would remark, as the result of an experience extending over the past twelve years, and embracing the manufacture as well as the use of some hundred thousand tons of Portland cement, with reference to what engineers must universally admit to be its most important characteristic, viz., its strength, or power of permanently binding together foreign substances. Admitting of course, in the abstract, the desirability of using the strongest cement procurable, he wished to give it as his decided opinion that a high tensile, or crushing strength, at a limited age, did not necessarily imply a good cement, and often indicated an exceedingly dangerous one—that was, one that was likely to disintegrate afterwards. This could not be too strongly impressed upon those who, like

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Mr. de Michele.

many at the present time, were commencing to use this material. There appeared to be a desire on the part of manufacturers to meet the requirements of some engineers in respect to high tensile tests, and in order to do so they were forced, under the present mode of manufacture, to produce a cement containing the maximum amount of lime in combination, with a small excess in a free state; and it was this excess in a free state which they attempted to neutralize afterwards by air slacking, technically called "purging." He must admit that sometimes this excess was so small that it could be dealt with so that its expansion was not apparent in the work, at any rate for some months, or perhaps years afterwards; but he maintained that properly manufactured cement—cement that would grow in strength and stand—was produced by the correct admixture of lime which was all thoroughly combined, and of which there was none left to require slacking afterwards. If there was any free lime in cement when used, no one could say for certain when it would expand; and for his part, he should feel safer in using a cement of only moderate strength at seven days, provided it was manufactured without any excess of lime. A stronger cement was universally desired, and efforts were daily being made in the direction of producing one; but as the manufacture stood at the present day, in order to ensure good and lasting concrete, he would suggest the following simple specifications:—

1. The Portland cement, before being used, to stand 300 lbs. tensile strain per square inch seven days after gauging; the average of not less than three breakings being taken.

2. The cement to be finely ground, leaving a residue not exceeding 10 per cent. after passing a sieve of 2,500 holes per square inch.

3. Pat samples ½ inch thick, made at frequent intervals, and immersed in water within one hour, to show no cracks from expansion within forty-eight hours after gauging.

He would discard the weight per bushel test, as being useless and misleading.

No doubt the greater the age at which the cement was tested the better, but for all practical purposes seven days was the longest time at which it could be conveniently managed, and tests at this age were found to bear a very fair, although not exact relation to those at longer dates.

With regard to testing with sand, this might be admissible if it were possible to procure standard sand of perfectly uniform quality in different localities; but it would hardly answer to export sand

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Mr. de Michele. all over the world from a central depôt. If it was known that fine cement would stand a higher strain when mixed with sand than coarse cement would bear, it was only necessary to specify the degree of fineness coupled with a neat cement test.

He wished to acknowledge his indebtedness to the Authors of the first Paper for their favourable reference to the appliances bearing his name for the manufacture and testing of Portland cement. He would also bear witness to the advantages of Mr. Johnson's chamber-system, which he had adopted largely at Messrs. Francis and Co.'s works, and which, after carefully considering many other plans, was, in his opinion, the best in existence at present.

The 1 square inch briquette was undoubtedly a better one for all purposes than that with an area of 2½ inches, and no substantial arguments could be found for not adopting it. The shoulders should have the largest possible curves. Perhaps the best results would be obtained if a circular section were adopted with 1 square inch area, the moulds for forming such briquettes being filled from one end, so that the breaking section would not be affected on one side by trowelling, and on the other by the plate on which the mould rested.

He had had the privilege of minutely examining the important works being carried on at Chatham under the superintendence of the Author of the second Paper, and he could testify to the admirable results obtained by the adoption of his excellent system of facing concrete. M. de Michele had adopted it with complete success in a tidal river embankment wall, constructed entirely of concrete *in situ*.

He had successfully employed Portland cement concrete for foundations, arches, tanks, buildings, engine beds, retaining walls, embankments, &c., and had lately prepared designs for a dock to be constructed entirely of Portland cement concrete *in situ*.

Mr. Adie. Mr. P. ADIE said that, having been associated with Mr. Grant almost from the commencement of these test experiments, he was much interested in the system. At first tests were made with water, sand, &c., but as the number increased, time and simplification became the great object. The Pooley system was then beginning to be tried, but the effect of the shaking of the hand acting on the end of the lever was considered a source of error, which led him to suggest the rolling weight, the strain of the hand acting then entirely on the fixed independent pillar at the end of the lever; jerking, in all cases where heavy weights worked at a long leverage, being the great thing to avoid. Objections

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were made at first to the shape of the moulds; these had been altered frequently, yet it was remarkable how consistent the results had been, and how considerably cement improved, especially at first, when regular testing was adopted. Passing by the mixing of the briquettes, which, though very important, since, if water was made to take the place of cement, strength would be sacrificed, he would only further remark on this point, that time, in making the test as referred to by Mr. Grant, had scarcely been enough attended to. If the briquette was broken in five seconds, it would stand a greater strain than if, say, three minutes were occupied in the test, from the low elasticity, he presumed, of the material. It was well that testers should fix a period for all tests, in addition to the mechanical regulator added to the machines he made, which was suggested by some of Mr. Grant's experiments on the subject of time; this he held to be of much greater importance, for exactitude and regularity, than any question as to whether any such gain was obtained by the less convenient methods of water or shot testing. He would only further refer to the interesting experiments described of the lateral strain applied to concrete bars; the explanation, he took to be, that every facet of sand impinging on the surface of the shingle reduced the cohesion, as sand naturally could have no cohesion to a flint or pebble surface. Mr. Adie

Prof. HAYTER LEWIS wished to say a few words with regard to what had been done by the Romans, to whose works he thought engineers were to a large extent going back. The old Roman works were composed almost entirely of concrete or rubble. The mediævals used it in the same way, and it was as hard as a rock. Some fine Roman remains could be seen at Pevensey and Richmond, and the work of the mediævals could be seen in the grand old keep at Rochester, where not only the walls, but the staircases, were built of concrete. It was stated by the old writers that the Romans depended entirely, or chiefly, not upon stone and bricks, but upon cements; and Vitruvius said that certain works were stronger than others simply because they admitted of a larger quantity of cement being used. He had lately brought from Egypt a portion of the mortar used in the great Pyramid, which was at least five thousand or six thousand years old. It was quite friable, and therefore it was evident that it was not age which gave strength to the Roman mortar. In the preparation of cement, the Romans appeared to have done very much what manufacturers were trying to do now, only in a different way. The general conclusion to which modern experience had arrived Prof. Lewis.

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Prof. Lewis. was, that first of all every particle of the lime had to be thoroughly slaked, and, secondly, that the cement when worked up and burnt, ought to be ground as finely as possible. The Romans certainly had that impression. They mixed up their lime in some cases and kept it two years before it was used, and in that time every particle of it must have been well slaked. With respect to fineness, he had been making microscopical experiments upon Portland cement mixed with very fine sand (using a power of 110 diameters), and it was quite clear that the lime did not form a matrix in which the sand was imbedded, but that each particle of sand was surrounded by a small film of cement; there were large vacuities between the particles of sand, and the cementing power which bound the particles of sand together was simply a film round each piece of sand. It was clear that fineness was of the greatest possible value, because lime not thoroughly fine would not give that coating to the particles of sand which evidently constituted the strength of Portland cement. He had also been trying some experiments upon the rather curious property of the setting of cement, and he had been aided by one of the best mineralogists, who had been examining it with the microscope and using other tests. The conclusion at which he had arrived was that it was a kind of semi- or imperfect crystallisation.

Major-General Scott. Major-General Scott, in replying upon the discussion, considered, from the observations of the various speakers, that there was far more unanimity on the subject of testing cement than he had anticipated. It must be remembered that English engineers who had written on the subject had generally declared in favour of testing Portland cement without sand, and in such a manner as to give the least possible chance to what he felt justified in pronouncing to be the finest qualities of the material. The careful tests of English engineers had certainly laid the foundation for the scientific method of testing cement, which had been so successfully introduced in Germany; and whatever might be the plan of testing ultimately adopted, there could be no doubt that those who had to make use of large quantities of cement would ere long find that by buying a finely-sifted sample they could, *pari passu*, get far more work out of it than from a coarse one. He believed it was quite possible that at the present time, while a vast amount of ignorance prevailed concerning cements, buyers would be found for the coarsely-ground, unsifted Portland, which readily satisfied the existing tests required by English engineers; but a time would come when a finely-ground, carefully-sifted cement would, on

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account of its greater sand-carrying power, command a much higher price than a less carefully manufactured article. It would be better economy, in fact, to pay £3 a ton for a high-class Portland cement, than to buy an unsifted cement at £2 per ton; and the sooner there was a system of testing which would enable the sand-carrying properties of the cement to be determined the better. The readiest mode of gaining an insight into the capacity of the cement in this respect was the sieve-test; and he believed that this test, combined with some simple chemical determination of the lime and the silica, would be found to give reliable results in an hour or so, when a delay of the twenty-eight days demanded by the German plan of testing with sand was inconvenient. There was no doubt that in many cases the period of twenty-eight days under experiment was an impossible one. It therefore behoved those interested in this question to find some shorter and more expeditious plan of judging of the quality of Portland cement. This was a problem well worthy of careful and painstaking inquiry, and he hoped it was one which might yet be solved in this country. He was somewhat reluctant to avow that, in reference to the chemistry of Portland cement manufacture, little had been done in England; and it was not altogether pleasant to admit that, in the practical application of those truths which had been learned from German laboratories, German manufacturers were treading on the English manufacturers' heels. Major-General Scott.

Exception had been taken by Mr. G. F. White to the proportions given in the Paper for the carbonate of lime and clay, and he had stated that a mixture of 72 per cent. of the carbonate yielded excellent results. General Scott was willing to admit that with less than 74 parts of the carbonate of lime a safe, though not the best, quality of Portland cement might be prepared. In fact he would personally incline towards the reduction of the carbonate to the extent mentioned; but a cement thus proportioned would not comply with the highest requirements of engineers, and though excellent for plastering, would scarcely compete, under the sand test, with the best foreign samples of Portland cement. In this matter the Table of analyses given by Mr. Grant in Appendix VI. was very instructive. It would be seen that all the German cements contained more lime than those prepared by English manufacturers. With due deference to Mr. White, he considered, therefore, the proportions he had named to be those calculated to give the best results in practice.

Mr. GILBERT REDGRAVE, in reply, wished at the outset to disclaim any intention of dictating to manufacturers the best plan of pro- Mr. Redgrave.

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Mr. Redgrave. ducing Portland cement. The aim of the Paper had been to describe briefly some of the most recent improvements in the method of preparing Portland cement, and to place upon record the important changes which had lately taken place in the system of manufacture pursued in this country. He was surprised at the remarks made by Mr. Henry Reid, who seemed, in his observations respecting the inutility of saving labour and fuel, to be scarcely conversant with the present state of the manufacture. Mr. Redgrave was so strongly impressed with the urgent need of reducing to a minimum the cost of preparing, burning, and grinding Portland cement, that he was convinced that any plan by which a material saving at any stage of the manufacture was attained must at once be adopted throughout the trade. The two points in the manufacture which at the present time needed the most careful attention of those engaged therein were, first, the admixture in the exact proportions and in a more methodical way than at present, of the raw materials; and, secondly, the sifting of the finished cement. It was here that English makers were being distanced, and the sooner the manufacturers of this kingdom could be induced to believe that all their energy must be directed to these points the better. It seemed somewhat strange that a foreign manufacturer should be present at the meeting to criticise, not only the mode of preparing the cement for sale, but also the plan of testing in general use. Yet the "Stern" cement, in which Mr. Grawitz was interested, was, bulk for bulk, worth about double the price of the best English Portland cement in the market. This result was due simply to the careful and exact apportioning of the lime and clay, and the extremely fine grinding of the clinker. If anything was needed to prove the lamentable carelessness which existed in English Portland cement manufactories, it was only necessary to consider for a moment the plea of Mr. Carleton Baynes in favour of the antiquated backs and drying floors as correctives of imperfectly compounded slip. In Germany the running of the slip was almost a chemical operation, so accurately and methodically were the percentages of each ingredient weighed out or measured; while the degree of fineness of the grinding was such that there was only a trifling residue on a sieve which would reject from 60 to 70 per cent. of a first-rate sample of English cement. This state of things had been brought about in Germany in a few years by the improved plan of testing, and similar results might shortly be effected in this country. No one must, however, expect to buy a cement capable of doing twice as much work as the material now sold as Portland at the same price, and engineers

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would have to pay for fine grinding. Perhaps this phase of the question was scarcely under their notice at present, but he quite agreed with Mr. Grawitz on this point. Mr. Redgrave.

The admixture of the carbonate of lime and clay had been described by Mr. H. Reid as a "mechanical combination ultimately improved by chemical action." This Mr. Redgrave believed to be scarcely a true view of the theory of Portland cement. The mixture was made solely to bring about in the kiln a definite chemical action. This action depended, it was true, upon the intimate and perfect admixture of the particles of lime and clay; hence the superiority of a dense slip; but instead of being a means of improving the previous mixture, the entire process consisted in the formation of silicates by the heat of the kiln, which silicates were ultimately rearranged by the difference of the affinities in the presence of moisture, when the cement was ground and used with sand.

The questions raised by Mr. Faija and Mr. White had been answered by previous speakers. He had been much interested to hear of the microscopic researches of Professor Hayter Lewis, and it might not be amiss to notice the fact that, in the work of a German writer on Portland cement, he had found an account of the use of the microscope in determining the difference in shape of the particles of good and bad Portland cement; the former being angular fragments like small scales or thin splinters, and the latter small nodules or rounded grains like sand. Amongst a large number of specimens this was found to be an unvarying rule, the shape of the particles being a true index of the quality of the cement.

Mr. Bernays. Mr. Bernays was glad to find that there had been few criticisms on the facts or opinions given in his Paper. Like all engineers, he would welcome any improvements in the manufacture of Portland cement that might render its use more economical and satisfactory; but he thought that, in the work he had executed, with the average quality of cement made by good firms, he had carried economy in its application as far as any one. Still better results might probably, hereafter, be reached, when finely ground, heavy cement, of reliable quality, was procurable at moderate cost. He believed that it was mainly due to the valuable and systematic experiments of Mr. Grant that Portland cement had reached its present state of comparative excellence.

An objection had been made by Mr. Faija to the free use of water in concrete making, and, to some extent, to the use of salt water. It was very well to gauge the water carefully in the testing-

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Mr. Bernays. room; but even there Mr. Grant advised the covering of the briquettes with wet cloths where the only loss of moisture was by evaporation at moderate temperatures. Mr. Bernays had found, in his large experience, that in making concrete out of doors where moisture was lost by draining, by soakage into the ground or adjacent concrete or brickwork, and by evaporation in hot weather, a free use of water was absolutely essential. In his experience the use of salt water in no way affected the concrete injuriously.

Doubts had been suggested as to the safe use of loamy gravel. Loamy gravel from the bed of the river had been used at Chatham, because it was plentiful, cheap, and (apart from the loam) good. The quantity of loam was small, not exceeding 1½ per cent., and the concrete made from it proved satisfactory. He should be at all times happy to show, to any one interested, all the work that had been executed with it. For ordinary building mortar he had abandoned the use of lime altogether; using 1 part of cement to 7 parts of coarse, sharp, clean sand, and 1 part of foundry sand. The foundry sand contained about 10 per cent. of loam, giving less than 1½ per cent. in the mortar as mixed. This loam was added to give consistency to the mortar, and to enable the bricklayer to use it on his trowel. It did not appear in any way to detract from its strength; while mortar of this composition was incomparably better, and decidedly cheaper, than ordinary lime mortar. Fine sand made bad mortar; and loamy sand, where each grain was covered with a coating of loam, did not make nearly as good mortar as clean sand to which loam was added. He believed that the walls of the Victoria Dock Extension were constructed wholly of concrete, in the proportion of 1 part of cement to 7 parts of gravel, while in the graving docks the proportion of cement was somewhat greater.

It had been suggested by Mr. Henry Reid that Portland cement might and ought to be prepared so as to allow of its use straight from the millstones. Mr. Bernays was so impressed with the danger of its use in a fresh state, that, even when packed in casks for months before it reached its destination, he considered it just as necessary to turn it out of the casks and expose it to the free action of the air, as if it had come from the stones but a few hours.

He hoped that, at no distant date, the researches of Mr. Grant and of others might lead to a mode of testing cement that would allow engineers and contractors to accept or reject it, decidedly, in a few days. A twenty-eight days' test was all but

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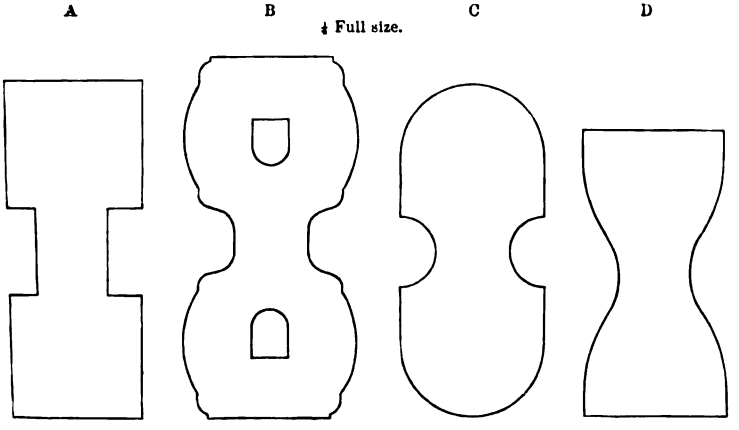
impossible on large works. His experience was that a seven-days' test of neat cement, though far from theoretical perfection, was fairly sufficient. In actual practice a skilled man could tell, in mixing up briquettes, how the cement was likely to turn out. Such a requirement as that specified by Mr. Grant, of keeping every 20 bushels separate, was practically out of the question. Mr. Bernays had thought himself fortunate, with a consumption of 600 tons per month, to be able to keep separate each cargo of 80 or 100 tons. He wished to draw attention to a fertile source of misunderstanding due to the omission to state, in most records of experiments on the tensile strength of cement, the precise form of briquette used. The greatly improved results due to recent improvements in the form of briquette and of the breaking clips went, farther than was generally believed, to account for the increased tensile strength of cement shown by recent tests over the results of experiments of earlier date. Mr. Bernays.

Since the reading of the Papers on Portland cement Mr. Bernays had made experiments with a view to determine, approximately, the variations in the tensile strain recorded by testing machines due to the form of briquette adopted. The undermentioned results showed the average breaking strain, after seven days, of the same quality of cement made up into briquettes of the following forms:—



Mean breaking strains of six tests.

It would thus be seen that the same cement was apparently stronger by 25 per cent. over form A when made into briquettes of forms B and C, and by 50 per cent. when tested by briquettes

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Mr. Bernays. of form D. C represented the briquette used at Chatham; D that used by the Metropolitan Board of Works. A and B were formerly used at Chatham, but had long since been abandoned.

*** The reply of Mr. Grant will be found at the end of the Correspondence.

Correspondence.

Professor Bauschinger. Professor BAUSCHINGER sent two pamphlets[1] containing the results of numerous experiments made with different kinds of cements. His observations had shown that there was no fixed relation between the crushing and tensile strength of cement. In a series of experiments made with nine cements, the ratio between crushing and tensile strength varied from 11 to 1 to 7 to 1. He had obtained much more uniform results by crushing briquettes having an area of 144 square centimètres, than by the tensile strain on a section of 5 square centimètres. Even when the briquettes were made exactly according to the standard rules by two different experimenters, the results obtained might differ widely. He advocated, in order to decide between competing cements, the adoption of more reliable methods and testing machines, which, though costly, might yet be made accessible to all through the medium of central testing stations.

Mr. Belk. Mr. WILLIAM BELK stated that works of a similar character to those described by Mr. E. A. Bernays had been carried out at Hartlepool. The Hartlepool Port and Harbour Commissioners had recently constructed a sea wall composed exclusively of blocks formed of Portland cement concrete. The concrete of which the blocks were made consisted of 1 part of Portland cement to 7 parts of Portsmouth grit and sand, each block measuring 18 inches by 9 inches by 9 inches. The parapet of this wall was composed of concrete made in boxes, each box of a length of 12 feet by 3 feet 6 inches, by 18 inches wide, the concrete in this case consisting of 1 part of Portland cement to 9 parts of Portsmouth grit and sand. A quantity of rock was also placed in the hearting of it. The face of the wall and parapet was quite uniform, and in appearance equal to any stone masonry. In addition to the above work, the Commissioners were at present engaged in constructing a breakwater for the protection of the harbour, which was also formed

[1] "Mittheilungen aus dem mechanisch-technischen Laboratorium der k. Polytechnischen Schule in München." No. 7, Munich, 1877. No. 8, Munich, 1879.

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of concrete blocks, consisting of 1 part of Portland cement to 10 parts of shingle, sand and rock, each block measuring 9 feet by 4 feet 6 inches by 4 feet. The seaward faces of these blocks, of a thickness of 5 or 6 inches, were, however, made of a slightly superior quality of concrete, consisting of 1 part of Portland cement to 7 parts of Portsmouth grit and sand. In the earlier stages of this work the facings were composed of Portland cement mixed with crushed granite or whinstone; experience, however, showed that, whilst the facings so composed were more expensive than those composed of Portsmouth grit, yet the latter were equally durable, and consequently grit facings were now exclusively used. Mr. Belk.

The parapet of this work was formed in boxes *in situ*. Each box measured 14 feet by 10 feet 6 inches by 7 feet; the ingredients in this case being used in the same proportion as in the above blocks. On the removal of the sides of these boxes, the facings were found to be perfect. The cement used in the construction of the above works was of uniformly good quality, finely ground, and weighed 115 lbs. to the striked bushel. The test briquettes of a section of $1\frac{1}{2}$ inch by $1\frac{1}{2}$ inch, after being kept in water for seven days, bore a tensile strain of at least 850 lbs. Great care was taken in the storing of the cement, it being turned out on the floor of the storing house to a height not exceeding 2 feet, and allowed a free current of air.

Herr F. Bömches sent some observations on the use of hydraulic lime in the harbour works at Trieste. The reason that hydraulic lime was used instead of Portland cement was that so little was known of the durability of the latter material in the waters of the Adriatic, while hydraulic lime had been successfully used for many years in different parts of the Mediterranean. The lime was obtained from Teil in France; its composition was:— Herr Bömches.

Insoluble silica	6·20
Soluble ,,	14·78
Alumina	1·61
Oxide of iron	0·99
Lime	61·83
Magnesia	1·15
Water	6·97
Carbonic acid	6·76
	100·29

The proportions adopted were: 1 cubic mètre of sand, 362 kilogrammes of lime, and 0·271 cubic mètre of water. The blocks were parallelopipeds of from 9 to 11 cubic mètres, and were provided

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Herr Bömches. with two grooves to receive chains. The blocks were built up in the same way as ordinary rubble masonry, care being taken that each stone was surrounded with mortar. The best stones were selected for the face, and dressed with the hammer if necessary. The corners and grooves were built with great care, and with a proper bond. No mould was used, but the grooves were built with the aid of posts 0·15 mètre square. The proportion of stone to mortar varied from 60 to 40 up to 65 to 35, according to the regularity of the stones and the coarseness of the sand. The blocks were allowed to harden at least three months before use. In twelve years 8,538 blocks had been immersed, of which 3,987 were raised again by divers, on account of alterations which had become necessary. Of this number 91·3 per cent. were in perfectly good condition, 6·2 per cent. in such a state that they could be repaired, and 2·5 per cent. beyond repair. Among those which had remained sound were some which had been immersed to a depth of 12 mètres below low water, and others which had been subjected to enormous strain through the settling of the wall of which they formed part. In most cases the fracture had taken place through the imbedded stones, showing the strength of the cementing material.

This communication was accompanied by the report of a committee named by the Austrian Association of Engineers and Architects, to consider the question of the uniform nomenclature and testing of hydraulic limes,[1] and by the rules adopted (April 10th, 1880), by that Association in conformity with the report of the committee.

Mr. Cay. Mr. W. Dyce Cay stated that he had tested and used about 15,000 tons of Portland cement at Aberdeen Harbour Works in the last ten years, manufactured by six different makers and delivered in one hundred cargoes. He used seven-day and fourteen-day tests for tensile strength, and occasionally broke some briquettes at twenty-eight days. All were made with neat cement, and many of them were immersed in water when gauged, were taken out when set and removed from the mould, and then at once returned to the water, where they remained till taken out to be broken. When the cement was to be used for concrete in bags or for concrete in mass, which was to be deposited in water before setting, he preferred this system of testing to the ordinary one of waiting till setting had taken place sufficiently for removal

[1] Wochenschrift des oesterreichischen Ingenieur- und Architektenvereines, No. 18. 1880.

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from the mould before immersion in water, as being more analogous with the use of the cement in the work. The proportion of water used for mixing with the cement, omitting exceptional cases, was 8 oz. of fresh water to 36 oz. of cement. He had also made a number of experiments with salt water for mixing, the proportion being 7 oz. of salt water to 36 oz. of cement. Mr. Cay.

The following Table gave instances of the great increase of strength obtained by the use of salt water, and would seem to show, as far as experiments with neat cement could show it, that in sea works the use of salt water for mixing in place of fresh is advantageous instead of being merely optional. Roughly speaking, the salt-water briquettes were as strong in a week as the fresh-water ones were in a fortnight, and as strong in a fortnight as the fresh-water ones were in a month.

Though the German system of testing with cement mortar mixed in the proportion of 3 parts of standard sand to 1 part of Portland cement, and broken after twenty-eight days' immersion in water, was in many respects superior to the old system of testing with neat cement briquettes broken after seven and fourteen days' immersion, he trusted the latter would not be altogether abandoned, as the twenty-eight-day tests would involve practical difficulties on many works, owing to the delay necessitating large storage accommodation to prevent stoppage of the works. The suitability of the sand employed also introduced a new element of dispute and investigation. He still thought that the seven- and fourteen-day neat cement tests, combined with a sufficiently severe test for fineness, would give a good idea of the quality. The invariableness of the specific gravity given by Messrs. Dyckerhoff's experiments, showed that the weight per bushel was not a criterion of the value of the cement, but rather an index of the grinding, the finer ground being the lighter. Having found the same result from practice, he had altered his specifications of later years, to avoid paying for the useless weight, and had specified that the weight was not to be less than 108 lbs. and not greater than 115 lbs. per bushel, the manner of filling the measure being also specified. The German test with cement mortar briquettes, however, did away with the use of the weight test, as fine grinding, or the lowest weight per bushel, was essential for high results with it.

Mr. C. Colson observed, with regard to the question of grinding, that in the earlier days of Portland cement the degree of fineness was never alluded to; now, however, the custom was to specify that the cement should pass through a sieve of a given number of

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TABLE SHOWING THE RELATIVE STRENGTH of BRIQUETTES of NEAT CEMENT when MADE with FRESH WATER and when MADE with SALT WATER.

Proportions used:—8 oz. of fresh water to 36 oz. of cement; 7 oz. of salt water to 36 oz. of cement.

Briquettes immersed in water when sufficiently set to allow of their being taken out of the mould.

Number of Cargo.	Tons Delivered.	Date of delivery.	Weight per Bushel, Average of 10 Bushels.	Fineness.		Tensile Strength.											
						Seven-day Tests.				Fourteen-day Tests.				Twenty-eight-day Tests.			
						Fresh Water.		Salt Water.		Fresh Water.		Salt Water.		Fresh Water.		Salt Water.	
				Weight of a Bushel which was Sifted.	Residue on Sieve with 900 Holes per Square Inch.	Number of Briquettes Broken.	Average Tensile Strength of $1\frac{1}{4}'' \times 1\frac{1}{4}''$ Area.	Number of Briquettes Broken.	Average Tensile Strength of $1\frac{1}{4}'' \times 1\frac{1}{4}''$ Area.	Number of Briquettes Broken.	Average Tensile Strength of $1\frac{1}{4}'' \times 1\frac{1}{4}''$ Area.	Number of Briquettes Broken.	Average Tensile Strength of $1\frac{1}{4}'' \times 1\frac{1}{4}''$ Area.	Number of Briquettes Broken.	Average Tensile Strength of $1\frac{1}{4}'' \times 1\frac{1}{4}''$ Area.	Number of Briquettes Broken.	Average Tensile Strength of $1\frac{1}{4}'' \times 1\frac{1}{4}''$ Area.
		1875	Lbs.	Lbs.	Lbs.		Lbs.		Lbs.		Lbs.		Lbs.		Lbs.		Lbs.
70	290	Sept. 3	120·0	118·5	6·8	14	836	15	907	4	994	8	1,044	3	1,088	2	1,179
71	220	„ 10	120·0	120·0	3·5	16	840	14	1,002	7	953	5	1,080	3	989	1	1,274
72	215	„ 14	118·5	119·5	5·7	17	782	14	908	5	954	6	1,042	3	1,041	1	1,300
73	135	„ 17	120·5	120·5	7·0	21	865	9	933	8	1,074	3	977	3	1,109	1	1,218
74	280	„ 29	122·2	121·0	5·0	15	720	13	938	9	879	5	1,114	3	1,134	1	1,220
75	213	Oct. 4	119·0	112·5	4·0	16	696	16	875	4	911	5	1,033	3	1,053	2	1,189

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meshes per square inch, and fixing a certain percentage of residue or coarse particles; but he would ask why any percentage should be allowed. The argument on the part of manufacturers was, he believed, that to grind to such an extent as to reduce the whole of the coarse particles to the requisite degree of fineness would raise the cost of production so much as to be practically prohibitory. The cost would of course be increased, but he doubted its being prohibitory; and were it understood that a specified degree of fineness meant that there should be no residue, the difficulty would soon be overcome. He agreed that the fineness should depend upon the process of grinding, and not simply upon the removal of the coarse particles by sifting, for the reasons given by Mr. Grant; but it was not that the whole bulk of the cement was to be passed back into the mill, and ground and re-ground until every particle of coarse material was reduced to powder, but that a given proportion had to be separated from the general bulk by sifting, raised to the stone and re-ground; the extra value of the cement would, therefore, be represented by the cost of those extra operations. He considered there was no insurmountable difficulty in the matter, and he believed that ultimately this very desirable condition would be complied with, viz., that the whole of the cement supplied should pass the specified sieve, leaving no residue. Mr. Colson.

With regard to the weight of Portland cement, in former Papers on the subject[1] he had alluded to the fact that the results of his experiments led to the conclusion that the weight, taken alone—that was, without reference to the degree of fineness—was no true indication of its quality; but he was prepared to admit, as pointed out in the first Paper, that with cements ground or screened to the same degree of fineness, the heavier sample would undoubtedly give the best ultimate results. He agreed that no sound conclusions could be arrived at as to the comparative value of different samples of cement with a seven days' test. With regard to the unit of weight, or measure, the bushel was almost universal. He endorsed the opinion expressed by General Scott and Mr. Redgrave, that the foot cube would be more convenient; it was the unit of proportion used generally on works, and would therefore be much more suitable than the bushel as a measure of capacity. Mr. Bernays appeared to doubt the value of fine grinding; but inasmuch as the power of cement to give off a greater strength when combined with sand was increased, beyond all

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xli., p. 125; and vol. liv., p. 264.

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Mr. Colson. doubt, by fine grinding, the utility of it was, he thought, manifest.

With regard to the method of testing the cement with the admixture of sand, this was a point to which he had before alluded, and he was glad to see that Mr. Grant had taken the initiative in the matter; it was undoubtedly the fairer way to test cement, in the interest of both manufacturer and consumer. There were, however, one or two points which might be raised as objections to this method of testing, viz., the possible difficulty of ensuring the same quality of sand being used by both manufacturer and purchaser. Should there be any variation in the quality of the sand, in regard to its being of a coarser or a finer character, angular or rounded grains, the resulting tensile strain would be affected to a great extent; the degree of dampness of the same would also have a marked effect upon the result. Objections such as these would undoubtedly have considerable weight, but could not in any sense be considered insurmountable, although attended with an increased expenditure of money and trouble.

In alluding to the method of mixing concrete, Mr. Bernays advocated the use of an excess of water, on account of the loss in getting the concrete into place. No doubt some advantage was gained in the increased facility with which wet concrete was manipulated, as compared with dry; but, on the other hand, there was great risk—indeed a certainty, of some of the cement being carried off by the excess of water, and thus acting detrimentally upon the mass in a two-fold manner; at the same time, an error could be made in having too little water. It was necessary that there should be sufficient water to act in some measure as a vehicle, by which the matrix was carried into the interstices of the mass. These remarks would also apply to brickwork laid in cement mortar; most engineers knew how difficult it was to get bricklayers to properly fill the joints, particularly with stiff mortar; under such circumstances, a very few units only of the full area of the joint were filled. It was better, therefore, that sufficient water should be used to ensure the whole of the joint being filled—with mortar of a reduced quality, it was true, but by reason of the whole area of the joint being occupied, a greater aggregate strength was obtained.

It had been the habit to value concrete from the point of view that no skilled labour was needed in its preparation; that it was a material of so simple a character that any man who could use a shovel could mix it. Was this correct? He believed that the more skill and thought exercised in the manipulation of con-

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crete, the more satisfactory would be the result. As a rule, a great want of attention was displayed in preparing and depositing the mass; it was left too often to the care of the men who had no feeling of interest in the matter, and therefore cared little whether the mass was properly mixed or not; and in specification little more was said than that the shingle or gravel was to bear a given ratio to the cement. Concrete was, after all, but a kind of rubble masonry, the shingle, gravel, or other material taking the place of the larger stones, and the cement and sand the mortar; therefore the strength of the mass would depend mainly upon two conditions, viz., the adhesive power of the material, and the quality of the mortar. Even in Mr. Grant's specification for concrete, no provision was made for ensuring a proper proportion of sand. The better way was, he thought, to provide that the concrete should be composed of 1 part of approved Portland cement, to n parts of clean shingle (or ballast, or other material, as the case might be), and sufficient sand to thoroughly fill the interstices. The quantity of sand required should be determined by experiment from time to time, by placing the clean shingle or other material in a known cubic measure, and filling up with water; the measure of the water, with a percentage added for shrinkage when wetted, to be the proportion of sand to be used. This being determined the specification would read, 1 part of cement to n parts of sand and n' parts of clean shingle, broken stones, &c. This was, in his opinion, one of the most important points to be attended to in the making of concrete, and one to which attention could not be too strongly drawn. Mr. Colson.

Another point, to which he should like to draw attention, was the proportion usually specified for cement mortar: 2 parts to 1 part appeared to be the proportion generally adopted. His experiments, however, showed that a much stronger mortar than any lime mortar could be made, and used with a much less proportion of cement. A mixture of 4 or 6 parts of sand to 1 part of cement would produce a mortar far superior to anything that could be made with lime. A less proportion of cement than this could be used, but it was not so convenient, being raw or harsh in character, so much so that an addition of lime would be required to render it plastic.

Mr. Thomas Dyke remarked that in the year 1869, being at that time the engineer to the Port and Harbour Commissioners of Hartlepool, he commenced the extension of the breakwater projecting from the Heugh, a headland which protected the entrance Mr. Dyke.

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Mr. Dyke. of the old harbour at Hartlepool. The breakwater several years before had been carried as far as the low-water line and left unfinished, and the exposed end stepped back, with a view to readily add to the work. It was composed of a hearting of concrete blocks formed of shingle and Portland cement faced with stonework, and though much exposed to the sea the concrete blocks showed no signs of damage. It was, therefore, determined to continue the work with concrete blocks alone, though of a larger size; but to provide against the effects of scour caused by the shingle cast up by the waves, and to give a better face to the breakwater, the common concrete composed of shingle and Portland cement was protected by a facing of superior concrete, consisting of Portland cement and whinstone in the proportion of 1 part of the former to 4 parts of the latter. The whinstone was broken in one of Blake's machines, so that the maximum size was ½ inch in diameter, and the fractures were found to be clean, sharp and angular.

The concrete blocks were formed in the usual moulds by filling in layers of concrete about 9 inches deep. The layers of whinstone face concrete were made alternately 9 inches and 18 inches wide, so as to break joint with the ordinary concrete forming the body of the block, and the two materials were kept distinct during the formation of each layer by internal partition-boards, with distance pieces alternately 9 inches and 18 inches in length. Experiments as to the relative degradation of superior concrete formed of like preparations of whinstone, granite and shingle, were made by applying small blocks of each material under the same pressure to the face of a revolving grindstone. The results were greatly in favour of the whinstone. It was found that the whinstone concrete formed a hard smooth face to the breakwater, and that on account of the angular form of the particles of whinstone they became firmly wedged together, leaving small interstices between them to be filled by the cement. Several blocks were broken up under blows from a ram, and no liability to fracture at the junction of the two materials was found.

Mr. Gostling. Mr. WILLIAM GOSTLING observed that the necessity now generally felt for improving the tests for Portland cement had given rise to much discussion. It was highly desirable that engineers' and architects' specifications should be more uniform. No qualified judge would maintain the proposition that many varieties of specifications were needed to adapt the material to a corresponding variety of uses. In truth, only one quality of cement was required

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Mr. Gostling.

to produce good concrete, and therefore one specification should be sufficient for all engineering purposes. However, on examining the specifications in use, it was difficult to find two which corresponded in all particulars. The vagueness and the curious variety of divergence which characterised them were remarkable, and it was evident that the subject of cement tests had not yet received that sustained attention from the great body of engineers which it deserved, otherwise greater agreement would prevail. It might not be amiss to exhibit the confusion which existed, by the citation of a number of specifications of recent date, taken at random as those readiest to hand, and which might be fairly accepted as a true representation of the state of the case. Those who might have doubted the utility of proceeding with investigations, having for their object the establishment of greater uniformity, might thus be brought to see the necessity for action. It was difficult to imagine that this state of things could be allowed to continue much longer, displaying as it did a backwardness on the part of those concerned, in comparison with German engineers, who had been so much later in entering the field, and who, from being disciples, now appeared as teachers and examples. With them there was a general consent with regard to tests, which was highly conducive to the interests both of producers and consumers. The evidence of this was furnished by published rules, adopted in common by the Society of Architects of Berlin, the Society of Builders of Berlin, the German Society for the manufacture of bricks, earthenware, lime and cement, and the Society of German Cement Manufacturers. These rules had been translated by the London Portland Cement Company into English, and they demonstrated the possibility of concerted action on this subject, and exhibited the points which the Germans had brought within the scope of their agreement. Their peculiar methods of testing might also serve as a criterion by which to judge of English methods, and they might even, in some respects, commend themselves, on trial, for adoption here. In fact, one specification that had come under his notice was based on the German tests, and although isolated attempts to introduce tests so different from those in general use in this country were to be deprecated, the fact that this specification had been put forth by a very influential body, furnished a striking proof of the importance of immediate action on the part of engineers and architects, for the establishment of an authoritative standard to which their specifications would conform, and which would serve as a guide to the public.

Certain specifications for Portland cement might be thus classi-

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Mr. Gostling. fied in reference to the three tests of fineness, weight, and tensile strain:—

1. *Fineness.*

In 3	specifications,	no mention of fineness.
5	„	finely ground.
1	„	very finely ground.
2	„	extremely finely ground.
2	„	residue not to exceed 10 per cent. with sieve of 1,600 meshes per square inch.
1	„	residue not to exceed 20 per cent. with sieve of 2,500 meshes per square inch.
1	„	residue not to exceed 15 per cent. with sieve of 2,500 meshes per square inch.
1	„	residue not to exceed 10 per cent. with sieve of 2,500 meshes per square inch.
1	„	90 per cent. to pass through a sieve having apertures of not more than $\frac{1}{70}$ inch in diameter.
1	„	no residue on passing through a sieve of 50 meshes to lineal inch.
1	„	80 per cent. to pass through sieve 5,800 meshes per square inch.
1	„	85 per cent. to pass through sieve 5,800 meshes per square inch.
1	„	fineness to be satisfactory to inspector; unsatisfactory if tests made from screened cement are stronger than those made from unscreened.
21	specifications,	with thirteen varieties of test.

It was scarcely necessary to point out the inconvenience of requiring fine grinding merely in general terms. Such specifications betrayed an inadequate estimate of the value of fine grinding, and opened a wide field for disputes. Of the other specifications, two indicated the use of sieves of 40 wires per lineal inch, and three required sieves of 50 wires. In using these the percentages varied, and only one specification demanded complete sifting. An important specification, lately issued, assumed either that there was no appreciable difference between screened and unscreened cement if finely ground, or that, if there was a difference, unscreened cement was the stronger, assumptions which were open to question. Then there was an isolated attempt to introduce the use of sieves of 5,800 meshes to the square inch, hitherto unused by the trade in England. All recent investigations in Germany and England demonstrated the importance of fine grinding, and surely it was time that this fact should be recognised, and that a uniform system, reconciling practice and theory, should be established and applied in drawing specifications.

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Mr. Gostling.

2. *Weight per bushel.*

In 1	specification	not less than	100	lbs.	per	striked	imperial	bushel.
1	„	„	110	„	„	„		
8	„	„	112	„	„	„		
1	„	„	114	„	„	„		
4	„	„	115	„	„	„		
1	„	„	116	„	„	„		
1	„	about	118	„	„	„		
1	„	not less than	108	„	nor more than	115	lbs. per	imp. bush.
1	„	„	112	„	„	118	„ „	
2	„	without any reference to weight.						

21 specifications, containing ten varieties of tests.

Sixteen of these specifications placed no limit to excess of weight per bushel, merely guarding against undue lightness. One specification demanded a specified weight, and two specifications only adopted the more rational method of confining the weight within definite limits. There was no guiding principle apparent. The fact that the weight should bear a definite relation to the strength and fineness was not recognised, and weight of itself appeared to be deemed an indication of quality. The new specifications of one important public body discarded the test of weight entirely, rightly deciding that fineness of grinding, and strength, were the true tests. Assuredly, if this test was to be retained, some kind of scale, by which the relation between the weight and strength might be determined, should be adopted.

3. *Tensile breaking strain, seven days after gauging.*

In 1	specification	not less than	200	lbs.	per sq. in., or	450	lbs. per	2¼ ins. section.
1	„	„	250	„	„	562½	„	„
2	„	„	267	„	„	600	„	„
5	„	„	300	„	„	675	„	„
1	„	„	311	„	„	700	„	„
1	„	„	333	„	„	750	„	„
2	„	„	350	„	„	787½	„	„
2	„	„	356	„	„	800	„	„
1	„	„	378	„	„	850	„	„
2	„	„	400	„	„	900	„	„
1	„	„	444	„	„	1,000	„	„

1 „ cement gauged with 3 times its weight of sand, to stand a strain of 140 lbs. per square inch twenty-eight days after making briquettes.

1 „ cement gauged with 3 parts sand, to bear 150 lbs. per square inch twenty-eight days after gauging, if the cement set neat in less than two hours, and 170 lbs. per square inch if taking more than two hours to set.

21 specifications, embracing thirteen varieties of tests.

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Mr. Gostling. Thus in these twenty-one specifications there were thirty-seven variations in the tests; and, as a greater number of specifications would doubtless add to these variations, and admit of the three tests being combined differently, it was difficult to estimate the number of the varieties in actual use.

In conclusion, it was earnestly to be desired that this subject would receive consideration by The Institution of Civil Engineers, who might elicit much valuable information, which would serve as a general guide, and would be adopted in all specifications in this country.

Dr. Heintzel. Dr. C. HEINTZEL sent a letter accompanied by an article on the physical properties of Portland cement, which was published in 1878.[1] He called special attention to those tests by means of which any increase of volume that might take place during the hardening of cement could be detected. These he considered sufficient to indicate whether the cement under examination could be used with safety, although they might not afford any insight into the strength.

Mr. Higgin. Mr. G. HIGGIN thought it might interest the members of the Institution to know the result of the employment of concrete in the City Improvement Works of Buenos Ayres. These works, upon which upwards of £2,000,000 sterling had been spent, under the direction, as engineer-in-chief, of Mr. J. F. Bateman, Past-President of the Institution, and of himself as Mr. Bateman's representative, afforded a good example of the use of cement concrete in almost every form that could be devised. No stone was to be obtained in Buenos Ayres; for a radius of 200 miles on the land side not a pebble could be found. At the time of commencing the works, the province produced no bricks fit for employment in such works, and it became necessary to have recourse to concrete. About 11 miles of large subterranean conduits, varying from 12 feet by 14 feet to 7 feet in diameter, had been built, almost entirely in concrete. In addition to this there were 12 miles of intercepting sewers, varying from 7 feet in diameter to 3 feet, and 20 or 30 miles of collecting sewers, egg-shaped, varying from 4 feet wide to 2 feet 6 inches, almost all of the same material. Concrete had also been used in building the workmen's houses; in the roofs of engine-houses, and in the copings of walls, caps of columns, heavy retaining-walls against the river, filters, settling pools, in fact in almost every conceivable way.

[1] "Jahreshefte des naturwissenschaftlichen Vereins für das Fürstenthum Lüneburg," 1878, p. 55.

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Mr. Higgin.

For all the fine work the mixture used was 1 part of Portland cement to 6 parts of coarse sand. The sand was of an admirable description; it was dredged up from the bed of the La Plata, on the opposite, or Uruguay, side, of the river, a distance across of 30 miles. It was clean and of any required degree of coarseness or fineness. The cement used was English, carefully tested in England, shipped in extra-strong barrels, and carefully tested again when put on the work. Great care was taken in the mixing of the materials, and in their measurement; no guesswork was allowed, but the various quantities were measured off in boxes constructed for the purpose. The materials were turned over three times when dry, and water was then slowly added by a rose-headed hose, or can, until the concrete had just sufficient consistency to retain its form when squeezed in the hand. Though Mr. Bernays seemed to think that an excess of water was no objection, Mr. Higgin was decidedly opposed to this view of the case, and considered an excess of water not only injurious to the quality of the material, but that it also interfered greatly with its proper manipulation. All the concrete used in the underground work was placed *in sitû*, with the exception of some places where there was a constant influx of water at the bottom. In such cases the inverts were formed of blocks, cast in boxes overground, the blocks being, as a rule, 3 feet long by 1 foot broad.

For the 12-feet by 14-feet tunnels, a thickness of concrete of 14 inches was used, and it varied from this downwards to 6 inches in the case of the smaller collecting sewers. In the large conduits, the earth having been got out to a template for a length of 12 feet, the lower half of the circle was put in, carefully pounded, swept by rods to the exact form, and smoothed with a kind of float. It was then left for forty-eight hours, or sometimes more, when it was sufficiently hard to allow the men to come in and set the centres. The concrete was then carefully rammed in behind the centres up to within about 1 foot 6 inches of the top. In the case of the large conduits the key was put in in brickwork, as it was found that by this means better facilities were given for the pounding of the concrete. The centres were allowed to be struck forty-eight hours after completion.

In the case of the egg-shaped sewers, drums were made in 6-feet lengths, to the exact section of the lower half of the sewer. The earth having been got out to the proper extent, a mass of concrete was thrown on the floor and punned, and the drums were then fixed to their right lines and levels; the sides were then filled in in thin layers carefully punned with small iron punners up to the

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Mr. Higgin. level of the top of the drum. When the concrete was sufficiently consolidated these drums were removed; straw was laid along the bottom to protect the outside skin, and the centres were set up. There were also drums in 3 and 4 feet lengths; they were put up one by one, the concrete being rammed in from the end and brought up to a face before the succeeding drum was put up. The concrete when finished had the appearance of a grey sandstone; it became exceedingly hard, and when properly made had a fine smooth texture outside. If the concrete was properly mixed, when punned, a slight moisture came to the surface; if too wet, it could not be punned, as the water spurted in the men's faces.

In using concrete for the caps of columns a cast-iron mould was made with the proper mouldings according to drawings. This was fixed up round the top of the pillar and the concrete rammed in to the top of the mould, the bevelled top being afterwards put on by trowel. The sand used for this purpose was rather finer than usual. When the mould was removed, the cap had the appearance of having been cut out of fine freestone. Difficulty was experienced in using concrete in large masses, exposed to the sun, the great variations of temperature making it expand and contract, and show cracks. To avoid this, joints were made by introducing, at proper distances, strips or sheets of thin plate iron. These were withdrawn when the concrete was partially set, and the joint afterwards made with mortar; this plan was found to obviate the difficulty referred to. In the foundation work, and in the large retaining walls, a mixture of 8 to 12 parts to 1 part of cement was used. In these cases the extra quantities of material were usually broken brick, which made an admirable concrete.

Concrete in the proportion of 4 parts of sand to 1 part of cement was also used for making flags, 3 inches thick; for pipes, 12 inches, 18 inches, and 9 inches in diameter, and in various other ways, and gave unvarying satisfaction. He certainly considered it the great building material of the future, especially in countries where other materials were difficult or expensive to obtain.

Mr. Mann. Mr. I. J. MANN could not agree with the Authors of the first Paper, that the time had arrived for the authorities in this country to interfere in prescribing any absolute rules or methods of testing cement. He believed that there was need of further investigation, and that the subject was far from being exhausted.

The expediency of bringing the time occupied in setting into specified or standard tests seemed doubtful, as cement could be made to set with any required degree of slowness by the simple process of air-slaking. The degree of fineness proposed by the

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Authors was, in his opinion, insufficient. Much could be said in favour of the German method of testing, after the admixture of what had been termed normal sand; so far, however, as he had observed, when the density and fineness of Portland cements were the same, the strength of the mortar was, *cæteris paribus*, almost invariably governed by the strength of the neat cement. Sand, particularly when fine, might be considered abnormal in one respect, namely, that the surfaces of the grains bore an exceptional ratio to their weight and cubic capacity. Hitherto attention seemed to have been directed to an examination of cohesive rather than adhesive strength; the latter was, however, probably the more important; the "mechanical agency" of the particles also appeared deserving of closer observation. Mr. Mann.

The requirements of the specification of the cement used at Chatham seemed to be rather more than moderate; the degree of fineness was apparently omitted, and the specified strain was much too low, the actual breaking strain of 773½ lbs., or about 300 lbs. per square inch, did not compare favourably with the general strength of neat cement, which not uncommonly exceeded 500 lbs., and averaged over 450 lbs. per square inch when seven days old. The Author's method of providing quay walls with a facing, or skin of strong concrete, was an admirable arrangement; but with respect to coping and steps, which were generally subject to rough treatment, he should prefer using the granite unbroken, *i.e.*, in the form of ashlar. The remarks of Mr. Bernays relative to the deposition of liquid concrete *in situ* were entitled to attention, being also supported by those of Mr. Grant on the same subject. It must, however, be admitted that increasing knowledge and experience of the material in question, together with improved methods of submerging plastic concrete, seemed to point to the conclusion that the deposition of liquid concrete *in situ* was destined to supersede, to a great extent, the more costly system of blocks. The use of an excess of water in mixing concrete had at present but few advocates, investigation having abundantly shown that in its early age such excess diminished its strength; in many works it was of importance that the gauged cement should acquire strength as rapidly as was consistent with good material, so as to be better able to resist injury.

Although Mr. Grant had treated the subject exhaustively, and had alluded to many points of great interest, yet he had not shown the relation of the weight of loose cement to its tensile strength. The density of cement might possibly be an important

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Mr. Mann. element, but was, of course, a different thing from the weight as usually obtained. He had recently taken the specific gravity of cement supplied by some of the best English manufacturers, and found that it slightly exceeded 3·0; on separating the coarse from the fine by a wire sieve of 2,900 meshes to the square inch, he found the specific gravity of the coarse particles to vary from 3·08 to 3·13, and that of the fine particles from 2·97 to 3·06. In one or two instances the coarse and fine particles of the same cement had the same specific gravity. Applying this test to a sample of inferior cement, its density was found to be 2·80, and that of the fine sifted portion of the same cement only 2·55.

Referring to the article quoted from the "Thonindustrie Zeitung," given in the Appendix to Mr. Grant's Paper, if the experiments were made on cements of very different qualities, the conclusion arrived at was obvious. The tensile strength of the different cements was, however, not given, and in the absence of this information it was hardly possible to form any definite opinion.

Whether the density of cement had any relation to its strength, or otherwise, it appeared tolerably certain that the specific gravity of good English Portland cement, fairly ground, varied between very narrow limits.

Mr. Meyer. Mr. C. H. MEYER observed that the date at which the term "Portland cement" seemed first to have been used in the specification for its manufacture was interesting; and though Aspdin might not have been the originator of the term, or have made what was now considered true Portland cement, his name should be mentioned, and also that of his son, to both of whom probably some credit was due for its early introduction, and possibly for its invention. It would seem well, while practical men who had to do with Portland cement from its earliest date might be still living, if a short but complete history of its use and early struggles as against rival cements and limes were contributed by some or one of them, for as yet he believed such a record was unwritten, and this should hardly be the case of the best modern cement.

The progressive steps in improving the manufacture of Portland cement, such as those mentioned in the Papers, were satisfactory so far as they went. They were, however, only such as might have been expected as the use of this cement increased, and there still seemed to be a wide field for the introduction of greater certainty in its manufacture, especially in determining the value of, and proportioning the ingredients of, its composition.

One of the most important of these improvements was doubtless

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the greater attention given to the subject of properly grinding the cement, and he would urge the necessity, to all who used Portland cement in any quantity, or took any care or pride in getting it good, to see that it was properly ground; for exactly in the degree that it was not so, was the cost of it, as cement, thrown away. He had seen cement, otherwise good, with $\frac{1}{3}$ of its weight useless, inasmuch as it was not ground fine enough to have any value as cement. This was an extreme case, and one not likely to be often met with; but taking good cements as now ordinarily found, there was still much room for improvement in this direction. There might be practical difficulties in more perfect grinding, but they should not be looked upon as insuperable, and it seemed unreasonable that users of Portland cement should receive what was certainly no better than sand at the cost of cement. Particles of hard cement clinker, that would only just pass through a sieve of 1,600 meshes to the square inch, would give no good result as cement. He considered that the general tests for English Portland cement, proposed by the Authors of the first Paper, rather erred in point of leniency than otherwise in all the conditions; and with regard to that of filling the measure from an inclined plane, care would have to be taken that the stream of cement was constant in volume and velocity. He was in favour of testing cement neat, but this simply on account of the difficulty of getting sand of uniform quality; a "standard sand" wanted as definite a specification as the cement itself; it might be of ground or crushed flints, or some other good stone, sifted so as to be of uniform size, and be of various sizes or grades from the same grinding, but each practically uniform. This would have the advantage of being more sharp and angular than any natural sand, and as the quantity required could not be very great, the cost would not necessarily be so. Mr. Meyer.

He wholly disagreed with the idea that it would be safe under any conditions to use cement directly it was made, his whole experience being opposed to such a view. Almost all Portland cement possessed the property of increasing in bulk in an uncertain degree after it had been ground; this increase sometimes being very considerable, on an average perhaps not less than 5 per cent. after delivery from the manufacturers. Some cements, when first made up into briquettes for testing, cracked and went to pieces; but when thoroughly aired they lost that property, and stood a high tensile strain, the briquettes being kept in air or water from twenty-one days to two years or more. An experiment that was made at Portsmouth with cement supposed to be delivered

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Mr. Meyer. thoroughly fit for use, viz., by filling a strong wooden box, 3 feet square internal measurement, with cement, well shaken down to a depth of 2 feet 6 inches, and keeping it a month in a dry store, resulted in the surface of the cement at the end of that time being found $\frac{3}{16}$ inch higher than it was originally put in; and it could not be said that under the conditions mentioned it had been very fully exposed to the action of the atmosphere; it would probably have increased in bulk considerably more had it been laid out upon a floor. All large users of cement must know the effect of storing cement to a considerable depth in comparatively rigid buildings such as of brick; how, even in a short time, they were sure to be rent by the expansion of the cement. Partly for this reason, but much more for other advantages, strongly-framed wooden buildings, covered say with weather boarding and properly roofed, the floor and lining to the height to which the cement was to be laid being of 3-inch planking, formed far the best stores that could in most cases be adopted.

No doubt the investigations of German engineers and others had already led, and would yet lead, to beneficial results; and it was a question whether it was not time that English engineers should also come to some definite and uniform rules and tests; for as long as so many varying tests were in use, no one could exactly say what progress was being made in the improvement of cement.

One objectionable feature was in some cases coming into practice in the use of Portland cement mortar. It was sometimes specified that the mortar should be ground; this with some cement was objectionable on account of the time that elapsed between the wetting of the cement and its use as mortar, though the grinding itself might perhaps be of great advantage. But when, to secure a supply of mortar early in the day, the mortar was ground in the evening or some time the day before, little could be said in its favour.

In the second Paper, it did not appear how far the consideration of the various circumstances which led to the substitution of Portland cement for other limes and cement named in the contract specifications for the extension of Chatham and Portsmouth dockyards, went on concurrently or otherwise. As stated by Mr. Bernays in the case of Chatham, so also of Portsmouth, no mention had been made in the contract specifications of Portland cement. Roman cement was specified, and this it was in some measure intended should have been supplied to the contractors by the Admiralty, by utilizing convict labour to make it upon the works at Portsmouth. This was at first in some degree done, but on

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the whole it was found that neither the quantity nor quality so produced were all that could be wished. Mr. Meyer.

The substitution of Portland for other cement and limes for the Portsmouth works was chiefly brought about by the efforts of the late Mr. Edward Pease Smith, who, from great experience of its good qualities and high value, was able strongly to urge its adoption. Though acting for the contractors he was able to do this without involving them in greater outlay, partly on account of the smaller quantity of it than would have been required for work performed in lias and other limes, and partly on account of the cost of the carriage of lias lime from Warwickshire, from whence it was specified to come. The adoption of Portland cement, however, had undoubtedly been most beneficial in its results upon both works.

Unlike Chatham, concrete at Portsmouth was not used in places where it would be permanently exposed, the original designs for the Portsmouth works being more strictly adhered to. And the proportion of cement used in the concrete at Portsmouth was rather greater than at Chatham, being 1 part of cement to 11 parts of shingle in all ordinary work, though in special cases it was of 1 part to 9 parts, or 1 part to 6 parts respectively, none of so small a proportion as 1 part to 12 parts being used, except in a few cases where it was adopted in filling in behind walls or other works complete in themselves instead of the ordinary earth filling. The means taken at Portsmouth to apportion the cement to the concrete or mortar, were different to those generally adopted; for having in mind the great variation that might occur in actual quantity, when cement was taken by measure according to the manner in which it was put into such measure, it was agreed that all the cement used should be by weight, and with this view careful experiments were made to determine the average weight of the cement supplied. This was found to be 89·2 lbs. per cubic foot nearly, and upon this datum all the cement used upon the work was taken. During the construction of the works no sufficient variation in the average weight occurred to necessitate any reconsideration of this question.

The shingle and sand, previously mixed in proper proportions, was measured by being put into a box composed of loose sides set upon a floor or platform, one side being easily removable, the internal dimensions being 8 feet by 9 feet by 2 feet = 144 cubic feet capacity. The shingle was struck off to a depth of 1 foot 10 inches, and five bags of cement, each containing 2·4 cubic feet, weighing 1 cwt. 3 qrs. 18 lbs., were equably spread on the top. A little

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Mr. Meyer.

cement next the removable end of the box was then transferred to the opposite end, to prevent the prism of shingle that fell upon the floor when the end was removed carrying with it too great a proportion of cement. It was then carefully mixed by hand. Concrete, consisting of 1 part cement to 9 parts shingle, was apportioned in the same way, six bags of cement being used with proportionately less shingle. All mortar used for brickwork was made of 1 part of cement to 2 parts of sand, and for setting masonry in some cases in the same proportion, but in more important masonry equal proportions of cement and sand were used, all joints being grouted with neat cement. After the concrete had been mixed on the floor, always as close to the point of deposit as it could conveniently be, it was put into barrows and dropped into its place, the specified fall of 5 feet not being in all cases strictly adhered to; it was then trimmed and well rammed. He here wished to remark, after taking great care to be well informed on the point, that all concrete made with Portland cement should be deposited as soon after it was mixed as possible, and should be at once thoroughly rammed. No fall or drop was equal in efficiency to this, and granting that it was well rammed, the fall or drop might be dispensed with. He agreed with Mr. Bernays in his advocacy of using the concrete sufficiently wet, one advantage being that it more readily took its densest form under the drop or by ramming than if deficient in water. On the other hand such an excess of water as would carry cement away with it should be avoided. He further agreed with Mr. Bernays as to depositing concrete in such structures as walls, &c., in layers of 18 inches; but he would not advocate their being thinner, for however carefully concrete might be put in, it always possessed a tendency to separate more easily into the layers in which it had been deposited than anywhere else. As at Chatham, so also at Portsmouth, care was taken to guard against this possible want of adhesion, by well wetting and sprinkling with cement any surfaces that had become dry or loosened, before adding another layer. Mr. Woodman Hill, who had had great experience in most kinds of high class concrete work, even took the precaution, in any case where it might seem necessary, to make a rough mortar joint or bed before depositing succeeding layers of concrete. His experience was that without such a procedure, or similar precautions, perfect adhesion could not be ensured. When, however, layers of concrete succeeded each other perhaps on the same day, such measures were not necessary and would be wasteful.

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Mr. Meyer. He remarked that concrete of 1 part of cement to 11 parts of shingle, used at Portsmouth, did not in any case appear unnecessarily rich, indeed he should have preferred an increase of cement. The shingle was of good quality with a fair proportion of sand, but the result in the work was concrete not looking so rich as that produced by Mr. Bernays at Chatham; indeed, in some cases the shingle used by him looked richer without cement than that used at Portsmouth did with it. He must confess to a feeling of great distrust at the idea of employing shingle containing loam for concrete. He should be much interested in the result if Mr. Bernays would experiment with concrete beams, such as had been mentioned in the discussion, made with the shingle he used, and also with similar shingle washed free from its loamy constituents, both with the same proportions of cement. These should be submitted to transverse strains wet and dry, and if the loamy shingle still gave the best results, the conclusion would almost necessarily follow that the loam mixed with the Medway shingle possessed some inherent cementing property. He did not like the principle of making the mass of such important walls as those at Chatham of a comparatively weak concrete simply faced with a better, as he feared that in course of time the facing might separate from the mass. He should prefer in any work for which he was responsible, and where cement was to be had at reasonable cost, to advise the necessary expenditure for making the whole mass (or at any rate the greater part of it), including the face, of the same uniform quality; for there must be at times in all such works, a fluctuation of pressure, and when this acted from behind, the finer facing, when it existed, offered undue resistance in consequence of its being less pervious than the rest, and was then subjected to the greater tendency to be forced off.

Though concrete was so valuable a cheapener of engineering works, it was necessary to give it fair play, and to guard against carrying its use too far; for no method of construction could well be more expensive or disastrous than one in which the first cost was put so low as to involve failure. The quantities of various items for which Portland cement was used at Portsmouth were approximately as under: Thus, for about 350,000 cubic yards of concrete; for about 30,000 cubic rods of brickwork; and for setting about 2,500,000 cubic feet of dressed masonry.

Dr. Michaëlis. Dr. MICHAËLIS remarked that if the question were raised as to testing cement neat or mixed with sand, and if it were acknowledged that only one of these two methods was permissible, then there was no doubt that the decision must be in favour of the sand

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Dr. Michaëlis. mixture. It was only when mixed with sand that one of the most important properties of cement could be appreciated, namely, its power of uniting other substances. This was totally distinct from its strength, and depended chiefly upon fine grinding, which was of primary importance. Fine grinding was the only rational method of utilizing the cement to its fullest capacity. The absolute weight of 1 cubic foot of cement was again dependent upon the grinding, and it must therefore appear hazardous to fix a weight of 85 lbs. avoirdupois per cubic foot as the minimum for cement loosely filled into the measure, as the most satisfactory cements would thus be excluded. The following results were part of a series obtained with a Portland cement of unrivalled quality. This cement weighed, ground in the ordinary way, as bought in the market, about 90 lbs. avoirdupois to the cubic foot. When, however, it was ground extremely fine, as was now done on a large scale in Germany, so that no residue remained upon a sieve with 32,000 meshes per square inch, its weight was only about 70 lbs. per cubic foot. With this finely-ground cement, which would have been excluded by a rule fixing the minimum weight at 85 lbs., the following figures were obtained—with 3 parts of sand to 1 part of cement in two days the strength was 115 lbs. per square inch, in seven days 338 lbs., in twenty-eight days 457 lbs., in one year 539 lbs. With 6 parts of sand the briquette broke at 170 lbs. per square inch in seven days, 215 lbs. in twenty-eight days, and 284 lbs. in one year. If, as Dr. Michaëlis would certainly not advise, any absolute weight per cubic foot should be adopted, then it ought not, in his opinion, to be higher than 75 lbs.

But what was the object of fixing such an absolute weight? It was evidently intended to exclude lightly-burnt cement. The idea that lightly-burnt cement should be rejected was, in Dr. Michaëlis's opinion, an erroneous one, if the present state of cement-making and testing were considered. No Portland cement was more reliable than one which gave good results, even when lightly burnt. Tested neat, lightly-burnt cement must, of course, fall far behind highly burnt; but the inferiority was not nearly so apparent when examined with regard to its power of uniting or cementing sand. Lightly-burnt cement, as was well known, was the first to show symptoms of "flying." If, therefore, a cement showed no signs of "flying" when lightly burnt, and if it possessed considerable strength when mixed with sand, then it would, perhaps, when heavily burnt, give a still higher strength with sand, and this strength would continue to increase for a longer period. Such a cement would undoubtedly be faultless. That light burning could

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not be very injurious to Portland cement was best shown by the examination of high-class Roman cements, which were burnt at a low temperature, and yet attained a tensile strength of 112 lbs. per square inch in twenty-eight days when mixed with 3 parts of sand. For the detection of faulty cement sufficient and unerring means of detection were at hand; of all of these the proposed minimum weight per cubic foot would be the least adapted to prevent the use of bad cement. The strength of a sand mixture would clearly indicate whether a deficiency in absolute weight were due to spontaneously disintegrated cement. Dr. Michaëlis.

A high absolute weight would therefore not only be of little use, but would exclude the most valuable cements. The next question was whether it was right to go from one extreme to the other by giving up the test with neat cement, which had so long been customary in England, and by substituting for it the test with sand. From the commencement Dr. Michaëlis had been of opinion that the proper course lay between the two. It was the test with neat cement alone that indicated what proportion of water was the most favourable for the particular cement under examination. No idea could be more erroneous than that the less the water used the stronger would be the cement. Cement could be spoilt by a deficiency of water as easily as by an excess. While one cement might give the highest results with 18 per cent. (by weight) of water, and was totally destroyed by adding only 17 or 16 per cent. of water; another by no means quick-setting cement might be completely spoilt by adding 22 per cent. of water, because it required 24 per cent. of water to attain a high degree of strength.

It was a mistake to think that the test made with sand, according to the German standard rules, gave more regular and uniform results than briquettes made in the same way with neat cement. A method of carrying out the latter test could quite as easily be prescribed as for the sand mixtures. He would recommend the retention of the test with neat cement. He now, more than ever, advocated the sentence placed at the head of his work (1876), which served as the basis of the standard rules existing on the continent. "Cement should be bought by weight and judged according to its strength, taken in conjunction with the fineness of grinding, as may be done by testing the strength of neat cement and of a mortar of 1 part, by weight, of cement with 3 parts, by weight, of sand." The only alteration the writer would now make would be to prefer a mortar of 1 part cement with 5 parts of sand, more especially if the sand test alone should be adopted. The

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Dr. Michaëlis.

cementitious value and trustworthiness of cement were more evident with 1 to 5 than with 1 to 3. Among more than 80,000 experiments it never occurred that good results were obtained in seven or twenty-eight days in any case where the cement had a tendency to "blow." This might, however, happen, with the proportion 1 to 3, deterioration taking place subsequently. No cement with any tendency to "blow," however slight, would give a favourable result if tested in seven days.

If the cement showed a high strength neat, it proved that the sample was highly burnt; if the mixture with 5 parts of sand gave high results, it indicated that the cement was faultless and finely ground.

Accurate comparative tests could only be made with cements ground in the same way, and the cement should be reduced by means of three sieves to a uniform grain. One of these sieves should have 32,000 meshes per square inch, the next 14,400 meshes per square inch, and the coarsest 5,800 meshes per square inch. The cement was first passed through the finest sieve, then through the second, and finally through the coarsest sieve. Sixty parts of the powder passing through the 32,000-mesh sieve were well mixed with 20 parts each of the powder passing through the sieves of 14,400 and 5,800 meshes. A preliminary experiment decided what proportion of water was most suitable for the cement under examination when mixed upon a non-absorbent surface. For each part of sand an additional 7 per cent. of water was added. A cement requiring 20 parts of water when gauged neat would therefore, when mixed with 5 parts of sand, take $20 + (5 \times 7) = 55$ parts of water per 600 parts, by weight, of the dry materials, or 9 parts, by weight, of water to 100 parts of the dry mixture. In respect of the time allowed for hardening, the Austrian rules were to be preferred to those of the Germans. The test after seven and twenty-eight days was undoubtedly of more practical value than the twenty-eight-day test alone. There could be no doubt that the results of a test must be the more reliable the longer the period of observation, and a ninety-day test would in its turn be preferable; still more so a test extending over a year or longer. Even the twenty-eight-day test, however, clashed with the practical requirements of the case. A point which had been completely lost sight of in abandoning the seven-day test was its bearing upon one of the most valuable properties of cement, namely, its hardening energy (Erhärtungs-Energie). In this respect Portland cements might vary considerably, especially on the continent, where Portland cement was made from raw materials differing widely from each other. Silica,

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alumina, iron, and magnesia, played highly important parts in this process, on which subject Dr. Michaëlis now believed himself to be perfectly clear. In England the character of Portland cement varied but little; nearly everywhere there was the same chalk, the same clay. On the continent no better cements were produced than when the raw materials used closely resembled those of the English manufactories. This initial hardening until recently had but little value attached to it, which was in favour of those manufacturers who could never produce a cement of first-rate quality because their raw materials would not permit it, whose cement was therefore for this reason much inferior. Dr. Michaëlis.

He need only refer to the fact that all cements of first-rate quality were especially prominent in this respect. The value of this setting energy, which must be of great importance in practice, had been ignored to such a point, that quite recently Mr. Henry Faija could suggest that a normal cement should possess, in twenty-eight days, a strength 25 per cent. higher than in seven days. No one can doubt that, all other circumstances being equal, he would attach more value to a cement which attained 90 per cent. of its final strength in seven days than to one which only possessed 50 per cent. of the strength which it would ultimately reach. The latter could easily show 25 per cent. more strength in twenty-eight days, which would be an impossibility with the former. General Scott suggested that cement should leave no residue upon a sieve with $40 \times 40 = 1{,}600$ meshes per square inch. On this he would observe that if the cement which had passed through such a sieve were further sifted through a sieve of 5,800 meshes (900 per square centimètre), the residue upon the latter would be in conformity with General Scott's stipulation, and yet be absolutely valueless as a cementitious agent.

In Germany, in consequence of his own efforts, cement was being made of which an amount of 10 to 3 per cent. was rejected with a sieve of 32,000 meshes per square inch; in some cases leaving hardly any residue. In this country, where cement has been too cheap to treat it rationally, such a sieve generally left 50 per cent. residue. Might it not be preferable to prescribe a sieve with at least 14,400 meshes per square inch, and a residue upon it of not more than 33 per cent. He had had the honour to express his views and to co-operate in framing the standard rules in Austria, Sweden, and Russia. With regard to the experiments of Messrs. Dyckerhoff, he did not think that the conclusions drawn from them could be applied to German cements in general.

Dr. Michaëlis submitted various printed documents, on the valu-

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Dr. Michaëlis. ation of cement;[1] two articles by himself on the same subject;[2] a copy of the German standard rules for testing Portland cement,[3] and of the rules adopted in 1878 by the Prussian Ministry of Commerce and Public Works;[4] an article on the testing of cement;[5] suggestions on the testing of Portland cement by several German manufacturers;[6] description of the apparatus sold by Dr. Michaëlis;[7] copy of the rules adopted in 1878 by the Austrian Association of Engineers and Architects;[8] and an article on hydraulic mortars.[9]

Mr. Porter. Mr. WILLIAM PORTER considered the most important point in connection with the subject to be that which related to the breaking tensile strain of Portland cement, considered as a standard of quality. About sixteen years ago the standard of strength required was a tensile strain of from 400 to 500 lbs. on a test-block having a sectional area of 2¼ square inches when seven days old. This standard had from time to time been increased, and there were a few cases where it had been placed at the high figure of 900 lbs. upon the same sectional area, and with the time remaining as before. In other cases engineers had advanced with more caution, being satisfied with a less tensile strain. Mr. Bernays, who had an intimate knowledge of the use of Portland cement, specified that test-blocks of the usual sectional area of 2¼ square inches should at seven days bear a weight of 650 lbs., and Sir John Coode, who had great experience in the use of Portland cement, required the test-blocks to bear a weight of 750 lbs. upon a like sectional area and at a like age. The following question thus arose: Had the high test of 900 lbs. above named been

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[1] Zur Beurtheilung des Cementes. Von Dr. W. Michaëlis. Berlin 1876.

[2] Zur Werthstellung des Zements. Von Dr. W. Michaëlis. Excerpt 'Deutsche Bauzeitung,' 1876, Nos. 23 and 101.

[3] Normen für die einheitliche Lieferung und Prüfung von Portland-Zement. Nach den Beschlüssen des Architekten Vereins zu Berlin, etc. etc. Berlin 1877.

[4] Normen für die einheitliche Lieferung und Prüfung von Portland-Zement, aufgestellt von dem königl. preuss. Ministerium für Handel, Gewerbe und öffentliche Arbeiten, mittels Erlass vom 10. November 1878.

[5] Die Prüfung des Cements. Von Dr. W. Michaëlis. Excerpt 'Baugewerks-Zeitung,' 1878.

[6] Vorlage zu Beschlüssen für einheitliche Lieferung und Prüfung von Portland-Cement.

[7] Apparate zur Ermittelung der Zug- und Druck-Festigkeit von Baumaterialien insbesondere der Mörtel und Cemente, &c. Von Dr. W. Michaëlis. Berlin, 1878.

[8] Bestimmungen für die einheitliche Lieferung und Prüfung von Portland-Cement. Wien, 1878.

[9] Zur Kenntniss der hydraulischen Mörtel. Von Dr. W. Michaëlis. Excerpt Deutsche Töpfer- und Ziegler-Zeitung, 15. May 1880.

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adopted without sufficient justification? It was stated by Mr. Grant that great improvement had been made in the manufacture of cement of late years, and that still greater was certain to be effected. This was true only if the fact that a much higher tensile strain had been obtained was considered evidence that a better cement had been produced. Experience led him to say that there was no conclusive evidence of such being the case. The higher tensile strain, obtained to-day as compared with that of past years, as Mr. Grant admitted, was due in a measure to the improved mode of filling the moulds, and to the improved appliances with which the cement test-blocks were broken. Then, he asked, to what was the balance of improvement due? The only possible answer (excepting fine grinding, which was of questionable value beyond a certain point,) was that an extra and possibly undue quantity of chalk or lime had been used in the manufacture of the cement; and it was against this latter point that he desired to protest, as being conducive, not to the improvement of the cement, but to its destruction. The use of chalk or lime in undue quantities, that was in excess of that which the clay could neutralise, was certain, sooner or later, to be productive of the worst results, with which results every manufacturer of cement was fully acquainted. He might add, that if an overchalked cement was not burnt hard, that was to a heavy weight, the results referred to would in all probability appear at an early date. If, on the other hand, the cement was burnt to a heavy weight, such results would show at a later, and probably a much later, date. With neat cement the results would probably appear in one of the following forms. It might be what was called "dust," showing that disintegration had set in, the corners most exposed falling away first, and at last the whole mass being reduced to a powder. Or cracks might be formed on the surface, and become visible at an early period, or they might exist for a long period, and be made visible only by wetting the surface of the cement. Or, again, the surface might become pitted, portions of the surface being thrown off until the whole mass had fallen to pieces; but this latter defect, he might add, might in some cases be ascribed to the cement containing small pieces of lime not properly amalgamated with the clay, and need not necessarily be caused by an undue quantity of chalk or lime having been used in the manufacture of the cement. Mr. Porter.

It might, he thought, be stated as a fact, that when engineers specified a high standard of strength, such as that of 900 lbs. upon a sectional area of $2\frac{1}{4}$ square inches at seven days, there was but one known course to adopt, in order to bring the cement up to the

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Mr. Porter. required standard, and that was to increase the quantity of chalk or lime used in the manufacture in conjunction with extra-hard burning, so as to produce a heavy cement. It must be borne in mind that as there was often so much difference in the results of the testing of similar cements when done by different men, and under different circumstances, as regarded the nature of the appliances with which the tests were made and broken, that the required test, were it great or little, must be made of a maximum strength, much greater than was required by the specification. The result of this was that a still greater quantity of chalk had to be used, and a quantity which, he believed, approached nearer the point of danger than was advisable.

It was stated in the Paper by Major-General Scott and Mr. Redgrave, that: "Cement mixtures, on the other hand, deficient in clay, and known as 'underclayed,' will stand the highest temperature in the kiln during the firing. When well burned they are extremely hard and difficult to grind; they produce, however, a heavy, dense Portland of a treacherous description, one which, unless it has been properly 'purged,' as it is termed, or exposed in thin layers to the atmosphere, in order to air-slake the particles in which the lime is in excess, is liable to 'blow,' or swell in the work." With this he agreed, excepting that he did not think any cement "underclayed" so as to "blow or swell in the work" could be rendered so that it would not be likely to blow and swell by any reasonable amount of air-slaking, and especially if such cement had been hard burnt; in fact if such cement could be so purged it would become dead and almost useless.

It had been asserted by Mr. Grant that: "The strength of cement depends, in great measure, upon the right proportion between the chief constituents being observed in the manufacture." To this he would object that it could only be true when considered as having reference to the strength of cement at a certain period after having been gauged, because if a moderately overchalked and hard-burnt cement was gauged neat, it would in all probability bear a considerable tensile strain at an early period, but would and must eventually fall to pieces. The truth would, he thought, be better expressed by using the words "ultimate strength."

In conclusion, although he thought the breaking strain of Portland cement would be still further raised by improved methods of testing, and by the utmost care in its manufacture being constantly observed, yet he was far from alone in thinking that it was most desirable to act with the greatest caution in the matter of raising

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the standard of strength, otherwise it might be found that the high tensile strain required had been productive of a result the opposite of that contemplated by engineers and manufacturers. Mr. Porter.

Mr. W. F. Reid remarked that allusion had been made to the failure of Hoffmann's ring kiln for burning cement in this country. Mr. White had given one reason why it had not met with success in practice; another reason was the difficulty experienced in regulating the draught. In Germany, where this form of kiln was successfully used, the raw mixture was moulded into bricks previous to burning. These bricks could be arranged in the chambers with great regularity, leaving the necessary interstices for the passage of air and fuel. With English manufacturers the lumps of dried slurry were so irregular in shape that it was extremely difficult to arrange them in the kiln in such a manner as not to interfere with the draught. The extra cost of moulding the raw mixture into bricks would be greater in this country than the economy in fuel effected by this form of kiln. General Scott and Mr. Redgrave suggested stamping the dry powder of the raw materials under great pressure, and burning the bricks or slabs thus obtained. He tried this experiment on a large scale several years ago, but the results obtained were not encouraging. The bricks did not possess sufficient cohesion; they would not bear handling, and "dusted" so much in the kiln that the draught was stopped. The silica and alumina were added either in the shape of powdered shale or of slag sand; the carbonate of lime was pulverised limestone. Under the pressure employed, the powdered shale alone became hard and compact; but with the addition of 70 per cent. of carbonate of lime the particles would not bind. The mixture of comminuted slag and limestone could not be moulded into a brick under any pressure. One point of great importance in the manufacture of cement had not been alluded to in either of the Papers, namely, the testing of the raw mixture as soon as made. The uniformity and reliability of German cement were in a great measure due to the care with which the composition of the slip was checked. The test used was a chemical one, and occupied about fifteen minutes; any error in the proportions of the ingredients could therefore be corrected at once. In some of the German manufactories the slip was thus roughly analysed every hour, so that the risk of loss from carelessness on the part of the workmen was reduced to a minimum. Most British manufacturers still employed the old method of sampling by drying a portion of the slip, burning and grinding it, and then mixing it with water in the ordinary way. At least Mr. W. Reid.

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Mr. W. Reid.

twenty-four hours must elapse before even an approximate idea of the composition of the raw mixture could be obtained in this way; in the meantime the whole day's washing or mixing might be faulty. He had found the chemical test of the utmost value in dealing with materials of varying composition, or which had never previously been used for making cement. With the aid of the new machinery and methods described by Major-General Scott and Mr. Redgrave, engineers could now in many cases make the cement required for works abroad cheaper on the spot than the price it could be exported at from England. Few localities were devoid of the materials for producing a good cement, and in some instances the saving effected in freight would be greater than the cost of constructing the manufactory. One great advantage of having the cement manufactured on the spot was that the quality was completely under control, and could be adapted to the purpose required, while there was no risk of deterioration during transport.

The Authors of the first Paper suggested that a minimum weight per cubic foot should be fixed. Such a coarse sieve as one of 1,600 meshes per square inch would allow a large portion of inert particles to pass, and the adoption of a minimum weight would, as Mr. F. J. Bramwell remarked in 1865, be simply offering a premium to coarse grinding within the limits fixed by the sieve. The present knowledge of the physical properties of cement indicated that the weight of cement had but little influence on its strength when mixed with sand. Numerous experiments had proved that there was no connection between the specific gravity of cement and its tensile strength, and as the absolute weight of a fine powder must depend upon its specific gravity, the adoption of a fixed weight per bushel might be misleading. Major-General Scott and Mr. Redgrave had given the strength specified by the German standard rules as 113·8 lbs. per square inch. This was the strength originally adopted in 1877, but in the beginning of 1878 the minimum was increased to 142·2 lbs. per square inch for a mixture of 1 part of cement to 3 parts of sand. The Austrian rules prescribed a still higher strength, namely, 170·7 lbs. per square inch. Many of the German manufacturers now guaranteed both greater fineness and higher strength than those fixed by their standard rules. These rules were originally framed by the manufacturers themselves, and had subsequently been adopted by engineers and architects throughout Germany. When first proposed, they were accepted by twenty of the twenty-five cement manufacturers of Germany, the five opponents including one of the firms mentioned by Mr. Grawitz and that firm which he represented. This minority,

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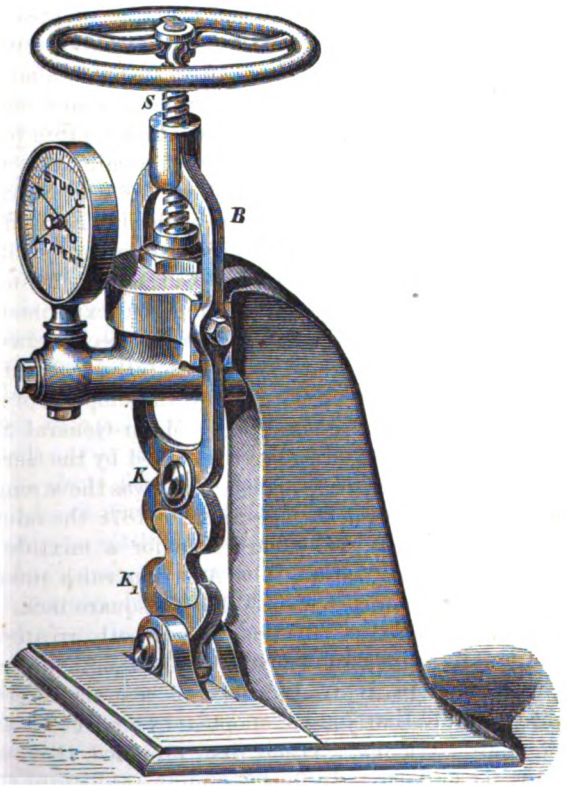
supported by Dr. Michaëlis, and strong in convictions if not in numbers, had since waged an unceasing warfare against the standard rules in Germany, and even carried their opposition into this country by taking exception to the results communicated to Mr. Grant by Messrs. Dyckerhoff. These latter gentlemen had done much to extend the knowledge of cement, and the results of their experiments had been accepted, not only by the great majority of German cement manufacturers, but also by the engineers and architects of that country. Mr. W. Reid.

Herr STUDT sent a description and drawing of his cement testing apparatus, which had also been used for testing leather, paper and cotton. The briquettes had a breaking section of 5 square centi- Herr Studt.

Fig. 1.



mètres, and were fixed in the clips K K, Fig. 1. One of these clips was hinged to the bed-plate of the apparatus; the other was

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Herr Studt.

jointed to B. The adjusting screw S raised or lowered B as required. The tension to which the briquette was subjected was measured by the point of the adjusting screw compressing glycerine in a vessel. The pressure communicated to the liquid was registered on a gauge indicating the number of kilogrammes per square centimètre of the area broken. The dial of the pressure-gauge was furnished with a maximum pointer, which should be brought back to zero after each experiment. The apparatus was said to work accurately, extensive series of experiments having been conducted with it.[1]

Major-General Scott.

Major-General Scott remarked that Mr. W. Porter had expressed a doubt whether cement so underclayed as to merit the designation of being "treacherous" when used fresh, could be rendered absolutely safe by exposure to the air. On this point General Scott was certain that it was possible, with a substance containing enough clay to merit the designation of Portland cement, to destroy all the elements of danger, as stated in the Paper. In fact he had made experiments with most satisfactory results in exposing Portland cement of the above character to the action of steam, which rapidly eliminated all these sources of danger without appreciably deadening the cement. He considered that the remarks of Dr. Michaëlis were entitled to the utmost respect, but he could scarcely follow him in placing the weight of the cubic foot of cement so low as 75 lbs., a weight reached by many of the native hydraulic limes. Whatever might be the degree of fineness in the grinding, he trusted that a standard would be fixed which would enforce the adoption of some mesh leaving no residue. A percentage of residue of coarse particles merely implied a percentage of valueless matter, and he thought the German regulations were defective in this respect. With reference to the double test advocated by Dr. Michaëlis, *i.e.*, neat and with sand, he saw no objection to it, but would remark that too much weight was placed on quick setting by Dr. Michaëlis, and too little weight on the general superiority of heavy cements over light ones; and that it would be quite possible, with a lightly burned cement, to attain to a rapid set without that great degree of ultimate hardness which Dr. Michaëlis believed must follow rapidity of set.

Mr. Grant.

Mr. Grant, in reply to the discussion and correspondence, wished to state that his Paper had been written chiefly with the view of drawing attention to certain important points affecting the quality of Portland cement, and as a contribution towards the

[1] "Glaser's Annalen für Gewerbe und Bauwesen." No. 76. 1879.

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adoption of a more uniform and accurate mode of testing it; and though the time which it was possible to devote to the discussion was limited, yet in the course of it, and in the written contributions which had been received, much valuable information had been elicited. Mr. Grant.

The merits of different modes of dealing with and drying the "slip," and afterwards burning it, were, both as questions of efficiency and economy, very valuable, but chiefly to those engaged in the manufacture. He should have liked to have heard more on the question of fine grinding. For twenty years or longer it had been stipulated that "cement should be finely ground." But the importance of this feature had been clearly demonstrated by the labour and experiments of Dr. Michaëlis, the Messrs. Dyckerhoff, and many other investigators in Germany, and by Mr. Colson, Mr. Mann, and others in England. Perhaps nothing had tended so much to make this, as a practical question, clear to all persons interested in the subject as the adoption in Germany, Austria, and other countries, of the sand-with-cement test, by which alone the cementitious value of cement could be ascertained. By innumerable tests and experiments made by various persons, it had been found that cement manufactured of proper materials, rightly proportioned and well burnt, but coarsely ground, might give the highest results when tested neat, and yet, when mixed with sand, not be one-half of the strength of similar cement more finely ground. The question then was, to what degree of fineness could this be economically carried out? To this the most satisfactory answer would be found in the experience of those manufacturers who had adopted this system of fine grinding. Unfortunately there was not much of this to appeal to in England, but it had been possible for a year or two past to get cement manufactured here that would pass the German standard, and be even so fine as to leave only 10 per cent. on a sieve of 5,806 meshes to the square inch. This latter degree of fineness was now very general with the larger manufacturers in Germany.

After much discussion, the Committee of the German Association at Berlin, in January and February 1877, adopted a sieve of 900 meshes to the square centimètre, equal to 5,806 per square inch, and allowed a residue of 25 per cent. Next year this was reduced to 20 per cent., and the Austrian Association of Engineers and Architects had since adopted the same standard of fineness.

In his communication, Dr. Michaëlis suggested a finer sieve (14,400 meshes to the square inch), with a larger residue of 33 per cent., and stated that in Germany cement was being made which rejected

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Mr. Grant.

only from 10 per cent. to 3 per cent., with a sieve of 32,000 meshes per square inch. This degree of fineness must be quite exceptional. The most finely-ground cement which Mr. Grant had ever seen, or had had an opportunity of testing, was a cask which, by the kindness of Dr. Michaëlis, had been sent to him from a manufactory near Hamburg. This, on the sieve of 32,000 meshes to the square inch, left 25 per cent.; on the sieve of 5,806, 10 per cent.; and on that of 2,580 meshes to the square inch, nothing. The "Stern" Company in the north, Messrs. Dyckerhoff in the south of Germany, and many other makers, guaranteed that the cement should not leave more than 10 per cent. on the standard sieve of 900 square centimètres; and though cement could not be too fine, it was difficult to see the practical advantage of using, for testing purposes, a finer sieve with a larger residue. At all events, in this country it would probably take some time for manufacturers to work up to this standard. That which was suggested by the Authors of the first Paper, viz., that the whole of the cement should pass through a sieve of 1,600 meshes to the square inch, was much too coarse, as was pointed out by Herr Grawitz, Dr. Michaëlis, and others, and was proved by various Tables in the Appendix. It appeared that only 75 per cent. by weight of the cement used by Mr. Bernays passed through a sieve of 50 meshes to the lineal inch. The Tables in the Appendix, more particularly the latter part of Table XLVII., proved that the 25 per cent. residue left on such a sieve was utterly worthless, and that the concrete of Mr. Bernays, nominally of 1 to 12, was in reality only 0·75 to 12, or 1 to 16.

Though extremely fine grinding offered a strong temptation to low burning, so as to make grinding easier, there could be no doubt that, however good in every other respect cement might be, it was only when finely ground that its cementitious strength was developed, that it did this at an earlier period, and with greater safety. Briquettes made entirely of the "core," or coarser particles left on a sieve of 2,580, and much of that which lay between this and a sieve of 5,806 to the square inch, would hardly bind at all. If this core was substituted for sand of equal fineness, and mixed, for instance, with a third of cement, the result was not much higher than if sand were used. If, as shown in the latter part of Table XLVII., the 5 per cent. to 15 per cent. of residue on a sieve of 5,806 meshes per square inch was left out entirely, and only the 85 per cent. or 95 per cent. of finer cement mixed with the full quantity of sand, the strength was not only as great as when the coarser part was left in, but greater. This seemed utterly incredible until the experiment had been repeated many times, with dif-

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ferent cements and by different operators, taking every precaution that the conditions were alike. From this it might be inferred that coarser cement than would pass through the sieve of 2,580 to the square inch was at best no better than sand, and that when it contained free lime it was a source of weakness, if not of danger. Repeated experiments had also shown that if the coarsely-ground part of good, well-burnt cement was well pulverised, it made the strongest of all. These facts showed clearly that the additional cost of grinding fine, estimated by various makers at from 2*s.* to 3*s.* 6*d.* a ton, or say 10 per cent. of its price, would be amply repaid by its strength being doubled, and by its greater safety. Mr. Grant.

This additional cost, with probably a considerable premium, would be paid when the importance of fine grinding was recognised by engineers and manufacturers; but it was not likely that the suggestion of Herr Grawitz would ever be adopted, that the price of Portland cement should be estimated by its apparent strength, at or near the time of delivery, as if it could be tested like iron or steel. If, at an additional cost of 10 per cent., the cementitious strength when mixed with sand or gravel could be doubled, it was not likely that 100 per cent. additional price would be obtainable. This, however, in any country in which trade was free, might safely be left to settle itself. With all the improvements that had been made in testing cement, it was not now, and probably never would be, possible within a few weeks to test its eventual or ultimate strength with the same degree of precise accuracy that was possible in the case of any finished article requiring no manipulation. As this had been already referred to in some detail, it was unnecessary to say more than that, apart from all other influences, the acquired dexterity of an experienced manipulator would sensibly affect the results. Thus in testing cement neat, if a shallow mould was used, and shaken or tapped whilst the surplus water was being absorbed, the briquettes might be made much denser than by any other means, and give higher results. It would, therefore, be necessary, if this mode were adopted, to make allowance for it. Other means, such as artificially prolonging the time of setting, and having the same effect as storing the cement, added to its density and apparent strength at least for a time. Cements which were slow-setting by nature, or were made slow artificially, and which were also ground extremely fine, showed to great advantage what was called by Dr. Michaëlis their "hardening energy" at the end of seven days, but did not increase so much in strength afterwards. This was confirmed by the strength of No. 14 and several other cements in

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Mr. Grant.

Appendix XLVII., at 4, 13, and 26 weeks. Whilst a quick-setting cement was often after twenty-eight days double the strength it showed at seven days, a slow-setting would show only 50 per cent. more. Above all, it would be practically most difficult to determine the time after which it would be fair to compare the ultimate strength of cements of dissimilar character.

One of the benefits which had resulted from the adoption of the mode of testing cement with a mixture of sand was that it had brought out prominently the importance of paying attention to the quality of sand, its mineral character, its coarseness or fineness, and its freedom from extraneous matter.

From the upper part of the Rhine an exceedingly good sand was obtained. The standard sand approved by the German Association was to be had in Berlin, and probably other places, at 4 marks for 50 kilogrammes, or about 4*s*. per cwt. That sands varied much had been referred to by Mr. Faija and others. Mr. Grant had recently met with two sands which, though both clean, sifted through the same sieves, and not much unlike each other even under the microscope, gave results that differed by 50 per cent. From this it was clearly as important to test the quality of the sand or gravel used with cement as it was to test the cement itself, and that for testing purposes a sand of uniform character should be used as a standard with which to compare that used upon the works.

With exceptionally thick dock walls, like those at Chatham, the somewhat loamy character of the gravel might not be perceptible; but for thin work, as in sewers, where concrete was used as a substitute for, or in combination with, brickwork, the gravel and sand could not be too clean. Where the proportion of sand in gravel was frequently changing, experience had generally to supply the place of measured proportions, which, however, were useful as checks.

As to the tensile strength of cement, and the mode of testing it, either with neat cement or with cement and sand, by the German rules the neat test at seven days was only used tentatively for controlling purposes; the test with 3 parts of sand after twenty-eight days being the most important. As already stated, this was at first, in February 1877, fixed at 8 kilogrammes per square centimètre. In 1878–9 it was raised to 10 kilogrammes per square centimètre, or 142·23 lbs. per square inch. The Society of Austrian Engineers and Architects, in December 1878, adopted a standard of 8 kilogrammes per square centimètre at seven days and 12 kilogrammes at twenty-eight days respectively, = 113·78 and 170·68 lbs. per square inch. Their seven-days test with sand

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was thus apparently the same as the twenty-eight-days test originally agreed upon at Berlin in February 1877, except that by the Austrian rules the average of the six highest out of ten was taken. The standard sand, instead of 60 and 120 per square centimètre = 387 and 774 per square inch as in Germany, was 64 and 144 square centimètres = 413 and 929 per square inch, or almost exactly 20 and 30 to the lineal inch. Mr. Grant.

Messrs. Dyckerhoff said that the testing of cement, since the introduction of the standard rules in 1877, as well as their own investigations of the influence of the time of setting, on the strength of cement-lime mortars, on the use of slow- and quick-setting cements, on the making of concrete, &c., had been published in the "Proceedings of the Association of German Cement Manufacturers." As regarded the testing of cement, they considered the method prescribed by the German standard rules as the most suitable at present for the valuation of cement, provided the time of setting was also taken into consideration. They guaranteed a strength of 20 kilogrammes for their slowest setting cement; and they voted for a higher minimum strength than that which was subsequently fixed. In 1878 they proposed to the Commission named by the Prussian Minister of Commerce to report on the standard rules, a classification of cement by the time of setting; according to which a strength of 10 kilogrammes should be the minimum for quick-setting cements, 12 kilogrammes for an average time of setting, and 14 kilogrammes for the slowest cements. At present their cement was made of from 12 to 20 and more kilogrammes, according to the time of setting, which varied from thirty minutes to ten hours. It was therefore an error to suppose that the adherents of the rules could not manufacture high-class Portland cements because their raw materials did not permit it. In reply to the remark of Dr. Michaëlis, that the conclusions which had been drawn from their experiments could not be applied to the German cements in general, it might be remarked that the experiments were made with different kinds of cements, among which were the best German, English, and French brands. As, therefore, cements made from very different raw materials were used in the experiments, they were of opinion that the results were applicable, not only to German cements, but to Portland cement in general.

At their meeting in February 1879, the German Association came to a resolution that as "the time of setting" had much influence on the tensile strength, the one should be stated in connection with the other.

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Mr. Grant. . High as the standards of strength adopted by the German and Austrian Associations might appear to English manufacturers, the principal manufacturers of Germany, of whom Herr Grawitz's firm in the north, and Messrs. Dyckerhoff's in the south, might be cited as examples, publicly guaranteed a strength for slow-setting cement double that of the standard rules, viz., 20 kilogrammes per square centimètre, or 284·46 lbs. per square inch, with 3 parts of sand to 1 part of cement, at twenty-eight days. Thus it was evident that, although the materials from which their cements were made varied as much as they did in England, the results were as high in the one case as in the other.

In testing the tensile strength of Portland cement, it was pretty generally acknowledged that its cementitious strength could best be ascertained with a mixture of sand of a given degree of fineness, and in a proportion fixed by the German and Austrian Association at 3 to 1. Dr. Michaëlis, in his communication, recommended that the proportion should be 5 to 1, which might or might not be better, but would involve a corresponding alteration in the breaking weight, and would require the most careful manipulation of an expert to ensure uniform results. He also recommended the retention of the neat test at seven days as obligatory, and stated that if the cement showed a high strength neat it proved that the sample was highly burnt. He, however, deprecated the rejection of lightly-burnt cement, and stated that "no Portland cement was more reliable than one which gave good results, even when lightly burnt," though "when heavily burnt it would give a still higher strength with sand, and this strength would continue to increase for a long period." Such a cement, he acknowledged, "would undoubtedly be faultless."

It was agreed that the test with sand was the most important. This was proved beyond doubt by several of the Tables in the Appendix, which showed that the test of neat cement alone would lead to great errors, reduced no doubt, but not eliminated, by coupling with it the test of fineness. Still the neat test had its uses, and he had always retained it, though he no longer depended upon it.

To meet the difficulty, mentioned by Mr. White and others, of giving the time and space required for twenty-eight-day tests, one at seven days with 3 parts of sand, like that prescribed in the 6th of the Austrian rules, might be adopted, though it would not be nearly so trustworthy as the former. The strength required was, as already stated, 8 kilogrammes per square centimètre, equal to 113·78 lbs. per square inch. This, with that for fineness, might be adopted in cases where it was impossible to wait

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longer than a week; but in no case should the test with sand be omitted, nor that at seven days be preferred to twenty-eight days, wherever possible to wait the longer time. Reference had been made by Herr Grawitz to his having specified so low a test as 170 lbs. per square inch for 3 parts of standard sand with 1 part of cement after twenty-eight days. This, however, was as high as the Austrian standard (practically higher, as it was the average of ten, not of the six highest). His reason for not going higher was, that he had found he could make sure of getting cement of this strength in England; but if a much higher test had been specified, it might have been necessary to import the cement at an additional cost for freight and other charges, of from 33 to 50 per cent. It was as cheap, therefore, to use a greater quantity of cement at a less cost. There could be no doubt that the manufacturers of this country would produce cement of as high quality in every respect as any made elsewhere as soon as there was a greater demand for it. Mr. Grant.

At present manufacturers of cement objected that the market price was ruled by the quality ordinarily in demand, and that it did not pay to add to their grinding power merely to supply an occasional order. The cement used by architects for plastering and for ordinary buildings was not generally so strong as that required for engineering works. Colour was for plasterers of as much importance as strength. It was desirable, however, that some points should be agreed upon, if only tentatively. No doubt there was yet much to be learnt about cement. If, however, the cement manufacturers of this country were, like those of Germany, to take the initiative and agree upon certain rules, it would be greatly to the advantage not only of themselves, but of those who use their product. These rules need be neither numerous nor complicated, but they should be subject to revision and improvement from time to time. At their annual meetings the German manufacturers, about five-sixths of whom belonged to the Association, discussed suggested improvements, and the results had been highly beneficial to all concerned. Most of those in a large way of business went much above their normal standards, and the character of their cement not only secured their home market, but an increasing export trade. The Association wisely declined to ask for any protective duty.

As to the specific gravity of Portland cement, referred to by Mr. Faija and Mr. Mann, Table XLVII. had been extended so as to show the specific gravity of thirty or forty cements, as well as their weight and their tensile strength, both neat and with

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Mr. Grant.

sand. The specific gravity ranged from 3·193 to 3·040. He had not found that "the specific gravity in combination with the weight" gave an accurate measure of the value of the cement. He wished they did, as these two tests could easily be applied. Nor "that a heavy specific gravity and a heavy weight per bushel would indicate a finely-ground cement." For instance, No. 14 in the Table showed a specific gravity of 3·130, a weight of 9·52 lbs. per tenth of a bushel, and a fineness that left no residue on a sieve of 2,580 meshes to the square inch, and only 10 per cent. on that of 5,806 meshes. The specific gravity had evidently no relation to the degree of fineness, nor apparently to the tensile strength. If there were any, the Table in question would give materials to Mr. Mann for further investigating it. But it showed conspicuously that which was illustrated by several other Tables, how much the tensile strength of cement when mixed with sand was dependent on its fineness.

It was considered by Mr. Mann that "the expediency of bringing the time occupied in setting into specified or standard tests seemed doubtful, as cement could be made to set with any required degree of slowness by the simple process of air-slaking," and, he might have added, by other means. But the necessity for taking the time of setting into account had been increasingly recognised in Germany and Austria, both by the Associations and by eminent investigators. An examination of some of the Tables would illustrate this.

The useful remarks of Mr. Colson on the superiority of cement mortar, made with 4 to 6 parts of sand, to any lime mortar, were confirmed by Table XLIV. To remove the harshness in working with mortar made with such large proportions of sand, Messrs. Dyckerhoff found that it was advisable to mix a small proportion of fatty lime, which added to the strength and was preferable to fine sand or loam.

The experiments on the use of salt water by Mr. Cay seemed to answer Mr. Faija's questions. If Mr. Cay continued to specify the weight of cement, he should combine with it the degree of fineness, as the one without the other was illusory.

Before concluding, he wished to say that several of his Tables had been given more to illustrate certain steps taken in the course of his investigations than as the latest and best conclusions arrived at. It was one of the inevitable consequences of an inquiry extending over many years, that much of the work done in its earlier stages was rendered useless by later experiments and further experience. Still it might not be without interest, and might

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save labour to other inquirers, to study some of these earlier tentative results. He was, perhaps, more sensible than any one else could be of the incomplete character of his investigation; but as it had been begun and carried on for the strictly practical purpose of ascertaining what was best suited for the works on which he had been engaged, the results might be of some use to those who had a like object in view. Mr. Grant.

In pursuance of the notice on the card of the meetings, it was resolved to adjourn for a fortnight, in order to avoid holding a meeting on Whitsun Tuesday, May 18th.

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25 May, 1880.

WILLIAM HENRY BARLOW, F.R.S., President, in the Chair.

The following Associate Members have been transferred by the Council to the class of

Members.

ROBERT WILLIAM PEREGRINE BIRCH.
OSWALD BROWN.
THOMAS CHARLES CLARKE.
ROBERT JOSEPH HUTTON, B.A.
MICHAEL LONGRIDGE, M.A.

The following candidates have been admitted by the Council as

Students.

JAMES SAMUEL BUTLER.
THOMPSON BERNARD BYERS.
JOHN PERCEVAL HENDERSON DUNSMURE.
EVAN DAVIES JONES.
WILLIAM THOMAS MARTYN MEAR.
GEORGE JOHN MONSON.
BASIL MUNDAY.
JOSEPH EDWARD WILLCOX.

The following candidates were balloted for and duly elected as

Members.

JOHN SAMUEL CHORLTON.
ROBERT ALLEN CORDNER.
THOMAS JOSEPH.
ALEXANDER ROSS.
JAMES THORNELOE SMITH.
JOHN TIFFIN STEWART.

Associate Members.

CHARLES HAMLET COOPER, Stud. Inst. C.E.
HERBERT DORNING, Stud. Inst. C.E.
BERNARD WILLIAM FLATT, Stud. Inst. C.E.
THOMAS PERCY GUNYON, Stud. Inst. C.E.
WOODMAN HILL.
SYDNEY HOWNAM-MEEK.
HENRY JAMES ODDIE, Stud. Inst. C.E.
WILLIAM ALFRED HARRY DE PAPE.
HENRY JOHN SAUNDERS, Stud. Inst. C.E.
RICHARD JAMES HARRIS SAUNDERS.
HUGH HAMILTON SCOTT, Stud. Inst. C.E.

Associate.

Lieut.-Col. GEORGE EDWARD LANGHAM SOMERSET SANFORD, R.E.

The discussion upon the Papers on Portland Cement, by Major-General Scott and Mr. Redgrave, Mr. Bernays, and Mr. Grant, occupied the whole evening.

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23 June, 1880.

The Session was concluded by a Conversazione, which was given by the PRESIDENT and Mrs. BARLOW at the South Kensington Museum, by permission of the Lords of the Committee of Council on Education.

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SECT. II.—OTHER SELECTED PAPERS.

(Paper No. 1706.)

"The Practical Strength of Beams."

By BENJAMIN BAKER, M. Inst. C.E.

THE theory of transverse stress has engaged the attention of mathematicians for many years, and certain hypotheses have been, and still are, generally accepted, although every practical engineer knows that, in the majority of cases, the calculated results based upon these hypotheses are widely at variance with those obtained by experiment. Engineers, however, cannot afford to wait until a rational theory of transverse stress is agreed upon, and no doubt many engineers besides the Author have framed certain rules for their own guidance, which have given results agreeing with experiment, and otherwise answered their purpose as well as if an unassailable theory had been arrived at. A comparison of these practical rules can hardly fail to be useful, both to the scientific experimentalist who has leisure to make special tests to elucidate a theory, and to the engineer whose first object is to make sure that his structure possesses the required strength. The Author, therefore, proposes to illustrate, as briefly as possible, the method of calculation which he has found, during the past fifteen years, to give satisfactory results in the instance of many thousands of tons of beams of every variety of cross section.

Of all classes of iron and steel beams, rails hold the most important position; for not only do they outnumber all other descriptions of beams by hundreds of millions, but at least a thousand pieces of rails are tested to destruction, purposely and in actual work, for every single specimen of rolled joist or riveted girder. Rails, therefore, and at the present time steel rails, are entitled to first consideration, and the general applicability of the methods of calculation set forth will be subsequently tested by a comparison of the calculated and experimental results in the instance of other forms of beams and girders.

The experience gained from the tests of upwards of a hundred thousand tons of steel rails, has satisfied the Author that there

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could be no more fallacious way of comparing the merits of two sections of rail, as regards strength, than by taking a specimen of each at random and testing one against the other as a beam. As ordinarily manufactured the strength of steel varies so widely that by such a process it might be concluded that a 60-lbs. rail was as strong as an 84-lbs. rail, both being well designed sections and of a good quality of steel. A large number of specimens must be tested to obtain average results equally trustworthy with those which can be obtained by any unskilled person, in less than an hour, by the simple mechanical process of investigation set forth in this Paper.

Although the stress occurring upon a rail in actual work is a matter outside the limits of theoretical investigation, it has been conclusively demonstrated in practice that a certain transverse strength is desirable; and it is expedient, therefore, for the engineer in all cases to ascertain whether a proposed rail possesses that desirable strength or not.

On paper, the problem presented by a cross-sleeper road appears to be identical with that of a continuous girder bridge of seven or eight spans, and the late Mr. Heppel and many others have so treated it.[1] As a matter of fact this method is entirely wrong, both on theoretical and practical grounds. Theoretically so, because the rail rests upon elastic supports in the form of compressible wooden sleepers, and practically so, because of the uncertainty as regards packing of ballast and state of decay of the timber. The experiments of Baron von Weber, M. Inst. C.E., have shown[2] that an average wooden sleeper compresses about one-fifth of an inch under a pressure equivalent to the weight on a heavy driving wheel; and as an ordinary rail would deflect only that amount if the sleeper were entirely removed, and the rail supported by the adjoining ones, it will be seen at once how utterly misleading must be any conclusions based upon the hypothesis of rigid supports.

Probably the most correct hypothesis will be to look upon a rail in the same light as the distributing girder of a suspension bridge, since, within certain limits, the required strength will not be affected by the distance apart of the points of support or suspension. Take for illustration the common case of a flange rail, laid direct on a bridge floor, formed simply of 8-inch planks spanning the 14 or 15 feet space between the main girders. Here the deflection of the rail between any pair of the most heavily

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xix., p. 89.

[2] "Die Stabilität des Gefüges der Eisenbahn-Gleise," 1869.

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loaded wheels will be small compared to the deflection of the planking, so the rail acts as a true distributing girder with calculable strains. To distribute the weight, say, of a 45-ton six-wheeled tank engine having a 15-feet wheel base, with approximate uniformity over the planking, the rail must obviously be strong enough, as an imperfectly continuous beam of 7 feet 6 inches span, to carry a distributed load of at least 1 ton per lineal foot. Allowing one-half of the maximum reduction obtainable by perfect continuity, the maximum bending moment on the rail will be $\frac{5 \times 7{\cdot}5^2 \times 12''}{6 \times 8} = 70$ inch-tons—a stress which an 80-lbs. iron rail could very well sustain, as it would be about one-fourth of the breaking stress.

Having reference to the elasticity of the sleepers, imperfections in packing, and other contingencies, it is probable that the above case not unfairly represents the condition of a rail in an ordinary piece of permanent way; and it follows that, however close the sleepers be spaced, even to touching, the rail must have the stated transverse strength, or it will not distribute the weight over the ballast without itself being strained beyond the limits found advisable in wrought-iron structures subject to repeated bendings.

Again, practical contingencies as regards decayed sleepers, and bad ballasting, clearly indicate that the strength of the rail in a cross-sleeper road should be sufficient to carry the load without exceeding the limit of elasticity, even if one intermediate sleeper were wholly removed from under the rail. Allowing as before for imperfect continuity, it will be obvious that the distance apart of the sleepers must be something less than one-fourth of the wheel base of the before-mentioned 45-ton tank engine, or 3 feet 9 inches, or the stress would be double that occurring on the planked floor, and consequently reach the limit of elasticity. With the sleepers 3 feet apart, the 80-lbs. iron rail would not be permanently bent by the heavy engine, even if an intermediate sleeper failed, as in practice is often the case, to yield any support to the rail.

On the Metropolitan railway the average breaking weight of the original rail, when partly worn, would not be more than 16 tons, if one of the intermediate sleepers failed to support the rail. As the weight on the driving wheel is 8 tons, plus the amount due to oscillations and other contingencies in working, it follows that, under the latter conditions, the strain would pass the limit of elasticity, and that after repeated bendings, the rail would break through the holes in the bottom flange. This was found to happen in so large a number of instances as to indisputably establish the

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fact that the limit of elasticity was frequently passed, and that the repeated bendings under the five-minute train service broke the rails by tension at a point where, if the supports were only approximately rigid, compressive strains alone would occur.

There are sound theoretical grounds, therefore, for the conclusion long since arrived at in practice, that an 80-lbs. iron rail, with sleepers 3 feet apart, is the lightest permanent way which it is expedient to adopt for heavy traffic, if it is intended to avoid strains beyond the elastic limit, and the "bad top" so characteristic of not a few lightly-railed but heavily-sleepered American lines.

A steel rail on the average may be considered as about 50 per cent. stronger than an iron rail of the same section, and it was not unreasonably assumed at first that the introduction of steel would lead to the use of correspondingly lighter rails; but this has not proved to be the case in practice, probably for the following reasons: The effective strength of a rail is not its strength when new, but when worn, and as a steel rail is expected to become disabled only by fair wearing away of the head for $\frac{3}{4}$ inch, or even more, and not by crushing or lamination, it is necessary to compare the strength of the steel rail so worn with that of the less worn iron rail; and if this be done it will be found that a considerable call is ultimately made upon the increased strength of steel, though the rails when new be of the same weight. The reintroduction of the "bull-headed" rail of 1835 is both scientifically and practically right, because it provides a large area for wear in the head, and recognises the fact that the top and bottom tables of a rail are each subject to alternating tensile and compressive strains of equal intensity, and require therefore in the worn rail equal areas. A well proportioned bull-headed steel rail will lose at least 25 per cent. of its weight, and 25 per cent. of its strength before the top table is unduly worn; so, having reference to this fact, and to the great variation in the strength of the steel in rails, it would be clearly inexpedient to make the large reduction in weight, which superficial investigation might at first indicate, as a consequence of the substitution of steel for iron.

A consideration of the probable strains occurring in a rail is of great interest, as affording beyond all comparison the most important data for arriving at trustworthy conclusions in matters relating to the endurance of iron and steel under severe stresses. As already observed, no other class of beam includes a tithe of the number of examples, nor is any other description of beam subjected to the millions of repeated bendings, and instantaneous reversal of strains, that a rail undergoes in ordinary working.

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One consequence of the substitution of steel for iron in rails has been a greatly increased difference in the maximum and minimum strength of a given piece of permanent way. It is extremely difficult to ensure even a moderate degree of uniformity in the strength of the steel rails, manufactured from a given specification. In one lot of about 20,000 tons, rolled in three different works, the Author found in each instance that the tensile strength of rejected rails ranged at times from about 32 to 54 tons per square inch, though the average of the whole, judging from the tests, must have been within 5 per cent. of that aimed at by him, namely, 40 tons. Here there occurs a range of nearly 70 per cent., which is far greater than anything the Author has met with in the instance of iron rails. It is worthy of note that the recent exhaustive inquiry of the Pennsylvanian Railroad Company into the comparative endurance of rails of different degrees of hardness, has led to the specification of steel having as low a tensile strength as 29 tons per square inch. Steel rails of this description would be little more than 10 per cent. stronger than good iron rails of the same section, and considerable further experience is required before this great sacrifice of strength can be said to be justified. Where the pernicious plan of making holes in the flanges of rails is still in force, as it is on some Irish lines, the steel undoubtedly can hardly be too soft; and in such cases the Author aims at a mean tensile stress not exceeding 35 tons per square inch, in lieu of the 40 tons which he otherwise adopts.

Although the tensile strength and ultimate extension afford perfectly satisfactory evidence of the quality of steel in the form of rails, the necessary tests are inconvenient and costly in application. The rough-and-ready falling weight test is simple and effective, but it is not possible to deduce directly therefrom the strength and ductility of the steel. The lever test is next in order of simplicity, and the results thus obtained, when properly interpreted, do disclose those elements, as completely as if the cost and labour had been incurred of planing out strips and testing them under direct tensile stress. Some simple and trustworthy plan, of converting results obtained under transverse stress into the equivalent results under direct tensile stress, is thus a desideratum of no little practical importance; and the Author now submits the method which he has found satisfactory in the instance of many thousands of tons of rails of varied sections.

The average results of a very large number of experiments show that as regards deflection under transverse stress, a rail as a beam behaves exactly in accordance with the ordinarily accepted theory,

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with this important distinction, that the maximum deflection within the elastic limit is greater than theory would indicate, by an amount ranging from 5 to 50 per cent., according to the cross section of the rail. Experiments by Mr. W. H. Barlow,[1] F.R.S., President Inst. C.E., on other descriptions of beams would have indicated such a conclusion, and that the increase in the elastic deflection, as in the elastic and ultimate strength, must necessarily be included within the limits of 0 and 70 per cent., because the increase is nil in the instance of a steel-plate girder with a thin web, and averages 70 per cent. in a solid bar of rectangular cross section. In estimating the probable increase in the case of a beam, such as a rail having a cross section between these two extremes of girder and bar, the first impulse naturally would be to assume that it would approach the limit of 70 per cent. in the same proportion as the section of the rail approached the solid rectangular bar, that is to say, that the increase would be 70 per cent., multiplied by the sectional area of the rail, and divided by the area of the enclosing rectangle. This simple assumption the Author has found to be sufficiently near the truth for all practical purposes, as it leads to equally useful results when applied to a 5-inch flange rail—the widest now rolled—and to a bull-headed rail with a 2-inch bottom flange. Any great refinement in calculations of this sort is wholly unnecessary, for there is good reason to suppose that every cubic inch of steel in a rail differs somewhat in tensile strength from its neighbour, whilst internal tension and other elements further complicate results. All that can be attained, and all that is practically necessary, is a knowledge of the relative strengths of different cross sections of rail, and of the absolute strength of a given rail made of steel of a stated tensile strength, within a sufficiently small percentage of the actual results obtained, not in a few, but in a fairly large number of direct experiments.

Accepting the above hypothesis as to increased strength under transverse stress, it is only necessary to know the moment of resistance of the cross section of the rail as a girder, or the effective depth in inches multiplied by the effective flange area in square inches, to be enabled to convert results obtained under transverse stress into their equivalents in direct stress.

The required moment of resistance, and other information, are readily obtained mechanically as follows:—

(1st.) Cut a template of the rail out of a sheet of tin-plate or thin zinc, and also a strip 1 inch wide, and about 10 inches long.

[1] Phil. Trans. Royal Society, 1855–57.

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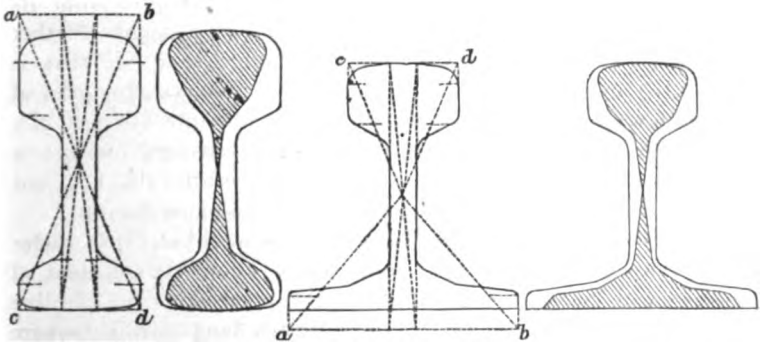
Place the template in one of a pair of letter scales, or cheap laboratory scales, and balance it by cutting a portion off the 1-inch-wide strip. The length so cut off will obviously give the area of the rail in square inches, and this multiplied by ten will be the weight in pounds per yard if of iron; if of steel, add from 2 to 3 per cent.

(2nd.) Balance the template flatwise on the point of a needle to obtain the centre of gravity and neutral axis of the given cross section.

(3rd.) Transfer the neutral axis so obtained to the drawing of the rail. In the bull-headed section this axis will of course be nearer the top than the bottom of the rail, in the flange section generally the reverse; in either instance set up, or set down, as the case may be, a horizontal line *a* to *b* at the same distance from the neutral axis as the part *c* to *d*. By a series of perpendicular lines, transfer the width of rail flange, thickness of web, &c., to the lines *a* to *b* and *c* to *d*, and draw lines radiating to the neutral axis, as shown on Figs. 1 and 3, the intersection of which, with the horizontal lines indicating the thickness of head and flange, &c., will at once give the boundaries of the areas of uniform stress, as shaded on Figs. 2 and 4.

(4th.) Cut templates of these figures out of tin-plate or zinc as

FIG. 1. FIG. 2. FIG. 3. FIG. 4.



before, place one in each scale-pan of the balance, and if correctly executed, the weight of the portion above the neutral axis will exactly balance that below. Put both templates into one pan, and balance them by cutting a portion off the 1-inch-wide strip, when the length so cut off divided by 2 will of course give the area of each template, or as it may be termed the effective flange area of the rail.

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(5th.) Balance each template on the point of a needle to obtain the centre of gravity. Transfer these centres to the drawing, and the distance between them will give the effective depth of the rail, which multiplied by the area will give the required moment of resistance. The latter may also be quickly obtained with a sufficient degree of accuracy by cutting the templates out of drawing-paper, and finding the centres of gravity as before by balancing, but calculating the areas instead of weighing the templates.

The moment of resistance so determined, will be the minimum moment applying to the lower portion of a bull-headed rail, and, generally, to the upper portion of a flange rail. The effective moment of resistance for the other half of the rail will obviously be greater, in the inverse ratio of the distances of the extreme fibres from the neutral axis, as exhibited in the application of the above method of calculation to the solution of the following problems respecting a bull-headed rail and a flange rail:—

(*a.*) A bull-headed rail, 5·6 inches deep, by 2·5 inches wide, weighing 82½ lbs. per yard, sustains an ultimate load of 35 tons applied at the centre of 60-inches bearings; required the equivalent direct tensile strength of the steel.

(*b.*) A flanged rail, 4·75 inches deep, by 4·75 inches wide, weighing 72½ lbs. per yard, is made of steel having a tensile resistance of 43 tons per square inch, and an elastic limit of 54 per cent.; required the weight applied at the centre of 60-inches bearings, which the rail will support without permanent set.

Dealing first with the bull-headed rail:—

(1) On weighing the zinc template of the rail the sectional area is found to be 8·05 square inches.

(2) On balancing the template on the point of a needle, the centre of gravity, or neutral axis, proves to be 2·57 inches from the head, and 3·03 inches from the bottom flange of the rail.

(3) The distance 3·03 inches being set up above the neutral axis, the figures of uniform stress are drawn, and templates in zinc prepared as already described.

(4) On weighing the two templates, their joint area is found to be 4·8 square inches, and the "effective flange area" therefore is 2·4 square inches.

(5) Balancing the templates on the point of a needle, the centre of gravity of the upper template proves to be 1·74 inch above the neutral axis, and of the lower template 2·31 inches below the same point. The "effective depth" consequently is 4·05 inches, and the moment of resistance M = 2·4 square inches × 4·05 inches = 9·7.

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The "apparent" tensile strain f, on the steel under the given load of 35 tons at the centre of 60-inches bearings will therefore be:—

$$f = \frac{35 \times 60''}{4 \times 9 \cdot 7} = 54 \text{ tons per square inch.}$$

The ratio of the rail to the enclosing rectangle is $\frac{8 \cdot 05 \text{ sq. in.}}{5 \cdot 6'' \times 2 \cdot 5''}$ $= 0 \cdot 57$, which, multiplied by 70 per cent., gives 40 per cent. as the probable difference between the "apparent" tensile strength developed under transverse stress, and the direct tensile strength of the steel of which the rail is made. Dividing the calculated 54 tons "apparent" strain by 1 + 40 per cent., the equivalent direct tensile strength $= \frac{54}{1 \cdot 4} = 38 \cdot 6$ tons per square inch.

Referring to Mr. Price Williams's Paper on the "Permanent Way of Railways,"[1] from which, for convenience of reference to the already published table of tests, the above example was taken, it will be found that in the four samples tested, the mean ultimate load at 60-inches bearings was 35 tons, and the mean direct tensile strength of the steel strips, cut out of the bottom flange, 39 tons per square inch.

The method advanced gives, therefore, satisfactory results as regards the bull-headed rail, and its applicability to the flange rail section will now be tested.

Proceeding with the 72½-lbs. flange rail in the same manner as with the 82½-lbs. bull-headed rail, the following data are as readily obtained:—

(1) Sectional area of rail = 7·1 square inches base.

(2) Centre of gravity = 2·5 inches from head, and 2·25 inches from flange.

(3) Effective flange area = 2·25 square inches.

(4) Centre of gravity of upper and lower areas = 1·75 inch and 1·85 inch respectively, from neutral axis. The "effective depth" therefrom = 3·6 inches, and the moment of resistance M = 8·1 in compression, and $8 \cdot 1 \times \frac{2 \cdot 5''}{2 \cdot 25} = 9$ in tension.

(5) Ratio of rail to enclosing rectangle $= \frac{7 \cdot 1 \text{ sq. in.}}{4 \cdot 75 \times 4 \cdot 75} = \cdot 31$; which multiplied by 70 per cent., gives 22 per cent. as the pro-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlvi., p. 188 *et seq.*

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bable increased strength in this instance, instead of 40 per cent. as in the bull-headed section.

The "apparent" tensile strength at the elastic limit, under transverse stress, with the given conditions of 43 tons ultimate direct tensile strength, and an elastic range of 54 per cent. will be 43 tons × 54 per cent. × (1 + 22 per cent.) = 28·4 tons per square inch; and the corresponding weight applied at the centre of 60-inches bearings required to produce an appreciable "set" will be, $W = \frac{4 \times 28{\cdot}4 \text{ tons} \times 9}{60 \text{ inches}} = 17{\cdot}04$ tons.

The mean result obtained by the Author in six experiments, on rails having the direct tensile strength of 43 tons per square inch, was 17·2 tons; and equivalent results were obtained with numerous other specimens having higher and lower tensile strengths.

The simple hypothesis, that the increase in the transverse strength of a flanged or double-headed steel rail, beyond what the ordinary theory would indicate, is equal to 70 per cent. multiplied by the ratio of the sectional area of the rail to the enclosing rectangle, thus proves true in the two preceding, as it has in hundreds of other, instances tested by the Author. In some recent examples, the bottom table of the rail is narrower than the top, the form of cross section approaching in fact to that of a ⊤ iron, and it is necessary to remark that the increase in such instances will be found equal to 70 per cent. multiplied by the ratio of the rectangle, formed by the width of the bottom table and the height of the rail, to the sectional area of the portion of rail enclosed in this rectangle. For a pure ⊤ section this of course would be equal to 70 per cent. multiplied by one, or, in other words, the increase would be the same as in a rectangular bar.

The following extreme case is selected for illustration of the practical sufficiency of the above empirical rule.

(c.) A built "channel" beam having a $6\frac{1}{4}$ inches × $\frac{3}{8}$ inch web plate, and two angles $2\frac{3}{4}$ inches × $2\frac{3}{4}$ inches × $\frac{5}{16}$, made of steel having a specified tensile strength of from 27 tons to 31 tons per square inch, is tested, web plate uppermost, at 3-feet bearings; required the weight applied at the centre which this beam would support without permanent set.

The elastic strength of the steel would probably range from about 15 tons per square inch to 10 per cent. above that amount. Cutting out a template of the beam in drawing paper, and suspending it, to find the centre of gravity, and otherwise proceeding as in the instance of the rails, the "effective depth" is

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found to be 2·1 inches, the "effective flange area" 0·76 inch, and the moment of resistance = 2·1 × 0·76 = 1·60.

A distinct permanent set in this instance, according to the theory advanced, would not be produced until the apparent tensile strain in the vertical webs of the angle-irons was equal to, from 15 tons × (1 + 70 per cent.) = 25·5 tons per square inch, to 10 per cent. above that, or 28 tons per square inch, which is not far from the ultimate direct tensile strength of the steel.

The equivalent load in cwts., (W) applied at the centre of 36-inches bearings, will be:—

$$W = \frac{25{\cdot}5 \text{ tons} \times 20 \times 1{\cdot}6 \times 4}{36''} = 90{\cdot}6 \text{ cwts.}$$

With an apparent strain of 28 tons per square inch the value of W would be 99·6 cwts.

The weight indicated by calculation as that which the described beam would support, without appreciable set, may thus fairly be stated as from 90 to 100 cwts.

Referring to the "rigidity tests" in Mr. Martell's Paper on "Steel for Ship-building,"[1] from which the above example was taken, the following will be found to be the results of direct experiment:—

Between 0 and 90 cwts. permanent set = ·00009 inch per cwt.
„ 90 „ 100 „ = ·00500 „

In this extreme case, therefore, calculation and experiment are in accord, as in both instances the required weight is found to be from 90 to 100 cwts.

In another experiment the angles were brought together back to back and riveted to the plate, thus making a built-up T beam, which was tested table downwards at 36-inches bearings, with the result as before of showing a practical accordance between the theoretical and actual elastic strength.

The former beam may be looked upon as an exaggerated example of a rail with no bottom flange, and the latter, as that of a rail with wide bottom flange and no head; hence it is no matter for surprise that the method of calculation advanced gives satisfactory results in the instance of rails of every variety of cross section met with in practice. An extension of the method to rolled joists, deck beams and built girders of every description is equally admissible, if it be clearly borne in mind that at stresses above the elastic limit

[1] Trans. Inst. Naval Architects, vol. xix., p. 20.

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a beam may, and often does, fail from local weakness before the resistance of the metal has been fairly developed.

From many hundreds of experiments on beams of every variety of cross section, the Author has been led to the conclusion that the elastic strength of a beam represents some 50 to 55 per cent. of the ultimate strength which will be developed, if the beam is free from local weakness. In the instance of rolled joists and built girders, the local weaknesses determining failure are generally narrowness of flange and thinness of web. A top flange may be made very narrow, if the bottom flange is wide and the web thick, as already instanced in the case of the inverted T-beam, and as will be further illustrated by the following example of an iron-flanged rail:—

(*d.*) A flanged rail 4·56 inches deep by 5 inches wide at the foot, and 2½ inches wide at the head, weighing 73 lbs. per yard, is made of iron having an ultimate tensile strength of 25 tons per square inch; required the ultimate strength at 48-inches bearings, assuming that the failure does not occur by the apparent local weakness of the relatively narrow top flange in compression.

Here the area of the rail = 7·3 square inches; the centre of gravity = 2·14 inches from the bottom, and 2·42 inches from the top; the "effective depth" = 3·61 inches; the "effective area" = 2·28 square inches; the moment of resistance in compression = 8·23, and in tension = 9·3; and the ratio of the area of the rail to the enclosing rectangle = 0·32. The ultimate direct tensile strength of 25 tons per square inch, would be increased to 25 tons × (1 + 0·32 × 70 per cent.) = 30·5 tons per square inch, under transverse stress; and the ultimate load (W) would thus be:—

$$W = \frac{9 \cdot 3 \times 30 \cdot 5 \times 4}{48} = 23 \cdot 6 \text{ tons.}$$

The preceding rail was one of a series tested for the Author, and was returned as having an elastic strength of 11·6 tons, and an ultimate strength, under a deflection of 3·38 inches in the 4-feet span, of 23·7 tons.

The "apparent" compressive strain upon the head of the rail under this load would be 34·5 tons per square inch, hence the fair ultimate strength of about double the elastic strength was fully developed, notwithstanding the narrowness of the top flange of this beam.

In the above case, the relatively great width of the bottom flange, and the thickness of the web, compensated for the narrowness of the top flange, or the result would have been very different,

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as will be seen from the following typical example of the behaviour of a rolled joist under transverse stress:—

(*e.*) A rolled joist 12 inches × $\frac{5}{8}$ inch × 6 inches × $\frac{7}{8}$ inch, weighing 56 lbs. per foot, is made of iron, having an ultimate tensile strength of 24 tons per square inch; required the elastic transverse strength at a span of 20 feet.

Here the area of joist = 16·8 square inches, the moment of resistance = 63·6, and the ratio of the area of the joist to the enclosing rectangle = 0·23. In the fibrous iron of which joists are made, the maximum increase is generally 60 instead of 70 per cent.; hence, taking the elastic tensile strength at 50 per cent. of the ultimate, or 12 tons per square inch, the "apparent" elastic tensile strength under transverse stress will be, 12 tons × (1 + 0·23 × 60 per cent.) = 13·7 tons per square inch, and the required load at the centre of 20-feet span will be:—

$$W = \frac{63{\cdot}6 \times 13{\cdot}7 \times 4}{20 \times 12} = 14{\cdot}5 \text{ tons.}$$

By direct experiment the load proved to be 14·7 tons at the elastic limit; but in this instance, owing to narrowness of flange, the full resisting power of the metal was never even approached, or the ultimate load supported would have been about double the above, or 29 tons, instead of the 19·2 tons actually obtained. In fact, owing to lateral weakness, the joint behaved as joists usually do, and failed by lateral flexure under a calculated unit strain only one-third greater than the strain at the elastic limit, instead of at, or about, double the latter, as in the instance of the iron rail, and other examples, where the full power of the metal was developed.

A beam may also fail through lateral flexure of the web, as instanced in the following examples of some riveted girders of the same span as the above, which the Author had manufactured to elucidate this and other disputed points:—

(*f.*) A riveted girder with a 24 inches × $\frac{1}{2}$ inch web, and with five 8 inches × $\frac{1}{2}$ inch plates, and two 3 inches × 3 inches × $\frac{1}{2}$ inch angle-irons in each flange, is made of iron having an ultimate tensile strength of 21 tons per square inch, and an elastic strength of 50 per cent.; required the weight which would be supported at the centre of 20-feet bearings without appreciable permanent set.

Here the moment of resistance in compression = 610, and in tension through the rivet holes = 432. Taking the mean of these = 521 as the effective moment in determining the point at which

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an appreciable set would occur—having reference to the fact of the plates being riveted, and not welded together, and for the latter reason also taking the increased strength under transverse stress as proportional to the minimum cross-section of the girder (where there is only one 8 inches × ½ inch plate in the flange) and the enclosing rectangle; then the 10·5 tons per square inch elastic strength will become $10{\cdot}5 \text{ tons} \times \left(1+\frac{25{\cdot}5 \text{ sq. in.} \times 60 \text{ per cent.}}{25'' \times 8''}\right)$ = 11·3 tons, and the required load will be

$$W = \frac{521 \times 11{\cdot}3 \times 4}{20 \times 12} = 98 \text{ tons};$$

which was the result obtained by the Author by direct experiment.

It is not contended, of course, that the correction for the increased strength under transverse stress is of any practical moment in the instance of ordinary riveted girders; but it is introduced here rather with a view of showing that the correction does not conflict with experimental results even in the extreme case cited.

(*g*.) A riveted girder identical with the preceding, with the exception that the bottom flange was made of eight 5½ inches × ½ inch plates, and two 2½ inches × 2½ inches × ½ inch angle-irons, was similarly tested at 20-feet bearings, and failed by distortion under a load of 102 tons; required the tensile and compressive strains under that load.

Here the moment of resistance in compression was 630, and in tension 450; hence the required unit strains will be—

$$\frac{102 \text{ tons} \times 20 \times 12}{630 \times 4} = 9{\cdot}7 \text{ tons per square inch compression;}$$

$$\frac{102 \text{ tons} \times 20 \times 12}{450 \times 4} = 13{\cdot}6 \quad \text{,,} \quad \text{,,} \quad \text{tension.}$$

The previous experiment (*f*) proved that the effective elastic strength of the flange in compression was at least as much as 9·7 tons per square inch, so this is a case in which failure occurred at, or below, the elastic limit, as far as the top flange was concerned. That the failure was not due primarily to the narrowness of the top flange is apparent at once, from the relatively high resistance of the joist at the same span, though the flange was narrower in the ratio of 6 inches to 8 inches.

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A tabulation of the results obtained in experiments (*d*), (*e*), (*g*), with some others, will render this still more apparent.

	Ratio of Span to Width.	Ultimate "Apparent" Compressive Strain.
d (iron rail) . . .	20	34·5 tons per square inch.
e („ joist) . . .	40	18·2 „
g („ girder) . .	30	9·7 „
h („ joist) . . .	48	17·9 „
i („ „) . . .	30	18·8 „

Experiment (*h*) refers to some joists 10 inches × 5 inches tested by the Author at 20-feet spans, and (*i*), to some joists 12 inches × 6 inches tested at 15-feet spans.

It is clear, therefore, that the failure of girder *g* was not due to narrowness of flange, but to the relative lightness of the web. The latter was much stiffer than usual, as it was ½ inch thick, in one length without joint, and stiffened every 5 feet with two 3 inches × 3 inches × ½ inch angle-irons and two 5 inches × ½ inch packing-strips under the same. Nevertheless, it did not suffice to maintain the rectangular connection of the several parts of the girder, and failure occurred by lateral flexure of the web at one end of the girder under a "shearing strain" of but 4½ tons per square inch.

This experiment is sufficient to enforce upon the attention of engineers the fact that width of flange is not necessarily an efficient substitute for rigidity in the connections of the main girders of a bridge. The Author in continental bridges has frequently employed flange-bars only 10 inches wide for lattice-girders of 66-feet span—a ratio of about 80 to 1; and in girders over 200-feet span he has been satisfied with a ratio of less than 110 to 1; but then the whole structure has been so rigidly connected together by gussets and bracing, that the top flange has had no more chance of evading its work than the head of the rail had in experiment (*d*).

Two sources of local weakness, namely, deficient lateral stiffness of flange, and want of rigidity in the web and its connections, have now been illustrated; but there are others existent which would no less vitiate the results deduced from any general theory of transverse stress, and of these the most important is the following.

The strength of a plate web, according to Professor Airy, M. Bresse, and nearly every other mathematician, is governed by the resistance of the web to the diagonal compression due to the shearing stress. This may be practically true in some few instances, but it was not so in that of the 24 inches × ½ inch web of

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girder *g*, or the shearing strain sustained would have been double the 4½ tons per square inch, which crippled the web; neither was it even approximately true in the instance of some girders with 3 feet 6 inches × ¼ inch webs, which the Author tested with the view of determining the real nature of the stresses in a plate girder as ordinarily constructed. These girders (*k*) were 31 feet 8 inches effective span, and the ¼ inch web was in five lengths of 6 feet 4 inches × 3 feet 6 inches plate, riveted together by T-iron stiffeners 5 inches × 4 inches × ⅜ inch, having stiffener-plates ¼ inch thick, and edge L-irons 2½ inches × 2½ inches × $\frac{5}{16}$ inch. The top flange was 20 inches wide by ½ inch, with edge L-irons 4 inches × 4 inches × ½ inch. The bottom flange was 20 inches × ¾ inch; and both top and bottom flanges were secured to the web by 4½ inches × 4½ × ½ inch L-irons. The effective area of the flange in tension was 19 square inches, and in compression 26 square inches; so that, having reference to the width of flange, in all probability, the girder tested to destruction would have failed by tension, unless the web first failed. The Author determined to test the elastic strength of the web of these girders. From previous experiments on similar girders with webs of double the thickness, he knew that, so far as the flanges were concerned, appreciable permanent set would not be exhibited until the tensile strain on the bottom flange exceeded 10 tons per square inch; and when, therefore, under a load of 70 tons, a slight set appeared, which at 75 tons had increased to more than $\frac{1}{16}$ inch, he knew that the set was wholly due to the web, because the unit strain on the flanges corresponding to the load of 75 tons was but 8·6 tons per square inch in tension and 6·25 tons in compression.

This load was applied opposite a stiffener, at a point distant 12 feet 8 inches and 19 feet from the respective abutments, and the maximum "shearing force," therefore, would be 45 tons, or at the rate of 4·3 tons per square inch on the gross section of the web. The resistance of the thin web to diagonal compression would be less than a third of this, so the strength was obviously not governed by the conditions laid down in the ordinary theory. The permanent set of $\frac{1}{16}$ inch could not be due to excessive compressive strains on the web, because the total deflection of the girder was far too small to permanently bend such an elastic long column as that constituted by the ¼-inch web. It could only be due, therefore, to the stretching of the web under the diagonal tensile strains; and the lines of greatest severity of strain from the bottom of one vertical stiffener to the tops of the adjoining ones were plainly marked by an apparent buckling of the web

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along those lines, when the girder was subjected to the stated load. From a careful consideration of the phenomena exhibited, the Author was led to the conclusion that at a point in the centre of the 6 feet 4 inches × 3 feet 6 inches web plate, where, by the ordinary theory, the diagonal strains would be about 4½ tons per square inch both in tension and compression, the strains were as a matter of fact about 11 or 12 tons in tension, and half a ton, or a ton in compression. Rankine has shown how little the change of form in a plate web conduces to the total deflection of a girder; and, for similar reasons, a set of $\frac{1}{16}$ inch from web strains indicates very clearly the severity of the strains.

The Author verified his experiments on the preceding girder by numerous others on five girders of equal size, but with varying proportions of flange and web, and obtained practically identical results. He also made models of the girders to scale, with wooden flanges and stiffeners, and paper webs. Testing these little girders to destruction, the lines of stress were indicated with conspicuous clearness; and the phenomena exhibited by the full-sized girders were exhibited also, in an exaggerated degree, by the models. Indeed, the latter experiments proved more suggestive than all the experiments on the iron girders, and all the mathematical investigations on the subject; and, after witnessing them, there was no difficulty in forming a clear idea of the nature and intensity of the strains occurring in a plate web as ordinarily constructed.

The local weakness in the preceding girders, which would have determined failure before the full strength of the flanges had been developed, was again thinness of web. In the three cases cited—the rolled joist, the 24 inches girder, and the 3 feet 6 inches girder—the strengthening of the locally weak portions would be a subject rather for practical experience than theoretical investigation. Many such cases are met with in practice, the minimum strength which must be provided in the bracing of the struts of lattice-girders being one such. So far as plate webs of medium size are concerned, the Author is of opinion that the general conditions laid down by Mr. Chanute in his specifications for the Erie Railroad bridges, meet all the requirements indicated by experiment, and he cites these in preference to his own practice as being independently deduced. These are, that the "shearing strain" shall not exceed half that allowed in tension on the bottom flange of a riveted girder, and that when the least thickness of the web is less than $\frac{1}{80}$ of the depth of the girder, the web shall be stiffened at intervals not over twice the depth of the girder.

If judgment be exercised in the design of girders so as to avoid

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local weaknesses, then, according to the Author's experience, the method of investigation which has been found to give trustworthy results in the instance of iron and steel rails will give equally trustworthy results in the instance of every other description of iron and steel beam.

The anomalies presented by beams of different cross sections, as regards strength, do not extend to their deflections except that, as already stated, the elastic range is increased.

The elastic deflection (δ) of a beam of any type, but of uniform cross section, of the depth (d) and span (s), will for a central load be given by the following equation :—

$$\delta = \frac{s^2 f \mathrm{E}}{6d},$$

when f is the mean of the "apparent" maximum tensile and compressive strains upon the metal in tons per square inch, and E, the modulus of elasticity expressed by the extension or compression, in terms of the length, for each ton per square inch strain. For a uniform load, the divisor will become $\frac{24}{5}$, instead of 6; and for a girder of uniform depth and uniform strain per square inch, however loaded, the divisor will be 4.

The value of E varies considerably, even in the same length of rail or plate; but, as the result of many experiments, the Author adopts the following average values :—

For iron beams, E = ·000085 to ·00010.
For steel beams, E = ·000075 to ·00009.

At working strains the value approximates more nearly to the smaller, and at strains near the elastic limit to the larger figures.

In the case of built girders, the calculated and experimental results compare best when the depth d is taken between the flanges, and not from outside to outside; and where the web is thin the value of E may be taken at ·00012. Although the Author has on several occasions tested built girders beyond the elastic limit, without detecting the slightest movement of rivets and plates, it is only reasonable to conclude that the riveted structure must be a trifle less rigid than a solid beam.

The variation in the value of the modulus is a matter which has not yet received sufficient consideration from engineers. In built girders the practical effect of this variation no doubt is, that whilst a uniform strain, say of 5 tons per square inch, is assumed to be acting on the flange, the real strain on the several plates may

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range almost from 4 tons to 6 tons per square inch. Mr. Bender, and other American engineers, have found the moduli of eye bars to vary considerably with the cross-section;[1] and other experiments also indicate the advisability of building up the flanges of girders with plates of uniform size, as well as quality.

Although, on the average, a steel rail or beam will be found stiffer than an iron one of the same cross-section, this will not be true of every individual specimen. Thus, in some recent experiments, conducted for the Author by Professor Kennedy, M. Inst. C.E., the moduli determined with great exactness for one piece of steel, and two pieces of iron rail of the same cross-section proved at low strains to be respectively ·000086, ·000078, and ·000089.

Frequent reference has been made to the terms "elastic limit" and "permanent set;" and it is necessary to explain what is understood by those expressions in the present Paper.

If deflections or extensions be noted in a microscopic manner, permanent set will be apparent under comparatively low strains; but if the sets are plotted as ordinates to a curve, it will be found that, at a certain point more or less defined, the curve sharpens in radius, and in some cases diverges almost at right angles. The occurrence of this curve of course marks the attainment of the elastic limit; but different observers would only by chance agree as to the exact point of commencement, and hence the differences which often arise as to the elastic limit. In the case of hardened steel the curvature is very gentle; in that of soft iron, a sudden flow of metal often makes the bend almost rectangular. In cases where there is doubt as to the fair position of the limit, the Author draws tangents to the deflection curve at points corresponding respectively to, say 40 per cent. and 60 per cent. of the estimated ultimate load, and takes the intersection of those tangents as marking the position. Except in the case of hardened steel, the elastic resistance considered in this broad practical sense will be generally found, both in iron and steel, to be equal to from 50 to 55 per cent. of the ultimate tensile resistance of the material.

In conclusion, the Author would remark that the experiments detailed in this Paper are but unselected samples of many hundreds, in which the same accord between calculated and experimental results is exhibited.

A word of caution is necessary to students; firstly, that differences of 4 or 5 per cent. between calculated and experimental

[1] Trans. American Society of Civil Engineers, vol. v. (1876), p. 147. "Continuous Girders," by C. Bender.

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results are suggestive of nothing, because different pieces of rail rolled from the same bloom or ingot exhibit that variation; and secondly, that in investigations of this sort it is absolutely essential to reject all tests made by unskilled persons. A single example will suffice: an iron rail which the Author calculated would exhibit an elastic strength at 5-feet bearings of 9·5 tons, and a practical ultimate strength of about 19 tons, was returned, firstly by the manufacturers, and afterwards by the Author's inspector, as exhibiting the strength and deflection set forth in the first line of the following Table, whereas the true experimental results were those given in the second line:—

Deflection . Inches	¼	1¼	2¼	3	4	4⅝
Weight in tons . .	14	24	34	40	43	48
	9·3	14·7	16·0	16·8	17·6	19·0

The results of the first line were confirmed by further experiments after the attention of the manufacturers and inspector had been called to the matter, and they adhered to their returns in perfect good faith.

By following the method of calculation indicated in this Paper, the Author, during the past fifteen years, has found no difficulty in specifying the strength which a rail should exhibit under the lever test, when made of steel or iron of the desired tensile strength; and much time and labour have been saved in dispensing with the planing out and testing of pieces under direct pull.

At the same time it is a practical convenience to be enabled to specify with exactness the tests for a new and untried section of rail. Thus, a few months ago (the fact is worthy of record for more reasons than one), a contractor offered to substitute steel for iron, without extra charge, in some 5,000 tons of flange rails he was delivering; and, as the rails had holes in the flanges, the Author especially desired to secure steel of uniform and relatively soft quality. He specified, therefore, that the rails, when loaded with a weight of 20 tons at the centre of 3 feet 6 inches span, should exhibit a permanent set not less than $\frac{1}{32}$ inch, nor more than $\frac{8}{32}$ inch. The test was arrived at as follows: the moment of resistance of the 70-lbs. rail was 8·75; the ratio of increased tensile strength under transverse stress 1·22; and, as the desired maximum direct tensile strength of the steel was 37 tons, with an

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elastic limit of 53 per cent., the maximum elastic transverse strength, at 42-inches bearings, would be:—

$$\frac{37 \text{ tons} \times 1{\cdot}22 \times 53 \text{ per cent.} \times 8{\cdot}75 \times 4}{42 \text{ inches}} = 19{\cdot}9 \text{ tons.}$$

A set of at least $\frac{1}{32}$ inch under a load of 20 tons would, therefore, ensure the steel being not more than 37 tons per square inch in tensile strength. But it was also necessary to define a test for the lower limit of its strength, fixed at 33 tons per square inch. Under the load of 20 tons the strain upon steel of this strength would be the following percentage of the ultimate strength:—

$$\frac{20 \text{ tons} \times 42 \text{ inches}}{33 \text{ tons} \times 1{\cdot}22 \times 8{\cdot}75 \times 4} = 60 \text{ per cent.}$$

Now the Author knew from previous experiments that, within certain limits, a rail at 42-inches bearings takes a set of about $\frac{1}{32}$ inch for each 1 per cent. strain beyond the elastic limit; hence, as the elastic limit in the above instance is assumed to be at 53 per cent., the set at 60 per cent. would be about $\frac{7}{32}$ inch, or say $\frac{1}{4}$ inch. The specified sets of $\frac{1}{32}$ inch to $\frac{1}{4}$ inch would, therefore, correspond to steel having a direct tensile strength not less than 33 tons, nor more than 37 tons. It only remains to add, that the rails as manufactured complied with these tests, and that the direct tensile strength of a strip planed from the bottom flange of one of the stiffest specimens was 36·7 tons per square inch.

As regards the possibility of substituting for the practical experience now indispensable in a designer, a general theory of transverse strength, universally applicable and wholly satisfactory from a scientific point of view, the Author is not at all sanguine. A careful observation of the behaviour of structures of every class under stress has satisfied him that sooner or later, in every instance, a stage in the investigation is arrived at where the general theory becomes valueless, and even dangerous, except in the hands of the experienced engineer. At the same time the purport of this Paper will be entirely misconceived if it is understood to reflect in any way upon the importance of direct experiment and strict mathematical investigation, of the value of which no one can be more alive than the Author.

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(*Paper No. 1650.*)

"Earthwork Slips in the Cuttings and Embankments of various Railways, with their causes and modes of treatment."[1]

By JOHN BARRET SQUIRE, Assoc. Inst. C.E.

DURING the construction of the Meltham Branch Railway, near Huddersfield, between 1867 and 1869, several serious slips had to be contended with.

The first of these worthy of notice was in the embankment at Dungeon Wood (Plate 9, Fig. 1). Where the mischief occurred the embankment was 44 feet high at the centre line, but the ground sloped towards the turnpike road, and further to a small river, at an average inclination of 1 in 3. No apprehension was, however, felt by those in charge of the works that a slip would occur, as the side-long ground was apparently of a rocky nature, and the material to be tipped consisted chiefly of loose rag rock from the neighbouring cutting. The embankment was scarcely completed, however, before a considerable settlement was observed, attended by serious consequences. The turnpike road skirting the hillside at a much lower level began to move, both laterally and downwards; a row of cottages near the place soon became untenable; a toll-bar close upon the point most affected was wrecked as by an earthquake; and the ground below the road shifted, rolled up, and at one time threatened to block up the river. The prevailing opinion as to the immediate cause of the damage was, at the time, that a lodgment of water between the railway and the road had been disturbed by the railway embankment. To ascertain if this was the case, a heading was driven from the river into the hillside, under the road; but although a considerable quantity of water

[1] Endeavours have been made for some time to obtain a complete Paper on "The Causes of Slips in Rocks and in different Earths, and the conditions that induce treacherous ground in railway-cuttings, tunnels, and the sides of valleys near reservoir-banks." Having so far failed in this respect, the next step taken was to collect the particulars of such isolated examples as might form the basis of a fuller Paper hereafter. It was hoped that other brief communications beyond those included in the present series might have been received, but in this too there has been disappointment.—SEC. INST. C.E., Sept. 1880.

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was met with, there was nothing like sufficient to justify this opinion. Fig. 1 shows what the Author believed to be the cause, viz., that the alluvial deposit, receiving the great weight of the railway embankment upon its wedge-shaped form, became detached, and slipped down upon the face of the rock. The railway embankment was little worse, and was made good with more material; the cottages were pulled down, the toll-bar was erected at another place, the road eased down to its altered level, and the fence walls were rebuilt.

The next slip of importance was within ½ mile of the above, in a deep cutting, and was attended with still more serious consequences (Plate 9, Fig. 2). It had, moreover, this difference from the foregoing, that the cause was apparent. The cutting was about 55 feet deep at the centre line, but in such side-long ground that, whereas the slope on the lower side only measured about 38 feet, on the higher side it measured 175 feet. The excavation on the lower side was almost entirely in shale, but on the higher side it was in shale only for about 20 feet above the formation level, all above that being in loosely bedded sandstone rock, dipping at an angle of about 30° from the horizontal, in the same direction as the slope of the hill. The consequence was, that the cutting had not long been completed before the shale began to perish by exposure to the weather, and the rock above it tumbled in. This action, it was afterwards discovered, was still further promoted by the shale extending under the rock, in a sort of dish. Thousands of tons of rock would fall in a night, portions of which were thrown into the valley for hundreds of yards, causing great consternation in the whole district. A mansion adjacent was considered unsafe to live in, its windows being smashed, the whole structure shaken, and much other damage done to the grounds, so that the owner was compelled at an early stage to remove his establishment. To effect a remedy, a retaining wall, with raking counterforts, was erected, covering the shale and supporting the rock. This wall was 12 feet thick at the bottom, and 4 feet thick at the top, about 60 feet in height, and 10 or 12 chains in length; its foundations were begun about 10 feet below the formation level of the railway; it was built of rubble masonry from rock found in the slip, and together with the counterforts contained about 17,000 cubic yards of material, and was spoken of as the largest retaining wall in England. The putting in of the foundations was attended with great difficulty, but was continued night and day, several reliable men being stationed at prominent points at all times to watch the hillside, to give alarm

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if they saw it breaking. The work was accomplished, however, without serious accident, and has proved a great success.

Another troublesome piece of work upon this railway was the construction of the Netherton tunnel; it was 345 yards long, built for a single line, upon an inclination of 1 in 95, and was 67 feet in the soffit below the surface at the deepest point. The difficulties arose from a misconception of the material to be cut through, and consequently, to some extent, insufficient timbering; but beyond this the strata proved loose and treacherous, and were heavily weighted with some old buildings on the top, so that several subsidences occurred, which necessitated the section of the tunnel being altered. (Plate 9, Fig. 3.)

The slips experienced on the Shawforth Branch Railway, near Rochdale, between 1869 and 1871, were both numerous and heavy. Some parts of the earthwork were a mixture of rock, clay, and sand; and in two or three cases, in the district of Broadley, running sand was encountered in short deep cuttings.

The worst instance of quicksands occurred in the cutting known as No. 11, about 10 chains in length, and for the greater part about 50 feet in depth (Plate 9, Fig. 4). It was intended that the slopes should be left at about 1 to 1, but so far from this, when the cutting came to be finished, no part of it was able to stand at a less inclination than 2 to 1, and a great deal of it had to be laid down to 3 or 4 to 1. In order to do this effectually, and considering the depth of the cutting, inclined roads were run up the slopes on benchings; even this did not overcome all the trouble, for during heavy rain, shortly after the branch was opened, a stream of water and quicksand suddenly burst out of the cutting, washing over the permanent way, and with considerable difficulty was prevented from putting a stop to the traffic. A row of piles was finally driven along the foot of the slope at this point, for 3 or 4 chains in length, about 15 feet in depth, braced together with walings at the formation level, cross cut about 2 feet higher, and a dry rubble drain, about 1 yard square, was inserted at the back of them.

A good deal of the material out of the above cutting was used for the embankment across the Roche valley, where, together with other contributory matters, it caused heavy slips (Plate 9, Fig. 5). The first part of the embankment was down an inclination of 1 in 95, 12 chains in length, commencing with a depth of about 16 feet, and terminating with a depth of about 45 feet, where it joined the Roche viaduct—a brick structure of eighteen arches, which at

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one time it threatened to overthrow. It was when the tipping reached about half-way down this incline that the most alarming symptoms were manifested. The material, as described above, was loose and soft in the cutting; this was made much worse by a journey of 2½ miles in wagons, so that when it came to be discharged over a tip about 35 feet in height, it spread out in all directions, ploughing and rolling up the whole surface of the ground in front. During a time when over two hundred wagons a day were being tipped, equal to 500 cubic yards of material, the tippers were known to have worked for more than a month off one pair of rails, without getting a yard advanced with the head of the tip. The earthwork operations were therefore for a time suspended; the viaduct, which was nearly completed, was re-centred, and supported with raking struts between each pier, in the direction of thrust from the bank; a considerable portion of the old surface was stripped, and a number of drains inserted in the slopes. After a short time a temporary bridge was erected to connect the tip-head with the top of the viaduct, and the dirt was conveyed to the other end of it, to counterbalance the pressure. Here again to some extent the same difficulty occurred, the tipping having to commence with a perpendicular drop of about 45 feet, which converted a good deal of the dirt into slurry, which spread about in the same manner as at the other end; in this case, however, it was an up-hill tip of 1 in 70, upon rising ground, so that level-tipping, aided by entrenchments, soon reduced the height and secured a footing. The other part of the bank was afterwards made good with better material, and the weak portions were supported by upright rubble drains, about every 20 or 30 feet apart, with relieving arches turned upon the slope in some cases, to connect them and support the formation level.

A troublesome piece of work through slips was the excavation of a sunk approach accommodation road alongside the railway near Shawclough (Plate 9, Fig. 6). The excessive quantity of dirt which slipped in, to the proportion first excavated, was due to the soft nature of the material. In this case, the slips were cleaned out to the solid ground; several dry rubble drains were inserted in hollow places, and a small retaining wall was built at the foot of the slope, with plenty of weep-holes through it; after which the slope was re-trimmed to an inclination of 2 to 1, and it has since stood very well.

A curious spectacle is presented within ¼ mile of the above place, as the result of a slip, in the existence of a twin bridge under the railway. At this point a short embankment had to be formed

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along a piece of side-long ground, with a reservoir and some mills at the foot of it; the greatest depth at the centre line was about 22 feet. In this place a bridge was built for a footpath and bridle-road; the embankment was made up to the bridge on each side, and the road laid over it; but during wet weather soon afterwards, a great part of the hillside began to slide down, blocking up a portion of the reservoir, and causing great alarm to the inhabitants of the valley lest the reservoir should in turn burst its banks. This, fortunately, did not follow, but the site of the embankment and bridge—the greater part of the former, and the low wings of the latter having been carried away with the slip—was considered unsafe for building upon, and the railway was accordingly diverted, by means of some sharper curves, nearer to the side of the hill; and the abutments of the old bridge seeming to remain solid, it was considered the best support that could be obtained for the new one, which was built alongside, and the wings of the two bridges were connected. (Plate 9, Fig. 7.)

The slips on the Ashby and Nuneaton Railway, between 1871 and 1873, were not of such great proportions individually, nor did they possess the same special points of interest as the foregoing; but they were numerous and disheartening, particularly on the southern portion, where at one time they extended over several miles.

One of the most serious cases of damage resulting from them was at the Sutton Lane bridge, near Shenton (Plate 9, Fig. 8). It was for a public road under the railway, at a depth of 25 feet. The material tipped on each side of the bridge was soft clay, which stood very well during the summer, but the first wet weather caused it to slip out into the fields, and to throw all the four wing walls of the bridge, more or less, into the road. These were rebuilt with counterforts behind them, and the dirt carefully replaced in position; but either the backing up was done while the brickwork was too green, or the provision made was insufficient, for in a short time another more serious collapse took place, which left little of the bridge standing save the bare abutments, and completely severed the connection of the railway above. New wings were then built, a timbered trench being driven in each case at the back of the wings up to each abutment corner; additional counterforts were inserted, the wings themselves were thickened and lengthened, and a thick lining of dry rubble was packed over the back of them. These measures proved efficacious, and the bank was made good with dry material.

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A large stream bridge under No. 20 embankment, at a depth of 30 feet, was on one occasion completely buried by the sudden collapse of the bank during a stormy night, and before it could be dug out, to let the water through, a considerable flood had occurred on the higher side, and much damage done to the adjoining lands. This bridge had to be lengthened twice, and was opened out and strengthened from end to end, while the embankment was resting upon it.

A number of embanked approaches for public roads, in the neighbourhood of Stoke-Golding and Hinckley (all formed of soft brown clay, which, though tenacious when fresh, crumbled and fell away when exposed for a while) were especially troublesome. In several cases, before they could be got to stand, almost the whole of the dirt had to be turned over on the adjoining land, burnt into brick rubbish, and put back again. This was an effectual, although expensive remedy, the cost of the conversion being equal to three times the original cost; in other cases not so bad, part of the dirt was burned and put back in trenches.

One great cause of the slips in the cuttings was the land drains, and although these were generally provided for by heading drains on the high side of the cuttings, with the field drains carefully puddled into them, a considerable quantity of water would follow the old course. The consequence was, that many of the cuttings, when finished and the slips cleared away, presented the appearance of a series of dishes or scallops all along the slope; the centre of each dish was generally then connected by a dry rubble drain with the side drain of the cutting, and gave little trouble afterwards.

In the embankments, where the slips were entirely the result of the soft and perishing clay, it was found best to allow the material to reach its natural slope, and then to run up to the formation level, at every ½ chain, rubble drains about 1 yard in width, and varying in depth to reach the bottom of the slurry. These drains were connected at the foot with another dry rubble drain, running parallel to the embankment to the nearest outlet, sometimes assisted by an earthenware pipe under the rubble to act as a carrier.

The Chatburn and Hellifield Railway, between 1874 and 1876, was subjected to few slips of importance, only two being worthy of mention.

The first slip was in an embankment crossing the valley of Stankhill Beck, at a height of about 50 feet above the stream. The material tipped was boulder clay, which, at a height of 30

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feet, began to roll away, and become unmanageable. Three deep drains were then cut, about 2 yards wide upon the surface of the ground, where the deep bank was to come, one along the centre line, and one at the foot of each slope, and they were filled with boulders picked out of the clay. The drains were connected at every chain by similar drains in a diagonal direction, from the centre to the sides, and an outlet was provided for the three main drains into the brook. An incline was also run down the side of the embankment, from the cutting, and the tipping was recommenced at a height of 15 or 20 feet above the surface, which was all covered over, first at this false level, the proper height being brought up afterwards. These precautions were successful in preventing further trouble.

The other case was No. 11 cutting, near Stock Beck, Gisburn. This cutting was supposed to be in rock, and the slopes were specified to be ½ to 1. That portion, however, which should have stood at this inclination, proved to be alternate beds of shale and rock, which, on the higher side of the cutting, dipped at such an angle that the slope had to be laid down almost to 2 to 1 before it could be considered safe.

On the West Lancashire Railway, from 1876 to 1878, the only difficulties experienced under the heading of slips were in keeping open the side drains in a cutting close to Southport; and the subsidence of some peat lands.

In the former case the material was sand, and the water had to be pumped out of the cutting, pending the completion of a permanent sewer, which was to take it away by gravitation. The consequence was that, during heavy rain, the water washed away the sand at the foot of the slopes, and occasionally gave rise to a slip; but this material was mostly of a restorable nature, and the evil was soon remedied.

In the latter case, the railway for 2 or 3 miles crossed some heavy peat lands, mostly undrained, and ditches were cut, of considerable size, on each side of the railway, to drain the formation. However, not only did they drain it, but to some extent they closed in again, and the site of the railway became depressed in level. This was remedied by bringing sand from Southport, which proved a good antidote to the wet peat.

The result of the foregoing experience has been to give the Author the following impressions:—

That the majority of slips which occur upon railways is the

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result of false economy, largely practised by engineers, in curtailing the angle of slope, so as to reduce the quantities of earthwork; the consequence often being, that the slip costs ten times as much to rectify as the extra excavation would have done to ensure safety.

That much greater care should be taken to ascertain the nature of the material to be dealt with, before commencing excavations, or engineering works depending upon them.

That no embankment of clay, or other loose material, should be tipped at one level, from a greater height than 20 feet, and in cases of soft clay than 15 feet; also that all cuttings of similar material, of great depths, should be taken out at two or three levels where practicable, as the case may require.

That no cutting, side ditch, or open ditch alongside a bank, should be made of such width, angle, or depth, as to trespass upon a line produced from the slope above.

That all waterways under deep embankments should be large enough for a man to creep through and inspect, however insignificant the stream; and a moderate margin allowed in their length.

That an embankment should always be tipped full width, with a little allowance for trimming down, rather than that any material should be added to the sides afterwards.

That tipping soft material in bad weather should always be avoided if possible, especially clay with intermediate layers of snow, which has caused many serious slips.

That heading drains for cuttings, soil stripping, draining the seats of embankments, and benching upon side-long ground, cannot be too carefully attended to, and amply repay the trouble and expense laid out upon them.

And that great care should be taken in applying stereotyped plans, and standard sections, to cases requiring special provision, from the fact of their peculiar position and surrounding circumstances.

The communication is accompanied by several drawings, from which Plate 9 has been prepared.

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(*Paper No. 1739.*)

"Earthwork Slips on the Castle Eden and Stockton Railway."

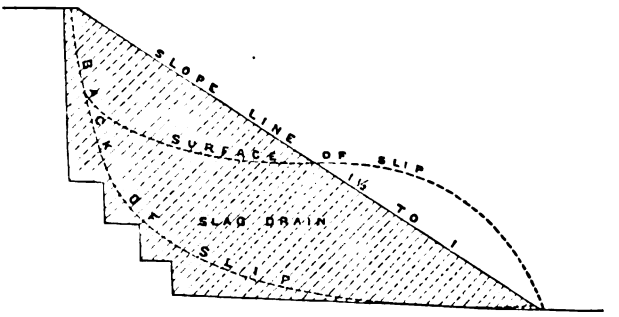
By Henry Michell Whitley, Assoc. M. Inst. C.E., F.G.S.

The Castle Eden and Stockton branch of the North Eastern Railway runs entirely through the boulder clay, and caused considerable trouble during its construction, by the occurrence of frequent slips both in cuttings and embankments. The clay, although so tough and tenacious as to give the utmost difficulty in excavation, after a short exposure, became soft and pasty, in the winter often jolting down to "slurry" in the course of its transit from the gullet to the bank-head.

The most troublesome cutting was that of the Leeds Northern Railway. The Castle Eden and Stockton line crosses over the former branch about ½ mile from its southern termination at Bowesfield Junction, and in consequence of the gradients not allowing full head-room, it was necessary to lower the Leeds Northern line about 6 feet at this spot. The lowering extended east and west about ¼ mile in each direction throughout the greater portion of the cutting, which was 12 to 15 feet deep, until it regained the original level. In order to avoid taking additional land, the existing slopes were cut down vertically at the toe, and a retaining wall was built to sustain them; but during the progress of the work through the winter the slopes began to slip, thrusting over portions of the walls, until at last nearly the whole cutting was on the move from end to end.

The slips came away in the form shown in Fig. 1, dropping

Fig. 1.



vertically at the top and lifting at the toe of the slope. The plan adopted to remedy this state of things was the insertion, in the slopes of the cutting, of deep drains 1 foot below the seat of

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the slip, and stepped at the back. These drains were at right angles to the line, 2 feet 6 inches to 3 feet in width, and on the average about 20 feet apart. There being no available stone in the district, they were filled with slag from the iron furnaces in the neighbourhood. The retaining wall at the toe of the slope was increased in thickness, counterforts were added, and a bed of slag 1 foot thick was packed behind, whilst the hollows in the slopes were filled up with ashes. These measures were successful, and the cutting, from being one of the most troublesome on the line, is now one of the best.

This system, omitting the retaining walls, was adopted in nearly all the numerous slips over the whole length of the line, the distance apart, and the number of the drains, being regulated by the magnitude of the slip. In all cases the drains were carried below the seat of the disturbance; this was essential, the attempt to drain deep clay slips by shallow trenches filled in with sleepers, &c., being in the majority of cases useless. In some instances the slag was as much as 30 feet below the slope line, and the slip extending below formation level, pipes were required to take the water away. The displaced lower portion of the slope was removed, and all above filled in with ashes, soiled, and made good.

Although in nearly every case this plan was adopted, in some instances another method was tried. The slip was trenched deeply, and the clay thrown up in mounds, mixed with fine coal and burnt, until the whole of the disturbed portion had been so treated, when it was thrown back into position, levelled, soiled and sown. Where coal is cheap this plan may be adopted with advantage; the handling of the wet clay during winter is, however, troublesome. The expenditure varying with the degree of saturation of the clay renders it scarcely possible to make a comparison of cost between the two methods, but in the cases named the former was found to be slightly the cheaper mode of draining the slopes.

The slips were not confined to the cuttings, the embankments, especially during winter, being a constant source of trouble. The clay jolted down to "slurry" in the tip wagons, and each winter's progress in a heavy bank was marked by the occurrence of considerable slips in that portion. In these cases the work could only be carried on with a single road, until the slip was passed, the additional weight adding to the mischief, and sending the bank far beyond the company's fencing. When dry weather set in again the whole of these slips were made up with ashes, until the road stood firm; the slip was then trimmed to shape, and the fencing carried across it.

Swampy ground increased considerably the difficulties in the

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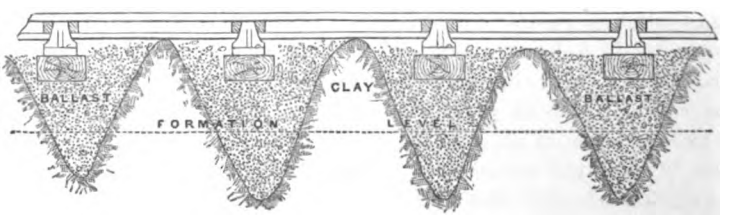
construction of the line. A peat bog, 16 feet deep and 4 chains long, near Hurwurth Burn, was dug out to the width of the formation, and the full depth, before the advancing tip, and gave no trouble after the bank was carried across it. But ¼ mile north of this spot, where an embankment of 25 feet in its highest part and 31 chains long was carried over a marsh, the most serious disturbance on the line occurred. The weight of the bank squeezed out the soil under it, raising on both sides a mound as high as the formation level; whilst an old culvert, laid at a depth of 15 or 20 feet below the surface, was lifted bodily, displaced, and some of the bricks were thrown up on the top of the slip. The appearance of the advancing tip was most singular, driving before it a rolling mound of peat as high as itself, which in its progress bore along trees, fences, and whatever else stood in the way. The bank itself went down to the firm ground, and was about 40 feet high. It was completed with ashes in the same manner as had been adopted for other slips, and the rails for many months sunk vertically often as much as 6 feet in a single night. After the bank had ceased to settle, the slip was trimmed and soiled in the usual manner. The finished slopes of both cuttings and embankments throughout the line were 1½ to 1.

Through such boulder clay, which was softened so rapidly by exposure, it was to be expected that the maintenance after the opening of the line for traffic would give much trouble, and this was the case. The formation was 30 feet wide, with a slope of 6 inches to the sides; the ballast consisted of broken slag, coke ashes, and gravel; the permanent way was laid with cross sleepers 3 feet 1 inch apart, and 2 feet 7 inches at the joints, with an 82-lb. rail carried on 40-lb. chairs. The thickness of the ballast under the sleepers was 10 inches, and, although the formation was hard and satisfactory before the road was laid, after twelve months' heavy traffic in some bad cuttings it presented the appearance

FIG. 2.



shown in Fig. 2, the clay rising up through the ballast to the surface between the sleepers, whilst under them in some cases

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there was a depth of as much as 4 feet of ballast. The only mode of remedying this state of things was by deep-draining the formation. A 12-inch pipe was carried up on each side of the cutting, its crown being 12 inches below the under side of the sleepers, with broken slag over it, and the clay taken out between the sleepers, and extra ballast filled in.

In heavy clay cuttings of this description, it would be desirable to carry out this mode of drainage before the permanent road is laid down, and also to allow an extra depth of ballast under the sleepers, if they will have to sustain a heavy traffic.

The Author's conclusions are as follow:—

1. That slopes of $1\frac{1}{2}$ to 1 will stand with care in cuttings through boulder clay, and in embankments up to 25 feet in height, but in higher banks a slope of 2 to 1 should be adopted.

2. That banks should be tipped full height and full width with three roads for a double line, unless in wet weather, when a slip has formed; the greater weight then only increases the mischief, and a single tip should be adopted to get past the slip, and the bank be afterwards made up with ashes or light material to its finished dimensions.

3. In some cases with bad material, and in wet weather, it may be expedient to form the bank in two lifts.

4. It is mostly impossible to stop work altogether during unfavourable weather. When tipping is resumed after a heavy snowfall, the snow should be swept away from the bank head, otherwise a slip will probably result.

5. No peat should be used under any pressure of want of materials in the formation of banks.

6. When slips have fully developed, the surface water should not be allowed to form pools, and sink into the soil, aggravating the mischief by further saturation.

7. Side drains should always be cut to divert the surface water before the excavations are begun.

8. In draining slips the drains should go below the seat of the moved clay; all shallow drains are, as a rule, useless.

9. Field drains, when not cut by the side ditch, should be conveyed down the slopes in pipes carefully jointed, and not by rubble drains; when many field drains are met with, and the cutting is wet, it will be advisable to cut them off from the formation by a pipe drain running along the railway fencing.

10. Barrel culverts are safest under heavy clay banks; they should be carried out to the foot of the slope, and the bank trimmed forward over them, thus allowing space for a slight slip. The

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wing walls should be at right angles to the centre line, and not parallel to it; and if the bank consists of bad materials, it is not advisable to build the spandrils and wings until the road stands firm.

11. Centres cannot be kept in too long when a bank is tipped over a bridge on to rapidly falling ground liable to move; if possible, they should be kept in until the banks meet, if the valley to be crossed is short.

12. Great care should be taken in the backing up of all bridges, retaining, and wing walls. In over-bridges the wings should be filled in with ashes, rubble, or other dry materials, and no clay should be used under any circumstances. In under-bridges a layer of 3 feet of rubble, ashes, or other dry material, should be placed behind the wings.

13. When a heavy embankment comes against the abutment of a viaduct, and a slip against it is probable, the abutment may be finished off with a "cutwater," or angle of 90°, at the back, instead of the flat end, thus relieving the pressure.

14. Bore-holes are desirable, especially when the line runs through a treacherous country; they should be taken at every 4 or 5 chains in all cuttings and embankments, and at the site of all viaducts, bridges, and heavy culverts.

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(*Paper No. 1744.*)

"Earthwork Slips on the Leeds and Wetherby Branch Railway."

By HAROLD COPPERTHWAITE, M. Inst. C.E.

THE Leeds and Wetherby branch of the North-Eastern Railway was commenced in 1871 and completed in 1876. In its construction the only important work was the excavation through the Scarcroft Hill, near Thorner. It had been originally intended to tunnel through this hill, but finally an open cutting was decided upon. The profile of the cutting is shown by the cross sections Figs. 1 and 2. The slopes were intended to be 2 inches to the foot up to the top of the rock, then a cess of 5 feet on the east side of the cutting, and of 7 feet on the west side, as the strata dipped from the west towards the east with a slope of about 1 in 30. Above the rock, the slope of the clay and shale was intended to be 1½ to 1. The longitudinal section (Fig. 3), shows the stratification of the cutting. The section is as follows:—

10 feet of marl.
2 „ broken shell bearing limestone.
35 to 37 feet of argillaceous yellow clay.
3 „ 5 „ strong limestone.
2 „ 4 „ black shale, like coal.
3 „ 4 „ sandstone.
5 „ 6 „ strong shale.
1 foot of sandstone.
Or about 66 feet in thickness altogether.

During the progress of the work no unusual difficulty was experienced, and after the railway had been opened for traffic, nothing worthy of comment occurred until the 21st of February, 1878, when, shortly after a train had passed, a large quantity of shale and clay suddenly slid down and partially filled the gullet, a mass of nearly 3,000 cubic yards having fallen in a few moments. The shape and extent of this slip is shown by the cross section Fig. 1. A large gang of men were soon at work, both night and day, and in sixteen days the traffic was resumed. At this time nothing was done to the slopes, except dressing them over and relieving the top weight; but the treacherous character of the material

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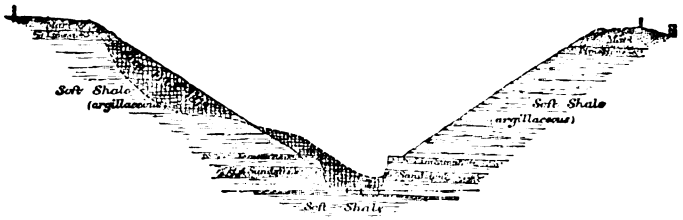
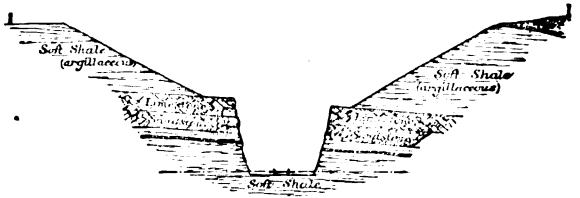
FIG. 1.



Cross Section, No. 1.

FIG. 2.



Cross Section, No. 2.

FIG. 3.

Longitudinal Section.

Scale for Figs. 1 and 2—about 1 in 1,100.
„ Fig. 3 „ 1 in 4,000.

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having been shown, a careful inspection was made daily, in order to have early knowledge of any "set" in the shale.

On the 10th of May another slip took place, but this time on the opposite side of the line; the quantity of shale in motion was small, and no delay to the traffic took place.

Again, on the 2nd of September, 1878, a slip occurred on the west side of the cutting, bringing down a huge mass into the gullet, and completely stopping the traffic on the railway until the 18th, during which period the passenger trains were brought up to each end of the cutting, and the passengers walked over the hill. Previous to this, however, or shortly after the slip of the 10th of May, it was decided to burn the shale down to the bottom of the slip, and with this object fires were lit on each side of the cutting, near the road bridge, and the shale was excavated and thrown back on the fires; when once fairly kindled, the shale burnt freely, and now formed a strong hard bank.

The *modus operandi* was as follows:—A narrow grip was cut from the level of the rock at the top of the gullet to the top of the slope, and the material excavated was removed and tipped to spoil. This grip was dug down to the bottom of the slip, and large fires being lighted in the bottom, the shale and clay were thrown back, and as the material became thoroughly burnt, the slopes were dressed to an angle of 1 to $1\frac{3}{4}$.

The peculiarity of these slips consists in the fact that they gave little or no warning. There is no reason to suppose that the men on duty neglected to make proper inspection, and yet they were as much taken by surprise as other people when a slip occurred.

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(*Paper No. 1741.*)

"The Seven Stones Light Vessel."

By JAMES NICHOLAS DOUGLASS, M. Inst. C.E.

THE "Seven Stones" are a cluster of dangerous rocks lying between Scilly and the Land's End, with only small portions uncovered at low water. They are exposed to the full fury of the Atlantic; therefore the difficulty of erecting a lighthouse thereon, although not impossible, would, doubtless, prove a tedious undertaking, and its cost be very considerable. In 1841 a light vessel was moored at a distance of about 1½ mile to the eastward of the rocks, in 42 fathoms, and, as may be supposed from her exposed position, is subject to heavy seas during westerly gales. Her moorings consist of a 40-cwt. mushroom anchor and 315 fathoms of 1½-inch unstudded chain cable. Until 1879 two fixed catoptric lights were exhibited from the vessel on separate masts, 20 and 38 feet above the sea. In 1871 the vessel was provided with a "Holmes" fog trumpet, worked by a 1½ HP. "Ericsson" caloric engine. In 1878 the Trinity House determined to improve the form and efficiency of the vessel, as well as the illuminating and fog-signal apparatus. The vessel (Plate 10), which was specially designed by Mr. Bernard Waymouth, Secretary to Lloyd's, is timber built, copper-fastened throughout, sheathed with Muntz metal, and of the following dimensions, viz.: length, 103 feet between perpendiculars; extreme breadth, 21 feet 3 inches; depth of hold, from the strake next the timbers to the upper side of the upper deck beams, 10 feet 3 inches. In the event of the vessel breaking adrift (a most improbable occurrence), she is provided with foresail, lug mainsail, and mizzen, the latter being frequently used with advantage for steadying the vessel at her moorings. The improvement effected in the illuminating apparatus consists in the adoption of a more powerful form of light, of the catoptric group-flashing-light class, for giving three flashes in quick succession at intervals of one minute. This distinction of light was first adopted by the Trinity House on board the light vessel at the "Royal Sovereign" shoal, near Beachy Head, in 1875. The apparatus consists of nine gim-balled Argand lamps and paraboloidal reflectors, of silvered copper, 21 inches in diameter. The lamps and reflectors are arranged on a turntable in the lantern, in three groups of three each, and are

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caused to rotate by clockwork at a speed of one revolution per minute. The intensity of the flashes from this light is equal to about 8,600 standard candles, and about 7½ times the intensity of the old fixed lights, with only three-eighths the consumption of oil. The lantern is cylindrical, 8 feet in diameter, constructed of wrought iron, and glazed with curved plate glass. It is fitted with doors fore and aft, for access from chain ladders suspended from the mast, and is large enough for the proper manipulation of the lamps during the night, without the necessity of lowering. The clockwork for driving the apparatus is fixed in the deck house, and is driven by a pitch chain and weights descending in a trunk to the keelson. The motion is transmitted from the clockwork to the catoptric apparatus by a light vertical shaft fixed on the aft side of the mast. The clockwork is provided with a centrifugal governor, by which the period of the flashes of the light are regulated during all states of the weather. In the day the lantern is lowered on to the roof of the deck house. The siren fog signal is arranged for giving three blasts in quick succession at intervals of two minutes. It consists of a "Holmes" self-acting cylindrical siren and vertical iron trumpet, the latter being arranged to rotate on its axis, and thus capable of being set, on all occasions of wind accompanying fog, with its mouth to the windward. The motive power consists of a pair of Brown's caloric engines, each of 5 effective HP., arranged for working singly or together. The engines are fitted with air pumps for supplying two compressed-air vessels, from which the siren is sounded at a pressure of 40 lbs. per square inch. The blasts of the siren are regulated by cams worked from the engines. The fuel consumed is locomotive coke, and the consumption is 18 lbs. per hour per engine. The "Harfield" windlass is fitted with a pair of cylinders and slide gear for working it, when required, with compressed air. This arrangement is found to be of great assistance to the crew, as with every opportunity of fine weather the cable has to be hove short for examination. The cost of the vessel, fully equipped for sea, with illuminating and fog-signal apparatus complete, was about £9,500.

The communication is accompanied by a tracing, from which Plate 10 has been engraved.

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(*Students' Paper No. 115.*)

"Small Motive Power."[1]

By HENRY SELBY HELE SHAW, Stud. Inst. C.E.

THE introduction of small motors has been very extensive of late years, and is still increasing. The object of this Paper is to consider in a brief but systematic manner the present state of the subject in this country, in order that a comparison may be formed of the relative advantages of the various agents now in use. In order to do this at all satisfactorily, an outline at least must be given of the modes of applying these agents for the purpose, and also the uses to which the motors themselves are put; so that, after a few preliminary definitions and remarks, the following method has been adopted:—

(I.) The working agents are classified, and the causes of loss by the transformation of energy on a small scale are briefly considered.

(II.) The agents are taken in order, and the types of apparatus for applying them are dealt with and classified, and their efficiency examined.

(III.) Finally, the relative advantages of the agents are considered, with reference to the various objects for which they are applied.

It is difficult to define exactly what is meant by Small Motive Power. Whether the size of the motor, the work performed in a given time, or the object for which it is applied be taken for reference, the difficulty of assigning an exact numerical limit exists, such a limit being after all quite arbitrary; for instance, a very small engine, driven at a considerable velocity by high-pressure steam, might develop as much power as an ordinary water-wheel, or a much larger engine, under different conditions; but though the term in question would include the first, it would

[1] This communication was read and discussed at a meeting of the Students on the 9th of April, 1880, and was awarded the Miller Scholarship in the Session 1879–80.

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commonly be held to exclude the two last; therefore, it will be interpreted as generally received by engineers, and will be taken to exclude locomotives and marine engines, factory and mill motors, but to embrace the large number of engines for what may be called auxiliary purposes, which are being made more and more to supersede muscular energy.

The only direct sources of power at present used for small motors are fuel and a natural head of water, fuel including every kind of substance which by chemical action, rapid or slow, develops kinetic or actual energy. No source of power can be utilized without some loss of energy, and the "efficiency" of the apparatus used is the exact numerical value of the ratio of the useful work produced by it to the energy expended upon it by means of the working substance or agent; this quantity is therefore always some fraction less than unity. Before the final application of energy takes place, it may undergo a number of transformations by means of various agents, two or more being often employed in the case of small motors; as, for instance, when steam power is used to produce an artificial head of water or a current of electricity, which latter may produce work; but since the resultant efficiency is the product of the fractions representing that of each intermediate piece of apparatus, the final advantage to be gained must be balanced against the loss necessarily entailed by the use of each extra agent.

The same source of power may be applied to impart energy to motors by various agents and in different ways, and in order to avoid confusion, in stating the efficiency of an agent, the source of power should also be stated; thus, taking gas as the source of power in the gas-engine, and coal in the steam-engine, the result of comparing these agents is very different to that obtained by taking coal as the source in both cases, and introducing as a factor in the former case the efficiency of the gas-making apparatus.

The extent to which an agent is to be used may have much to do with determining its suitability for any purpose, and may considerably modify its application; indeed the choice of the agent may depend on very different considerations, according as it is to be used on a large or a small scale. The importance of this will be shown hereafter, and leads to the agents applicable for use with small motors being more numerous than with large ones.

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Section I.

The agents may be thus classified:—

Steam	. . . . .	Heat engines.
Gas	Coal	
	Petroleum, &c. .	
Air	Heated . . .	
	Compressed	(*a*)
Water	Natural head.	
	Artificial head	(*a*)
Electricity	By direct chemical action.	
	By dynamo-electric machine . . .	(*a*)

The agents classed under "heat engines" form the most important portion, and will be to a certain extent treated of together, a heat engine being regarded simply as an apparatus by which the action of heat is caused to expand the agent, and thus to do work. Those marked (*a*) (*a*) (*a*) may be regarded as merely transmittors of energy, and acting in the secondary way already referred to; the respective efficiencies of two of these, and also of steam, for this purpose, have been dealt with in a Paper by Mr. Robinson,[1] M. Inst. C.E., from which Paper it appears that water stands the highest, but the loss of head varying inversely as the 5th power of the diameter of the transmitting pipe, would cause its utility to diminish rapidly with the size of the motor. It is only recently that electricity has been much thought of for this purpose, or at any rate has been practically applied, and that agent is treated in Section II. almost entirely with reference to this object.

Before proceeding to examine the efficiencies of the agents separately, it will be well to point out the losses of different kinds attending the transformation of energy, which are common to all. These take place—

(1.) In dissipation, caused by the tendency of the agent to lose the energy imparted to it by communicating it to surrounding bodies, as, for instance, by conduction and radiation in the case of heat, and by leakage with a head of water.

(2.) In the necessary rejection of energy due to the conditions of working.

(3.) In the mechanical arrangements, in connection with which there are two principal losses, the one by friction, which is unavoidable, but may be reduced to a minimum by judicious design, the other by an improper supply of the agent, which supply may be either insufficient or excessive; in the former case the friction of the working parts absorbs an increasing proportion of the energy

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlix., p. 1.

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expended; in the latter the velocity of the motor increases, until the resistances, both useful and prejudicial, are equal to the power applied to overcome them.

As already stated, heat engines are most important among small motors, the use of gas and hot air being almost entirely applied to operations on a small scale; therefore it seems appropriate to deal in this place with the losses common to them.

The first cause of loss, viz., by conduction and radiation, is proportionately greater for small than for large engines, not only from the fact that the heated agent is generally contained and conveyed in cylindrical vessels and pipes, in which the volume varies as the square of, but the surface only directly as, the diameter, and thus the radiation is proportionately greater, but loss by leakage and imperfect lagging is also generally greater; furthermore, the loss of heat in its transference from the fuel to the agent is greater, for, as will be shown by the results of experiments, the conditions of economical combustion are harder to maintain. Both these sources of loss may, however, be considerably modified by mechanical arrangements.

The second cause of loss, from the necessary rejection of heat, is often overlooked. There is not space to examine the question as fully as it deserves, but the conclusion to be drawn is that the agent should be used between as great ranges of temperature as practicable. This is an important point in discussing their relative efficiency, and since the proportionate range for hot air is greater than for steam or gas, the efficiency of the former in this particular is the higher; but at the same time this very quality renders it less capable of developing so much power, since only small differences of pressure accompany this range, which is limited by practical considerations, such as lubrication, packing, &c. There is, however, another and a more obvious way of regarding the action of these agents so as to compare their efficiencies: the heat rejected in the waste steam or gas has to be entirely restored to the new portion of the agent, by the expenditure of fuel, while in the air engine this is partly effected by compression in the return stroke; and so, though the loss of fuel is not so great in the air engine, the high back-pressure resulting from compression makes the resultant work also not so great, and leads to the conclusion, which is verified in practice, that air engines are not so powerful as steam or gas engines, though more economical.

The higher the initial temperature of the agent the greater will be its possible efficiency, for the lower limit cannot at the

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best differ much from the temperature of surrounding bodies, but the upper is only limited by mechanical difficulties; and though it may be shown that it is impossible to abstract all the imparted heat in the form of work, the proportion of heat so abstracted being in fact never greater than one-seventh in the best steam engines of the day, yet the efforts made in this direction must be attended with success in proportion as those difficulties are overcome. In the discussion which followed the reading of Mr. Flannery's Paper[1] on high-pressure steam boilers these difficulties seem to have formed the only ground of objection to their use. Pressures of from 300 to 500 lbs. per square inch have been successfully used by Mr. Perkins, and the application of high pressures and speeds is greatly increasing for small steam engines.

The third cause of loss, viz., that from friction and imperfection of machinery, has a special interest from the high speeds now used in some small engines. It may be regarded as certain that the proportionate loss from these causes is greater on a small than on a large scale; but, again, the proportionate waste of fuel is nearly always of less consequence. From the recently issued first reports on "Friction at High Speeds," of the Institution of Mechanical Engineers, it would appear that, at any rate up to the velocities at present used, the friction seems slightly to decrease as the velocity increases.

Section II.—Steam.

Steam engines are at present by far the most extensively used of small motors, some on a very small scale being made to develop considerable power.

The generation of steam on a small scale is almost entirely limited to vertical boilers—at any rate, for purposes on land—though the horizontal form, as well as sectional boilers, are also coming into more general use, the portability of the first being a strong recommendation. Figs. 1, 2 and 3 (Plate 11) are sections of vertical boilers in common use, the general form being a cylindrical wrought-iron shell containing a furnace, also cylindrical and concentric with it, and fired through an opening in one side. In other particulars there is considerable difference. In Fig. 1, which, though extensively used, is deservedly falling into disfavour, the gases pass upward to the funnel through a number of vertical tubes, either a cast-iron top or an enlarged crown being necessary to allow their escape to the funnel; this latter device is shown in

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. liv., p. 123.

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the figure, and also an ingenious arrangement for preventing the earlier destruction of the central tubes by the tendency of the flames to ascend through them, which is especially the case when the fire is low. This consists of a concave wrought-iron plate (D), by whose under side the gases are reflected and are compelled to ascend round its edge, where combustion of some portion of them takes place, and the side of the furnace is acted on by the flame instead of by the current of cold air, which otherwise would be drawn up and be in contact with it. Fig. 2 is a still more common form, the gases passing up a central flue; but there are a considerable number of different devices for robbing them of their heat before this takes place; the oldest and most usual is that of the cross tubes *c*, *c*, whose section is, however, generally circular; these have the advantage of adding to the strength of the furnace; the furnace, besides being subjected to external pressure, is the vulnerable part in the, by no means uncommon, event of shortness of water. Another plan is to have pendent tubes *p*, *p*, *p*, of which the "Field" type is a good example, as it allows a complete circulation of water by separating the ascending and descending columns, by an inserted tube shown in the diagram. The success of this plan is shown from the fact that no less than 134,700 are now in use. Another good device is applied in the "Davy-Paxman" boiler (Fig. 4), in which the tubes, instead of ending in the furnace, pass down and communicate with the water in the lower part of the boiler, and so establish complete circulation, which is prevented from acting too violently by bafflers placed at their upper ends. These and various other arrangements, though adding to the complication of the boiler, are very desirable if effective in action, for the loss of heat in them, which experiments indicate, is thereby much diminished. Thus the boiler of Latham and Bradley, 10 feet high and 4 feet in diameter, has 132 square feet of heating surface. Fig. 3 is an excellent design known as the "Talbot," which presents considerable heating surface; the furnace is of cast iron, which in a recent modification is lined with firebrick, and the ash-box acts as a water-heater. These boilers have given good results in practice, and the advantage of a non-tubulous boiler with large heating surface is realised by those who have experienced the cost and trouble which tubes often entail. Fig. 5 is a view of an ordinary sectional boiler, and it will be seen that the amount of heating surface exposed must cause it to be a rapid steam generator. The arrangement *a*, *a*, *a* of firebrick and the iron plates *b*, *b*, *b* divert the flames, and compel them to pass well round the tubes, after

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which they escape by the flue *c*. A portion of the steam space is shown at *d*. Another form of sectional boiler may be briefly described as a square box of tubes, which run from side to side in two directions, and through which the flames are made to pass successively. Yet another form, which is used in America, consists of a series of cast-iron spheres with necks, which are faced, and so connection is made by means of long bolts. The advantages of sectional boilers are summarised in the Paper of Mr. Flannery,[1] where there is also a quotation from the third report of the Admiralty on the subject. There are a large number of inventions of both vertical and sectional boilers, but the foregoing examples are typical of the forms generally used. A small vertical boiler commonly has the engine attached to it, and forms its support; this may be effected by bolting the engine either to its side, or by means of a cast-iron bed-plate or a wrought-iron ring securing it upon its top. Portability is thus secured, and the evils arising from alternate expansion and contraction of the boiler, which would be felt in a large engine, are not in this case appreciable, chiefly because when used on a small scale the engine is only connected with a fixed external object by a belt or bearing at a little distance from it; but it has been remarked that with small marine engines, where the case is different, the objection is considerable. One excellent example of the latter method is afforded by the design shown in Fig. 3, in which the cylinder is let into the boiler, and, besides the benefit of short steam connections, a perfect steam jacket is formed.

The efficiency of small boilers is a most important thing to consider, and, so largely are they at present in use in conjunction with small engines, that it would be impossible to form a satisfactory comparison between small motors without some reliable data on the subject. Now the Paper of Mr. Flannery indicates a high efficiency for sectional boilers, but these are not used to anything like the same extent as the vertical form; and on turning to different sources for information, the Author was unable to obtain independent results. For instance, in the comprehensive manual of Mr. D. K. Clark,[2] M. Inst. C.E., although boilers of marine, locomotive, stationary, and portable engines are fully treated, yet the class in question is not mentioned; and the ratio of heating surface to grate area and other conditions are so different in these latter, that no comparison can fairly be drawn. This

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. liv., p. 128.

[2] A manual of "Rules, Tables, and Data for Mechanical Engineers." Blackie and Son.

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information being required, and also data concerning the working of small steam engines of the ordinary type, through the kindness of Mr. Fry, Managing Director of the Bristol Wagon Works, and of Mr. Arrowsmith, Steam Printing Works, Bristol, two series of experiments were made upon a 2-HP. vertical engine and boiler, manufactured by Dodman, of King's Lynn, belonging to the former, and a 4-HP. horizontal engine called the Soho, and a vertical boiler made by Tangye, of Birmingham, belonging to the latter. The data now given will refer only to the boilers, that of the engines being introduced hereafter. During the two days' trial of the former, which will be called No. 1, and one day's trial of the latter, No. 2, the difficulty was experienced of keeping uniform the quantity of water and the pressure of steam; but during a run of three hours on No. 1, and of four hours with No. 2, by careful stoking and attention, and by taking observations every quarter of an hour—of revolutions, pressure of steam, and supply of feeding water,—a close approximation to regularity was obtained. Both the dynamometer and the indicator were used, and the quantity of feed-water and coals carefully weighed, and, as will be shown in No. 2, the volumes of steam used agreed fairly well with the volume of the cylinder and ports obtained by actually filling these spaces with water afterwards, so that little, if any, priming could have taken place in No. 2, while in No. 1 the difference must not be overlooked, and the boiler efficiency in this case can only be approximate. No. 1 was of the form shown in Fig. 1, and was well lagged all over; No. 2 was of the form represented in Fig. 2, but was deficient in heating surface, having no pendent tubes and but one cross tube, circular in section.

TABLE of RESULTS of EXPERIMENTS on SMALL VERTICAL BOILERS.

Boiler.	Height.	External Diameter.	Number of Tubes.	Diameter of Tubes.	Length of Tube.	Diameter of Furnace.	Area of Grate in Sq. Ft.	Height of Furnace in Feet.	Heating Surface in sq. ft.	Ratio of Heating Surface to Grate Area.	Mean pressure on Boiler in lbs. per Sq. Inch.	Water Evaporated per Hour in lbs.	Coal used in lbs.	Evaporation in lbs. of Water per lb. of coal from 100° F.	Efficiency of Boiler.
	Ft. In.	Ft. In.		In.	Ft. In.			Ft. In.							
No. 1.	4 6	2 6	7	2½	2 2	..	1¾	1 9½	21·2	12·0	51·5	121	36⅔	3·3	0·26
No. 2.	5 4	2 6	1	8	2 0	..	3½	3 0	26·8	8·54	32·0	170	34½	4·9	0·39

The feed-water was warmed to about 100° Fahrenheit. The coal used with No. 1 was Parkfield; an analysis, with which the Author

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was kindly furnished by Mr. Handel Cossham, shows 82 per cent. of carbon, 5·6 per cent. of hydrogen, and 6·1 per cent. of oxygen, and has a heating power of 14·3 lbs. of water, at 212° Fahrenheit, converted into steam; so that, theoretically, the evaporation should have been from 100° Fahrenheit, about 12·5, instead of 3·3. ∴ Efficiency $= \frac{3 \cdot 3}{12 \cdot 5} = 0 \cdot 26$. With No. 2 the evaporation should have been about the same, making its efficiency = 0·39. Thus, although the ratio of heating surface of No. 2 was considerably less than No. 1, the evaporative power was greater, which seems only to be accounted for by the fact that most of the heating surface of the latter was vertical. If the average evaporative power of large boilers from 100° Fahrenheit for this kind of coal be taken at 0·65, it is seen how much inferior these small boilers are to larger ones, although from what has been said it is seen that these boilers are being superseded by more efficient ones, with larger heating surface, as Latham's and Bradley's, which, though little larger than No. 2, has five times as much heating surface, and the Field, of which there are 1,380 in use; but the introduction of more heating surface by tubes, &c., offers a larger surface for corrosion and leakage, and therefore involves more repairs; and the general conclusion is that the necessity for small boilers is the weak point in the use of steam on a small scale.

There are four ways of using steam on a small scale, which seem to lead to the following classification:—

(1.) Single-acting engines using high pressures and speeds.
(2.) Double-acting engines using moderate pressures and speeds.
(3.) Rotary engines.
(4.) Apparatus for causing the pressure or impulse of steam on fluid surfaces to directly raise or force that fluid.

The first three are always non-condensing engines; the last kind can hardly be called engines, being apparatus of the injector or pulsometer type; but as they are used principally as a substitute for other kinds of steam pumps, or manual operations, they must certainly be considered as included by the term Small Motive Power. Thus it may be said that all small steam engines are non-condensing. This is obviously because the gain due to the partial absence of back pressure, which condensation secures, would not be sufficient to compensate for the increased complication and first cost which would at the same time be entailed; while the difficulty of maintaining a good vacuum increases, as also does the

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proportionate work done by the air pump, as the size of the engine diminishes. This fact has an important bearing on the pressure used; for it must be remembered that the effective pressure is the difference between the forward and the back pressure, the latter being, in the above cases, nearly constant. Low forward pressures must be very wasteful, the limiting case being when the forward and back pressures are equal, for then the whole imparted heat would, in a non-condensing engine, be absolutely thrown away.

Single-acting Engine.

(1.) These engines have been largely introduced for high speeds, so as to save the necessity of intermediate gearing, and to develop considerable power with a small motor. They almost invariably have multiple cylinders, generally three, as in the well-known Brotherhood example, and in those of Watt, Wigrell and Hasley, and Willans; while Vosper's engine has four. The steam only acts on one side of the piston. The great advantage of this is, that there is no shock from the wearing of the connecting-rod ends, or "backlash," as it is called. This is most important, at the almost incredible velocities at which some of these little motors work—many by the first-mentioned maker working at 1,400, and some even at 1,600 to 1,800 revolutions per minute. Moreover, the piston-rod and guide-blocks are dispensed with, and parallel motion is secured by having a deep piston, to which the connecting rod is attached, and thus compactness is obtained; the absence also of eccentrics and eccentric-rods renders the working parts few in number, while the use of the flywheel is entirely obviated. Of the numerous forms, that of Brotherhood has by far the most extensive application; and it may be said that the one exhibited by the inventor at the Vienna Exhibition, in 1873, which gained a silver medal, was the first of the class of which several hundreds have been made by him alone, and a large number by other inventors, who have since worked in this direction. It is thus seen that there is a movement in favour of a system by which considerable power is obtained from a small motor. Of this type a brief description of the Brotherhood engine only will be given, as engravings and descriptions of the others are to be found in comparatively recent numbers of various engineering journals.

Fig. 6 is a section through the three cylinders of a Brotherhood engine; the crank being balanced by a counter-weight A, and the three connecting-rod ends merely butting against the crank-

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pin, to which they are held by two steel rings. The valve is a rotary one, and its action is shown in Fig. 7, which is a longitudinal section. The steam is being admitted to the top of the piston by the port J, the opening in the valve putting it in communication with the steam chamber G. The exhaust is made by the passage N′ being placed in communication with the annular space in which the crank works, and finally escapes through the exhaust pipe, Q, placed at the bottom of this chamber. The diagram (Fig. 8) was obtained by a committee appointed by the Industrial Society of Rouen to examine the engine, and from whose report[1] Fig. 7 is, on a smaller scale, reproduced. The steam pressure was about 70 lbs. per square inch, with 250 revolutions per minute. The compression, which commences rather before half-stroke, can scarcely be a source of loss, as it allows the entering steam to rise to the full pressure at once, and certainly results "in the complete suppression of all species of shock." This, in a single-acting engine, with no arrangement for tightening the connecting-rod bearings, is a desideratum. The wire-drawing, obvious from the diagram, is the result of the circular valve, which, advantageous as it is for many reasons, is not moving at its greatest speed, as with the ordinary slide-valve, when the engine is near its dead centres. Fig. 9 shows the period of its action. The efficiency of the machine itself, that is the ratio of the indicated work to that obtained at the brake, is 75 per cent. The developed power was 10 HP. It is to be regretted that no determinations of fuel and steam used were taken. But although it has been asserted that these engines are wasteful of steam—and certainly the length of steam passage must entail a loss—yet on some trials made by the Royal Engineers, in which these engines were used to drive Gramme machines, the consumption of steam was 41·1 lbs. per hour per HP.,[2] revolutions 500 per minute, pressure of steam 80 lbs. per square inch, about 13 HP. being developed. This agrees with the consumption of steam obtained by officers of the French navy, which, the inventor states, was 40 lbs., and is equivalent to an expenditure of from 4·5 to 5 lbs. of coal with a good boiler, or 8 lbs. with one of the type already examined.

Double-acting Steam Engine.

(2.) The second class of small engines, viz., those which are double-acting, and generally work with a single short D-slide-valve,

[1] Bulletin de la Société Industrielle de Rouen, March and April, 1878.
[2] "Engineering," vol. xxviii., p. 328.

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are at present by far the most common, and a section of one of this type is shown (Fig. 3). Now, although the framing is made to take every conceivable shape, and they are made to work in every position, and have slight differences of detail, yet the principle of action is the same, and is so well known as to need no explanation. The point of cut-off of the steam is from $\frac{5}{8}$ to $\frac{3}{4}$ of the stroke, the corresponding grade of expansion being from $1\frac{3}{5}$ to $1\frac{1}{3}$, and more expansion than this cannot be economically effected with a single valve. The two engines before referred to cut off steam at about the latter point, their diagrams being given (Figs. 10 and 11). The details of the experiment were as follow: Both the indicator and the dynamometer were used, the latter being of the ordinary form, that is Prony's dynamometer lined with blocks of elm, embracing pullies respectively 2 feet 7 inches and 3 feet in diameter in the two cases. No. 1 was a vertical engine, and was bolted to the boiler. No. 2 was horizontal, and rested on a foundation of brickwork and stone. The number of revolutions varied to some extent, but were taken every quarter of an hour. The experiments would perhaps have been more satisfactory if a speed counter had been applied, since with a brake on a small engine the action cannot be kept perfectly regular, and the governors were purposely disconnected. However, the following Table is without doubt a near approximation to the truth:—

TABLE of DATA from ENGINE TRIALS.

Engine.	Diameter of Cylinder.	Stroke.	Number of Revolutions per Minute.	Average Pressure in the Boiler, by Gauge, in lbs. per Square Inch.	Mean Pressure in Cylinder by Indicator, in lbs. per Sq. Inch.	Indicated HP.	Developed HP. (brake).
	Ins.	Ins.					
No. (1) 2 HP. nominal . .	$4\frac{1}{4}$	7	130	51·5	39·0	2·57	2·011
No. (2) 4 HP. nominal . .	$6\frac{1}{2}$	$7\frac{1}{2}$	133	32·0	22·3	3·75	3·040

Engine.	Efficiency of Machinery $= \frac{\text{D.HP.}}{\text{I.HP.}}$	Steam in lbs. per Hour per I.HP. by Weighing Feed-water.	Steam in lbs. by Calculation.	Coal in lbs. per Hour per HP.	Efficiency of Engine supposing Efficiency of Boiler = 0·7.	Real Final Efficiency of Boiler and Engine.
No. (1) 2 HP. nominal . .	0·78	47·2	42·32	14·3	0·035	0·013
No. (2) 4 HP. nominal . .	0·80	45·3	44·0	9·2	0·039	0·022

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These results show that in this class of engine, at any rate, the consumption of fuel is at least from four to seven times greater than in the best kind of large engines, and that it is therefore beside the question to quote the performance of large engines when comparing the working cost of small motors. In connection with the indicated power of No. 2, which is less than the nominal, it is only fair to state that the engine often works with about 40 lbs. pressure and 180 revolutions, which would cause it to indicate more than 6 HP. A similar remark applies to No. 1. Again, it is well to note that the final efficiency of the whole is only about 0·19 in No. 1, and 0·3 in No. 2, that is theoretically possible for an engine using steam at those pressures and with those grades of expansion, but employing a condenser and having a boiler of 0·7 efficiency.

An ingenious kind of steam engine is used in the engineering laboratory, University College, London, invented by Mr. H. Davey, M. Inst. C.E., of Leeds, which is the only one of its class yet made. A small quantity of water is injected at each stroke into a coil of pipe heated by a furnace, and is at once converted into steam, and so drives the engine, which is single-acting, about ¾ HP. being developed. Improvements are being made in the design, and Professor Kennedy, M. Inst. C.E., thinks the invention a promising one.

Small oscillating steam engines have been used, but the admission and release of steam, to be effected economically, require rather complicated valve gearing.

There is another class of double-acting steam engines which are not rotative, and since merely reciprocating action is obtained, the slide-valve has to be driven by some arrangement other than an eccentric. Such engines are often used as donkey pumps and often as steam rock-borers. An instance of the former is the "Special Steam Pump"; a description of its action is to be found in the pamphlets of Thurston or Evers on the steam engine.

Rotary Engines.

(3.) It was stated in "Engineering,"[1] six years ago, that "most mechanical engineers nowadays have a deeply-rooted antipathy to rotary engines." Nor has the appearance of any successful patent between that time and this caused an alteration in opinion. Rotary engines are understood to be those which obtain circular motion directly by the action of steam upon some revolving piece,

[1] Vol. xvi., p. 398.

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and so avoid the necessity for the conversion of reciprocating into circular motion. It is not to be wondered at that a large number of ingenious attempts should have been made to thus obviate the use of the crank and the connecting-rod. For instance, thirty years ago, one of the form known as a "disc" engine, was for some years used to drive the printing machinery in "The Times" office, and is described by Rankine;[1] but although according to that author "the number of rotatory engines which have been patented in Britain alone is certainly upwards of two hundred," yet "very few have been brought into practical operation, and those to a limited extent only; for their friction and liability to wear have been found to be greater than those of ordinary engines, and they have no advantage except compactness." There is, however, one purpose to which they have recently been applied with some success, viz., to fire-engines, where economy of fuel, which the difficulty of keeping the revolving portion steamtight renders impossible, is not the chief point, and where the use is only occasional, and so the wear not of the first importance. Fig. 12 shows a simple form which is used for this purpose. Here the steam entering at S drives round the discs A, A, in opposite directions, and, finally escaping at T, A, A, give motion to two similar discs, which act as the pump by a precisely similar action, and so great compactness is obtained. The method of packing is ingenious and effective, and is formed by the metal pieces B, B, being pressed outward by springs, their centrifugal force acting with a similar effect. Behrens' engine is similar in action, and is much used in America as a pump.

Steam Action on Fluid Surfaces.

(4.) Two kinds of action are used. The first, Mr. Bramwell, F.R.S., M. Inst. C.E., has said, is expressed by one word "Concentration," and may be said to act by impulse, to which belong the Giffard Injector and the Inspirator. The second uses the principle of the Savery engine, and acts chiefly by pressure, of which the Pulsometer and Pulsator are types. As before stated, this class of apparatus is employed for pumping purposes, and this may be said to be its exclusive duty; its use in this direction is increasing, and whenever there is a supply of steam the simplicity of action and remarkably small weight and size of the whole machine are great recommendations.

The theory of the action of injectors is now well known, so that

[1] "A Manual of the Steam Engine and other Prime Movers," p. 504.

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it will not be necessary to describe any one of the numerous forms in use, although a reference to Hancock's inspirator may be made. This little instrument is becoming very popular, as it admits of accurate adjustment, after which little attention is required; while the weight of one capable of feeding a 48-HP. boiler is only 6 lbs. The undoubted function of all injectors is the foregoing, viz., the feeding of boilers, and they are universally applied to locomotives for this purpose.

The second kind are really steam vacuum pumps. Fig. 13 is a section of the "Pulsometer" (taken from the prospectus of the company), which is a very successful example. It consists of two chambers in one casting, communicating by a neck with the steam-pipe K. When the ball L, which acts as a valve, is in the position shown, steam from the boiler is forcing (that is, raising) with a steady motion the water in one chamber A, and will continue to do so till the level falls below the opening H, when the agitation produced causes the steam to condense and a partial vacuum to form. This brings over the ball R, to cut off the steam connection, and as the valve V now opens, the valve communicating with H closes, and the water rises into A, while the opposite chamber B, now full of water, has its lower valve W, shut, and is being emptied by the pressure of the steam. The action is thus automatic and alternative, and the arrangement is, in fact, a self-acting Savery engine. As with the Savery engine, however, the consumption of fuel is considerable. Trials were made at the Cincinnati Exhibition in 1875, quoted by Mr. D. K. Clark,[1] and at the Friedrich Lead Mine, Upper Silesia, recorded in the Abstracts of Foreign Papers.[2] In the former case, 53·1 lbs. and 43·4 lbs. of coal per hour per HP. for water actually raised were expended on two respective trials; in the latter 52·4 lbs. of slack were used for the same amount of work; but in the latter trial a "Tangye" pump consumed 40·5 lbs. for the same duty. The conclusions drawn from this trial, and other data obtained by experience, were that the total outlay for stores and repairs with the pulsometer was 1·68*d.* per hour per HP., that for the piston pump being 1·44*d.* The great recommendation of the former, however, is its portability, as it is as well able to work when slung by a chain as in any other way; also it will, in the words of the advertisement, "pump almost anything," including tar, sewage, chemical liquids, and even liquid cement, and is one-half cheaper in first cost than an ordinary pump of equal power;

[1] "A Manual of Rules, Tables," &c., p. 969.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. lvi., page 371.

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thus there is evident reason for the extensive sale which it enjoys. A recent modification, under the name of the "Hydrotrophe," is being employed to feed boilers, and both this and the injector must be economical, the surplus heat imparted to the water being returned to the boiler.

Gas.

Gas is a convenient source of power; and in towns, where it is already supplied almost to every building for purposes of illumination, it is at once obtainable in any moderate quantity. Moreover, the principle of adopting a large centre of supply, which is employed in the case of gas, is, on scientific grounds, truly economical, for that substance is supplied in the state of fuel, and involves no more loss in its transmission than would occur in the transference of any other fuel. But in spite of many attempts to use it for small motors, it has only recently been much adopted. Air is used in a peculiar way in the gas engine, and it is only in a similar way that gas can be profitably employed, viz., as the working agent, at the same time as the source of power; for the calorific power of gas, taken in conjunction with its present cost, at once puts out of the question any idea of using it as a direct substitute for coal.

The original method of using gas in this way was to admit it to the cylinder of the engine, together with air in such proportions as to form an explosive mixture, which was ignited, and work obtained by the consequent expansion. Lenoir's engine, which was one of the first, resembled an ordinary horizontal engine, effecting the ignition by an electric spark; but the difficulty of utilizing this sudden effect was a cause of considerable loss, and it is stated by a German writer on the subject [1] that 3 cubic mètres (about 106 cubic feet) of ordinary coal-gas are required per hour per HP. for a small-sized engine. This corresponds to the figures quoted by Mr. D. K. Clark [2] from the experiments of M. Tresca, two successive trials of this engine giving 112 and 97 cubic feet respectively, the mean of which is 104½ cubic feet per hour per HP. at the brake, being an efficiency of little more than 4 per cent. Though this engine had an extensive sale in Europe, it was to a great extent superseded by the Otto and Langen motor. In this the sudden expansion of the gas was allowed to raise a piston against the pressure of the atmosphere alone, which pressure, upon

[1] "Klein-Kraft-Maschinen," p. 27. Von Peter Hell, Braunschweig.

[2] "A Manual of Rules, Tables," &c., p. 921.

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the cooling of the heated gas in the cylinder, hastened by a water jacket, drove down the piston and so performed work, the piston-rod being a rack which geared with a pinion on the horizontal shaft. This engine is a regular and efficient motor, and its consumption of from 22 to 30 cubic feet of gas per hour per HP. is vastly superior to the Lenoir engine, and is even less than in some engines which have superseded it. One engine, which has been at work for ten years in Bristol, is in good condition, and has cost during that period very little for repairs; but its noise in working is much against its general adoption. Again, it is necessarily a vertical engine, by no means so popular as the horizontal form, and is anything but compact. Thus when the new engine of Otto was introduced into this country by the same manufacturers, Messrs. Crossley Brothers, of Manchester, which was at once compact, economical, and above all, silent, they almost at once ceased to make the Otto and Langen, and have already sold, since 1877, upwards of eight hundred of what are known as the Otto Silent engine, more than two thousand being the number sold in Great Britain and on the Continent. The principle of action employed, as indeed of nearly all the many kinds since patented, is intended to meet the difficulty of utilizing the energy of the gas consequent upon the sudden explosion in former engines. The method of doing this is best stated in the words of the specification of the English Patent, No. 2,081, 1876: "A combustible mixture of gas or vapour and air is introduced into the cylinders, together with air or other gas that may or may not support combustion, in such a manner that the particles of the combustible mixture are more or less dispersed in an isolated condition in the air or other gas, so that on ignition, instead of an explosion ensuing, the flame will be communicated gradually from one combustible particle to another, thereby effecting a gradual development of heat and a corresponding gradual expansion of the gases, which will enable the motive power so produced to be utilized in the most effective manner." Fig. 14 is a sectional plan taken from the same source, and is similar to the engine now manufactured, except that a single instead of a double crank is used. "The cylinder is constructed of greater length than the stroke of the piston, so that there is a space beyond the latter when it is at end stroke. Assuming this space to be filled with a portion of the gaseous products of combustion resulting from the last stroke, the piston, in performing one part of its stroke, draws in atmospheric air, after which it will draw in combustible mixture during the remainder of the stroke." These three strata of gases are compressed in the

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return stroke, and ignited, when the principle above quoted comes into operation; and the next forward stroke does useful work, the fourth, or next return stroke, expelling the product of combustion. The slide valve is made alternative in its action by being driven through a bevel wheel on the main shaft of half the diameter of that on the slide-valve rod. The mixture used is 1 part of gas to 16 parts neutral; the latter being made of air and products of combustion in the proportion of 5 to 3. Some recent inventors adopt the main principle involved, but they employ a separate compression cylinder, and by advertising a combustion at each revolution, seem to imply the alternate action to be objectionable; and it must be confessed that the Otto engine is not perfectly regular in its action with a light load, combustion taking place perhaps only once in five or six revolutions. At the same time, with a proper load and a moderately heavy fly-wheel, this is hardly appreciable, and is of undoubted benefit to the cylinder, which, being also single-acting, is thereby only heated once in four strokes. One such engine has been running day and night at the Hinckley Gas Works for fourteen months, this being equivalent to three years' ordinary work, without needing any repairs, which, notwithstanding the water-jacket surrounding these cylinders, is a satisfactory result, and is contrary to many predictions concerning it. Such a result may possibly not attend those burning gas at every revolution.

The latest trials of the amount of gas used are, according to Mr. Crossley, 24 cubic feet per hour per HP. for the 1 or ½ HP. engines, and 18 cubic feet for the 16 HP. engines.

Another engine, the Eclipse, of Messrs. Simon Beechey and Co., of Nottingham, with a separate compression cylinder, has a novel feature, in the use of steam, which is generated by the heat abstracted from the cylinder in order to keep it moderately cool. This steam is used in the cylinder not only to assist the action of the expanding gas—which it certainly does, being capable of driving the engine for several minutes after the supply of gas is turned off,—but it also acts as a lubricant, by which it is claimed that a great saving in oil and tallow is effected. Its action is fully described, and drawings are given in the "Engineer," 1879,[1] and in the "Textile Manufacturer," May 1879. In the former it is stated that in a trial of one, the working cylinder, which was 8 inches in diameter, with 16 inches stroke, indicated 6·03 HP., and the compressing cylinder, which was 7 inches in diameter,

[1] *Vide* vol. xlvii., p. 3.

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with 10 inches stroke, indicated 1·87, leaving 4·16 HP. as the net indicated HP. of the engine. The consumption of gas was from 22 to 26 cubic feet per HP. per hour.

The objection to the foregoing type of engines is that they have to be started by hand and turned through a revolution or two—although the makers of the latter engine are said to have obviated the necessity for this by an invention. With very small powers this objection is not felt, nor is it with a recent novelty, the Bisschop. This little motor, which is made from 1-man power upward, has had a sale of three hundred during the first nine months since its introduction; the consumption of gas is greater in proportion than in other larger gas engines, but its first cost is very small, and being advertised to work for ½*d.* per hour, although by no means a silent engine, it has decidedly met a long-felt want.

The theory of gas engines is yet imperfect; but some things are certain with regard to them, and one is, that the absence of a boiler in connection with them gives a great advantage over the steam engine. The absence of risk either from explosion or conflagration is another strong point; while the scientific application of production on a large scale, in the form of the gas used, is perhaps the strongest of all, in leading to the conclusion that their present popularity is likely to last, gas engines being a step in the right direction.

Hydro-carbon Motors.

Another class of engines must be alluded to, although not much in use in this country, viz., hydro-carbon motors. In America, where petroleum is abundant, successful attempts have been made thus to apply it, and its use is now rapidly extending. The principle of action is much the same as with a gas engine. In the Brayton motor, described in "Engineering,"[1] a jet of air is forced into fibrous material soaked in petroleum, and this substance is deposited on the meshes of wire gauze, from which it is evaporated. The vapour forms with the supply of air a combustible mixture, which is, as in the Otto silent engine, not explosive, but admits of gradual combustion, with the attendant advantages. In Germany the Hock motor is commonly adopted; its appearance is similar to an ordinary horizontal engine, and the German writer already quoted[2] describes

[1] "Engineering," vol. xxiii., p. 127.
[2] "Klein-Kraft-Maschinen," p. 32.

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it as sucking in a small quantity of the fluid to about $\frac{1}{3}$ of its stroke, and also a certain quantity of air, when ignition and gradual expansion take place through the remaining $\frac{2}{3}$. Brayton's motor, in the article referred to, is said to use a gallon of crude petroleum per HP. per day of twelve hours, this amount being slightly exceeded in engines of less than 3 HP. The Hock engine is stated to use what is equivalent to 2·75 lbs. of naphtha per hour per HP., at the cost of about 3*d.* per hour, a 1-HP. engine being in first cost about £50. Petroleum motors may be advantageously used in place of gas engines where a supply of gas cannot be obtained, and where petroleum is abundant; but this leads to the conclusion that, although in America and in Germany their use will probably increase, in this country, at present, it is not likely to do so.

Air.

After some long and thorough trials on a large scale of hot-air engines, the most important of which were at the Dundee Foundry, about 1845,[1] and on the ship "Ericsson," 1852, hot air has been universally acknowledged to be adapted only to perform operations requiring but little power, its present application in this country being almost entirely confined to the immediate supersession of hand labour. The hot-air engine has, however, a high efficiency, and in the first of the above cases, Mr. J. Stirling, the son of the original inventor, stated that the Stirling engine then described used only $2\frac{1}{2}$ lbs. of coal per hour per HP., which was said to be $\frac{1}{3}$ of that used by the best steam engines of the day; and in the discussion which followed, the Author stated that he had "every reasonable confidence in its ultimate success." Again, in the second case in which Ericsson's engine was used, the action of which is described by Professor Rankine,[2] the consumption of anthracite was 1·87 lb. per hour per HP., where, "notwithstanding the low efficiency of the furnace, ... the efficiency of the fluid was so great as to give a resultant efficiency superior to that of almost all steam engines at the time of the experiments referred to." In spite of these facts, it was not till a few years ago that small hot-air engines had any considerable use in this country. The reason for this has been already referred to—the high temperatures required, and the narrow range of effective pressure; the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iv, page 348.

[2] "A Manual of the Steam Engine and other Prime Movers," 8th ed., p. 361.

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latter rendering bulky apparatus necessary to produce much power, the former rendering the mechanical difficulties in dealing with that apparatus very great, as, for instance, the permeation of the glowing fire-box by the air under compression, which it has been proved takes place. Now, however, there are several successful patents for hot-air engines whose great recommendation is the absolute freedom from danger of explosion, and almost noiseless action, together with a high efficiency. There are two kinds of engines which, according to the method of using the working fluid, are called "closed" or "open." The two engines above mentioned are prototypes of these two classes. In the Stirling engine the same mass of air under pressure was used continuously, and by alternate heating and cooling was made to do work; it is therefore called "closed." In the Ericsson engine a fresh supply of air was taken in by the engine at every stroke, in a similar way to steam from a boiler, and after doing work by the application of heat, was rejected in a similar way to steam; it is therefore called "open." With regard to the latter, little will be said; for as far as the Author is able to learn, they are scarcely if at all used in this country. In Germany the open engine of Hock, and in France that of Belou, give satisfactory results, but these differ in an important point from the Ericsson engine, the air not being heated by mere contact with a metallic surface, but being made to pass through the fire and support combustion, thus bearing a resemblance to the action of gas engines. In a trial of the Belou engine at Cusset, quoted by Mr. D. K. Clark (p. 918, "Rules and Tables"), the consumption of coal was 0·735 lb. per hour per I.HP., and 3·24 lbs. per net HP. at the brake. In a trial of a Hock engine by Professor Jenny, of the Imperial Technological School of Vienna,[1] 7 kilogrammes of coke were used in sixty-three minutes by an engine developing 1·58 HP. at the brake, which is almost exactly equivalent to 9¼ lbs. of coke per hour per HP. These results compare favourably with the work done by most closed air engines, but the Belou engine was of large size—of more than 27 HP.; and it is the Hock engine, or one similar to it, which is of low first cost, and has many advantages, that must be regarded as the one whose introduction might profitably take place, and which is spoken very highly of in the report referred to.

Closed air engines are numerous; those of Laubereau, Lehmann, Stenberg (the Calorisca), D. van Rennes, and Rider being the principal. With each there is some difference in theory, as shown

[1] "Klein-Kraft-Maschinen," p. 42.

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by Dr. A. Slaby.[1] A distinction can, however, be made between single and double-acting engines. Laubereau's, which is a modification of Stirling's, is commonly used in France; while in Germany Lehmann's is most popular, as testified by the fact that over a thousand are there in use. Both Lehmann's and Stenberg's have a brickwork erection at the end distant from the crank shaft, and, being horizontal, considerable space is necessary. While the machinery of Lehmann's is decidedly complicated, Laubereau's is vertical, and very compact and portable, and, in spite of the alleged defect pointed out by Dr. Slaby, which is avoided in Lehmann's engine, viz., that the heating chamber communicates directly with the working piston, and so renders the packing liable to rapid deterioration, it has worked satisfactorily, using, in a trial quoted by Mr. D. K. Clark, 4·8 lbs. of coal per hour per HP., and 11 lbs. per HP. at the brake. Lehmann's engine has been recently introduced into this country, and was awarded the first prize at the Manchester and Liverpool Show, 1879; but at present the engine most generally used is that of Rider, of which, since its introduction from America three years ago, upwards of nine hundred have been sold; therefore of this only will a description be given. Fig. 15 is a sectional view taken from the prospectus of the company; it is there seen to be single-acting, and to consist of two cylinders, A and B, in which two vertical hollow plungers, C and D, work air-tight for a portion of their length, driving cranks set at 95° on the shaft above. The method of packing is most ingenious, consisting of two reversed leather collars, which seem to wear satisfactorily, although in direct communication with the heating chamber. A is the cooling or compression cylinder, in which, by the device of an annulus of air between the plunger and casing E, round which water circulates, a rapid cooling can be effected; and in the same way an annulus of air in the other, or working cylinder B, enables a rapid transfer of heat to take place when this is necessary. The action is as follows:—when the air in C is compressed by hand at starting to about $\frac{1}{3}$ its original volume, the rising of the piston B, which is of equal area, enables it to be transferred without change of volume to that cylinder with which there is a communication. Here the heating, which is facilitated by the shape of the bottom of the plunger, takes place, and the consequent expansion causes the continuance of the upstroke of D. Upon the return stroke of D, the air is transferred to the compression cylinder, but is made on

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lvi., p. 370.

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the way to give up heat to the thin plates in the regenerator H, of which a partial view is shown, and this heat is restored when the repetition of the first operation takes place; the rest of the heat which must be abstracted is taken away by the water in the casing, and the engine now continues to work, the difference between the positive work in the working cylinder, and the negative work in the compression cylinder being the effective work. The ½-HP. engine has been found to consume 4 lbs. of coke per hour; the 1-HP. a little more than twice that amount. One was tested at the Royal Agricultural Show at Birmingham, and the work done by pumping showed a consumption of 13 lbs. of coal per hour per HP., or a little more than ¼ that used by the pulsometer pump, or ⅓ of that in the Tangye pump, in the experiments already referred to. The cost of coal for a week's work of six days, working ten hours a day, is advertised not to exceed 2*s.* 6*d.* for a ½-HP. engine. These engines are thus economical; they are reliable and simple in action, and require no skilled attendant; they are safe, and, in pumping operations, for which they are usually applied, the water pumped can be made to circulate in the casing, and so act as a cooler; but, in common with nearly all hot-air engines, they are heavy in proportion to their power. Hot-air engines, then, have decided advantages, and in the country their employment might, and probably will, be profitably extended.

Compressed air has been applied to transmit power for a variety of objects; but the purpose for which, on a small scale, it seems specially adapted, is to supersede manual and animal labour in rock-boring and mining operations. For mines and tunnels there are many advantages attending its use; for not only is the air which is compressed by external machinery of great importance for ventilation, but the fall in temperature by expansion, which accompanies the necessary loss of heat occasioned by its use, is valuable, as tending to reduce the temperature in the close and heated workings. The principal objects to which it is put are for underground haulage, pumping, and rock-boring or coal-cutting operations. The first of these has been considered by Mr. W. Daniel, in a Paper before the Institution of Mechanical Engineers,[1] and is rather applied to motors of a size not here dealt with; the second may use any of the ordinary steam pumps; but it is the last which is particularly an example of the successful application of machinery to replace individual physical effort. A vast amount of attention and in-

[1] *Vide* Institution of Mechanical Engineers. Proceedings, 1874, p. 204.

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genuity have been bestowed upon rock-boring and coal-cutting apparatus, of which drilling shot holes in the former is the most important and toilsome part of the labour required, and one to which the application of motive power has been most beneficial. Only one form of rock borer will be described, but one which at the Bristol docks has proved efficient and durable. Figs. 16 and 17 are two views of the drill of R. Schram; the action simply imitates that of hand-boring, viz., a succession of blows, accompanied by a turning motion. The machine consists of a strong cylinder supported by three legs, in which works a solid piston rod, driven by a double piston, the end of the rod carrying the drill. The blows are given as rapidly as 400 or 500 per minute, by means of the valve *f f*, which acts in a somewhat similar way to that of the special pump; when the opening *o*, shown by dotted lines, in the cylinder is open to the pressure of the air, the opposite end of the valve will be also under pressure, and will remain in one position; but directly it is opened to the exhaust, by the edge of the piston passing it, the end of the valve will also be opened to the exhaust, the pressure removed, and the valve thrown over, and the action on the piston reversed. Similarly for the other opening *o'*, communicating with the other end of the valve. The second action, or turning, is effected by means of a small piston *p*, shown in section, Fig. 17, which acts at right angles to the stroke of the drill, but is not quite in the same centre line, and therefore every stroke it takes will turn the ratchet wheel *w*, which is in that line, and, consequently, the position of a spiral rod *s* fitting into the end of the piston rod. This happens when the drill is down, and the spiral rod free from it; but when the drill and piston rod make the in-stroke, the spiral rod running into the former, and being itself held firmly, turns it through the necessary angle; in the out-stroke no turning takes place. The feeding is effected by the hand-screw T.

It is well known that compressed air necessarily involves considerable loss, from the fact that most of the heat developed by compression cannot at present be retained, so as to act when the converse expansion takes place in the motor. This subject has been fully treated, both theoretically and experimentally, by many engineers, especially in France. From Mr. Robinson's Paper,[1] already referred to, the total loss appears to be never in practice less than 50 per cent. of the energy used

[1] *Vide* Minutes of Proceedings Inst. C.E, vol. xlix., p. 17 *et seq.*

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in compression, and sometimes as much as 75 per cent. Again, the result of some experiments by Mr. W. Daniel shows a loss[1] from 54·2 per cent., with 19 lbs. per square inch air pressure, to 74·2, with 40 lbs. air pressure.

But the work lost is more than compensated for by the attendant advantages, and where, as in the Mont Cenis tunnel, a natural head of water can be employed, it must be superior to all other agents; though for purposes above ground, notwithstanding several attempts to introduce it, and except in the Westinghouse brake, the loss with compressed air is sufficient to prevent its general adoption, and even rock-boring drills are then worked by steam.

Water.

A natural head of water was, perhaps, the first power applied to take the place of manual labour, and though used all over the world on a large scale, and in Switzerland and some other countries for small powers—where mountain streams are employed even for such domestic purposes as churning and rocking cradles—yet in this country the extension of small water motors has been confined almost entirely to towns having artificial sources of supply. Nevertheless, as has been forcibly brought forward on several occasions of late, the natural power at present running to waste might, by means of more efficient transmitting agencies, be taken advantage of. There are several instances in which this is being done, as at Tortona, in Italy, where, since 1876, the force of the torrent Scrivia has been made to supersede steam by applying telodynamic transmission, and a daily saving of 60 per cent. in cost thereby effected.[2] Again, on the estates of M. Menier, the power derived from the river Marne is used, by means of electric transmission, for ploughing and other agricultural purposes, and it is proposed to extend it to a distance of 3 miles from the source. Also, in America the use of the almost boundless supply of natural head of water is being rapidly extended for similar labour-saving objects; but it is a significant fact with regard to this country, that although Sir W. Armstrong, who, if not the first, has certainly been the chief, engineer in introducing the present hydraulic system, was led to the subject by noticing the waste above referred to, his first idea, like that of many others, was to prevent that waste, and he has established a magnificent system, not, however, based

[1] *Vide* Institution of Mechanical Engineers. Proceedings, 1874, p. 210.
[2] *Vide* Minutes of Proceedings Inst. C.E., vol. l., p. 192.

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upon the use of the natural source of power, but upon a source whose essential principle is the production of an artificial head of water—in most cases by the use of steam. The fact is, that the supply of power referred to must be turned into work at its source, or stored up under a, so to speak, higher pressure; since, when it is the power of the water, and not the water itself that is required, the proportional loss by transmission would otherwise render its use impracticable. Now the obvious advantages to small industries from localisation seems to account for the undoubted tendency in this country to carry on small manufactories in towns, to which the power must be conveyed; therefore their connection with the natural source is an important problem, the solution of which necessitates (1) an abundant supply, and (2) an efficient means of transmission. England cannot be said to be rich in the former, and the latter is far from being in a satisfactory or settled state; so that, until the want of fuel is more keenly felt, artificial sources will in towns, no doubt, continue to be principally used. Still in the country small water wheels, or turbines, are often conveniently applied, and many of the former have been erected by Mr. W. Anderson, M. Inst. C.E. (of the firm of Messrs. Easton and Anderson), of 0·018, 0·04, 0·26, &c., HP., chiefly for pumping purposes.[1]

The two sources of water power in a town are:—

(1) The reservoirs for supplying water for domestic purposes.

(2) The accumulators specially erected for obtaining a head of water.

Up to the year 1849 the supply in towns was drawn from reservoirs, and it was one of the original ideas, set forth in a letter by Sir W. Armstrong, F.R.S., V.-P. Inst. C.E., to the "Mechanics' Magazine," and referred to by him in a Paper before the Institution,[2] that "the water already supplied to towns for domestic purposes could in many cases be advantageously employed for working cranes, printing presses, and in short, all kinds of machines where manual labour was usually employed." This is an artificial source, since steam engines are generally employed to raise the water into the reservoirs. The expense, however, is a serious consideration, for it must be remembered that the water is supplied for a different purpose, and the head is only made sufficiently great to distribute the water to the summit of the various buildings, and in London, for instance, it is not even so

[1] *Vide* Transactions Inst. C.E. of Ireland, vol. ix., p. 78.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. l., p. 66.

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great as that. Besides being small, the pressure is found to vary considerably, and not only by diurnal changes, due to reasonable causes—it being, for example, 45 lbs. per square inch at Westminster in the morning, and rising to somewhat over 60 lbs. in the afternoon, and in Bristol from 40 lbs. to 70 lbs. —but also to sudden and erratic changes, most trying to the water motor employed. The consumer is nevertheless charged for the quantity used, independently of the pressure; and as inquiry seems to indicate that this is often highest in towns where the average pressure is lowest, the system must be far from satisfactory. These causes no doubt led to the second method, viz., the use of the accumulator for supplying water under considerable pressure, which brought out the advantages of water as an agent, and showed its superiority under great pressures, from its incompressible nature, which both renders it capable of transmitting great power and at the same time obviates all danger from explosion; and the size of the motor can be so reduced as to render the amount of water used but trifling. The pressure under which the water is used has everything to do with the kind of motor employed; and before comparing the cost of the two foregoing modes of supply, the types of apparatus must be discussed.

No doubt the motors giving the highest efficiency, under proper conditions, are turbines and reaction wheels, but these conditions are such as to exclude them for water under much pressure, and even with water from the mains the use of the former is practically out of the question, for the linear velocity of the rim of the wheel should bear some ratio to the velocity due to that pressure, and as the size of the wheel diminishes, its number of revolutions must, for a constant head of water, increase; so that to obtain any reasonable efficiency, the velocity for a very small wheel would have to be as much as 4,000 or 5,000 revolutions per minute. The inward-flow turbine of Professor James Thomson is made to very small sizes; but in a letter to the Author the inventor says: "I do not recommend any kind of turbines for ordinary use with very small water supplies and high water pressures." The reaction wheel can be made to work economically up to moderately high pressures, because the radius of its discharge orifices can be increased, and so the law connecting the head with the linear velocity of the jet (which is velocity = $8\sqrt{h}$) can be nearly satisfied. In a Paper read by Mr. W. C. Kernot, M.A., C.E.,[1] at Melbourne, a small motor of this

[1] Notes on Small Motors. Royal Society of Victoria, Oct. 9, 1879.

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kind, shown in Fig. 18, is advocated, in which, by means of a counterweight *a*, one arm is dispensed with, and the hydraulic radius doubled, all sharp bends are avoided, and, as a result of experiment, with a consumption of 2·8 gallons of water per minute (at 1*s.* per 1,000 gallons), pressure by gauge 75 lbs. per square inch, speed of 1,300 revolutions per minute; 0·055 HP. were obtained to drive a small lathe, the efficiency being 40 per cent. An ingenious form of governor was used, in which the increased speed, by the centrifugal force of a weight, closed the orifice of escape and acted most effectually to check the racing and variation in speed, reducing the water used from 2·8 gallons per minute in full work, to 0·75 gallon when all the machinery was disconnected. There are numberless cases in which such a motor as the foregoing might be advantageously employed in towns, and where its use would compare favourably in efficiency with some of the engines at present chiefly employed and known as "water-pressure engines."

The form of water-pressure engine which is almost universally adopted for obtaining rotary motion is the oscillating type. A sectional view is shown in Fig. 19 of Haags's engine, which is extensively used on the Continent, and is largely supplied by Schmid, of Zurich, where small water motors are used to the number of one hundred and thirteen, as alluded to by Mr. E. Matheson, M. Inst. C.E.[1] The action of the engine is extremely simple. The oscillation of the cylinder about its centre alternately opens the opposite ends of the cylinder to the supply and exhaust of water. There seems to be a large amount of clearance by the long ports which would entail waste, but otherwise the engine is cheap and efficient. It is being introduced into this country by Messrs. Bailey and Co., of Manchester. Another form is Ramsbottom's patent, of which a general view is shown in Fig. 20. This, from its small first cost and simplicity of action, is at present the most extensively used in this country. Three cylinders oscillate about their lower extremities, and work upon a hollow cast-iron pipe, which is divided into two parts by a vertical diametral partition running its whole length. One side conveys the water under pressure to the cylinders by ports, which, when the cylinders are in an inclined position, communicate with corresponding ports in their bases; in a similar manner the other side conveys away the water when the cylinder is inclined in the opposite direction. Experiments were made with a dynamometer upon two of these, through the kindness of Mr. Camp, of Bristol, the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlix., p. 35.

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inventor of hair-brushing machinery, and which was used for that purpose, the other being erected at The Institution of Civil Engineers, Great George Street, for driving the ventilating and warming apparatus. The annexed Table gives a tabulated result of the experiments, from which the curves (Fig. 21) have been constructed. The pressure of the water-gauge was taken with every change of load on the dynamometer; but since the gauge was fitted by a pipe at right angles to the pipe, and some feet from the engine, it would not be right to assume this as the pressure in the cylinders; the flow of water past an orifice being well known to affect the pressure in a channel from that orifice. Therefore no deductions are drawn as to the efficiency of the motors at any but the lowest speed; for it was found that the cylinders, according to the reading of a water-meter in the first-mentioned case, did not fill with water at a much higher speed. But the supply pipe in that case was 1½ inch in diameter, by reason of a decision of the Waterworks Board of Bristol; while in the second case the diameter was 2¼ inches, or considerably more than twice the sectional area. This accounts for the differing results in the two cases, and the consequent very different curves, the engines being exactly the same in every other respect, the length of stroke being 9 inches, and the diameter of the rams 3½ inches.

EXPERIMENTS with RAMSBOTTOM WATER-MOTOR.

Water-motor at Camp's, Bristol, D.HP. = 0·4 .	Revolutions	15	18	20	24	27	28
	Pressure .	60	50	45	40	34	30
	Foot-lbs. .	12,257	12,728	9,428	7,512	5,476	5,280
Water-motor at Inst. C.E., London, D.HP. = 0·8. . . .	Revolutions	25	30	42	48		55
	Pressure .	43	40	35	30		25
	Foot-lbs. .	21,214	23,570	26,400	25,646		24,420
Water-motor at Inst. C.E., London, D.HP. = 0 8 . . .	Revolutions	56	58	60	63		66
	Pressure .	24	24	23	23		22
	Foot-lbs. .	23,084	20,050	18,856	15,810		12,446

The curves drawn from this Table show revolutions as abscissæ and work in foot-pounds per minute as ordinates. The best results obtained in the first case were at the cost of about 2*s.* 10*d.* per HP. per hour; in the second case, at the cost of about 2*s.* 4½*d.* per HP. per hour. These figures were calculated from the greatest work produced, which corresponded to about the highest efficiency;

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taking the prices charged for water to Mr. Camp at 1*s.* 2*d.* per 1,000 gallons, and to The Institution of Civil Engineers, at 1*s.* per 1,000 gallons. Of course the cost for water is much less than this in some towns, being, according to Mr. Hastie, in Glasgow, 4*d.* per 1,000 gallons, at a pressure of 50 lbs. per square inch, and in Greenock, 5*d.* per 1,000 gallons, at 120 lbs. per square inch; but still the prices, as compared with the cost of a gas engine at 1*d.* per HP. per hour, are high, and in the case of some engines of a different kind driving the bellows of a large organ in Bristol, the rate is still higher. There is a considerable difference, however, between 5*d.* for 1,000 gallons at 120 lbs. pressure and 1*s.* 2*d.* for the same quantity at 60 lbs., the former being 5·6 times as cheap. In Greenock it is found convenient to use water motors for many purposes, especially for intermittent work, such as hoisting.

An important question and one that has often been raised, with regard to the use of water for the purpose of developing motive power, is the waste sustained by a varying load; for the non-expansive nature of water causes a full complement to be used at each stroke of the engine, whether the load be great or small. This subject was discussed in the Paper of Sir W. Armstrong with regard to cranes, where it is said: "It is far less important to consider economy of fuel in the engine, than simplicity of construction in the cranes."[1] But the arrangement of cranes referred to was not automatic. In the discussion which followed, Mr. Duckham, M. Inst. C.E., showed the considerable loss which might be entailed, and referred (without contradiction) the cause of the objection of Sir W. Armstrong rather to "the necessity of depending upon the intelligence of the workmen, which was far more variable than the crane power." Now, in a recent invention of Mr. Hastie, of Greenock, this difficulty is overcome for water motors by using an automatic appliance of admirable design and simple in principle, thereby meeting the objection above quoted, which of course applied to all water engines. It may be briefly described as a means of varying the quantity of water used by a flexible connection between the power and the resistance, which principle seems capable of the widest application. From the curves and tables already given it will be seen how much power is lost at the high velocity of the motor which ensues when the supply of water is not regulated to the load. The invention provides for this in the following manner:—Fig. 22 shows a front elevation of

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. l., p. 78.

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the two-cylinder form, the cylinders oscillating about their middle point. The piston-rods are attached to a crank-pin, which slides in or out on the crank-plate so as to alter the stroke according to the work to be done. Fig. 23 is a sectional view, showing a drum A, which is attached at one end to a hollow shaft driven by the crank-plate, and communicates motion to the solid shaft by means of a spring, of which there are three forms, according to the degree of force transmitted, but which in the present and simplest case is like the spring of a watch. The action is thus:—Suppose no load on the machine, then the spring will be uncoiled and the relative positions of the crank-plate and solid shaft will be such that the cam shown in *a*, Fig. 24, which is driven by the solid shaft, will allow the crank-pin to approach near the centre of the shaft, and so a small stroke will result, and a consequent small consumption of water; but if a load be put on the engine, the effect will be transmitted by the solid shaft to the crank-plate through the spring, which will be proportionately coiled up, the relative positions changed, and the crank-pin driven out by the cam so as to increase the stroke, and consequently the amount of water used to a proportionate extent. In some experiments made by Mr. Kinipple, M. Inst. C.E., Engineer to the Greenock Harbour Trustees, 7½ gallons of water were used in a hoist with the chain alone, 10 gallons with 427 lbs., the amount of water increasing with the load, until 22 gallons were registered for raising 1,193 lbs.[1] Brotherhood's three-cylinder engine has been successfully modified for use as a water-pressure engine, and a description of its action, as well as drawings of it, are given in a Paper by Mr. Tweddell, M. Inst. C.E., read at the Cardiff meeting of the Institution of Mechanical Engineers.[2]

So far no results from the second of the two sources, viz., water under accumulator pressure, have been given; but taking the average pressure as between 700 lbs. and 800 lbs. per square inch, and the charge when sold between 3*s*. and 4*s*. per 1,000 gallons, it is evidently far more economical. This question has been so fully discussed by Mr. Robinson in his Paper, and the prices of water-power from the principal dock systems so completely stated, that only the average cost need be quoted, being 1·26*d*. per 100 foot-tons of work, taking 80 per cent. as the efficiency of water. This corresponds to about 1·14*d*. per hour per HP., but of course the efficiency of 80 per cent. could only be obtained for large

[1] *Vide* Institution of Mechanical Engineers. Proceedings, 1879, p. 487.
[2] *Ibid.*, 1874, p. 173.

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motors, and would certainly not be much more than half this for small motors; but even this compares favourably with the use of water from the town mains. It is in the use of high-pressure water for varying loads that an automatically regulating engine, such as the one above described, is found to be economical; and this at such rates as 4*s.* per 1,000 gallons, as charged by the Hull Water-Power Company, is at once evident.

Electricity.

Although the precise nature of electricity is not yet determined, it is known to be a form of energy, and many of the laws which govern its application to the production and transmission of power are understood. Although it cannot be said to be at present to any extent thus practically applied in this country, yet in France its use for the latter purpose is already an undoubted commercial success, and there is every probability that its universal adoption, under certain conditions, is only a matter of time. Therefore it is highly important to compare it with the other agents, the word "agent" in this case not being taken to imply anything material. In order to do this, however, a rather different treatment of the subject will be necessary to that previously adopted, as the machines which may be used, or which are at present used for other purposes, will not be described, but an attempt will be made to present a concise view of the conditions under which electricity must be employed, and of the experimental results recently published, so that the above comparison may be made.

The original method of obtaining an electric current for the performance of work is analogous to the generation of steam in a boiler, fuel being used in both cases; but the energy represented by zinc, which is the substance commonly so employed, is only about $\frac{1}{10}$ of that which an equal weight of coal would produce. As the cost of zinc is about £25 per ton, and of coal only about 10*s.*, the energy obtained from the former is about five hundred times as expensive as from the latter. However, as the efficiency of a small steam engine would be, perhaps, at the best $\frac{1}{10}$ that of a small electric engine, though often nearer $\frac{1}{20}$, the final cost of the work performed would be from fifty to twenty-five times as great.

These figures suffice to show why this method of producing electricity has been abandoned where power is required, and unless some cheaper substance than zinc can be obtained for the purpose, it is never likely to be re-adopted. Nevertheless, ever since the discovery of Oersted (1820), which led to the manufacture of the

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first electro-magnetic motor, there has been a continual production of such machines, though no attempts to apply them on a large scale have been made since the experiments of Jacobi on the Neva in 1838, whose engine developed about $\frac{3}{4}$ HP. Yet for many small purposes they have been adopted, especially in France, for working ruling machines, sewing machines, &c.; but it is a significant fact that the electric pen, in which an engine is actually present, though for a purpose requiring a minimum force, is about their only present use as motive power, even the manufacture of the latest and very efficient Howe electric machine, invented to drive sewing machines, and developing about $\frac{1}{10}$ HP., having been now given up.

There is another mode of producing an electric current, viz., by the expenditure of energy from any available source, such as steam or water power, on a magneto- or dynamo-electric machine. The current so produced is identical in nature with that from a battery, but very different in cost—and upon this point turns the whole question of its possible introduction, for these are practically the only two methods of generating electricity. The latter would obviously only be used for the purpose under consideration, when the steam or water power producing it could not be directly applied, that is, could not be obtained on the spot where the application of their energy was needed. This, therefore, reduces the question to the discussion of the efficiency of the transforming apparatus used; and upon the result, that is, upon the percentage of the useful work obtained of that given out by the prime mover, the use of electricity as a transmitter of power depends. In order to do this in a lucid manner the two actions will be discussed separately.

(1) The efficiency of the generator of electricity, giving the loss of power in the production of the current.

(2) The efficiency of the machine which re-transforms electricity into work.

Of course the resultant efficiency is the product of the two: but though, as is often the case, the two machines may be identical in construction, yet the efficiencies may not be the same, since the conditions under which they are respectively used are not identical; that is to say, the efficiencies of the operations are different.

(1.) The first has been made the subject of direct experiment by Dr. Hopkinson, Assoc. M. Inst. C.E., and others. In a Paper read before the Institution of Mechanical Engineers by the former,[1]

[1] *Vide* Institution of Mechanical Engineers. Proceedings, April 1879, p. 238.

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the results show an efficiency of $\frac{9}{10}$, exclusive of friction; and from the whole set of experiments Dr. Hopkinson deduces a mean total loss of 12 per cent. and of 13·8 per cent. respectively in producing the current; that is, the useful work represented by it is from 86·2 to 88 per cent. of the work applied to produce it. He quotes the results by Mr. Schwendler, M. Inst. C.E., and Mr. Trowbridge, the former obtaining 88 per cent., the latter 76 per cent. All these experiments were made with the machine of Siemens, which undoubtedly gives as high a result as any, and perhaps higher than some machines; but the fact remains, that a return may be obtained which, in connection with the comparison already made between the cost of boiler and battery power, renders the former, as applied in this way, immensely superior to the latter, and proves the loss in producing electricity to be less than in bringing either water or compressed air to a similar state of stored up energy.

(2.) But the next point is to examine the further loss, viz., in turning the current so produced into work; and this is by no means so easily determined, nor does it yet appear to be a settled question. An electric current may drive either an electro-magnetic engine, or a magneto- or dynamo-electric machine, and the result is theoretically the same. The principle by which motion is caused is the attraction of two pieces, one fixed and the other movable, which may be either one or both temporary magnets, and with this effect: as long as the driven machine is at rest, the full force of the current is expended in overcoming the resistance of the circuit, but immediately upon the load being so reduced that a slow motion is the result, the needle of a galvanometer placed in the circuit will be deflected, showing a diminution of current strength. This is caused by the return current, which it is obvious—at any rate with a magneto or dynamo machine—must be produced immediately it begins to rotate, as it may be supposed to generate an independent current, opposing the original one. Now, the expenditure of energy in the first machine—or the consumption of zinc, whichever it may be, as either may be supposed to be producing the current—is thereby reduced; and this reduction will continue as the speed of the driven machine increases, the needle of the galvanometer showing all the while a fall in current strength. The load on that machine must be of course correspondingly reduced, and the theoretical limit is easily seen to be that point where there is no load at all upon it, the return current equal in strength to the original one, and therefore no current passing, and the velocity of the second machine equal to that of

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the first, and therefore driving it with equal force to that with which it is driven by it; or if a battery be used, the velocity of the driven machine would depend in a definite way on the battery, producing an equal and similar effect. These conditions it is of course impossible to realise; for, as it is evident that then no work is being done by the source, the friction of the driven machine in practice would prevent this limit being attained. But it is possible to conceive the friction being so reduced that the limit may be closely approached; although as the load is reduced, the useful work done will grow less, and will bear a decreasing proportion to the work wasted in friction. It becomes a most important point to consider the extent to which this can practically be carried—that is, what is the load and corresponding speed giving the highest efficiency?—and is, in fact, an answer to the question as to the amount of work reclaimable from the electric current. In the first place, it must be noticed that the work done at the two limits, viz., when at rest, and when no current is passing and the machine has its maximum velocity, is zero; and it can be proved in several ways that, as might be anticipated, the greatest amount of work in a given time is realised half-way between these limits. In fact, when the return current is just equal to the forward one, then the efficiency is $\frac{1}{2}$, or the work reclaimed is 50 per cent. This fact was stated in a Paper read before the Institution[1] by Dr. P. Higgs and Mr. R. Brittle, Assoc. MM. Inst. C.E.; in which it was also said that, "supposing two equal machines arranged for the transmission of power, the amount of work reclaimable from the second machine will be 50 per cent. of that employed upon the first, and the number of revolutions of the armature of the second machine corresponding to the maximum of work reclaimed will be half the number made by the first." Experiments were made with a steam engine as prime mover, which showed in one case as much as 49 per cent. of returned energy, at which point the number of revolutions, as nearly stated above, was 1,400 for the driving machine, and 691 for the driven; in other cases the maximum percentage of work returned also corresponded nearly to these conditions, and curves were constructed showing the maximum percentage of work as ordinates, and the revolutions as abscissæ. If, however, 12 per cent. of the work be lost in obtaining the current, then, according to the above theory, only 44 per cent., which is half the remainder, is the amount of work finally reclaimable. Work reclaimed was measured by a

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lii., p. 36.

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dynamometer, which does not register the work done against the friction of the second machine; and this, taken in conjunction with the significant shape of the curves, which all show a more gradual slope as the revolutions increase, after the highest ordinate, and when the ratio of work lost in friction is also increasing, may put the point of maximum efficiency beyond that where the revolutions of the second machine are ½ those of the first, and nearer the point suggested by Dr. Siemens, viz., ⅔ of this. This important question was discussed by Professor W. E. Ayrton, Assoc. M. Inst. C.E., in a discourse delivered to the working men of Sheffield, at a meeting of the British Association for the Advancement of Science in 1879, on "Electricity as a Motive Power." He considers that, by obtaining a high speed with the first machine, and also with the second running with a light load, "the combined efficiency of the arrangement can be made to closely approach the square of 0·86, and not merely one-half, as commonly supposed."[1] The high speed being necessary to develop a reasonable amount of work in a given time with a light load, the above conclusion really means that the only work lost by the transformation of the current into work need only be just the same as in the production of the current. This being possible, even in theory, would enable it to be predicted that the 49 per cent. already referred to could be considerably increased by improved mechanical construction.[2] Some experiments by Professor W. C. Unwin, M. Inst. C.E., the drawings and data of which he has kindly placed at the disposal of the Author for publication, seem to have a decided bearing on the subject, as they appear to indicate that the theory which requires a light load, in order to obtain a high efficiency, is modified in an important manner by the friction of the machine itself. The current was obtained from a battery, but the conclusions as to the driven machine seem in no way altered. Fig. 25 is a general view of the arrangement adopted; A is a Howe electric motor, of which Fig. 26 is a sectional sketch showing its general design. It consists of a revolving axis, on which are four electro magnets, B B B B, and which by means of five fixed electro magnets, A A A A A, receives twenty attractions in a revolution. The motor drives a brake wheel, C, by means of a band, D, and also an apparatus, E, for recording the number of revolutions. The brake designed by Professor Unwin, although it appears

[1] *Vide* "The Electrician," vol. iii., p. 191.

[2] Since the foregoing was written, Dr. Siemens has stated in a lecture at the Royal Institution, that 60 per cent. had been obtained.

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to have been previously used by Mr. Bramwell, is a most convenient one for small powers, and merely consists of a band passing over C, having a Salter balance on one side, and a scale pan on the other, a side view of this being shown in the figure to the left. Then

P = Force in pounds on brake-rim = pull in balance — weight of and in pan.

V = speed of effective pulley-rim in feet per minute.

$P \times V$ = foot-pounds per minute.

The time of 100 revolutions was taken by a chronograph in fifths of seconds, and a Table is given of the results of six series of experiments of batteries of various kinds and powers. In the three marked * (Fig. 27) the batteries did not work properly; still the results are given with the others as leading to the same conclusion. From the Tables the experimenter constructed the curves shown in Fig. 27, which have for ordinates the actual work done in foot-pounds per minute, and for abscissæ the number of revolutions per minute.

Now, according to theory, if there were no friction in the machine, the work should vanish for a number of revolutions just double that at which the work was greatest; that is to say, the ordinate should become zero at a distance from the origin just twice that at which it is a maximum; but in every case this, as would be expected, takes place at a point not only less, but very considerably less, than twice this distance, which means, that at the higher velocities the friction due to the machine itself (assuming the friction due to the load to vary with the load) bears a considerably increasing proportion to the useful work done, and finally causes the latter to vanish, so as to affect in an important way the theoretical efficiency. Assuming the attractions to act so that their influence on the friction is balanced, and the effective circumference of the pulley to be 1 foot, then an expression similar in form to the following will obtain:

If W_1 = load,

W_2 = load due to machine itself,

n = number of revolutions per minute,

μ = some multiplier for friction,

then $n\{W_1 + \mu(W_1 + W_2)\}$ = work done per minute.

Now, as n is increased, W_1 must be diminished, and finally when W_1 vanishes and n becomes N,

$$N\ \mu\ W_2 = \text{work done};$$

which may be considerable, but is all wasted in friction, this

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quantity being most important in the question of the possible highest efficiency.

Referring to the curve with six Bunsen cells, the maximum useful work is seen to correspond to 300 revolutions. Now the reading of the galvanometer, which was taken for each experiment, when properly reduced, shows a reduction in current of nearly one-half, thus proving this to be nearly the position of maximum total work; and accordingly, by theory, the efficiency should be also nearly one-half; but assuming 12 per cent. of the work to be lost, as already explained, in obtaining the current, the greatest return of work would be one-half of 88 per cent., or 44 per cent. Now the efficiency would approach 88 per cent. as the revolutions approached 600, but the useful work vanishing at 430, the highest possible efficiency could not exceed $\frac{88 \times 430}{600} = 63$ per cent. But the effect of friction is such that in the present case anything like this is quite unattainable.

The foregoing reasoning cannot pretend to do more than point to the practical bearing that the friction due to the weight of the motor, and its connection, by bands or otherwise, with the work to be done, has upon the efficiency at high velocities, showing that for small powers it is likely to be nearer 50 per cent. than 80 per cent. Messrs. Higgs and Brittle failed to obtain more than 49 per cent., their mean result being $44\frac{1}{3}$ per cent. There is a further point to be noticed in connection with the effect of reducing the scale of operations, viz., that with six Bunsen cells, the best results were nearly three times as great as the best results with three, instead of twice, given by applying Ohm's law; and again, that the number of revolutions for which the useful work was a maximum, and also the number for which it became zero, was less as the battery power decreased, showing that the ratio of loss by the friction of the machine increased with lighter loads and higher speeds.

Still it may be assumed that an efficiency of 50 per cent. may be expected, even on a small scale of application, and this compares favourably with that obtained with other agents. For instance, it is greater than with compressed air, and, under the conditions now considered, than with water; whilst the necessary use of pipes, respectively air- or watertight, is certainly more expensive than the use of wires, and in point of convenience also the advantage is greatly on the side of the latter; so that it is probable that the use of electricity will, before long, be applied for many purposes to distribute power and to take the place of the other agents, and even of lines of shafting.

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Section III.

In the foregoing section the efficiency of each agent has been stated, as far as possible in terms of the fuel used, but this is only one factor in the question of their relative economy, which includes—

First cost { Outlay on apparatus, taken in connection with probable durability.
Expense of working { Cost of agent and its efficiency.
Cost of attendance, repairs, &c.

Now in the present state of small motors, which is not a settled one, the cost of apparatus for some agents, such as gas or electricity, has, it is to be hoped, by no means reached a minimum; while for others, steam, water, and hot air, competition has brought prices to a point below which they cannot be much reduced. Moreover, the question of durability and repairs is with some of them difficult to settle. Again, the same agent may have very varying efficiencies in different motors; while, lastly, an examination of the price lists will show how different are the prices quoted by various makers for the same kind of engines and of the same nominal power. This latter discrepancy partly arises from the present unscientific procedure of defining "nominal" apart from "actual" HP., the evils arising from which would be considerably modified if the pressure, number of revolutions, and the actual power were to be advertised as well as the price, as done by Mr. Brotherhood and others; this would enable the purchaser to judge for himself, and thereby avoid the anomalous varieties in advertised power which visitors to agricultural shows must have noticed in connection with some small motors, and which must be quite inexplicable to the uninitiated. Variation in quality and workmanship has also, of course, a good deal to do with the difference alluded to. For the foregoing reasons it seems impossible to give a tabulated, or even concise, comparison of the agents, as far as their relative cost and efficiency is concerned; but this is, after all, not so important on a small scale as on a large one, the differences not being so great as to make this, in the majority of cases, the predominant one, which is more often rather one of suitability, and which can only be discussed by considering the objects for which the power is required, many of which have been already incidentally mentioned, and which may require either constant or intermittent use, and may give security, regularity, cleanliness, or compactness more or less importance. Therefore, as

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stated at the commencement of the Paper, it seems most satisfactory to discuss their relative advantages in connection with the purposes to which they are applied. In order to do this it must be remembered that the great increase in the number of small motors is the natural result of the progress of applied science, by which the substitution of machinery for manual operations tends to bring about a displacement of muscular effort by the application of natural sources of power; but it is important to observe that this is taking place under two different conditions.

(1.) Where an extensive source of power is not directly available, as in small isolated factories, in shops, private houses or in the country.

(2.) Where—as on board a steam-ship, or a large factory, or in a system of docks—there is already a supply of the working agent on a large scale, often for driving a prime mover of considerable size, which supply may in many ways be turned to use by small motors, for superseding manual labour.

These conditions may materially modify the conclusions as to the choice of a small motor. For instance, the steam engine which is less economical than the others, was shown to be so chiefly on account of the small boiler, but may give a very different result if supplied with steam from a large and efficient one, where, in addition, one attendant only is required, for perhaps a score of engines instead of for the single small one; so that these two cases will be treated separately.

(1.) A special aspect of the former has been considered in the pamphlet by Peter Hell, already referred to, in which the writer earnestly advocates the increased application of small motive power, now to be obtained at moderate cost, for the revival of the domestic industries of Germany, which have suffered so severely from the introduction of large factories with powerful engines. He takes as a particular example the case of the weaver, who might, he considers, be restored to his former position of comfort, by the use of a small cheap motor, and "might be himself able to employ his supposed deadly enemy, the mechanical loom."[1] He also deals briefly with the use of small motors for agricultural purposes. This accounts for the conclusion arrived at by him, viz., that the only suitable agents are gas and hot air; his opinion being that the motors of Otto and Langen, for the former, and Lehmann's "closed" and the Hock "open," for the latter, are the most efficient. From what has been shown, there is no doubt that the

[1] "Klein-Kraft-Maschinen," p. 9.

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conclusion, as far as the agents themselves go, is, under the special circumstances, a sound one. For small manufacturers, for private individuals, in shops, &c., and for the many subsidiary industries carried on in the large towns of this country, the recent silent gas motors have supplied a long-felt want, this being abundantly testified by their remarkable sale. Gas is immediately accessible, no special attendance is required, the engines work in the same room with the other machinery, performing the most delicate work; they are clean and noiseless, and always ready at a moment's notice to commence work. Some of these advantages pertain to the use of hot air, and one is certainly common to both, viz., the obviation of all danger of explosion, a consideration of great importance. But the great disadvantage of hot air is the limited power which small engines develop; though for light purposes, where gas cannot be obtained, the hot-air engine of Rider, or Lehmann, forms an efficient substitute. In analysing the list published by Messrs. Crossley Brothers, of the silent gas engines sold by them during the two years or so since their introduction, 40 per cent. of the 3½ HP. went to small manufacturers, including boot and shoe manufacturers (of which six went to Bristol alone) jewellers, turners, and for sawing, weaving, clock-making, spring-making, and aërated-water machinery and for many like purposes; while 31 per cent. of the 1 HP. were supplied for printing and lithographing machinery, for which, especially the latter, the absence of dust and dirt is a desideratum. For the foregoing purposes and for lifts for hotels, infirmaries, warehouses, &c., the slight attendance required with gas or hot air is a great advantage, a small steam engine being really a troublesome thing, the regulation of the water to the boiler, &c., requiring almost the full attention of one man. Water from the mains may, however, be conveniently applied to all the purposes mentioned where, as in Glasgow or in Greenock, it is cheap and under considerable pressure. It possesses all the advantages already claimed for gas or hot air, with the additional one of absolute immunity from the danger of causing a conflagration. Mr. Hastie, of Greenock, in a letter to the Author, states that "the purposes to which water motors are applied in Glasgow are as follow:—hoists, very extensively; by carpenters, for working circular saws; by bookbinders, bakers, hairdressers, at churches for organ blowing, in public institutions for washing and wringing machines, and also for chaff cutting and meat mincing." He goes on to say that the expense for water is in some cases very little; in one case, to a printer, it was 9*s.* per quarter, and in many cases in Greenock the

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minimum rate charged by the water company, viz., 20*s.* per quarter, is not exceeded. However, these liberal terms, unfortunately, cannot be obtained in the majority of large towns, and then gas is generally the best agent.

For private houses, laboratories, and shops, where the power required is often little more than nominal, and its use intermittent, the small first cost of a water engine (the Ramsbottom being about £30), in conjunction with the other advantages, may be often sufficient to more than counterbalance the high rate of the water from the mains; but for such purposes, especially when a water meter is used, the custom of charging a high minimum rate, often considerably exceeding the actual cost of the water used, stands in the way of its adoption. In one case in Bristol a minimum rate of £20 per annum is charged for three pairs of small engines, which are only required for six or eight hours per week. In the country a small fall of water from a stream may often be used for pumping purposes, when a water wheel or small turbine affords a very efficient method of utilizing it.

One application of gas not yet mentioned is that to the electric light. It is found for some purposes more economical to use gas indirectly to produce illumination, rather than to use it directly. From the Paper of Mr. Alexander Siemens, read April 2nd before the Society of Telegraph Engineers,[1] it appears that a saving of from 47 per cent. to 87 per cent. is thus obtained. In the British Museum a saving of 60 per cent. is effected by the substitution of electric light for gas; but in this case the motor is a steam engine, and it is necessary to keep the fires alight all day in order to be ready at a moment's notice, the cost of attendance being 1·2 of the light itself. In the Albert Hall the saving is, in the same way, 66 per cent.; so that, whilst the absolute cost of steam is perhaps less than that of gas, its convenience and readiness of application are also less. Where gas is not available, then steam, supplied generally by portable engines, must be used.

For agricultural purposes gas is out of the question; and where water-power is inaccessible, as is generally the case in this country, either steam or hot air must be resorted to. For purposes requiring much power—as thrashing, ploughing, &c.—steam must hold its own; but for light work, such as fodder-cutting and pumping, the hot-air engine is beyond all doubt the most suitable, that of Rider, which is semi-portable, and requires no skilled attendant, being often used.

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[1] *Vide* "Journal of the Society of Telegraph Engineers," vol. ix., p. 89.

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For purposes where small portable motors are required—as for contractors' work, for cranks, for rather large pumps—small vertical or horizontal steam engines and boilers will no doubt always be used, from the fact of the considerable power developed by them in comparison with their weight and size.

(2.) In the second division, where a source of power is already at hand, the circumstances are altered. On a steam ship or in a large factory, where there is an abundant supply of steam, produced economically because on a large scale, no other agent can compare with it. In the first instance, viz., on a steamship, where the area of distribution is limited, this is especially the case; and for steering, hoisting the cargo and anchor, turning the capstans and windlass; for ventilating, pumping, &c., small auxiliary steam engines are invariably used, when these duties are not performed by hand. In the second case, it is often found to be more desirable to use auxiliary engines, for driving machines—as for instance the centrifugal machine in a sugar-house, or the punching and shearing machines of a shipbuilding yard, both these being formerly driven by shafting; but to the former small Brotherhood three-cylinder engines are often now directly applied, and the fluctuation in speed on the main engine, caused by the intermittent use of the machine, is thus avoided, and a much smaller one required.

Again, in a system of docks where an accumulator is used for supplying water under great pressure for large cranes, it is more convenient to use small high-pressure water-engines than any others. For instance, in connection with the Cumberland basin, Bristol, there are twenty-three sets of small oscillating water-engines, supplied by Sir W. Armstrong, there being sixty-six small cylinders used, averaging not more than 2 or 3 inches in diameter; these are applied to move the bridges, gates, and capstans connected with two docks, and are easily and rapidly put into operation. During the last two winters of severe frost, not a single accident has happened through the bursting of pipes, and the suitability of water for this purpose is undoubted. In a large system of warehouses, such as at Birkenhead, water-power is certainly to be preferred to any which necessitates the introduction of fire or light, and at Hull the system has received considerable development.

The conclusions are, briefly, that gas is generally to be preferred as an agent for small manufacturing operations—for hoists in buildings, &c.; but water and hot air both have decided advantages—the former, when obtainable at a low rate, the latter for light purposes, when neither of the others are available. For private houses, shops, &c., water, even at a dear rate, may often

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be applied. The proper applications of steam have been indicated, and though likely to be more and more superseded by the other agents in the foregoing cases, particularly by gas, yet there is a large field in which small steam engines must continue to hold their own.

In conclusion, the Author wishes to record his thanks to Professor Unwin, for the data and suggestions supplied by him; to Dr. Main, Professor of Mathematics and Engineering, University College, Bristol, and to Messrs. C. D. Selman and A. W. Metcalfe, students; as well as to those gentlemen who have allowed him to test their engines, or have supplied him with information.

The communication is accompanied by numerous diagrams, from which Plate 11 has been prepared.

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(*Students' Paper No. 120.*)

"Light Draught Steel P. S. 'Terranora,' for Ocean and River Navigation."[1]

By JOHN AUGUSTUS THOMPSON, Stud. Inst. C.E.

IN the year 1878 a requisition was received from Australia for a paddle steamer to fulfil the following conditions:—

To carry 200 tons weight of cargo; two days' consumption of coal, say 15 tons; passengers, with luggage, crew, provisions and water for two days' consumption, say 6 tons; making a total weight of 221 tons; and the steamer was to act as a tug-boat when required. Her draught of water, so laden, was not to exceed 5 feet 9 inches in fresh water; and without the 200 tons of cargo, it was not to exceed 3 feet 5 inches; and the right was reserved to the purchasers of rejecting the vessel should such draught be exceeded.

The dimensions of this vessel were strictly limited to—length, 141 feet 6 inches; beam moulded, 27 feet; and depth moulded amidships, 10 feet 3 inches. These dimensions gave a builder's tonnage of 485 tons, and worked out a gross register tonnage of 349·58 tons. After making deductions for propelling and crew spaces, amounting to 150·38 tons, the net register tonnage was 199·20 tons. It was further a *sine quâ non* that the vessel should make the voyage to Australia fully laden with coal.

The above order was placed in the hands of a firm, with which the Author is associated, to superintend and see carried into effect; and the whole came under his observation.

On going into the calculation of displacement, it was found that, upon the dimensions given and the limited immersion prescribed, the lines of the vessel would require to be as full as possible, and a coefficient of 0·7 was adopted; it was also found that the hull must be built of the lightest possible scantling. To have followed the ordinary rules for building iron vessels of this size would have resulted in the vessel being too heavy; and consequently steel was

[1] This communication was read and discussed at a meeting of the Students on the 30th of April, 1880, and was awarded a Miller Prize.

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selected, affording equal strength with less weight than iron. The principal items were as under:—Frames of steel angle bars $2\frac{1}{4}$ inches by $2\frac{1}{4}$ inches by $\frac{5}{16}$ inch, spaced 24 inches apart generally, but 21 inches apart in the machinery room. Reverse frames of steel angle bars 2 inches by 2 inches by $\frac{1}{4}$ inch on every frame carried up to the deck. Outside plating, sheer strake $\frac{5}{16}$ inch thick for a length amidships of 70 feet, and tapering down fore and aft to $\frac{3}{16}$ inch; and all the other plating followed the same disposition. Beams on every frame of steel $2\frac{1}{2}$ inches by $2\frac{1}{2}$ inches by $\frac{3}{8}$ inch amidships, reduced to $\frac{5}{16}$ inch and $\frac{1}{4}$ inch at the ends. These scantlings were the extreme of lightness, seeing that the vessel had to make a sea voyage of several thousand miles.

In addition to the ordinary longitudinal stringers, two fore and aft bulkheads, running nearly the entire length, were introduced so as to divide the cross section of the vessel into three compartments. These bulkheads, in the engine and boiler spaces, were built watertight, being plated up from the bottom to the deck, and forming the sides of the coal bunkers; whilst in the cargo holds they assumed the form of lattice girders, in order that the stowage of cargo should not be interfered with, which would have been the case had they been plated up as in the engine-room, and then two separate hatches would have been required for each compartment of the hold to give access from the deck. These longitudinal strengthenings were designed to protect the vessel against the upward pressure of the water acting on so large a flat surface as that presented by the bottom, as well as the liability to straining when only partially waterborne in a sea way.

Four athwartship bulkheads were placed as follows:—One forward, being the collision bulkhead; one at each end of the engine and boiler space; and one aft. These all reached from the outside plating or skin of the vessel, and were secured to the upper deck beams. One peculiarity of these bulkheads was, that no sluice-valves were permitted, but the pumps were led into each compartment, so that in the event of accident, through stranding or collision, there would be no chance of a sluice-valve being left open and allowing the water to enter two or more compartments and sink the vessel. In this way the effects of injury would be localised.

As an element of strength the deck was made of steel, but it was not sheathed with wood. For the hot climate in which this vessel was intended to trade a wooden sheathing would have been better, but the additional weight prohibited its use.

To secure good steering power in light draught vessels the rudder

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must be of ample size, and its largest dimensions should be at the water line. Such would have been observed in this case but for the fact of the vessel having to make a long ocean voyage; a smaller rudder was therefore fitted, which although answering tolerably well, still required great attention when the ship was under steam. On arriving in Australia a rudder was shipped of dimensions suitable for river work.

The vessel was built by Messrs. D. and W. Henderson, of Glasgow, and was fitted by that firm with a pair of surface condensing diagonal disconnecting paddle engines. The principal dimensions and design of the engines were:—Diameter of cylinders, 30 inches; length of stroke, 4 feet 6 inches; condenser cooling surface, 800 square feet; boiler heating surface, 1,290 square feet; boiler grate surface, 60 square feet. The cooling surface of the condenser is large in proportion to the HP. that should be indicated by cylinders of this diameter; but it was necessary that it should be excessive on account of the high temperature of the water in the shallow rivers of Australia. The circulating pump was one of Gwynne's manufacture, being of the centrifugal type, and was driven by its own engine, which exhausted into the condenser. Each engine had its own air pump, driven by an eccentric; and the feed and bilge pumps were bolted on to either side of the air pump, and driven off a crosshead secured to the trunk of the air pump. The boilers were two in number, oval in shape, and of the ordinary return tubular type, built principally of steel. The shell-plating was made of mild steel $\frac{5}{16}$ inch thick, double riveted in the circumferential seams, and treble riveted in the horizontal seams. The furnaces, combustion chamber, plates and back tube-plate were of Farnley iron, that material being considered preferable to steel, when exposed to the direct action of the fire. There were seventy iron tubes, $3\frac{3}{4}$ inches diameter, in each boiler. The staying was arranged for a working pressure of 45 lbs. per square inch, and on the flat sides of the oval there were stiffening plates of iron, 27 inches broad by $\frac{3}{8}$ inch thick, for the entire length of the boiler, through which the athwartship stays passed.

This vessel when in the water with steam up, and coal, water, and stores for two days, had a mean draught of 3 feet $3\frac{1}{2}$ inches, leaving $1\frac{1}{2}$ inch to the good.

The trial trip took place on the 13th of September, 1878, when the vessel steamed from the Meadowside dock, on the Clyde. She was under steam at 9 A.M., and got under weigh at 10 A.M., with a draught forward of 3 feet 9 inches, and aft of 3 feet 11 inches, a

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pressure of steam of 24 lbs. per square inch, the engines making twenty-seven revolutions per minute, gradually increased to thirty-four revolutions per minute. At 1 P.M. the engines were running at thirty-three revolutions, with a pressure of 22 lbs. of steam per square inch, and 26¼ inches vacuum, the barometer on deck standing at 29½ inches. During the afternoon experiments were made with the expansion gear, cutting off at various portions of the stroke from ¼ to ⅝; indicator figures being taken at the same time. The disconnecting clutch was used, the engines working separately at the rate of about thirty-four to thirty-six revolutions per minute. At 4.52 P.M. she was put past the first mile-post, and at 5.25½ P.M. had run a distance of 4 statute miles against the tide, which tide might be taken at 2½ miles per hour, thus giving a rate of speed of 9·88 miles per hour; the engines on the average making thirty-three revolutions per minute, with 25 lbs. of steam and 26¾ inches vacuum. The vessel then proceeded to the Meadowside dock, and the engines were stopped at 6 P.M., it being considered unsafe to run the vessel in such a river as the Clyde after the day had closed.

During the whole of the run the engines and boilers worked most satisfactorily, averaging thirty-four revolutions per minute, 25 lbs. of steam with 26½ inches vacuum, the engines indicating 270 HP. At no time were the engines and boilers pressed to their utmost; although, had it been desired, there is no doubt they could have been forced to develop a much greater power; but, bearing in mind the long voyage the vessel had to make, it was not thought desirable to press the machinery beyond a fair ordinary day's working at sea. Care was taken during the day to examine the foundations and fastenings of the engine, and these were all found to be satisfactory in every way.

Having had her official trial with results that were deemed highly successful, she was loaded with 200 tons of coal, and her spare gear and sea stores were also put on board, the draught of water then being 5 feet 6¾ inches, or 2¼ inches under the maximum permitted, equivalent to 16 tons displacement to spare. Being so freighted she left the Clyde on the 26th of September, 1878, and made a successful voyage under steam to Sydney, *viâ* the Suez Canal, without injury to hull or machinery, or mishap of any kind, and when near her destination was able to tow a stranded ship off the rocks. The average consumption of coal throughout the voyage was about 8 tons per diem.

This vessel presents a practical example of the advantages offered by the use of mild steel, manufactured by the Bessemer or

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Siemens-Martin processes, in the construction of light draught cargo steamers especially, or indeed for ships and steamers generally. The tests applied to the material used in her construction were severe, and proved eminently satisfactory. It is evident that great advantages and substantial benefit will be found to accrue from the use of steel in preference to iron; but the question of oxidation is a serious one when so great a reduction in scantling is adopted, and it remains to be seen to what extent that will operate adversely to its use for these purposes.

The Paper is illustrated by several drawings and diagrams, from which Plate 12 has been prepared.

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(*Paper No. 1703.*)

"Notes on the Principal Systems of Electric Light in use in England and in the United States."

By KILLINGWORTH WILLIAM HEDGES, Assoc. M. Inst. C.E.

ALTHOUGH the progress of the application of electricity to lighting purposes has not been so great as predicted, during the year 1879 some large installations of the light have been made with success. The details of the various systems of electric lighting in use here have been so fully described[1] that it is not thought necessary to more than briefly mention the most important work to which each light has been applied.

The following remarks only treat of those machines that give a continuous current, which in every instance was used to produce the voltaic arc, mainly because they are of the kind principally employed, and because the working of the best known alternating system, the Jablochkoff, has been fully discussed. The exhibition of the light nightly on the Thames Embankment is familiar to all.

The three systems which have made the most progress in practice are,—the Gramme, the Siemens, and the Brush. The latter will in all probability prove a formidable rival to the two former systems, and as its success in the United States proves that the electric light can be subdivided with economy, the means employed deserve attention.

The most important installation of the electric light during the year 1879 was probably the lighting of the Picton Gallery, Liverpool, for which purpose the Gramme machine was employed. This is a large building used as a public reading room, and is somewhat of the shape of the Albert Hall. The method adopted is by reflecting the electric light from the ceiling. Three Serrin lamps are enclosed in an umbrella-shaped reflector, which screens the direct rays from the observer's eye, and throws the light upwards. Although by this plan light is lost by absorption,

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lii., p. 36. *Also* Institution of Mechanical Engineers. Proceedings, 1878, p. 529.

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the intensity is not so marked, nor is the eye so fatigued by the glare. With the exception of a certain amount of hissing noise, which appears inseparable from the electric arc with carbons as now made, the lighting of the gallery may be considered a success. The actual cost of the electric light is 1*s.* 9*d.* per hour, including carbons (9*d.* per hour), interest, depreciation, wages and coals, as compared with 7*s.* per hour for gas lighting. In this case the electric light was adopted after a fair competition with what was considered the best system of gas lighting, solely on account of its cheapness. The gas burners are occasionally lighted for the purpose of warming the building, showing what a small effect the electric light has on the temperature. The St. Enoch Station, the terminus of the Glasgow and South Western Railway, was at first lighted by five Serrin lamps fixed near the roof, and arranged so that the rays of light were thrown in a direction parallel with the platform. The roof was boarded over on each side, and formed a species of reflector which equalised the distribution of the light. A plan suggested by Sir William Thomson is now adopted, having been found to give a better result. Six Crompton lamps arranged in lanterns having octagonal mirror reflectors, are slung about 35 feet above the platform, and 27 feet from the side walls. The span of the roof is 198 feet, and the height from the platform 80 feet. Each lamp is connected with a Gramme machine, of the nominal power of six thousand candles, the conductors being led along the outside of the roof. All the machines are worked by a small horizontal engine, fixed in the basement of the adjoining hotel, and used during the day for laundry purposes. By the use of this engine the cost of working and attendance is largely reduced, steam being available as soon as the lights are required. The cost for the six lights is 3*s.* per hour, including carbons, but independent of the driving power. The interior of the station is well illuminated, in a manner which was found to be impossible with the gas lighting as arranged previously, the cost of which was 4*s.* 5*d.* per hour.

The Gramme machine has also been adopted for lighting several ocean steamships, and for the process of photolithography.

The Siemens machine has been largely used, and it is worthy of notice that this system was the first to be employed for street lighting, on the arrangement advocated by Dr. Siemens, and known as light centres. The esplanade of the town of Blackpool is lighted by four lamps, each worked by a separate Siemens

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generator. The lamps are fixed on the top of poles, about 60 feet in height, and enclosed in a lantern furnished with a reflector that throws the light for about 150 yards in each direction. A similar arrangement is placed on each of the piers.

The total cost of the lighting by six lamps, with a power of six thousand candles each, is stated by Mr. Alexander Siemens to be for five hours £3 6*s.* 10*d.* for electricity, against £7 5*s.* for gas, showing a saving of 54 per cent.[1] This gain is mainly due to the situation of the work, but as a rule it is doubtful whether this or any other application of the voltaic arc to street lighting will at present compete with gas, if the latter is properly employed. The plan advocated by Dr. Siemens is decidedly more economical and effective than that of having numerous lamps as in the Jablochkoff system, but the larger lights are at first fatiguing to the sight.

A new form of gas burner, designed to give similar illuminating power to the electric light used for street lighting in Paris, is now being tried in competition with the latter. As this gas burner is arranged so that the light can be turned down to that of an ordinary street lamp at the same time as the electric lights are extinguished, a fair comparison can be made.[2] The area illuminated by this burner is much larger than that from the small electric arc of the Jablochkoff candle, thus reducing the effective illuminating power of each of the latter to less than that of a group of six jets burning at the most 45 cubic feet of gas per hour.

The Siemens system has been successfully applied to the experimental lighting of the British Museum. In the reading room four ordinary lamps, supplied by separate dynamo machines, are used, each of which is said to be of the nominal illuminating power of six thousand candles. Taking the actual illuminating effect at four thousand candles, it would require two hundred and fifty Argand burners giving the light of sixteen candles each, and each consuming 5 cubic feet of gas per hour, to produce this amount of light, which, at the rate of 3*s.* 9*d.* per 1,000 feet, would cost nearly 4*s.* 9*d.* per hour. The cost of working the dynamo machine and that of the carbons to produce the light, may be taken at 4*d.* per hour, to which must be added an amount for interest, depreciation and repairs, which, however, would not bring the total cost to more than 8*d.* per hour, as against 4*s.* 9*d.* for gas. The

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[1] *Vide* Journal of the Society of Telegraph Engineers, vol. ix., p. 102.

[2] A burner of this description has been fixed at the corner of St. James' Street and Pall Mall, London.

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total cost as paid by the Museum authorities, including seven other four-hundred-candle lamps, amounts to 6*s*. per hour.[1] The saving in the cost of lighting one of the picture galleries at the South Kensington Museum by electricity was found to be one-half of the amount paid for gas.[2]

In America the system which has made the greatest progress is the Brush, the invention of an American engineer of that name. As this system has only recently been put to practical work in this country, a short description of it may not be inappropriate. Of the many instances where it is at work in the United States, it may be sufficient to quote that of the Willemantic Linen Company, where two lamps each costing 2*d*. per hour displaced sixty-two 5-feet burners costing 1*s*. 8*d*. per hour, the price of the gas being 4*s*. per 1000 cubic feet.

The Brush machine differs from the Gramme and the Siemens machines in several points. It is specially designed to generate and maintain a direct-acting current through a great external resistance. The ordinary practice, when such currents are required, is to employ two machines, a small one known as the exciter or primary machine, and a larger one, in which the current created by the primary machine is distributed in such a manner as to produce the amount of tension required. These currents then become alternating in direction. In the Brush system the primary machine is done away with, and an ordinary direct-acting current of high tension is produced, without any complication of coils. This is effected principally by the arrangement of the field magnets and annular armature, which consists of a wheel of large diameter, nicked out at intervals, to contain the coils. The inventor claims that although the resistance of the armature conductor, measured through the brushes on the commutator, does not exceed 4 Ohms, when the armature is rotated at the normal speed of seven hundred and fifty revolutions per minute, the electro-motive force developed in its conductor is sufficient to maintain a normal volume of current through an external resistance of 80 Ohms. The current thus operates from sixteen to eighteen lights placed in circuit, giving to each an arc of about 1½ millimètre. The division of the electric current is thus much more favourably accomplished than is generally supposed. The light given out by each lamp does not appear to the ordinary observer to be greatly

[1] *Vide* Journal of the Society of Telegraph Engineers, vol. ix., p. 102.

[2] *Vide* Twenty-sixth Report of the Science and Art Department of the Committee of Council on Education, p. 561; and Twenty-seventh Report, p. 530.

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augmented or diminished by altering the number of lights in circuit to a certain extent, although doubtless there is a loss of economy in driving power when only a few lights are used.

An account of some experiments with this machine in August 1879, for the purpose of ascertaining the amount of driving power absorbed by a 16-light machine, driven at seven hundred and seventy revolutions per minute, has been furnished to the Author by Mr. Brush. The following Table embodies the results obtained :—

		HP.	
Total power developed with the 16-light machine at 770 revolutions "closed"[1]		18·73	
Less friction load of engine "light"	2·44		
„ „ due to increase of load (18·73 − 2·44 = 16·29) at 5 per cent.	0·81		
		3·25	
Total power absorbed			15·48
Total power developed with same machine "open"		4·23	
Less friction load of engine "light"	2·44		
„ „ due to increase of load (4·23 − 2·44 = 1·79) at 5 per cent.	0·09		
		2·53	
Total power absorbed			1·70
„ „ in production of current (15·48 − 1·70 =)			13·78

Experiments were made to ascertain the amount of current furnished by the same machine. The first electric measurements were for determining the difference of potential existing at the terminals of each lamp. This was done by the use of a battery of forty-eight small Daniell's cells, constructed on the gravity plan, and carefully insulated. The sixteen lamps having been adjusted to furnish arcs as nearly equal as possible, the positive terminal of one lamp was connected with the positive terminal of the battery, and the negative terminal of the same lamp with the negative end of the battery, a sensitive galvanometer being interposed. Any number of battery cells could be included in the circuit at pleasure, and such a number was chosen that the galvanometer indicated next to no current. Each of the lamps having been measured, the difference of potential of the average lamp was thus found to be equal to 42·46 cells of the battery, at an average speed of seven hundred and seventy revolutions per minute. The resistance of

[1] The terms "closed" and "open" refer to the external circuit of the machine.

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each lamp was then found by the ordinary method—a coil of wire —to be, when measured, 4·51 Ohms. Taking the conditions of the difference of potential as above stated into account, the actual resistance of each lamp was 4·56 Ohms, which, multiplied by 16, gives the total resistance of the lamp circuit as 72·96 Ohms. The resistance of the machine itself was found by careful measurement to be 10·55 Ohms. This resistance, added to the lamps, gives a total normal external and internal resistance of 83·51 Ohms, of which 87·36 per cent. or 72·96 is external. Hence, an amount of 87·36 per cent. of the current developed is available for work. The total electro-motive force of the current was then easily found to be equal to 839·02 Volts, which, by Ohm's formula, would make the current in circulation equal to 10·04 Webers, with a total resistance of 83·51 Ohms. Calculations were made by Mr. Brush to show the amount of absorbed power converted into current, which was stated to be 81·89 per cent. Taking the percentage of current appearing as light in the arcs at 84, then $81·89 \times 0·84 = 68·79$ per cent. of the entire power absorbed in the production of current present is heat and light in the sixteen arcs.

There is no reason to doubt the accuracy of these experiments, which tend to prove the fallacy of supposing that division of the current would result in a loss of light. This latter opinion has been put forward by many telegraph engineers, notably by Mr. Schwendler, who, in his excellent report, says, "that the division of the electric light is impracticable, except at a heavy loss."[1] To understand why this statement was made it is only necessary to experiment with the machines used by Mr. Schwendler, and it will be found that beyond a certain limit it is uneconomical to continue the division of the current. However, experiments with the Gramme machine show that by increasing the speed and enlarging the diameter of the bobbin, a current of much greater tension is produced, and also that a larger amount of external resistance can be maintained. The coils in the Brush machine are arranged so as to pass through a very large magnetic field. It is not, however, advisable simply to enlarge the present type of single light machine with a view of making it operate a number of lights; it should be redesigned, and special attention should be paid to the important subject of ventilation, the overlooking of which has been the source of failure of more than one system. The Brush system is now fairly at work in London. At the South Kensington Museum

[1] *Vide* Report of Louis Schwendler to the Indian Government, 1878.

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two ten-light machines are used, and the Liverpool Street terminus of the Great Eastern Railway is nightly lighted throughout by thirty-one lamps. A contract has been concluded with the railway company to light the terminus at a price which shows a considerable saving over that paid previously for gas.

The question now arises as to which is the most economical system to employ for lighting purposes, the single or the multiple light? Both lights have their advantages, no rule can be laid down, but the exigencies of the case must govern the choice.

As previously stated, the great drawback of having numerous lights on one circuit is, that almost the same amount of power is required to drive the dynamo-machine, whether all the lights are employed or only a few. Thus, for example, in the Brush machine an amount of 13·78 HP. is required to produce sixteen lights; suppose ten of these are turned out, in each of the lamps extinguished the current is doing an equivalent of useless work, passing through a resistance coil attached to the lamp, which is necessary to ensure the uniform working of the series of lights. In the single-light system, directly a lamp is put out, the circuit becomes "open," and only the power absorbed by the friction of the machine is required to drive it. The great gain of the multiple over the single light is in the cost of conductors to lead the electricity from the machines to the lamps; and under certain circumstances, such as the lighting of railway stations, public parks, and factories, where a number of lights are required, it is certainly the best. For general purposes, especially where the electric light is the only source of illumination, it is better to employ several machines, each actuating two or three lights. In some cases, such as the lighting of engineers' shops and for contractors' work, the dynamo machine can be placed close to where the light is required, thus saving the cost of long conductors.

The difficulties which have interfered with the full development of electric lighting have mainly been those of minor details, which are being gradually overcome. The chief of these has been the lamps, or regulators, used for maintaining the position of the carbon electrodes. Nearly all of these are dependent on some elaborate arrangement for the control of the carbons. Almost all are wasteful, from the fact that nearly 25 per cent. of short lengths of carbon remain unconsumed.

A still more important point seems to have been overlooked, namely, the colour of the light. The electric light is composed of two kinds of rays; that from the carbons being white, while the

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arc itself is a blue light. For this reason a short arc is preferable to a long one in point of colour. It is useless disguising the fact that often, as at present arranged, the electric light is far from being a pleasant mode of illumination, the source of complaint being the abundance of violet rays, which, besides giving objects a bluish tinge, are absolutely useless. By breaking up the light by reflectors the rays are in a large measure rendered invisible. The simplest plan is to prepare the carbons in such a manner that the effect of violet rays is partly annulled by the rays from the substance introduced.

Most substances which do this increase the resistance of the carbons. After many experiments, the Author has found great advantage from the addition of iron to the carbons, either in the form of an oxide during the process of manufacture, or by depositing a thin coating on the exterior afterwards. If the latter means be employed the advantage is doubly apparent, as the iron coating gives greater conductivity without the drawback of the poisonous fumes of a copper coating. According to M. Carrè, the addition of iron enhances the value of the light in the proportion of from 1·6 or 1·7 to 1.

Experiments have also been made with a view of ascertaining the effect of causing the voltaic arc to heat to whiteness a block of lime in a somewhat similar manner to the lime light. Some difficulty was found at first owing to the disintegrating action of the arc producing a hole in the block. This was overcome by making the latter circular, and causing it to revolve slowly. The amount of light gained by the incandescence of the block was estimated at 15 to 20 per cent. A slightly reddish tinge in the light is probably due to small particles of the lime becoming consumed; but if found objectionable, this colour might be done away with by a better adjustment of the speed of the block, in proportion to the heat evolved by the arc.

The plan of lighting by means of a substance rendered intensely hot has been the subject of numerous experiments since the year 1845, and is now so far improved that it has been put to practical use.

In the autumn of 1879 it was reported that Mr. Edison had perfected a lamp, which was to work unattended for a considerable period. But the Edison incandescent lamp, with its vegetable carbon of horseshoe form, failed practically, not so much from its design as from the difficulty of working a number of lamps of this description, owing to their high resistance. Vegetable carbon has

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been experimentally used in France for incandescent lighting for some time,[1] but the heat evolved renders the glass enclosing the lamp liable to crack. The Edison lamp has been burnt for three weeks before the vacuum failed from this cause.

The two systems which have been worked in this country are the Werderman and the Andrè. The former consists of a long pencil of carbon, pressing lightly upwards on to a bun-shaped copper disc, which forms the negative contact and reflects the light downwards. Eight of these lamps were placed in the Art Library of the South Kensington Museum, and worked off a Gramme machine.[2] The light was steady and the room kept cool, but the cost was found to be greater than that of lighting by gas. The new library, where the lamps will be tried again, is much larger and more suited to the greater power of the electric lamps.

The Andrè lamp, as at present constructed, is an adaptation of that designed by M. Reynier in 1879, with the addition of a glass cylinder, which forms an almost air-tight casing round the carbon, on the plan used by Konn in 1875. The carbon in this lamp is 2 millimètres in diameter, and 1 mètre in length. It is contained in a tube and is pressed downwards by a weight on to a copper stud, which forms the negative contact. The current passes in to the carbon a little way above this stud, causing the small portion of carbon to become intensely hot. Eight of these lamps were used by the Author for lighting the Orient Company's steamship "Chimborazo," five being placed in the saloon and three in the steerage. This mode of lighting is particularly well adapted for steamships, owing to the absence of glare and shadows, the extra amount of power required to work the dynamo machine not being so important. All the lamps were arranged in series, and were worked from an A size Gramme machine. In order to make the lamps independent, it was found necessary to place a shunt and resistance coil between each. These coils give some trouble; they will probably be done away with by altering the current produced by the dynamo machine in proportion to the lights required. Until this is done, where a reduced amount of light is wanted, it is better to arrange the lamps so that they are alternately worked from two machines. One machine can then be stopped, with the effect of reducing the light by one-half, and the equivalent in power saved.

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[1] *Vide* Comptes rendus de l'Academie des Sciences, vol. xc., p. 64.

[2] *Vide* Twenty-seventh Report of the Science and Art Department of the Committee of Council on Education, p. 531.

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If 1 mètre length of carbon be used in this form of lamp, the light should be maintained for about twelve hours with the glass cylinder as ordinarily fitted. If extra precautions be taken to exclude air, the same lamp will burn nearly seventy hours, the rate of consumption for the first hour being about six times as much as each hour afterwards.

This description of lamp differs only from that of Edison's in that a partial vacuum is formed, due to the combustion of the oxygen, leaving the nitrogen, which has no effect on the combustion. The cost of the carbon employed is $4\frac{1}{2}d.$ per mètre, which, for the eight lamps of the "Chimborazo," makes a total cost of $3d.$ per hour. In this case the total amount of light from the incandescent lamps was not more than one-ninth of the total amount given out by an arc lamp which had been provided for illuminating the deck of the ship, and for general purposes when in port.

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MEMOIRS OF DECEASED MEMBERS.

General ARTHUR JULES MORIN was born in Paris on the 17th of October, 1795. Owing to his mother being attached to the Court of the Princess Elisa Bonaparte his early education was conducted in Italy, but he returned to France in 1814 to complete his mathematical studies at the École Polytechnique. The events in which the school was concerned in those troublous times constituted a grave cause of interruption to his studies, and prevented young Morin from being nominated for the public service in his year (1816). But in 1817 he came out first in some special examinations held at Metz by the École d'Application de l'Artillerie et du Genie, and he afterwards devoted himself to the Artillery, in which service he was destined, long before the close of his career, to achieve the highest grade.

His scientific aptitude manifested itself at once on his being released from the routine of the school; and when, in 1823, he was called as a simple lieutenant to take part in the Spanish war, the Commander-in-Chief was able to write of him, with reference to the siege of Urgel:—"Lieutenant Morin, of the 5th regiment of Artillery, has rendered most important services during the whole time he has been under my orders, exhibiting boundless zeal in the service of the king, and remarkable knowledge in the preparations for, and in the carrying on of, the siege of the forts. With such an officer all difficulties disappear. The construction of trestle bridges for the passage of troops and of artillery between the right and left banks of the Bolina and of the Segre; the preparation of depôts for the wounded and for warlike stores; the establishment of forges for repairing artillery, &c., and of furnaces for making charcoal, in a country destitute of natural resources; the superintendence of artificers in wood and in iron; and, in addition, the command of Captain Ginquele's battery on the death of that officer. Such were the services rendered by Lieut. Morin."

On his return to France, Morin was soon posted to Metz, as Assistant Professor of Mechanics; and it was in this position that he had the good fortune to edit and publish the celebrated "Leçons" of Poncelet, whom he was destined shortly after to succeed as Professor. This epoch in his career established his reputation as a skilful experimentalist, and it was also that part

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of it in which science profited the most. Encouraged by the Minister of War, who liberally placed at his disposal the necessary resources, he undertook his beautiful experiments on friction, on slipping, on rolling, on the traction of wheeled vehicles, on the resistance of belts; and in this way constituted himself the successor of Coulomb, who was obliged to content himself with much less efficient apparatus in his researches on the laws governing these phenomena. The improved processes were due in a great measure to the employment of different forms of dynamometer, of which the invention was itself characteristic of Morin's genius. What is perhaps less well known is the considerable share he had with Piobert and Didion in the remarkable labours of a commission, designated the Commission on the Principles of Fire-arms, but which were in reality neither more nor less than a determination by actual experiment of all the elements of ballistics, and of the most efficient employment of these arms. Of this vast programme the parts in which Morin was more personally concerned were the laws of the penetration of projectiles, of the resistance of air and water, and of hydraulic wheels, and, later on, of the study of all the known hydraulic motors.

After 1839 his time was divided between his duties of Professor at the Conservatoire des Arts et Métiers, Paris, where the Chair of Applied Mechanics had been specially established for him, and the various positions he successively occupied in the direction of the Government powder and saltpetre works. His election in 1844 to the Academy of Sciences of the Institute of France did not interfere with his devotion to his favourite studies; and his appointment, five years later, as Director of the Conservatoire des Arts et Métiers, only served to confirm him in these two branches of experiment,—the industrial applications of mechanical science, and useful researches on the improvement of modern weapons. In both directions it was reserved to him to achieve the greatest success.

As an artillerist, the different grades were, so to speak, thrust upon him as soon as the prescribed regulations made him eligible; and his official labours no more hindered him from taking part in the siege of Antwerp than from carrying out his various studies on the central Artillery Committee. Appointed General of Division in 1855, he made successively five general inspections, of which one was in Algeria; and it was also about the same time that he commanded the Artillery at the camp of Boulogne, where the late Prince Consort never ceased to lavish upon him marks of esteem altogether special. Indeed, General Morin was well known

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in England, not only by his scientific works but also from various military missions he had fulfilled in this country, for studying the English powder factories, and for arranging the supply of hydraulic presses for compressing forage for the Algerian campaign, which he had been charged to obtain from Messrs. Fawcett, Preston and Co.

The London Exhibitions of 1851 and 1862 had, moreover, brought him into relations of real friendship with William Fairbairn, with George Rennie, with John Penn, and especially with the Rev. Dr. Moseley, whose labours are highly appreciated in France, Mr. Scott Russell, and Mr. Charles Manby. General Morin was, naturally, a member of the Juries of these Exhibitions, and as a general Commissioner of the Paris Exhibition of 1855 he frequently had to concern himself, and with his customary fairness, with the interests of the English exhibitors. It may be added that of the French works which are known in England, the "Aide Mémoire" of General Morin is one of the most popular. This is easily explained by the circumstance that in it each question considered is accompanied by a solution concise, simple, exact and altogether in harmony with the genius of the nation. This earliest work of General Morin, brought up to date in each of its seven editions, is in reality a *resumé* of the numerous treatises published by him on different branches of mechanical science. His "Cours de Mécanique Pratique" was composed at first of three volumes: fundamental elements, hydraulics, and the steam-engine, but each of these parts has received since the first publication important developments. "Kinematics" was added to the fundamental elements. "Hydraulics" was increased by a treatise on water-raising machines; and the extended use of the steam-engine necessitated a considerable enlargement of that part of his work. One volume, and afterwards two others, were devoted to the strength of materials, and the "Treatise on Ventilation," originally in two volumes, was very advantageously followed by the "Guide pratique de Ventilation et de Chauffage," in which are perpetuated the same essential qualities which had been so approved in the first "Aide Mémoire."

In limiting the present notice to an account of General Morin's claims to distinction as an engineer, it will suffice to mention, his "Aide Mémoire," the numerous forms of dynamometer which he devised, and which allow of the measurement under all conditions of the work expended in industrial operations, his ballistic pendulum, in which the shock is produced at the centre of percussion, that is to say at a point where all vibration from the axes of

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suspension is annulled; lastly, his numerous works of ventilation, notable among which are the Corps Legislatif, the Châtelet, Gaîté, and Vaudeville theatres in Paris; and, above all, his studies on the sanitation of hospitals, a question on which he was always happy to be able to assist architects. He was also for a long time one of the Directors of the Northern Railway of France.

M. Tresca, Hon. M. Inst. C.E., who, having been associated for more than a quarter of a century with General Morin, knows perhaps better than any one else how to appreciate the nobility of his character, publicly expressed the following opinions at Morin's tomb:

"As a Philosopher his career was laborious, useful, and well filled, and he arrived at the first rank.

"As a Soldier he did his duty under all circumstances, in the field of battle as in the council tent. He occupied the lowest grades without complaining, while the highest ones, so to speak, waited for him.

"As an Administrator his life was fruitful in works of moment, and the 'Conservatoire des Arts et Métiers' alone would suffice amply as a monument to his memory."

General Morin was elected an Honorary Member of the Institution of Civil Engineers on the 2nd of March, 1875, on the grounds that "his many elaborate investigations in various branches of mechanics" had "tended greatly to advance and encourage the applications of science to practical purposes, more particularly in those branches of the constructive art which come within the province of the engineer." The distinction was one on which he set the highest value. It recalled to him a large number of friendships broken by death; and he was accustomed to say that the connection impressed him, if possible, more than ever with the duty of appreciating invention, especially such as was destined more or less to approach perfection in the means of production.

This man of worth died on the 17th of February, 1880, in the middle of his eighty-fifth year, after a short but painful illness, in the full possession of his reason and of the religious sentiments of his whole life.

Mr. JOHN LAWTON HADDAN was born on the 3rd of June, 1841. He was educated at a private school at Brighton, on leaving which he joined the classes for mechanics at King's College, London, where he early evinced a predilection for mechanical subjects. At this time he also attended lectures on chemistry at

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the City of London School, where his experiments in this branch led to several narrow escapes. His introduction to the engineering profession was as a pupil to Mr. Henry Ashton, architect and surveyor, with whom he remained from 1855 to 1857. He then entered the works of Messrs. C. De Bergue and Co. at Manchester, where he passed through the shops and afterwards the office. He attained considerable skill in modelling iron girder-bridges; one model about 20 feet long taking him more than nine months to complete. The late Mr. Charles Blacker Vignoles, F.R.S., Past-President Inst. C. E., was at this time constructing the Tudela and Bilbao railway, and he offered Mr. Haddan an appointment as chief draughtsman, from which he rose to take charge of a section, and finally of all the station arrangements, besides being occupied on calculations of the velocity of the river Ebro, deep-sea soundings for a harbour in the Bay of Biscay, &c. On leaving Spain he proceeded to India, and for two years was engaged by Mr. Berkley, M. Inst. C.E., on the preliminary surveys of the Sholapore to Raichore Extension of the Great Indian Peninsula railway, and in the survey of the town of Sholapore; but the climate not suiting his health, he again took employment under Mr. Vignoles, and was for two years occupied on the construction of the Warsaw and Terespol railway in Poland. On returning to England he entered the Surveyor's department of the Metropolitan Police, where he devised an ingenious plan for regulating London cab fares, which he entitled the "Course System."

In March 1868, he again left England, and until 1873 he held the responsible position of Chief Engineer and Director of Public Works for Syria and the Lebanon in the Ottoman service, and in that capacity constructed 45 miles of carriage roads, besides various iron and stone bridges, a model of one of which he prepared for the Sultan, who, for his services to the Porte, presented him with the Order of the Medjedièh. He projected the Beyrout water supply, built the College of Science and Arts, executed the Sejour irrigation works, and made surveys of the province of Syria for the Euphrates Valley railway, his report on which was embodied in the consular reports presented to the House of Commons. About this time the Emperor of Austria visited Jerusalem, and Mr. Haddan was deputed by the Porte to show his Majesty the objects of interest, and his Majesty presented him with a valuable diamond ring on leaving that city. During his service under the Porte he laboured under the disadvantage of having to train his staff, instruct native workmen, and prepare his own materials without the assistance of expert

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foremen as in Europe. From 1873 to 1875 he was in Constantinople in connection with narrow-gauge railways from Moundania to Broussa, the Ismid railway, and the Roumelian railways, and was appointed a member of the Technical Council of the Ministry of Public Works. In 1876, Mr. G. P. Harding, being much interested in the question of steam tramways of Paris, engaged Mr. Haddan as chief of his staff, and there he remained until 1878.

His extensive acquaintance with foreign countries and their requirements led him to devise a system of communication termed "Post and rail," being a single rail combined with a system of continuous driving for use in countries where the traffic would not support railways on the European system, and he devoted the major part of his time during the latter portion of his life to promoting his "pioneer" system of railways. It is believed that over-anxiety in regard to this matter hastened his death, which occurred at the early age of thirty-nine years, on the 17th of March, 1880. Mr. Haddan was elected an Associate of the Institution on the 24th of May, 1870, and was transferred to the class of Members in December 1873.

MR. WILLIAM JOHNSTONE was born at Bombay in September, 1844; but at an early age he was removed to Glasgow, where his scholastic training was pursued. Having displayed a liking for engineering, at the age of fifteen he became a pupil of Mr. Hugh H. Maclure, Civil Engineer and Architect. He then entered the office of Mr. William Johnstone, M. Inst. C.E., Engineer of the Glasgow and South-Western railway, under whom he was engaged for part of the three years of his servitude on the construction of branch lines for the company. During the session 1864–65 he attended the late Professor Rankine's class for Civil Engineering and Mechanics in Glasgow University, and afterwards until October 1867, he was an assistant to Mr. Ronald Johnstone, Civil and Mining Engineer, principally occupied in office work. Mr. Johnstone was for the next three years in the service of the Great Indian Peninsula Railway Company, as a third-class Resident Engineer, and was employed on construction and maintenance works between Hurda and Seonee, near Egutpoora, at Shapoor, at Massawud and Myjee, and at Munmar. In October 1870 he obtained an appointment in the railway branch of the Public Works Department of the Government of India, and until March 1874, was engaged under Mr. Horace Bell, M. Inst. C.E., on the survey

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and construction of the first division of the Holkar State railway. After three months' privilege leave spent in England, on returning to India he was placed in subdivisional charge of the Oojeen branch of the Neemuch State railway. His exertions in mitigating the sufferings of the famine-stricken population, added to his professional duties, proved too much for his strength; and in May 1878, he obtained leave of absence for eighteen months, but his constitution had been irretrievably injured, and he died of diabetes in April 1879. At the time of his death Mr. Johnstone had been on the roll of the Institution for three years, and had held the rank of Assistant Engineer of the first grade in the Public Works Department of India for seven years.

Mr. EDWARD TICKELL LANG, who was born in the year 1849, was a Student in the Applied Sciences Department of King's College, London, from October 1866 to July 1868, from which latter date he was for two years an articled pupil of Mr. C. P. B. Shelley, M. Inst. C.E. In July 1870, he passed third in the open competitive examination for appointments in the Public Works Department of the Government of India, and on his arrival in that country was appointed an assistant engineer, third grade, on the Sirhind Canal, Punjab, attaining the rank of second grade in November 1871, and of first grade in October 1874. For the first seven years of his Indian career he was employed in connection with the Sirhind Canal, being successively occupied as personal office assistant to the executive engineer, in charge of 5 miles length of earthwork, then of the Raipore subdivision of the same canal, consisting of earthwork, brickmaking and lime-burning. He built three stone bridges of 200-feet waterway and 45-feet span, and rather more than half a brick siphon for carrying drainage under the canal. He also sank some wells for the foundations of a large regulator and escape head at the 12th mile of the canal. In 1877 he returned to England for a few months, and for the remaining two years of his service held charge of a subdivision of the main line of the Western Jumna Canal, a canal having a discharge of 2,000 to 3,500 cubic feet per second. This work consisted in keeping the canal in order; collecting information as to the flow of the water; distributing water to cultivators; the general jurisdiction as to the uses and rights of the flow of water to the crops; and arranging for the drainage of the country

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affected by the canal. Mr. Lang was elected an Associate Member of the Institution in April 1880: he died on the 5th of the following August, aged thirty-one years.

Mr. DAVID LLEWELLIN was born in the year 1826, and was educated as a civil and mining engineer in the office of his uncle and brother, with whom he remained six years as pupil and assistant. In 1849 he commenced business on his own account, and obtained an extensive connection in South Wales, becoming in course of time mineral agent for Lord Aberdare and nearly every one of the principal mineral owners in Glamorganshire. In this capacity he laid out several branch and other railways, incline planes, tunnels, reservoirs, weirs, and bridges, and supervised their construction. As viewer and manager of extensive collieries he had the construction of such engineering works as pit-sinking, the erection of stationary engines, the construction of railway sidings, coal tips and screens, ponds, and the underground works and engines appertaining thereto. In the Vale of Neath he constructed extensive tunnels for the diversion of rivers and brooks, also one of the most important inclined planes in South Wales. In public life he was universally respected for his straightforward character, dauntless spirit, and strict integrity. He was a member of the Board of Guardians of Pontypool Union, the Llanfrechfa Upper Local Board, and the Llanfrechfa Upper School Board, and took an active part in the transaction of public business. His connection with this Institution dates from 1864, and he was one of the original members of the South Wales Institute of Engineers. He was also a Fellow of the Geological Society, a member of the Institution of Surveyors, and a member of the North of England Institute of Mining Engineers. He died, after a lingering illness, at Pontrhydyrun, on the 29th of July, 1880, in his fifty-fourth year.

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SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Regulations for the Uniform Testing and Nomenclature of Roman Cement.

By the Cement Committee of the Austrian Association of Engineers and Architects.

(Wochenschrift des österreichischen Ingenieur- und Architekten-Vereines, May 1, 1880.)

This committee was first named in November 1877, for the purpose of drawing up standard rules for testing cement in conformity with those then existing in Germany. The rules elaborated were published in June 1878, and have been generally accepted throughout Austria, although the conditions relating to fineness of grinding and the minimum tensile strength are much more stringent than in Germany. In November 1878 it was decided that the committee should extend its labours to hydraulic limes. As different hydraulic substances were frequently confounded with each other, the committee found it necessary to draw up rules for their uniform nomenclature. According to these all hydraulic cementitious substances are classified under the following headings:—

I. *Hydraulic Lime*, which comprises all poor limes brought into the market in pieces, and which harden under water some time after immersion. When exposed to the air or sprinkled with water they slake to a fine yellowish powder. They should be allowed to harden in the air for some time before immersion, but may be used for masonry in damp situations.

II. *Roman Cement* (Cement-Kalk) is a lime with such highly-developed hydraulic properties that, when the burnt pieces are ground by mechanical means, the powder hardens in a very short time under water.

Roman cements do not slake, and must be ground; they give a yellow or brown powder, darker than that of hydraulic lime. When this powder is mixed with water a slight increase of temperature takes place; but the resulting mortar does not expand.

III. *Portland Cement* consists of clay and lime mixed in certain proportions, burnt until clinkered and then ground. There should be no increase of temperature when Portland cement is mixed with water.

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IV. *Hydraulic Admixtures* are such substances as puzzuolana, Santorin earth, trass, &c. They are usually of volcanic origin, contain a small portion of lime, and occur in nature either in the form of powders or as rocks. They cannot be used alone, but when ground and mixed with rich lime they yield a hydraulic mortar which hardens very slowly; but after a lapse of several months approaches Portland cement mortar in strength. Having thus explained what they understood by the term Roman cements, the committee proceeded to draw up rules for testing and supplying them uniformly. The following are some of the most important of these rules:—

All sacks or casks are to bear the date on which they were filled. There must be no change in the volume of the cement mortar either in the air or under water. Thin cakes made with neat Roman cement must not, therefore, curve or crack even after twenty-eight days in air or water. The cement must be so finely ground as not to leave more than 20 per cent. residue on a sieve with 900 meshes per square centimètre (5,806 meshes per square inch), and made of wire 0·10 millimètre (0·0039 inch) thick. The tensile strength is to be ascertained by testing a mixture of Roman cement and sand. The briquettes must have a breaking section of 5 square centimètres (0·775 square inch), their shape being that prescribed by the German standard rules. They are to be made of a mortar composed of 3 parts by weight of sand and 1 part of cement. The sand must be prepared from clean washed quartz sand by sifting first through a sieve of 64 meshes per square centimètre (413 meshes per square inch), made of wire 0·22 millimètre (0·0086 inch) thick, and then through a sieve of 144 meshes per square centimètre (929 meshes per square inch), made of wire 0·18 millimètre (0·0071 inch) thick. The residue upon the latter sieve is the standard sand. The amount of water is to be 12 per cent. of the weight of the dry materials, unless the manufacturer should recommend another proportion; but he must do this before the test takes place. Ten briquettes are to be used for each test; the average of the six highest results is to be considered decisive.

Tests are to be made after seven and after twenty-eight days. During the first twenty-four hours the briquettes must be exposed to the air, then immersed in water until immediately before breaking. For Roman cements which set within fifteen minutes the minimum tensile strength in seven days is fixed at 1·5 kilogramme per square centimètre (21·3 lbs. per square inch); for slower setting cements 3·0 kilogrammes per square centimètre (42·6 lbs. per square inch). In twenty-eight days quick-setting cements must resist a strain of 4·0 kilogrammes per square centimètre (56·9 lbs. per square inch); slow-setting, 6·0 kilogrammes per square centimètre (85·3 lbs. per square inch).

Each rule is accompanied by explanations, and minute directions are given for making the briquettes.

W. F. R.

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Experiments with Appliances for Testing Cement.

By ALFRED NOBLE, C.E.

(Transactions of the American Society of Civil Engineers, vol. ix., p. 186.)

This series of experiments was undertaken with the object of selecting a form of mould and clip which would give uniform results and develop the full strength of the cement. The water and cement were weighed and mixed in a box by means of a hoe, which was considered to give better results than a trowel used in the ordinary way. In some cases the temperature of the water used was that of melting ice. All the experiments were made with neat cement. In filling the moulds about $\frac{1}{6}$ of the total mortar required was first tamped in with a light stick, the remainder was then added, and pressure applied with a piece of board held in the hands. The briquette was levelled off to the mould with a broad chisel after the mortar had set. All briquettes were left in the air twenty-four hours, and then kept in water six days; they were broken immediately after being taken from the water. The breaking section was $1\frac{1}{2}$ inch square. In the first experiments two sides of the briquettes were flat, and they were held by friction, the pressure being produced by set screws. In order to prevent fracture at the point of contact with the clips, slips of india-rubber $\frac{1}{8}$ inch thick were interposed. The results obtained by this method were high, the breaking strain averaging 500 lbs. per square inch for Portland cement. It was, however, found difficult to give the required amount of friction to hold the briquette during the application of the breaking weight without crushing it. From some cause, which was supposed to be due to the clutch, the breaking weights sometimes varied as much as 40 per cent. with this method. It was therefore abandoned, and a new circular form of briquette adopted, in which the shoulder was a frustum of a cone, forming an angle of 45° with the axis of the briquette. Some tests were made with briquettes which had been subjected in the moulds to a pressure of 32 lbs. per square inch of section immediately after filling. The pressure was only applied for two minutes, as the full effect appeared to be obtained in that time. The strength of the mortar increased 30 per cent. under this treatment; but there was no improvement in uniformity. In general it was found that the apparatus giving the most uniform results developed the least strength. The Paper is accompanied by plates showing the forms of moulds and clutches used; also by eight Tables, containing the breaking weights obtained with the various forms of clutches.

In the discussion on this Paper, Mr. D. J. Whittemore stated that he had used a briquette and clutch similar to one of those adopted by Mr. Noble; but he had been unable to obtain uniform results until he had discarded the use of india-rubber rings between the bearing surfaces of the briquette and clip-clutch.

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He suggested the use of a form of briquette which should fit into the clutch like a ball and socket joint. By lubricating the bearing surfaces of the clutch the briquette would adjust itself easily. An illustration of this form of briquette and clutch is given; also of a clutch which can be used as a mould.

W. F. R.

On the Extension of Metals under Tensional Stress after Rupture.

By J. Barba.

(Mémoires de la Société des Ingénieurs civils, 1880, p. 682.)

M. Barba communicates a few new facts, deduced from experiments made at Creusot. He testifies to the constancy of the volume of mild steel when submitted to tensile stress: the extension longitudinally being accompanied by transverse contraction in proportion. A specimen, rectangular in section, about 3 inches wide and $\frac{1}{2}$ inch thick, and $4\frac{1}{8}$ inches in clear length, with two large square heads to receive each a traction-bolt, was stretched to a length of $5\frac{3}{4}$ inches, when it broke. The volume was augmented by only $3\frac{1}{2}$ per thousand, or one-third per cent. Two round specimens, 1 inch in diameter and 8 inches in clear length, were only augmented in volume, after rupture, by 0·70 per thousand, or one-fourteenth per cent.

In the extension of the rectangular specimen it was found that, practically the length and the breadth were reduced proportionally; so that they maintained the same ratio to each other.

Similar specimens were affected similarly. For round steel bars of from $\frac{1}{4}$ inch to $1\frac{1}{4}$ inch in diameter, having effective lengths $7\frac{1}{2}$ times the diameter, the elastic strength per unit of section was practically the same.

The variation of resistance with the breadth of the specimen was exemplified in samples of mild steel and of copper. The steel samples were 0·39 inch thick, and of widths of from twice to ten times the thickness. The breaking strength varied, as the breadth increased, from 27 tons to $25\frac{1}{2}$ tons. For similar specimens of copper, it varied with the width from $15\frac{1}{4}$ tons to 14·7 tons per square inch. The Author ascribes the decrease of resistance to the greater stress on the sides of the central holes, which take the pull, in the wider than in the narrower samples.

The influence of the duration of the test was exemplified with three bars of mild steel, 0·63 inch in diameter, and about 4 inches in effective length. The first was broken in $2\frac{1}{2}$ minutes, with a force of 25 tons per square inch; the second in 75 minutes, with a force of 23·6 tons; and the third with a force of $26\frac{1}{4}$ tons, when the stress had been intermittently applied ten times, at intervals of five minutes.

D. K. C.

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Tests of Iron and Steel Shafting. By J. Howard.

(Boston Journal of Commerce, vol. xvi., No. 12.)

Recently six specimens of turned and cold-rolled iron and Bessemer steel shafting were submitted to tensile tests in the proving machine at the Watertown Arsenal, Mass. The bars were supplied by Messrs. Jones and Laughlins, Pittsburg, Pa. The Author believes the cold-rolled bars to be the largest yet tested, the steel being 3 inches diameter, and the iron 3 and 4 inches diameter. By the cold rolling the bars are reduced in diameter about $\frac{1}{8}$ inch, being at the same time considerably lengthened.

Mark.	Metal.	Diameter.	Length.	Area.	Elastic Limit.		Ultimate Strength.		Total Elongation.	Contraction of Area.	Fracture.
					Load.	Lbs. per Sq. In.	Load.	Lbs. per Sq. In.			
		Ins.	Ins.	Sq. Ins.	lbs.		lbs.		Per cent	Per cent	
A 1	Turned iron	3	50	7·068	151,962	21,500	349,000	49,380	16·8	36·1	Fibrous.
A 2	Cold-rolled iron	3	50	7·068	339,264	47,500	339,264	47,500	..	..	Granular.
B 1	Turned steel	3	50	7·068	282,720	40,000	471,600	66,720	4·7	4·9	Granular.
B 2	Cold-rolled steel.	3	50	7·068	454,500	64,300	454,500	64,300	..	..	Granular.
C 1	Turned iron	4	50	12·566	226,188	18,000	608,500	48,420	13·4	23·5	Fibrous and granular.
C 2	Cold-rolled iron	4	50	12·566	502,640	40,000	above 720,000	above 57,220	not determined	not determined	Not determined.

Bars marked by the same letter are of the same metal, No. 1 being turned and No. 2 cold-rolled.

The benefits of cold-rolling appear most conspicuously by comparing the elastic limits, the treatment raising the elastic limit till it is nearly or quite coincident with the ultimate strength. The fracture of the cold-rolled 3-inch iron bar showed defect at surface, due probably to overheating in the early stages of manufacture. The character, as shown by the fracture, was changed from fibrous to granular, and it broke without permanent elongation or contraction of area. The granular appearance of the Bessemer steel bars was nearly the same in both fractures, and, as with the iron, there was no permanent elongation.

The 4-inch turned iron developed at fracture about 40 per cent. fibrous structure, and about 60 per cent. granular. The 4-inch cold-rolled iron was strained to 40,000 lbs. per square inch, and in that condition allowed to rest three days, when strains were again applied. The bar sustained a total load of 720,000 lbs., or 57,220 lbs. per square inch, when it broke in the eye. After the load was off it was found that an elongation of only 0·04 inch had taken place. W. P.

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Report on the Island of Cyprus. By Luigi Luiggi.

(Giornale del Genio civile, 1880, p. 337.)

Having been appointed, in January last, a pupil Engineer in the Royal Corps of Civil Engineers, and directed to study abroad, Signor Luiggi was ordered to proceed to the island of Cyprus, on which he drew up a report to the Minister of Public Works.

Commencing with a general description of the island, the report points out its favourable conditions for the site of a great naval station. The coasts are broken into bays and naval roads; the sea is deep close to the shore; sandbanks and strong currents are absent. Cyprus is 42 miles from the coast of Caramania, 60 from that of Syria, 300 from Crete, 200 from Port Said. It is thus destined to become the first station on the great commercial line, so necessary to English communication, which will bring Europe into direct relation with India, by the Euphrates Valley and the Persian Gulf.

The military importance of Cyprus is due to its position—250 miles from the mouth of the Suez Canal, 1,100 from Malta, and 800 from Constantinople, so that it forms the key of the Archipelago, of the Red Sea, and of the Black Sea, and affords a suitable locality for an immense maritime arsenal.

The area of Cyprus is 3,678 square miles according to Keith Johnston; 3,788 according to Doctors Unger and Kothscy, and 5,342 square kilomètres according to Ravenstein. But a trigonometric map of the island is now for the first time in course of construction by Lieut. Kitchener, R.E.; and there is great incertitude as to topographical details until this map is completed. The general plan of the island is that of a large plain enclosed by two chains of mountains, lying nearly east and west. The northern chain, divided into the hills of Cerigne and those of Carpazo, has a length of 103 miles from Cape Cormachiti to Cape St. Andrea, and has at its base a narrow zone of well-irrigated land, in the freshest part of the climate of the island. The chain consists of a grey chalk formation, called by Italians the 'calcare giurassico.' It is penetrated by trap rocks, which form their highest summits, rising to from 2,080 to 3,210 feet above the sea, each of which is crowned with the ruins of a mediæval castle. To the south of this range lies the large plain extending from the bay of Famagosta to that of Morfo, which is principally formed of alluvial deposit, varied with marshes on the east, and with sand dunes on the west. The Pidias, 65 miles long, the Idalia, 38 miles long, which falls into the former, and the Cupris and the Osidena, derivatives of the Pidias, are torrential in their character. They enrich the plain by their winter floods, but cause miasma in the summer. To the south of this plain the chain of Mount Olympus rises, in its highest peak, Tröodos, to the height of 6,470 feet. Springs of excellent water abound on the hills, but water is scarce and brackish in the plains.

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The population of the island has been variously estimated at from 60,000 to 200,000 inhabitants. Signor Luiggi thinks that it is certainly above 100,000, of whom one quarter are Moslem. Nicosia, the capital, contains 18,000 inhabitants, and Larnaca, the principal port, 15,000.

The roads in Cyprus are few, and in bad condition. They have only been made practicable for wheeled carriages within the past year. Previously it was more easy to make one's way over the fields than over the roads. The roads run between the chief towns; and with the exception of that from Larnaca to Nicosia are little frequented.

There are two telegraph companies on the island, the Ottoman, with its lines in bad condition, and sustained on wooden posts; and the Eastern Telegraph Company, with excellent lines, fixed on elegant iron supports. The wires of the Ottoman Company run from Larnaca to Carpazo, passing by Nicosia, and joining the lines of Asia Minor by a submarine cable. Those of the Eastern Telegraph Company join Cerigne, Nicosia, Larnaca, Famagosta, Limasol, and Baffo (the ancient Paphos). From Limasol a submarine cable goes to Syria.

A project exists for a narrow-gauge railway from Larnaca to Nicosia, with a branch to Famagosta. Mr. Brown, the Engineer, says that the works will be shortly commenced. The line will be of great service to the country, and is expected to pay the company.

The weights, measures, and money of Cyprus are in great confusion, the Turkish, English, and metric systems being all in use. The principal units are these:—

Weights.

The Cantaro	= 44 oche	= 55 kilogrammes	= 121·0 lbs. avoird.
„ Oca	= 400 dramme	= 1·25 „	= 2·75 „
„ Dramma	= 3·12 grammes		= 48·15 grains.

Measures.

„ picco	= 0·70 mètre	= 2·296 feet.
„ scala	= 1600·7 square mètres	= 1,914·4 square yards.

Money.

„ piastra	= 40 para	= 0·1428 lira	= 1·4*d.*
„ para		= 0·00358 „	= 0·36*d.*

The report next describes the climate of Cyprus, and the prevailing winds. The mean rainfall is estimated at 325 millimètres (= 12·79 inches) in the year. But the rainfall observations were made at two different stations, one for the autumn, and the other for the rest of the year, at heights respectively of 300 feet and of 25 feet above the level of the sea.

The products of Cyprus comprise 1,002 species of phanerogamous plants, which have been described by Dr. Kotschy, and 1,572 species of animals, together with a large number of minerals, described by Gaudry. Wood for construction and for fuel, canes, straw, and flax, are important materials for the workman in Cyprus. Wood of

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large dimensions is rare, owing to the destruction by the Turks of the magnificent ancient forests of the island. The timber required for building is almost all imported from Caramania or from Syria. The maritime pine (*pinus maritima*), the Caramanian pine (*p. lariccio*), and the cypress (*cupressus horizontalis*), grow at heights between 1,800 and 4,000 feet above the sea. Asses, mules, and camels are used for work. The asses will carry from 220 lbs. to 275 lbs. for a distance of 25 miles in a day; the mules will carry from 396 lbs. to 440 lbs. The camels can carry as much as 1,100 lbs., but are generally loaded with from 686 lbs. to 825 lbs. Oxen and horses are inferior. An ass can be hired for 1*s.* or 1*s.* 2*d.*, a mule for double that price, a camel at from 1*s.* 6*d.* to 2*s.*, and a saddle-horse at from 2*s.* 6*d.* to 3*s.* a day.

Among minerals rich copper mines are found in Mount Olympus, as well as iron and manganese. Brown ochre, *terra verde*, amianthus, sulphates of soda and magnesia also abound; and jasper, onyx, and the crystals known as Paphos diamonds occur at Baffo and Rilpatrik. No marble has been found in Cyprus. There is a fine calcareous stone, which dresses well, but is perishable. A clear yellow sandstone, resembling the sandstone of the Paris basin, occurs in regular beds, but will not stand the weather. A quaternary conchiferous conglomerate also occurs in beds, and is an excellent building stone. The chief monuments in Cyprus are built of this stone; and the Gothic architecture of Famagosta shows its durability for five or six centuries. Limestone is found in the Cerigne chain of hills, and a compact, granular, and laminated *gesso* is used for paving, for building, and for converting into cement. The island abounds in good brick earth. The ordinary bricks are mixed with straw, or with seaweed, and dried in the sun. Bricks and tiles of finer clay are burnt in kilns; and pottery clay has been found in small quantities.

Signor Luiggi gives details of the domestic architecture of Cyprus. One peculiarity is the regular orientation of the houses, to which so much attention is paid (in order to secure shelter from the sun), that when the ground floor of a house is situated in a street that does not run east and west, the upper storeys are built with the required orientation, being supported by cantilevers of ornamented wood. The characteristic peculiarity of the architecture of Cyprus is the substitution of large arches of stone for beams or trusses for the support of the floor. The area is divided by these into rectangles of from 10 feet to 12 feet wide. On these arches are laid cross beams of native timber, which can be obtained of sufficient size, placed about a foot apart. These are covered by whole canes, laid parallel to each other, or by cane mats, on which is laid an inch or $1\frac{1}{2}$ inch of sand or fine gravel, and then a pavement of slabs of *gesso*. This mode of construction is so common in the island that when arches of stone can not be used on account of their thrust, they are built of blocks of wood, and covered with plaster to resemble stone. The span of these arches varies from 18 feet to 30 feet, and the height is from one-half to two-thirds of the span.

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The roofs are made like the floors, except that they are covered, in lieu of stone slabs, with earth mixed with straw, beaten hard, and dried in the sun. A second layer 8 inches or 9 inches thick is added when the first is dried, and the second layer is renewed every thirty years, having a little earth added to it year by year. A table of the prices of the work is added.

An account follows of the town, bay, and port of Famagosta, which under the Venetian rule was one of the most important commercial emporiums of the Mediterranean, but is now a mass of ruins. The inhabitants, formerly 30,000 in number, are now reduced to 685, all Moslems; as under the Turkish rule no Christian was allowed to dwell within the walls. The air of the city is fatal to Europeans owing to neglected drainage. The harbour is more capacious than the great harbour of Malta, and with proper repair would be of the first value. The report concludes by expressing the hope that under the English rule Cyprus may soon become again the fortunate island that she was in the time of the Greeks.

F. R. C.

State and Communal Expenditure on Public Works in Italy.

(Giornale dei Lavori Pubblici, an. 7, p. 281.)

The "Giornale dei Lavori Pubblici" of the 26th of May, 1880, contains an article on the subject of the material interests of Italy, and the public works of that country, from which a summary of the most important facts is now taken. The article enters at some length into the projects for public works which were brought forward by the Minister Baccarini in 1878, and into the political changes which interfered with the execution of the scheme. It proceeds to describe the project of law presented on the 12th of April, 1880, for the construction of new roadways and hydraulic works, and gives a table of the annual outlay on these objects for the decade 1869–1879.

For the communal roads, which are declared to be obligatory, the State, in accordance with the provisions of the law of the 20th of August, 1868, furnishes a subsidy of one-fourth of the cost, the remainder of the expense being borne by the Communes. In 1869, works were sanctioned to the amount of £117,000, on which subsidies to the amount of £28,700 were accorded. Out of these, however, only works to the amount of £16,400 were carried out in that year, on which a sum of little more than £3,000 was paid by way of subsidy. The figures thus given show a steady annual increase till the end of the decade. In 1879 they were as follow:— For works sanctioned within the year, £1,288,964; subsidies granted, £320,068; works actually carried out, £771,860; subsidies actually paid, £17,720. The annual mean figures for the decade are as follow:—For works sanctioned, £674,132; subsidies promised, £167,372; works carried out, £338,748; subsidies paid,

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£78,588. Thus the sum of £3,387,480 has been spent on these communal roads in the ten years, including £785,880 furnished by the State.

To complete the network of necessary communal roads throughout Italy, it is estimated that the sum of £8,000,000 will be required, by way of subsidy, making the total contemplated outlay amount to £32,000,000. To meet this demand, Signor Baccarini proposes to charge the budget with an annual sum of £640,000 for the next twelve years. The payments for the coming eight years are to be divided between the provinces of Italy as follow:—

	£.
Upper Italy	691,200
Central Italy	1,840,000
Southern Italy	2,652,800
Sicily	928,000
Sardinia	288,000
Total from 1881 to 1888	6,400,000

To the above expenditure, which is regarded as absolutely necessary for completing the highway accommodation of the country (without reference for the moment to railways and tramways), has to be added that required for hydraulic works, including the construction or improvement of ports and harbours, and the reclamation of marsh land, as well as other roads that do not come under the category of obligatory. The sum required for this purpose during the next ten years is estimated at £13,823,420, and is thus divided:—

	£.
Upper Italy	3,081,128
Central Italy	3,308,499
Southern Italy	5,307,015
Sicily	1,416,899
Sardinia	709,889

Giving a grand total for the next ten years of £39,423,420.

Of this sum, the expenditure of £3,180,000 is authorised by existing laws, and that of £16,640,000 more, by laws already brought before Parliament. The distribution of this sum is shown in a Table which, from the peculiar character of its arrangement, must be cited in the Italian units of kilomètres and lire.

——	Superficial.	Population.	Per Square Kilomètre. (a) Lire.	Per 100 Inhabitants. (b) Lire.	Mean. $\sqrt{a\,b}$ Lire
Upper Italy	81,584	10,261,333	944	750	841
Southern Italy	75,822	6,711,177	1,090	1,232	1,159
Lower Italy	85,316	7,401,941	1,555	1,792	1,669
Sicily	29,241	2,736,545	1,211	1,294	1,252
Sardinia	24,342	658,479	729	2,695	1,401
Totals and means	296,305	27,769,475	1,166	1,244	1,204

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The last column, giving the square root of the multiples of the area by the population, is one hitherto unusual. It will be observed that the industrious population of Upper Italy is far denser, not only than that of Sardinia, but also than that of the richer provinces of the South, being one hundred and twenty-five souls per square kilomètre in the North, eighty-seven souls per square kilomètre for the rest of Italy, and only twenty-six souls per kilomètre for Sardinia.

F. R. C.

Report on Public Works made to the Belgian Chamber of Representatives, in the Name of the Central Section.

By M. LE HARDY DE BEAULIEU.

By a law passed in 1834, the budget of the Belgian minister of public works is deposited two months before it is called into exercise. The budget for 1880 was deposited at the end of February 1879, and amounted to £3,366,507. Amendments proposed by the minister in the session of 1879–80 raised this amount to £3,445,073. The chief items in this amount, according to a *note explicative* furnished by the minister of public works, are as follow:—

	£.
Central administration	28,945
Roads and bridges	449,698
Mines	17,096
Railways	2,408,312
Posts and telegraphs	408,158
Marine	126,754
Minor items	6,110

Under the second chapter, roads and bridges, the report remarks that the sum of £175,128, asked for the maintenance of roads, is the same as for the preceding year, having risen from £128,360 in 1871. The sum of £35,080 is allotted to the maintenance and repairs of one hundred and sixty-three palaces, hotels, monuments, squares and gardens, in the nine provinces of the kingdom.

Under the head of hydraulic service, which forms part of the second chapter, minute details are given, as to the Meuse, the Ourthe, the coal canals of Hainault, the improvement of the Scheldt, and sixteen other items, chiefly relating to canals and to ports. An explanation is also given of the steps taken by the Government to prevent the pollution of the streams which flow from France into the Scheldt and the Lys, running through Belgium, which are fouled by the residual products of the wool factories of Roubaix and Tourcoing.

Under chapter III., which regards mines, the Commission opposes the efforts which are continually made to induce the Government to undertake the working of the coal-mines, with a view to equalising the price of coal. It points out that if this plan be adopted, it must be extended to the manufacture by the State of

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iron and steel, of linen and of cloth. The Commission asks for the completion of the general chart of the mines of Belgium, which has been in hand for upwards of thirty years.

Two official accounts exist of the cost of the railways of Belgium. According to the "Compte Rendu" of the State railways, the total is £37,663,910; while according to the "Situation générale du Trésor Public" it amounts to £41,210,154. Explanations are given in detail of the causes of this difference. The Commission remarks that at a given moment a definite sum has been expended on the lines, and that this figure ought to be adhered to in all the departments of the public service.

The report then enters on a comparison of the financial state of the Belgian lines with the results afforded by four English, and by two French companies, viz., the Great Eastern, the Midland, the London and North Western, and the Great Western; and the Northern and the Eastern of France. The comparison of the foreign lines is given in the following Table. The Commission remarks that the Belgian network has cost nearly as much as the English lines, and much more than the French lines of the Northern and Eastern; and that its working plant is more costly than that on the English, and far more costly than that on the French lines.

COMPARISON of BELGIAN and FRENCH RAILWAYS.

Belgium.	Length. Kilomètres.	Total Cost. Francs.	Per Kilomètre.	£. per Mile.
Lines constructed by the State	811	470,266,563	580,000	37·420
„ purchased „	1,117	annuities	285,360	18·403
Total of lines constructed and purchased	1,929	790,005,194	409,540	26·403
Cost of plant	..	153,549,826	75,350	4·860
Northern of France	2,441	825,736,000	316,716	20·249
Cost of plant	..	191,494,540	75,370	4·861
Eastern of France	2,844	948,989,057	387,550	25·000
Cost of plant	..	160,001,833	56,338	3·634

Dividing the two French systems into the old and new networks, in each case the results are:—

Northern, old network	1,296	..	420,500	27·129
Plant	..	..	136,800	8·825
„ new[1]	1,130	..	227,440	14·672
Plant	..	..	25,000	1·612
Eastern, old	not given	..	501,650	32·354
Plant	..	..	117,420	7·573
„ new	not given	..	320,000	20·645
Plant	..	..	42,490	2·740

The Belgian lines have avoided the centres of population, and have forced their customers to come to them. The English lines have shrunk from no expense to gain central depôts. The policy of the Belgian lines has rendered junctions and intercommunication difficult. The stations are of the rudest kind; level crossings are

[1] The slight discrepancy in the lengths of the Northern line is in the report.

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very numerous; and Brussels presents an obstacle to the union of the different lines, although a bridge of little more than a mile in length would have rendered possible the construction of a central station at Brussels. In the same way the stations at Ghent, at Verviers, and at Tournai, are inconvenient.

The mean distance apart of the stations on the Belgian lines is 4,700 mètres (5,123 yards). In France it is 6,150 mètres (6,703 yards) for the Northern, and 7,000 mètres (7,630 yards) for the Eastern. In England it is estimated by the reporter at 5,000 mètres (5,450 yards).

At the end of 1878 the Belgian railways employed 1,080 locomotives, of which 212 were engaged in shunting at the stations. They had besides 13 steam coaches, 50 "locomotives de route," and 5 for stations, 2,379 passenger vehicles, and 31,784 vehicles for merchandise. They thus employed at that date 1 locomotive for every 3 kilomètres of line (= 1·86 mile) and 1 passenger carriage, and 13 merchandise vehicles for every kilomètre (0·62 mile).

At the same time the Northern of France employed 1,127 locomotives, 1,975 passenger carriages, and 31,020 vehicles for merchandise; being at the rate of 1 locomotive for 2·4 kilomètres (1·49 mile) and 1 passenger carriage, and about 13 merchandise vehicles per kilomètre. The Eastern of France employed 870 locomotives, 2,391 passenger carriages, and 22,131 other vehicles, giving about 1 locomotive to 4 kilomètres (2·48 miles), and about 1 passenger carriage and 8 different vehicles per kilomètre.

The comparative receipts and expenses are as follow:—

RECEIPTS.

	Passengers.	Goods.	Total.	Francs per Kilomètre.	£. per Mile.
	Francs.	Francs.	Francs.		
Belgian lines . .	29,881,416	61,711,590	94,205,915	41,925	2,735
Northern of France	48,767,639	75,320,311	119,088,000	48,786	3,146
Eastern „	35,096,254	69,525,425	104,621,677	36,838	2,375

EXPENSES.

		Per Kilomètre.	
	Francs.	Francs.	Per Cent.
Belgian lines . . .	56,555,999	25,144	59
Northern of France .	62,677,216	25,676	53
Eastern „ .	54,043,552	22,726	60

It follows from the comparison (omitting the English lines), that the Belgian railways are those which, with the exception of the Eastern of France, have at the same time the lowest receipts and the highest proportional expenses.

The want of correspondence between the lines, their short lengths, and their mutual competition, are the causes of their low receipts. The mean receipt per passenger on these lines is 3·276 francs (2·73*s.*), while on the network of the Northern of France it is 7·41 francs (6·17*s.*), though the tariff of prices is only a fraction lower in Belgium than in France. The report then enters in

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detail into the causes which render the working of lines by Government officials both more costly and less efficient than those directed by the officers of commercial companies. It points out that the low Belgian tariffs did not prevent an enormous rise in the price of coal, iron, and all industrial products in 1872. It calls attention to the fact that in the countries which surround Belgium, and contend with her products in the markets of the world, the railway companies are paying off their bonds, extinguishing their capitals by sinking funds, and advancing towards a period when the railways will be in the hands of the State, free from all charges for interest on capital. What then, the report asks, will be the condition of that industrial people which has neglected thus to extinguish the charge weighing on its traffic?

It clearly follows, says the report, that the revenue of railways should provide, not only for their maintenance and working expenses, but also for the payment of interest, and the extinction of their capital by a sinking fund.

The report then gives an example of the manner in which the administration, by its hesitation to accept tenders at 108 francs 55 centimes per ton for iron rails, and 139 francs 25 centimes per ton for steel rails, in October, was obliged to pay the respective prices of 170 francs, and 189 francs, for the supply in the December following. It gives details of the prices at which locomotives and other working plant were purchased in December 1879. It refers to the responsibility of the State in case of injury to passengers, and gives particulars of the works sanctioned by the Chamber, and provided for in the present budget. It then discusses the details of the telegraphic communications.

F. R. C.

Note on the Port of Cette.

(Revue Maritime et Coloniale, July 1880, p. 89.)

The harbour of Cette was commenced in the year 1666. The situation, at the eastern foot of the mountain of Cette, was chosen, in order that advantage might be taken of the proximity of a vast sheet of inland water, called the Etang de Thau, which it was thought advisable to connect with the sea by means of a navigable channel. The site was also well sheltered from the prevalent north-west winds, but the port, unless protected by artificial works, would be very much exposed to the winter seas, to currents, and to silting up. The first work constructed for the protection of the port was the mole of St. Louis, which in 1672 was sufficiently advanced to afford shelter to numerous vessels. About the same time a work called the Jetée de Frontignan was commenced on the east side of the port. The object sought to be attained by this work was to prevent the silting up of the port. The jetty was extended from time to time, and was only finished in 1831. It

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has, however, but imperfectly fulfilled the object of its designers. The traffic of the port increased so much that in 1840 it was quite unable to accommodate the vessels which resorted to it, and new works had to be commenced. A basin, called the Port Neuf, was excavated, and finished in 1848, and was put in communication with the basin which connected the Canal de la Peyrade and the ancient channel by means of the so-called Canal Maritime, which latter was prolonged and finished in 1862, by the construction of the lateral canal and basin of the Southern railway. The waters of the Port Neuf were thus connected with those of the Etang de Thau.

The station of the Paris, Lyons, and Mediterranean Railway dates from 1839, and that of the Southern Company from 1855. The average annual traffic of the two stations is not less than from 2,500,000 to 3,800,000 tons.

While the accommodation of the interior of the port was being increased, attention was also being paid to the condition of the mouth of the harbour, which was exposed to the sea, and was continually suffering from the silting of sand. A breakwater was constructed in the space between the heads of the mole of St. Louis and the Jetée de Frontignan, leaving two openings to the harbour at either end, each of them being 984 feet in width. Its primary purpose was to shelter the port from the sea, but it was also hoped that the silting would be at least partially remedied. It was commenced in 1821, and only finished in 1855. It is 1,856 feet in length.

The silting up is a perpetual source of uneasiness to those who are interested in the future of the port. Every day the depth of water at the entrances, especially at the north-east, becomes more and more inadequate. At present the average depth only permits of the passage of vessels whose draught does not exceed 18 feet.

The following new works are now projected or actually commenced:—

1. The construction of a spur 1,968 feet from the eastern end of the breakwater, running E¼ N.E. into water of the depth of 33 feet. This work is intended to provide immediate shelter from south-easterly winds, and allows of an easier entrance to the roadstead.

2. The removal of the Jetée de Frontignan, so as still further to enlarge the north-eastern entrance.

3. Systematic dredging so as to permit of vessels of any draught of water entering the port.

4. The construction of a spur 482 feet long from the western end of the breakwater, so as to enlarge the western entrance to the port, and make it safer, by permitting the stone packing of the mole of St. Louis to be removed.

G. C. V. H.

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Repair of the Sill of the Duquesne Lock at Dieppe Harbour.

By M. ALEXANDRE.

(Annales des Ponts et Chaussées, 5th series, vol. xx., p. 46, 1 pl.)

The leakage through the Duquesne lock had been considerable for some years past, owing to the bad state of the lock gates, and the defective condition both of the oak sill-piece, which was very much worm-eaten, and of the point of the stone sill in which it was embedded. In 1878 the leakage was so large as to lower the water-level of the basin (whose area is nearly 10 acres) 6½ feet between each high tide, which was very inconvenient for the shipping. The sill should have dried at low water spring tides; but a troublesome leak at the sill of the Bérigny lock always sent a stream of water over it at that time. The work of renewal had to be accomplished without interfering with the navigation; the entrance channel to the other basins being through the Duquesne lock. A movable caisson, without a bottom, constructed so as to fit exactly to the apron, sill and invert, and sunk into place at low water, was first tried; but the rush of water, at each side, frustrated all efforts to make the caisson watertight at the bottom and to pump out the water, so this plan had to be abandoned. It was then arranged to pen back the stream coming from the Bérigny lock, in the Duquesne basin, during the interval of about 2½ hours at low water, that the repairs could be carried on. The rise of water, owing to the leak, during this space of time, over the whole basin was estimated at a maximum of 1 foot 10 inches. A cofferdam, placed across the lock on the gate floor, raised 6½ feet, was sufficient to provide against this rise. The two ends of this cofferdam, abutting against the walls of the gate recesses, being below the level of the curved lock invert, and consequently not in the way of the shipping, were fixed in place; forming, as it were, two abutments against which the movable barrier closing the opening between them (25 feet 10 inches wide) could rest. As the sill of the Bérigny lock is 1 foot 2 inches higher than the sill under repair, and the Duquesne basin was just then not available for vessels, small fixed cofferdams were placed, without inconvenience to the shipping, nearly up to the level of the Bérigny sill, round the portion of sill to be repaired. The lower portion of the opening in the cofferdam across the lock was closed up to the same level by balks fixed in place. The remainder of the opening, 4 feet 5 inches high, was closed at each low tide, when the repairs were being done, by movable balks. As soon as the balks were in place, a sheet of sail-cloth, weighted at the bottom, was spread against their upper face; and the water leaking through was removed by a centrifugal pump, and the water in the inclosure formed by the low cofferdams was bailed out. Closing the cofferdam and pumping out the water occupied about half an hour, and the available working

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time in one tide was, on the average, 1½ hour. The oak sill was renewed, and as time did not allow of procuring a granite stone to replace the central sill stone, which was found to be considerably worn away by the incessant rush of water through the leak, the injured part was filled up by a large sheathed block of oak, bedded in cement, and held down by iron bolts. A rail, bent to the shape of the apron, was fastened down just below the point of the sill, to protect the sill from being struck by the keels of vessels, and the apron from being worn by the chains. The whole of the operations occupied one hundred and twenty tides, of which fifty were devoted to the actual work of repair; and no mishap nor any delay to the shipping occurred. The total cost of the works was about £720.

L. V. H.

Clip Calliper for Lifting Waste Weir Planking. By A. Hayes.

(Professional Papers on Indian Engineering, vol. ix., p. 263, 1 pl.)

A calliper has been designed to facilitate the frequent operation of raising and lowering the planks on the canal calingulahs during the irrigation season, and to obviate the necessity of sending men into the water to attach lifting-ropes to the wooden pins driven for this purpose through each end of the planks. The calliper is provided with two sockets, by means of which it slides on a guide-rod, and its two jaws have cylindrical lead weights fastened to their upper extremities. The pin connecting the two jaws is fastened to the lower socket, and the upper ends of the jaws are each connected with the upper socket by a bar, which can turn, at its extremities, on a pin at the centre of the lead weight, and on a pin in the centre of the upper socket. A rope, fastened to a ring on the top of the upper socket, serves to raise or lower the calliper. When the rope is pulled up it raises the upper socket, which, by means of the bars, pulls together the upper part of the calliper and closes the jaws. On releasing the rope the lead weights fall, and the jaws open and are kept extended by a bent hook catch curving down slightly below the roof of the jaws. For raising a plank, the guide-rod is dropped ahead of the planking, and fits vertically against it by means of an elbow-jointed end; the calliper is then lowered with its jaws opened out, and as soon as the convex part of the catch comes in contact with the top of the planking it is forced up, the catch is set free, and the calliper grips the plank, and the plank can be raised by hauling up the callipers gripping it at each end. In replacing a plank the callipers holding it are lowered, and when it has reached its place the ropes are slackened, and the jaws of the callipers open and are retained in that position by a catch, above the pivot of the jaws, fastened to one jaw and falling into a notch in the

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other. The calingulah planks are 5 feet long by 1 inch thick by 2½ inches wide; but stop-lock planks 20 feet long by 6 inches thick by 4 inches wide can also be lifted by a pair of callipers.

L. V. H.

The Mulatière Weir on the Saône at Lyons.

(Annales des Travaux Publics, vol. i., p. 147, 1 pl., 1 woodcut.)

This weir, which is in course of construction, is situated on the Saône at its confluence with the Rhone. The object in view is to raise the navigable depth of the Saône, in the Lyons reach, from 2 feet to 8 feet 2½ inches. The works comprise: (1.) A lock, having an available length of 525 feet between the gates, a width of 52½ feet, and a height of 24 feet 7 inches above the sill. (2.) A navigable pass, 340 feet wide, stretching from the lock situated on the right bank to the opposite bank of the river, without any intermediate piers. Its sill is 4 feet 7 inches below the lowest observed water-level; and it is to be closed by the Pasqueau system of shutters, which will raise the water 8½ feet above the ordinary summer level. (3.) A regulating overfall, nearly at right angles to the navigable pass, 276 feet long and 8 feet 2½ inches high, closed by panels on the Boulé system. It is situated on an extension of the embankment separating the two rivers, and the water passing over it will fall into the Rhone. The estimated cost is £100,000.

The excavation for the foundations of the lock was commenced towards the end of 1877, and was performed by a steam-dredger which could work at a depth of 46 feet below water. The material thus removed, consisting of gravel, amounted to 36,600 cubic yards, and was lifted by a steam elevator into wagons, and deposited on the adjacent land, and by merely passing it through a screen excellent sand was obtained, and almost as much gravel as was required for concrete. The site of the lock floor was enclosed by sheet piling, and the concrete forming the floor was deposited from five bridges, each 105 feet long, and stretching across the lock foundations. These bridges moved sideways on rollers, running on rails supported on staging, along the whole length of the lock. Each bridge was provided with two lines of way, one being used by the small wagons conveying the concrete, and the other serving for the cranes employed in lowering and raising the boxes, into which the concrete was tipped from the wagons, and in which it was lowered through the water to the foundations. Each wagon contained 1⅓ cubic yard of concrete—just sufficient to fill a box. The bridges followed one another in their journey along the lock foundations with an interval between each of 6½ feet; they each deposited about 3¼ feet thickness of concrete over the whole foundation, thus bringing up the floor by successive layers to its full thickness, which in some places amounted to 19½ feet. In this

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manner as much as 420 cubic yards of concrete have been deposited in one day from the five bridges, in a depth of from 33 to 49 feet of water; and the quantity might have easily reached 650 cubic yards if the materials could have been supplied fast enough. In five months 36,600 cubic yards of concrete were supplied and deposited. Messrs. Pasqueau and Givoiset are the engineers, and M. Belin the contractor for the works.

L. V. H.

Canalisation of the Meuse between Namur and the French Frontier. By MARTIAL HANS.

(Annales de l'Association des Ingénieurs sortis des Écoles Spéciales de Gand, vol. iii., p. 119, 6 pl.)

The Belgic Meuse is canalised between Visé and the French frontier by means of locks and movable weirs. Needle weirs were adopted for the earlier works below Namur; but when, in 1866, the navigation was extended above Namur shutter weirs were erected at La Plante, Tailfer, and Rivière. These shutter weirs consist of a navigable pass with a sill 2 feet below summer water-level, and of an overfall whose sill is 2 feet 1½ inch above that level. The navigable pass is closed by twenty-three shutters, 10 feet 6 inches high and 3 feet 11 inches wide; the overfall has forty-three self-adjusting shutters, 6 feet 10½ inches high and 4 feet 3 inches wide, with their axes of rotation so situated that the shutters open as soon as the sheet of water falling over them rises 6 inches above them. The overfall weir is raised from a foot-bridge on movable frames, and the navigable pass from a barge. The Author gives details of the construction and method of working of these weirs, which resemble the Chanoine shutter weirs recently described in the Minutes of Proceedings.[1] It was found in practice that the raising of the last shutters of the navigable passes of these weirs was both difficult and dangerous, and that it could only be satisfactorily accomplished by closing the weirs in succession proceeding up stream, or by letting down the water-level below the regular navigation level. Also the tripping bar is liable to be broken, to be clogged with the gravel which the Meuse brings down in large quantities, and to be pulled out of place by the chains attached to the shutters; and the shutters are sometimes torn from their fastenings. This system of weir, moreover, necessitates abrupt variations in the water-level, when the weir is being closed. Directly the navigable pass is completely closed, the water-level above the weir, which was previously low, rises rapidly about 3 feet 9 inches.

In consequence of these inconveniences, the six weirs subsequently erected in the upper part of the river, to render it navigable to the French frontier, have been made with overfalls

[1] *Vide* Minutes of Proceedings, Inst. C.E., vol. lx., p. 33.

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similar to those already described, but with a navigable pass closed by needles resting against movable frames. These needle weirs are closed without difficulty, and enable the level of the upper pool to be maintained at any desired height; and the overfall self-acting shutter weirs secure the foot-bridge of the needle weir against submersion in the event of a sudden flood. The overfalls are 179 feet long, and the navigable passes vary from 150 feet to 135 feet according to the discharge of the river. These weirs can retain the water to a level of 10 feet 2 inches above the sill of the navigable pass, or about 8 feet 2 inches above the summer level. The locks adjoining these weirs have an available length of 328 feet, and a width of 39 feet 4 inches. Full details are furnished in the article of the various parts of these locks and weirs.

The frames of the needle weirs are 3 feet 11 inches apart, and 11 feet 6 inches high from the apron to the movable bar; they are formed of rectangular bar iron. The weight of a frame alone is 798 lbs., but including the footway, movable bar and chains, the average weight amounts to 1,109 lbs. The frames are firmly connected together, when upright, by the sheet-iron footway, which is hinged to the upper bar of each frame and catches on to the upper bar of the next frame. The Kummer system for releasing the needles has been adopted for all the needle weirs erected in Belgium since its invention in 1845. It consists of a bar with a double eye at one end which fits on to a vertical spindle forming the continuation at the top of the front bar of the frame. The bar revolves round this spindle in a horizontal plane, and it has a ring at its other extremity with an opening at one side slightly wider than the radius of the spindle, so that it can fit on to the portion of the spindle of the adjoining frame in the space between the two eyes of the adjoining bar. To admit the bar the spindle is made semicircular at this part, being circular elsewhere, and, after the bar is fitted on, by giving a quarter of a turn to the spindle the bar is held fast. The needles rest against this bar, and by turning the spindle back again the bar is released at one end, and revolving round its other extremity, away from the needles, sets them free. The needles are 12 feet 4 inches long; they have a width throughout of 4 inches, and a thickness varying from 4½ inches at the most strained part to 4 inches at the bottom and 3½ inches at the top.

The shutters at all the weirs on the Meuse have been provided with butterfly valves of iron, which make them close more readily. These valves, moreover, suffice to regulate the water-level above the weir when a small flood occurs, obviating the necessity of opening some of the shutters.

The following order is adopted in raising one of these weirs. When a flood has lowered to the navigation level, the frames of the navigable pass are first raised, and then the frames of the overfall, the shutters being left open. As the river falls some of the needles are put in place to maintain the river above at its proper level, and more needles are deposited in proportion as the water lowers till at last all the needles are in place, and the whole discharge takes

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place by the overfall weir. With a further fall of the river some of the shutters close of their own accord, the weir-keeper closes the rest from the foot-bridge by means of a boat, and lastly he shuts the butterfly valves. Covering pieces are then put against the spaces between each shutter, and the interstices between the needles of the navigable pass becoming stopped up with floating weeds, twigs, and mud, almost the whole of the discharge passes over the top of the shutters. The water-level in summer is regulated by the butterfly valves.

When a flood comes down, the shutters open of themselves one after another; then the weir-keeper releases as many sets of needles as are necessary to keep the river nearly down to its proper level, and when the fall at the weir is reduced to 1 foot 4 inches the remaining needles are set free, the shutters are lowered on to the apron, the frames of the overfall bridge are then laid down, and lastly the frames of the navigable pass.

These composite weirs can be both raised earlier, and kept up much longer than the weirs closed entirely by shutters. Within a period of a year and a half the former were only lowered twice, and remained down for seventeen days; whilst the latter were lowered five times, and remained down for one hundred and sixteen days.

The average cost of each of these weirs, including the lock, was about £34,700. The cost of the navigable pass per lineal foot was £29 11*s.*; and of the overfall £30 10*s.* The total cost of the canalisation of this portion of the river, which is 29½ miles long, will amount to about £324,000, or £11,330 per mile.

L. V. H.

M. de Lesseps' Project of an Interoceanic Canal at Panama.

(Comptes rendus de l'Académie des Sciences, 1880, pp. 200, 264.)

A commission of the Academy of Sciences has reported on the project of M. de Lesseps for a canal across the Isthmus of Panama. The first part is devoted chiefly to a historical notice of various projects for traversing the Isthmus. The second part is devoted to the consideration of the plans of M. de Lesseps for the construction of a canal.

The narrowest part of the isthmus is 30½ miles from Panama, between the mouth of the Bayano and the Bay of San Blas on the Atlantic. The seas at this place are 31 miles apart; at Panama they are 36 miles apart. The general direction of the isthmus in this neighbourhood, for a length of about 370 miles, is east and west; the waters of the Antilles are on the north coast, and the Pacific is on the south coast. These seas are known locally as the North Sea and the South Sea. The canal begins on the north side of the isthmus, in the Bay of Limon, crosses the threshold of Loma del Mono, stretches along the valley of the Chagres, which it

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leaves at Matachin, where it enters the valley of the Obispo, and, following the valley of the Rio Grande, reaches the South Sea near Panama, facing the Island of Perico. The general direction of the canal is from north-north-west to south-south-east, making a total length of 45⅓ miles.

The floor of the canal, elsewhere than in the Culebra cutting, is 72 feet wide, as at the Suez Canal; the depth of water is from 26 feet to 29 feet, for the passage of ships. In the cutting through the Cordilleras,—a length of 15½ miles,—the sides of the rock are at a slope of 1 in 4¼, the width at the bottom is 78¾ feet, and the depth of water is 29½ feet, for additional margin of security in the cutting. Fenders of whole balks are to be fixed to the rock at each side.

The grand difficulty of the enterprise is the formation of a canal at the bottom of a valley traversed by a river affected by high and sudden floods—the Chagres. To meet the conditions, it is designed to construct a dam, at an elevation sufficient for the collection of the greatest floods; and a conduit or water-course to convey the flood-water to the sea, with a maximum discharge of 7,000 cubic feet per second. This conduit would collect also the influx from lateral streams on the right bank of the Chagres, and would discharge into the sea to the east of the island of Manzanillo. The littoral current here runs eastward, so that the mud deposited in that locality will not be carried into the Bay of Limon. A second conduit is to be placed alongside the canal on the west side to receive the Rio Trinidad and the other affluents of the left bank: occupying for a considerable length the bed of the Chagres.

By a dam placed equally distant from Matachin and Cruces, from 1,650 to 1,750 yards in length, between the Cerro Gamboa, on the south, and the Cerro Baruco, on the north, raising the level of the waters 40 or 45 feet above the lowest waters of the Chagres, the reservoir thus formed will have a capacity of 1,000,000,000 cubic mètres, a storage that would be more than sufficient for the requirements. The dam may be constructed of the broken rock from the neighbouring cutting of Culebra. Its leading dimensions will be as follows: apparent height, 147½ feet; width at the crest, 787 feet; width at the bottom of the valley, 3,150 feet; length of the crest, 1,650 to 1,750 yards; maximum depth of water in the basin, 125 feet. The excavated material at Culebra will amount to 37,000,000 cubic yards. Of this, 26,000,000 will suffice for the formation of the dam, faced with clay; and the remainder, of which a portion will be used for the construction of a lock, will be deposited in the small valleys near the Rio Grande. The reservoir will be formed with tunnel outlets.

For the works now noticed, and other contingent works, the estimated quantity of cutting amounts to 100,000,000 cubic yards, of which nearly one-half is in rock. The rock is principally of volcanic origin.

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The rise and fall of the tide at the north, varies from 7½ inches to 19 inches; and at the south, from 8 feet to 21¼ feet. To provide against the fluctuations of the tide, a lock will be constructed at Panama, consisting of three independent chambers, each of which will have four pairs of gates. A tidal basin will be constructed in connection with the lock.

The power, mostly steam power, estimated to be employed in the construction of the canal amounts to 15,000 HP., together with 9,000 men. The cost of the work, as estimated by the technical commission, amounts to £33,720,000, as follows:—

	£.
Excavation, above water	20,920,000
Dredging and excavation, under water	1,880,000
Dam at Gamboa	4,000,000
Conduits or water-courses	3,000,000
Lock at Panama	480,000
Jetty in the Bay of Limon	400,000
Contingent expenses	3,040,000
	33,720,000

But MM. Couvreux and Hersent, contractors, estimate that the total cost will not exceed £20,480,000, exclusive of general charges of the company, and the cost of the lock at Panama. It is estimated that the work can be executed in eight years.

D. K. C.

Ice-Breaking in the Vistula. By Hr. DÜSING.

(Deutsche Bauzeitung, 1880, p. 352.)

The Vistula at the Montauerspitze, the point where it enters the Dantzic territory, divides into two branches; that to the right, known as the Nogat, flows past the town of Marienberg, and, after a course of 22¼ miles, empties into the Frische-Haff, whilst the left arm, which retains the name of Vistula, after a course of 13⅔ miles, passes Dirschau and then turns eastwards, cutting across the Marienberg-Dantzic lowland (Werder), and, after running a further 13⅔ miles, again divides into the Dantzic main (Haupt) and the Elbingen Vistula, the former running westwards for 9⅓ miles, and debouching into the Baltic at Neufähr, and the latter pursuing an easterly direction and emptying into the Frische-Haff.

Every winter great quantities of ice come down from the upper parts of the river, and by damming up the waters endanger the dykes protecting the lowlands. The Dantzic main being the channel through which the greatest volume of waters flows, it is between Neufähr and the Montauerspitze that ice-breaking operations are principally conducted. Up to within the last two years it was customary to clear the channel of ice by gunpowder, a fair-

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way of 164 to 246 feet being maintained in this manner. During the winter of 1878–79, experiments were made with an ice-breaking sledge (Eisbrechschlitten), and it was more generally adopted in the past winter.

This ice-sledge is of simple construction. The length is 73 feet 9 inches, with a breadth of 8 feet 4 inches throughout; its greatest depth, viz., 4 feet 9 inches, is at the centre, from which the under-side curves upwards to the deck level at stem and stern. The sides of the vessel are made up of oak balks $7\frac{1}{8}$ inches square in section, firmly bolted together, and are connected by eight transverse partitions constructed in a similar manner. Along the bottom run longitudinal balks 2 feet apart, all those portions which are liable to abrasion being sheeted with wrought-iron plates $\frac{1}{8}$ inch thick, three of the under longitudinals being shod with plates $\frac{3}{8}$ inch thick. The deck is sheeted with strong planking, and carries amidships a raised cabin. The total weight is about 25 tons (500 Z.). Four men, under the direction of one man who is acquainted with the navigable fairway, mark out on the surface of the ice the course of the intended channel, and are followed by a gang of about two hundred men, who with ice-axes make a continuous cut about 1 foot 8 inches broad, care being taken to penetrate the whole thickness, as otherwise the action of the sledge is less efficient. Three sledges are required for the prosecution of the work, one in the centre and the others on each edge of the intended channel; or, if the latter is made of great breadth, they require to be repeatedly hauled up and down stream until the whole area of ice has been broken up. Each sledge has four cables attached to it, which are hauled upon by a gang of two hundred and twenty men, the ice being smashed by the weight and oscillation of the sledge. The length of channel, 394 to 492 feet in breadth, cleared in this manner varies from $1\frac{1}{4}$ to $1\frac{3}{4}$ mile per day. Where heavy accumulations of ice occur, gunpowder is still occasionally used in charges of from $4\frac{1}{2}$ to 11 lbs., ignited by the Bickford fuse. The cost of the above operations is considerable, the average wage per man per day being 2*s*., and it was sought to make use of horse power instead, sixteen horses being tackled to each sledge, but, owing to the difficulty in getting them to haul simultaneously and in transferring them from place to place, manual power had to be again resorted to.

D. G.

A Storage Reservoir in the Achterfeld.

By JOHN G. GAMBLE, M.A., M. Inst. C.E.

(Trans. South African Phil. Society, 29 October, 1879.)

Irrigation in South Africa is a matter of serious importance to the colony, and the Author has constructed a reservoir for this pur-

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pose near the village of Brandoley, situated between the villages of Calvinia and Kenhardt. A narrow "poort" above the village was selected as a suitable site. At this point the river Zak has a drainage area of 14,000 square miles; but in consequence of a rainfall of only 6 inches per annum, this river is dry for a large portion of each year, and in some years there is no flow. In January and May, 1879, it ran for fifteen days through three distinct channels, but no record has been kept of the number of times the river has run, and its depth on each occasion. A great amount of the water is lost by evaporation and absorption, the rain falling chiefly in thunderstorms; and it is known in India that, at the beginning of the monsoon, the loss from these causes is 95 per cent. The reservoir embankment crossed the "poort" on a rock foundation, where, but for the cost, a concrete or stone dam would have been adopted; this being out of the question, two trenches were cut across the "poort" parallel to the line of the embankment, and were filled with clay puddle. The embankment was made in a similar manner to most English reservoir embankments, the heart being put on in layers of 6 inches in thickness, and the clay being well wetted and trampled. The inside slopes were 3 to 1, and the outside slopes 2 to 1. The adoption of slopes of 1 to 1 by the Boers is usual, but unsafe. These slopes depend for their security on the general gradient of the ground, and the nature of the material; the angle of repose for clay necessitating a gentle slope, and the action of waves tending to do damage to a relatively thin bank. The supply is given through a channel 3 feet in width and 6 feet in depth, cut in the rock at a depression close by, although a siphon was suggested at first, but was not considered advisable in this case. Pipes directly through an embankment of this height are not open to the objection which they would incur in high embankments if the inspection of the work is properly carried out, which in this instance was impossible; and the design adopted was probably the best. The embankment settled at one point, but is now in good repair. The area of the reservoir at present is 2 square miles, and the mean depth 5 feet, but an additional embankment has been proposed of nearly 1 mile in length, and 5 feet high; this would give 2 feet extra depth of water, and increase the area to 3 square miles. As a rainfall of 6 inches is all that can be depended upon, reservoirs of large capacity at small cost are necessary, for even a small proportion of actual rainfall, if stored, would be invaluable for irrigation and other purposes. One of the three channels of the Zak river is beginning to scour, and the Author is making obstructions in the bed of the river to check this tendency. The cost of the work was £670.

C. J. W.

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The Pumping Machinery for the New Waterworks at Hanover.

By H. BERG.

(Zeitschrift des Architekten- und Ingenieur-Vereins zu Hannover, vol. xxvi., p. 322.)

This article forms portion of a detailed description of the engines, pumps, and buildings (illustrated by numerous diagrams) erected for the above waterworks, a continuation of the Paper remaining to be published.

There are three compound Woolf-engines, each similar in all respects, transmitting motion to the three corresponding double-action vertical pumps by the intervention of rocking bell-cranks. The diameter of the high-pressure cylinder is $20\frac{7}{8}$ inches, and that of the low-pressure cylinder $36\frac{5}{8}$ inches, with a stroke of 53 inches. The normal working steam pressure is 80 lbs. per square inch, and number of revolutions twenty-four per minute.

The piston rod, of cast steel, passes through both high- and low-pressure cylinders, the cross-heads working in slipper-guides with a connecting-rod to the crank-axle of the fly-wheel at one end of the bed-plate, and another to the main pump rocking bell-crank at the opposite extremity. The fly-wheel is 19 feet 8 inches in diameter, and weighs 12 tons. The barrel of each main pump is $19\frac{3}{4}$ inches in diameter, and $29\frac{1}{2}$ inches stroke. The plunger is hollow and encircled by four brass expanding rings. The two air-vessels are $30\frac{1}{4}$ inches in diameter, communicating by valves with the main air-pressure chamber (of which there is one to each pump), of wrought iron on a cast-iron base 3 feet 7 inches in diameter, and 16 feet 5 inches high, from which a pipe of $19\frac{3}{4}$ inches diameter connects with a pipe of $23\frac{5}{8}$ inches common to all the pumps, and communicating with the main pipes to the reservoir. For increasing the air-pressure there is a separate air-pump worked from the lower arm of the rocking bell-crank, the diameter of the cylinder being 5 inches, and stroke $14\frac{1}{2}$ inches. The suction-pipe of each pump leads to an exhaust chamber $36\frac{1}{2}$ inches in diameter, and 5 feet 11 inches high, to which is connected the suction-pipe of $19\frac{3}{4}$ inches diameter from the well.

The double-action air-pump for exhaust of the low-pressure cylinder is situated near the latter below the bed-plate level, and is actuated from the upper arm of the bell-crank. The diameter of the cylinder is $17\frac{3}{4}$ inches, and the length of stroke is $21\frac{5}{8}$ inches. The condenser is supplied with spray from a cold-water pump with a cylinder $7\frac{1}{2}$ inches in diameter and 18 inches stroke.

There are four boilers, each of which is 7 feet in diameter and of 26 feet 3 inches outside length, resting on cast-iron supports. The steam drum is raised above the boilers, and is 2 feet $3\frac{1}{2}$ inches in diameter, and 24 feet 7 inches long. The boilers are double fired, the flues varying from 33 inches to $30\frac{3}{4}$ inches in diameter, the grate being 5 feet 11 inches long. They are supplied with water by two double-action steam-pumps. In the specification for the

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manufacture it was required that 1 kilogramme (2·2 lbs.) of coal consumed should lift at least 116 cubic mètres (4,060 cubic feet) of water to a height of 1 mètre (3 feet 3 inches). On trial the result per kilogramme of coal was 204 cubic mètres of water raised to a height of 1 mètre. Steam-indicator diagrams are also given of the working of the cylinders and pumps, and also detailed description of the engine-, pump-, boiler-, &c., houses.

In the engine- and pump-house the four engines occupy a length of 66 feet, which, together with foot- and stairways of 8¼ feet at each end, leading from the level of the engine-room floor to that of the pump-room, 12 feet lower, give a total inside length of 82 feet. The clear breadth is 65 feet 7 inches. Above the pumps is a travelling crane with lifting power of 4½ tons. The boiler-house is of the same breadth as the engine-house. The length is sufficient to allow room for six boilers (at present there are four), each occupying, including setting, a breadth of 9 feet 10 inches. Between the engine- and pump-room and the boiler-house is a space of 19 feet, occupied by a workshop, the attendants' room, stores, and passages connecting the pump- and boiler-house. The chimney is of octagonal section and 115 feet high. The foundations of the machinery and buildings are of concrete, those places subject to great stress being finished with dolomite blocks. The walls of the buildings are of red brick with sandstone plinths, the window frames of cast iron 8 feet 6 inches broad and 15 feet high. The walls of the boiler-house are constructed in bays of 8 feet 2 inches clear span, filled in with thin walling, the piers being 1 foot 8 inches by 4 feet 3 inches in section. The engine-house, in addition to ten side-windows, is also lit from above by a clerestory 16 feet 7 inches broad running the whole length of the roof. The engine- and pump-house roofs are lined with a double sheeting of boarding, with an intervening space of 1¾ inch. The rafters of the former, 6 inches by 8 inches, are 3 feet 3 inches apart, and carried on wrought-iron purlins 8 feet 4 inches apart, 9⅞ inches deep, with a flange breadth of 3⅞ inches. The purlins of the eaves are of rolled iron 4⅞ inches by 3 inches. The pump-house roof, which is of small span and nearly flat, is carried by rolled joists 13¾ inches deep, with a flange breadth of 5¼ inches. The boiler-house and workshop roof is lined with single boarding with a louvred clerestory 55 feet 9 inches long and 8 feet 2 inches broad. The rafters are 3 feet 3 inches apart, the principals in this case being only 9 feet 10 inches apart, the purlins are of timber 8 feet 2 inches pitch, and 6 inches by 8 inches in section. The upper member of the trussed principals is of T-iron 4 inches by 5¼ inches by ¾ inch. The tie-bars of the truss vary from 1⅞ inch to ¾ inch diameter, with cast-iron struts immediately beneath each purlin. A water-level indicator is fixed in the pump-house connected electrically with floats in the high-level reservoir and main well, there also being communication by a speaking instrument, with the reservoir attendant. This reservoir is situated at a distance of 2,515 yards from the pump-house, and at an altitude

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of 133 feet above datum. (The level of this latter is not given.) There are two parallel pipes between the pumps and the reservoir. They are socketed and of cast iron, each 13 feet $1\frac{1}{2}$ inch long, $23\frac{5}{8}$ inches diameter, and $\frac{3}{4}$ inch thick.

D. G.

On the Causes of the Internal Corrosion of Steam Boilers.

By M. Lodin.

(Comptes rendus de l'Académie des Sciences, 1880, p. 217.)

Experimenting on iron wire, with various solutions in water, M. Lodin ascertained that the dominant action upon iron, in ordinary waters, was that of the oxygen of the air dissolved in water; and that that action was little greater in contact with heated distilled water than with calcareous waters. In presence of distilled water, the oxygen absorbed at 68° Fahrenheit was about 0·258 grain per square foot of surface per hour; and at 212° Fahrenheit, about 2·364 grains. In presence of calcareous water, the oxygen absorbed was 0·330 grain and 2·579 grains respectively.

The decomposition of water by iron, is, to a less extent, a cause of oxidation. The disengagement of hydrogen was constant for all the waters tested. It was lowest with distilled water, for which, at about 260° Fahrenheit, it corresponded to an absorption of 0·01 grain per square foot per hour; for calcareous water, 0·0129 grain; for sea-water, 0·067 grain; for water saturated with chloride of sodium, 0·05 grain; and for water containing one-fifth part of crystallized chloride of magnesium, 0·182 grain. These results of oxidation are of much less magnitude than those of oxidation by dissolved air.

As the calcareous deposits only take place on surfaces whereon oxidation has begun, the action of empirical remedies, it was supposed, was due to the prevention of oxidation. Zinc, for instance, decomposes water at 212° Fahrenheit much more energetically than iron does. Samples of iron and zinc were sealed up in a tube, with water at above 212° Fahrenheit. The iron preserved its polish, though when it was enclosed alone with the water it became rapidly oxidised.

Logwood has frequently been employed as an anti-incrustant. The principle of logwood, hematoxyline, absorbs oxygen above 212° Fahrenheit, in the presence of water, though it appears to stimulate the disengagement of hydrogen instead of reducing it. The resulting liquid holds in suspension a solution of iron. Potatoes do not absorb the oxygen of air; but they appear to cause the decomposition of water, and the resulting liquid holds iron in solution. The compounds which are formed by logwood and by potatoes with iron oxide are very slightly adhesive to iron plate, and they readily admit of the separation of calcareous deposits.

D. K. C.

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Comparative Experiments on Woolf-Engines and Marine Compound Engines. By O. HALLAUER.

(Bulletin de la Société Industrielle de Mulhouse, 1880, pp. 171–265.)

M. Hallauer, having before made an experimental study of the comparative action of single-cylinder engines and Woolf-engines,[1] now compares, by direct experiment, the action of Woolf-engines and receiver compound engines, fixed engines, and marine engines, which differ in the ratio of the capacity of the cylinders, which vary from $\frac{1}{5}$ to $\frac{1}{7}$ for the Woolf-engine, and from $\frac{1}{2}$ to $\frac{1}{3}$ in marine engines. In the former, also, the steam passes direct from the first to the second cylinder; in the latter, there is an intermediate receiver, by means of which the cylinders are separated, and the steam works independently in them.

In the Woolf-engines, it is shown that the intrinsic or absolute work done by the steam varies to a very slight extent—not above 2 or 3 per cent.—with the degree of expansive working, ranging from $\frac{1}{5}$ to $\frac{1}{14}$, cutting off the steam at full pressure into the first cylinder at one-fourth, one-half, or three-fourths of the stroke, and expanding it further into a cylinder of six times the capacity. Allowing now for the loss by back-pressure in the condenser—from 15 to 20 per cent.—the most economical ratio of expansion is $\frac{1}{12}$, while cutting off at half-stroke in the first cylinder. Again, it is found that, supposing the power generated with a total ratio of expansion of $\frac{1}{8}$ is to be reduced to one-half, if the reduction be effected by wiredrawing the steam, there is a loss of efficiency of 4 per cent.; whereas, by cutting off earlier, and expanding more, there is a gain of 3 per cent.

Turning to the marine engine under trial, in which the ratio of the cylinders is $\frac{1}{2}$, it is deducible from the experiments that a Woolf-engine, having the same ratio of cylinders, would work with precisely the same degree of efficiency as the marine engine for equal degrees of expansion. It was, besides, found that the Woolf-engine, expanding 12 times in cylinders as 1 to 6, made just the same efficiency as the marine engine expanding 8 times in cylinders as 1 to 2.

As to the most suitable ratio of cylinders with respect to the variation of expansive working, it was found in the Woolf-engine, having cylinders as 1 to 6, that the expansion could be varied from 8 times to 24 times, without affecting the consumption of steam more than 3 per cent.; whilst, in the marine engine, having cylinders as 1 to 2, the expansion was varied from $3\frac{1}{2}$ times to 20 times, when the consumption varied 18 per cent. The Author recommends the ratio $\frac{1}{4}$ to $\frac{1}{5}$ for the cylinders.

The Author concludes generally that compounded engines of all forms, having two cylinders steam-jacketed, may be classed as one

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lx., p. 475.

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type which, for the same ratio of cylinders, and the same rate of expansion, will give equal consumption of steam; and that for different proportions of cylinders, different adjustments of the expansion are required for obtaining the minimum consumption. Also, that compound engines having three steam-jacketed cylinders, of which the first cylinder discharges simultaneously into the other two cylinders, give the same results of efficiency as the two-cylinder compounded engine.

The annexed Table contains general results of trials of simple and of compound engines:—

CONSUMPTION of STEAM.

Engine (Steam-jacketed).	Indicator Horse-Power.	Ratio of Cylinders	Ratio of Expansion.	Consumption of Dry Saturated Steam.			Effective HP. at Brake.
				Per Absolute HP.	Per Indicator HP.	Per Effective HP.	
	I.HP.			lbs.	lbs.	lbs.	Per cent.
One cylinder, Corliss	158	..	1 to 7·3	16·1	17·5	19·1	92
Do. do.	137	..	1 „ 9·4	15·8	17·3	19·3	90
Do. do.	105	..	1 „ 15·1	15·7	17·4	19·5	88
Woolf beam . . .	220	1 to 5½	1 „ 12·8	15·1	17·7	20·7	86
Do. . . .	150	1 „ 5½	1 „ 26·0	15·0	18·1	22·0	82
Two compound cylinders, Marine . .	6,360	1 „ 2	1 „ 3·5	17·7	19·9	..	..
Do. do.	3,900	1 „ 2	1 „ 7·9	15·1	18·3	..	..
Do. do.	1,665	1 „ 2	1 „ 19·2	17·9	23·0	..	..
Do. compound horizontal . .	78·5	1 „ 3	1 „ 7·6	14·7	16·2	18·7	87
Do. do.	64·5	1 „ 3	1 „ 13·1	14·4	16·2	18·9	86

Absolute HP. signifies the total work done in the cylinder measured down to the line of absolute vacuum; whilst indicator HP. is measured down to the line of back-pressure from the condenser. Effective HP. is the power measured by the brake. Back-pressure on the piston is far from following the ratio of the work done on the pistons: it decreases less rapidly than the work, and so forms a larger proportion of resistance, as the work is reduced.

D. K. C.

Balancing Locomotive Engines. By C. A. SMITH, B.S.

(Van Nostrand's Engineering Magazine, vol. xxiii., p. 9.)

The Author, after some preliminary remarks on the importance of balancing locomotives, proceeds in the first place to consider theoretically the conditions which govern the weight and position of the counterpoises, and in the second the adjustment of the latter

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as to position and weight on the wheel in accordance with the formulæ deduced, this including a dynamical test.

The perfect balance of a machine requires an equilibrium of both the centrifugal forces and the centrifugal couples. It is of primary importance that the wheels should be properly balanced when the cranks are on the centres, and the balancing of the reciprocating parts should be divided among all the drivers in order to distribute the effect of the overbalancing which takes place in all other positions of the crank.

In considering the forces acting on a wheel which are to be balanced, the Author assumes the force due to the momentum of the reciprocating parts as equivalent to the centrifugal force of an equal weight concentrated at the crank-pin.

Let W = weight of reciprocating parts;
P = that part of the weight of coupling rod (or rods) which is supported by the crank-pin of the wheel under consideration;
w = combined weight of counterpoise and crank of one wheel;
r = distance from centre of axle to centre of gravity of counterpoise and crank;
c = length of crank;
a = distance between centres of cylinders;
b = distance between middle of wheel centres;
d = distance between middle of coupling-rod brasses;
ϕ = angular velocity of wheel;
g = force of gravity;
θ = angle formed by line from centre of wheel to centre of gravity of counterpoise and crank with crank line;
n = number of driving wheels on one side of locomotive;

then $$\tan\theta = \frac{\frac{W}{n}(a-b) + P\,(d-b)}{\frac{W}{n}(a+b) + P\,(d+b)};$$

and $$w = \frac{c}{r}\sqrt{\frac{\left(a\frac{W}{n} + P\,d\right)^2 + b^2\left(\frac{W}{n} + P\right)^2}{2\,b^2}}.$$

The above equations determine respectively the angular position and the weight of the counterpoise.

It is demonstrated by the formulæ that a perfect balance can practically never be attained by the usual practice of placing the counterpoise opposite the crank with inside connections, and is impossible with outside connections.

The adjustment of the counterpoise, as described by the Author, is effected with the assistance of scales and plumb-line, and varies according as the counterpoise is cast solid into the wheel, or is made removable in several pieces.

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The dynamical test referred to consists in suspending the engine by four points, and by means of an attached pencil allowing it, when set in motion, to describe a diagram representing the amount of oscillation. G. R. B.

Surmountable Gradients. By C. Boissay.

(La Nature, 4 Sept., 1880, p. 211.)

Stating the mean of ordinary railway inclines in plains at 1 in 200, and in hilly districts at 1 in 50, the Author gives the following Table of road and railway gradients in actual practice—

Name of Route.	Gradient.	Angular Equivalent.	Remarks.
		° ′	
High road, Simplon Pass	1 in 33	1 43	Least inclined of any road across the Alps.
Saint Germain and Pecq, Alessandria and Genoa, and Bardonneche and Susa railways (maximum for each) .	1 „ 28	2 0	
Enghien and Montmorency railway .	1 „ 22	2 35	Steepest incline in Europe worked by ordinary engines.
Certain railways in America (*sic*) . .	1 „ 20	2 52	Limit of ordinary engine power.
Rueil and Marly-le-Roy tramway . .	1 „ 16	3 26	Fireless tramway engine.
Temporary single-rail line from Raincy to Montfermeil (maximum) . . .	1 „ 13	4 24	Suppressed.
Main roads (*grandes routes*) . . .	1 „ 12	4 46	Maximum.
Temporary (Fell) railway over Mount Cenis[1]	1 „ 12	4 48	No longer worked.
Railway from Santos to Jundiahy, Brazil (rope traction)	1 „ 10	5 43	
Steepest incline surmountable by wheeled vehicles on roads . . .	1 „ 7·5	7 30	
Railway from Lyons to Croix Rousse (rope traction)	1 „ 6·25	9 7	Maximum.
Railway from Lyons to Saint Just (rope traction)	1 „ 5·4	10 22	Maximum.
Rigi railway (central rack)[2] . . .	1 „ 4	14 2	Maximum.
Steepest incline surmountable by beast of burden (pack saddle)	1 „ 3·7	15 0	
Giessbach railway (rope traction)[3] .	1 „ 3·6	15 39	
Mount Washington railway (central rack)	1 „ 3	18 16	Maximum.
Normal inclination of stairways . .	1 „ 2·47	22 0	
Mount Vesuvius railway (rope traction)	1 „ 1·6	32 13	
Steepest incline surmountable by a pedestrian	1 „ 1·43	35 0	On hard soil.
Ditto ditto ditto	1 „ 1·1	42 0	On friable soil.

F. G. D.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxvi., p. 313.
[2] *Ibid.*, vol. xxxvi., p. 103. [3] *Ibid.*, vol. lx., p. 454.

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The most suitable Dimensions for and Number of the Piers of Iron Railway Bridges.

(Zeitschrift des Vereines deutscher Ingenieure, vol. xxiv., p. 169.)

The object of this Paper is to determine, for a bridge of a given length, the number of spans required to make the cost of the work a minimum. The Author deals only with bridges subject to average conditions, and not such as are exceptional in their character as regards height or other features. Empirical formulæ, deduced from practical examples, are given for the approximate weight of the iron girders, exclusive of the permanent way, in the case of a single and of a double line of rails respectively. For the cubic capacity of the piers themselves, which are assumed to be entirely of masonry and in the first instance solid throughout, the Author also gives a formula, the values derived from which are an average between certain standard proportions adopted by him and a number of examples taken from actual practice.

No theoretical investigations are undertaken with regard to the stability of the piers, but it is shown that the proportions obtained by the above-mentioned formula compare favourably with those of good samples of modern practice such as some of the Rhine and Danube bridges, where the piers are exposed to strong currents and the impact of large masses of floating timber or ice.

By a simple combination of the expressions for the weight of the girders, the cubic capacity of the piers and the number n of the latter, exclusive of the abutments, and the use of factors of cost, a general formula for the total cost of the bridge, with the above exception, is obtained, and by the application of the rules for determining maxima and minima that value of n is found for which the total cost is a minimum. For a double line of rails this is:

$$n_2 = 0{\cdot}063\ \mathrm{L}\sqrt{\frac{\mathrm{L} - 10\,\psi\,\mathrm{H}}{\psi\,\mathrm{H}\,\mathrm{L}}} - 1;$$

and for a single line:

$$n_1 = 0{\cdot}045\ \mathrm{L}\sqrt{\frac{\mathrm{L} - 10\,\psi\,\mathrm{H}}{\psi\,\mathrm{H}\,\mathrm{L}}} - 1;$$

Where H = the total height of each pier (measured from the bottom of the foundation),

L = the total length of bridge,

$$\psi = \frac{\text{Price of a cubic mètre of masonry}}{\text{Price of a ton of iron}}.$$

The application of these formulæ is limited to bridges with piers not exceeding 30 mètres (98·4 feet) in total height.

The Paper is accompanied by numerous diagrams showing the relations between the different dimensions and quantities, numeri-

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cal examples of the application of the formulæ given, and tabular statements of the results.

After determining, in the first instance, the dimensions requisite for solid masonry piers, the Author gives the modifications necessary when the piers consist each of two cylindrical (masonry) columns.

The number of piers required, as obtained from the above formulæ, is but slightly affected by very considerable variations in the price of materials.

G. R. B.

On the Durability of Railway Sleepers. By Herr FUNK, of Cologne.

(Organ für die Fortschritte des Eisenbahnwesens, 1880, p. 62.)

The writer was reporter to the Committee of the German Railway Union, which, in 1876, sent round a circular to collect information on the life of sleepers; and has also collected many details on the subject during nearly forty years' experience on permanent way. These he has embodied in a set of Tables, and in a diagram, showing graphically the percentage of sleepers changed at the end of each successive year, for a number of large lots of sleepers, of various woods, and treated in various manners.

He first observes that the decay of timber is always due to the sap, which, originally liquid, becomes gradually solid, and then ferments under the influence of the atmosphere, the process being greatly assisted by damp and heat. Hence decay may be in great measure prevented, (1) by excluding all air, (2) by keeping the wood perfectly dry, (3) by a sufficient degree of cold. None of these methods, however, are applicable to sleepers. Something may be done in getting rid of the sap altogether, as by felling only in winter, by seasoning, by steaming, or by steeping in water; or in preventing its fermentation as by charring, or otherwise protecting the surface. The best plan, however, and the only one which has achieved wide success, is to impregnate the wood with some antiseptic, which will stop the fermentation, even in unfavourable conditions. Of the many antiseptics which have been tried, only four have been thoroughly successful; and one of these, sublimate of mercury, is excluded by its unhealthiness and high cost. The other three are sulphate of copper, chloride of zinc, and creosote. These are all applied, in the best practice, in a similar way. The timber is placed in a large closed chamber, from which the air is first exhausted, so as to suck out the sap; the antiseptic is then admitted, and raised to a high pressure (7 to 10 atmospheres), which forces it into all the pores of the wood. This is the method patented by Bethell in 1840.

The cost of "pickling," as it is termed, may be divided into three heads: (1) material, (2) working, (3) interest and renewal fund for plant. The cost of material is of course subject to great

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fluctuations. Chloride of zinc costs from 15*s.* to 22*s.* per cwt., and is mixed with about 60 parts of water. Sulphate of copper is also mixed with about 60 parts of water, but costs 80*s.* to 100*s.* per cwt. Creosote (or the liquid sold under that name) costs 15*s.* to 17*s.* per cwt. in London, but only 11*s.* to 13*s.* in Frankfort. The cost of working varies chiefly with the completeness of the mechanical arrangements; which, as above-mentioned, are very similar for all three processes. The capital required for plant is less per sleeper as the scale of operations is larger. The total cost for two tanks may be taken at from £2,000 to £3,000. Combining the best data, the cost of pickling per sleeper, for different kinds of wood, is about as under:—

System of Pickling.	Description of Wood.					
	Oak.		Beech.		Pine.	
	From	To	From	To	From	To
	d.	*d.*	*d.*	*d.*	*d.*	*d.*
Chloride of zinc . .	2·9	6·7	5·9	9·6	3·8	6·1
Sulphate of copper .	4·3	9·0	10·8	12·0	7·2	10·2
Creosote	10·6	16·2	..	21·4	17·5	27·6

It thus appears that the cost with creosote, at least in Germany, is from two to three times that with chloride of zinc. At the same time the efficiency of the latter, according to experience, appears to be fully as great. It is true that this can only be proved by observations on the average life of sleepers treated with the different processes, and that this life is affected by the condition of the timber, the nature of the ballast, and many other circumstances. But on the whole it is fully established, especially for the softer woods, by the statistics given, which may be summarised as follows, see page 392:—

From these statistics is collated the following Table, showing the average of increased life due to any good system of pickling under pressure:—

Average Life.	Oak.	Pine.	Fir.	Beech.
	Years.	Years.	Years.	Years.
Unpickled	13·6	7·2	5·1	3·0
Successfully pickled .	19·5	15·0	9·0	16·5

The statistics also show that the method of merely dipping or boiling the sleeper in the pickle is comparatively useless; and, in fact, it has been everywhere superseded by the pressure process.

As regards the antiseptics used, sulphate of copper is declining

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Timber.	How Pickled.	Name of Railway.	Number of Sleepers laid.	Percentage changed at end of—				Average Life. Years.
				Five Years.	Ten Years.	Fifteen Years.	Twenty Years.	
Oak.	Unpickled	Emperor Ferdinand Northern.	615,968	0·54	25·70	unknown	unknown	10·0
		Hanover	565,261	0·61	14·92	35·91	77·32	16·0
		Cologne and Minden	340,108	0·29	20·29	63·13	all	13·5
		Berlin and Potsdam	180,204	0·00	8·12	41·69	75·40	16·0
		Altona and Kiel	167,000	0·06	6·71	46·83	91·57	15·1
	Chl. of zinc	Hanover	168,690	0·15	2·20	unknown	unknown	19·6
	"	Rheine and Emden	18,600	0·00	1·00	6·50	24·00	25·0
	Creosote	Cologne and Minden	67,678	0·05	0·78	19·94	36·72	19·5
Pine.	Unpickled	Tilsit and Insterburg	68,291	1·16	55·82	all	all	9·4
		Leipzig and Dresden	93,543	11·72	73·70	all	all	7·9
		Schleswig	146,803	2·00	75·50	all	all	8·6
		Oppeln & Tarnow	79,200	16·60	91·90	all	all	7·0
	Sul. of copper (saturated)	Berlin, Potsdam and Magdeburg	36,648	0·93	12·11	50·20	unknown	14·0
	Sul. of copper (dipped)	Lübeck and Büchen	60,000	0·00	5·80	57·00	unknown	13·9
	Sul. of copper (pressure)	Magdeburg and Wittenberg	111,044	0·20	5·80	19·40	unknown	16·0
	Chl. of zinc (pressure)	Rheine and Emden	161,515	0·06	1·10	3·50	26·90	22·8
Fir	Unpickled	South and North Union	233,640	40·6	all	all	all	5·2
	"	West Saxon	26,720	24·9	all	all	all	5·1
	Chl. of zinc (dipped)	Altona and Kiel	3,899	24·0	91·00	100·00	all	6·6
	Sul. of copper (dipped)	Aix and Düsseldorf	32,348	14·0	49·00	all	all	9·6
Beech	Chl. of zinc (pressure)	Hanover	81,002	0·86	4·90	34·50	unknown	14·8
	Creosote (pressure)	Cologne and Minden	21,440	0·04	3·91	22·49	46·91	17·8
	Chl. of zinc (pressure)	Brunswick	600	0·00	7·20	42·00	unknown	13·0
	Unpickled	Various trials.	..	..	..	..	..	3·0

in estimation, as being very expensive, and not entirely satisfactory. Chloride of zinc and creosote are about equally effective, but the much lower cost of the former is bringing it more and more into favour. Whereas in 1865 there were fifteen German railways using sulphate of copper, eight chloride of zinc, and four creosote, in 1877 the corresponding numbers were five, twenty, and thirteen.

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The following rules are given for lengthening the life of sleepers, in addition to those connected with the pickling process; they are derived from the Report of the German Railway Union in 1878:—(1) The ballast should be free from earth, not liable to weather, and easily permeable by water; (2) The sleepers should be entirely covered up in clean gravel; (3) Air-drying of the sleepers before laying, whether pickled or not, increases their life; (4) The timber should be felled in winter; (5) The sleepers should be thoroughly dried before pickling, if with creosote; with other materials this is not so important.

W R. B.

Central Pacific Railroad Company's Transfer Boat "Solano."

(Railroad Gazette, 1880, p. 406.)

This vessel, used to convey the trains of the Central Pacific Company across the Straits of Carquinez, is supposed to be the largest ferry-boat in the world. The "Solano" is 424 feet long over all, 64 feet moulded beam, 116 feet extreme width over the guards. Draught 5 feet light, 6 feet 6 inches loaded, 3,541 tons registered. Her deck carries four lines of rails, and to afford the necessary stiffness for supporting the trains, four Pratt trusses are worked into the body of the ship, directly under the railway tracks. The vessel thus constitutes a large floating girder bridge. There are four bridges athwartships, of which the two end ones, at a lower level, carry the pilot houses, which are connected by another bridge passing fore and aft, under the two central transverse ones. The strength of the craft is further ensured by eleven transverse water-tight bulkheads, dividing the hull into twelve compartments. There are four balanced rudders at each end, coupled together and worked by hydraulic gear.

The "Solano" is propelled by two vertical beam engines, with 60-inch cylinders and 11 feet stroke. Common paddle-wheels, 30 feet in diameter, with twenty-four floats, 17 feet on the face. Steam is supplied by eight steel boilers, each 28 feet long and 7 feet diameter, containing one hundred and forty-three 4-inch tubes, 16 feet long. The total heating surface in the eight boilers is 19,640 square feet; grate surface, 288 square feet. The boilers are placed in pairs on the guards forward and abaft the paddle-boxes, so that one and all may be used at pleasure. There are four chimneys. The engines are placed on the centre line of the boat, fore and aft, and not abreast in the usual way, the object being to provide space for the four lines of rails, two of which are situated on each side of the engines. The boat works end on, both extremities being alike, and when in dock connecting with the slips by aprons 100 feet long, laid with rails to correspond with those on the deck.

F. G. D.

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Continuous Electric Railway Brake. By M. ACHARD.

(Mémoires de la Société des Ingénieurs civils, 1880, p. 45.)

This continuous electric brake has been employed by M. Regray, on the quick trains between Paris and Avricourt. Alongside and parallel to each axle of the train, a tubular electro-magnet is suspended. Two springs, bearing on the revolving axis of the magnet, serve to maintain it within a short distance of the axle, and act as conductors for the electric current. By exciting the electric current all the electro-magnets, at whatever speed, are attracted by the corresponding axles, and are by contact instantly set in revolving motion. The two chains fixed to the axis of the magnet, right and left, are wound on it, and so they pull the levers by means of which the brake-blocks are brought into contact with the tyres of the wheels, with a force such that in the space 1·6 second all the wheels of a train may be completely brought up.

The train is thus converted into a vast sledge sliding on the rails, and may be brought to a stop in a space of about 220 yards, for a speed of fifty miles an hour. But, if the force of the current be moderated so that the adhesion of the brake-blocks may be just a little less than sufficient to grip the wheels, the train can be stopped in a distance not exceeding 160 yards.

The van at each end of the train carries a generator of electricity, —the pile of M. Planté, or a dynamo-electric machine—with a commutator for delivering the current through the train. The conducting cables consist of twelve copper wires, 1 millimètre in thickness ($\frac{1}{25}$ inch), covered with gutta-percha and a plait of linen cloth.

M. Planté's pile is a real accumulator; it consists of plates of lead, charged by the decomposition of acidulated water, and discharged by the recomposition of the same water, without loss. The Daniell pile is used for charging Planté's pile.

The electric brake has been employed with success in goods trains.

D. K. C.

Electrical Inter-communication in Trains. By G. K. WINTER.

(Professional Papers on Indian Engineering, July, 1880.)

The Author, by preliminary investigation, discovered that no reliance could be placed on the wheels and their connection with the rails for use as part of the electrical circuit; for even supposing the wheels to be always in good contact with the rails, the

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separate lengths of the latter are by no means in perfect connection, at least in the dry climate of India; and further, that a system which requires the joining up of a special conductor at each time of shunting was inadmissible owing to the extra care and labour demanded. His system, which avoids these objections, is as follows: Two separate conductors, insulated from each other, are fixed under each carriage, which, by means of a flexible wire rope passing through the buffer-board and the links of the safety chains at each side of the carriage, are always in perfect and permanent connection with the safety-hooks to which this rope is firmly soldered. These hooks are slightly altered in shape, and lined on the inside with copper and a ridge of gun metal. When the carriages are hooked together, electrical communication is at the same time established, which is in no way vitiated by grease or dirt on the hooks, owing to their improved form. No extra work is thereby entailed on the employees, and all chance of error or omission in the electrical connections is removed. This system has been in use on the Madras railway since January 1879, being tested every time a train passes a station, as the "all right" signal is given from the guard to the driver by its means; and has given such satisfaction to the engineers of the line, that all the carriages are now being so fitted.

The electrical apparatus in use may be on the open- or closed-circuit system. The advantage of the latter is that in case of the train parting a signal is at once automatically given, and the only objection, that when a train is purposely disconnected for shunting the bell is continuously ringing, unless stopped by an alteration of the circuit, which has to be re-adjusted when the train is again made up, thus introducing an element of error. To obviate this objection, the Author proposes to use a relay for completing a local circuit to ring the bell. This relay has two contacts, and either contact can, by means of a switch which is under the control of the driver, be put in connection with the bell circuit. When the train circuit is complete the armature rests against one contact which is not in local circuit; on the train circuit being broken the armature moves over and the bell commences ringing; the driver then changes his switch into connection with the other contact and the bell ceases to ring. When, however, the train is again made up, the armature moves over to this contact, and the bell begins to ring, thus warning the driver to return his switch to its original position. To the Paper are added drawings of the hook, and its mode of connection to the conductors.

F. J.

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A Comparison of Different Methods of Colliery Ventilation.

By J. MAYER.

(Oesterreichische Zeitschrift für berg- und hüttenwesen, vol. xxviii., p. 287.)

The object of this memoir is the description of the results obtained with different ventilating arrangements at the collieries belonging to the Emperor Ferdinand's Nordbahn at Pölnisch Ostrau, in Moravia. The district, an extensive one about 1,200 yards long by 800 yards broad, is worked from three principal shafts of the following depths:—

1. Hermengild shaft, in the centre of the basin, 292·18 mètres.
2. Wilhelm shaft, 400 yards west of the preceding, 283·9 mètres.
3. Jacob shaft, on the rise of the seams to the east, 168·8 mètres.

Up to within the last ten years the workings were of comparatively small extent, and the whole of these shafts were used as downcasts, the return current being maintained by a furnace placed at the bottom of a special upcast-shaft, 56·9 mètres deep, about midway between Nos. 2 and 3 of the above list. This is now principally employed in ventilating the shallower workings on the higher seams, those in connection with the deeper shafts being served by the following special machines:—

1. A Rittinger ventilator at the Wilhelm shaft, which has been divided by a partition into up-cast and down-cast sections, the area of the former being 2 square mètres.
2. A Körting aspirator at the same shaft, as a reserve to the preceding.
3. A Guibal fan; and 4, a Rittinger ventilator in a new up-cast shaft, 102·41 mètres deep, and 9½ mètres sectional area, near the old Jacob shaft.

The instruments used in the comparative experiments were, a large Biram anemometer of 32 centimètres diameter, and three of Casella's, made by Fuess of Berlin, which gave results varying only about 5 per cent. as a maximum. The observations were made at a depth of 60 mètres in the Jacob up-cast shaft, a special annular platform being erected for the observers and the support of the instrument, which was screwed into a clamp at the end of a flat iron bar, and projected over the edge of the platform to the required distance. The observations were made in the centre and at twelve other points of the shaft, the latter being equally distributed about the four arms of a right-angled cross. The observations in connection with the Wilhelm shaft were made in the drift connecting the up-cast with the ventilator house, which is of a nearly rectangular section.

Guibal Fan at the Jacob Shaft.—This is 7 mètres in diameter, and 2·1 mètres breadth of face; the horizontal steam engine driving it has a piston 0·356 mètre diameter, and 0·632 mètre length of stroke; the air is admitted by a channel of 1·7 square mètre area

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on either side of the axis. The discharge passage has the usual curved slide-valve for regulating the area of the outlet, the length of its travel being about 5 mètres, giving a range in the variable dimension of the rectangular outlet between 0·4 mètre and 1·27 mètre. Numerous experiments were made with the slide in different positions, which showed the loss of effect to increase in nearly the same proportion as the diminution of the area, at all speeds between forty and sixty revolutions per minute, the work done by the engine being very nearly constant for any particular speed; and therefore the Author is inclined to consider the slide-valve as unnecessary, at any rate when of the enormous length currently used; as the result of experience and calculation shows that the necessary adjustment theoretically required may be obtained with a very much shorter one.

Under the most favourable conditions the following duty was obtained at different velocities :—

Number of Revolutions.	Depression of Water Gauge.	Volume of Air per Second.	Corresponding Useful Effect.	Indicated Power of Engine.	Proportional Duty.
	Millimètres.	Cubic mètres.	HP.	HP.	Per cent.
40	16	20·52	4·38	9·03	48·5
50	24	24·25	7·55	15·45	50·2
60	34	27·67	12·54	23·05	54·4
70	47	32·04	20·07	34·37	58·4

These results agree with those of previous observers, who assigned a duty of from 50 to 60 per cent. to this ventilator. It is, however, to be remarked that in these experiments the mean velocity of the air is taken and not merely that in the centre of the current, as is usually done, which gives a quantity about 15 per cent. lower than that indicated by the latter method.

Rittinger Ventilator at the Jacob Shaft.—This fan, which is similar in construction to that described in the inventor's work on centrifugal ventilators, is intended to draw 18 cubic mètres of air at 40 millimètres water-gauge per second. The diameter of the inlet passage is 0·75 mètre; the extreme diameter of the disc carrying the fan blades, 1·5 mètre; the breadth, 0·375 mètre, and the number of revolutions, 180 per minute. The engine is of 0·369 mètre piston diameter, and 0·790 mètre length of stroke, the power being transmitted by a belt and pullies, which increase the number of revolutions fourfold. The fan of the same pattern at the Wilhelm shaft is somewhat smaller, being calculated only to remove 10 cubic mètres at 30 millimètres water-gauge per second. It is driven direct by an upright cylinder engine, 0·349 millimètre diameter of piston, and 0·422 mètre stroke.

The useful effect realised with these fans is generally reputed to be about 30 per cent. of the power expended, but this is not

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borne out by the experiments, as will be seen in the following Table, the first series referring to the geared, and the second to the direct-acting machine :—

Number of Revolutions.		Depression of Water Gauge.	Volume of Air per Second.	Useful Effect.	Indicated HP.	Proportional Duty.
Engine.	Fan.					
		Millimètres.	Cubic mètres.	HP.		Per cent.
35	140	11·0	13·53	1·99	19·20	10·4
40	160	19·0	15·88	4·02	26·54	15·1
45	180	26·0	17·71	6·13	32·30	19·0
50	200	33·0	19·16	8·43	41·14	20·5
55	220	42·0	21·59	12·09	54·19	22·3
..	60	8·0	9·03	0·96	5·23	18·3
..	80	17·0	10·09	2·27	9·32	24·2
..	100	26·5	11·56	4·08	15·28	26·7
..	120	34·5	13·51	6·22	23·25	27·0
..	140	46·0	15·57	9·55	33·39	28·6

From which it appears that the higher duty of the second series is to be attributed to the more direct application of the driving power. The application of fixed outlet or diffuser blades to this fan was found to increase the duty from 2·3 to 2·6 per cent.

The comparative expenditure of fuel by the two kinds of ventilators reduced to the amount necessary to remove 1 cubic mètre of air per second was, 11·5 kilogrammes with the Rittinger, and 5·3 kilogrammes with the Guibal per hour, or more than twice as much for the former as for the latter. This, upon the 25 cubic mètres exhausted per second from the Jacob shaft, corresponds to an annual consumption of 2,520 tons in the first, and 1,160 tons in the second case; the difference between these figures, taking the coal at 6*s.* per ton, corresponds to a saving of £400 per annum in favour of the Guibal fan, apart from that due to diminished wear of boiler.

Körting Exhauster at the Wilhelm Shaft.—The exhauster is one of the largest size made, the steam jet having a diameter of 26 millimètres. It exhausts 13 cubic mètres, at 32–33 millimètres water-gauge, per second, corresponding to a useful effect of 5·7 HP., with a consumption of steam equal to 190 HP., or the comparative duty is only 3 per cent. The corresponding expenditure of coal per hour, for an exhaust of 1 cubic mètre per second, is 25·8 kilogrammes, or more than twice as much as that of the Rittinger, or nearly five times that of the Guibal fan.

Ventilating Furnace at the Hermengild Shaft.—This furnace, with 1·7 square mètre of grate surface, is placed at the bottom of a shaft 56·9 mètres depth, the draught being augmented by a chimney 12 mètres high at the surface. It is principally employed in ventilating shallow goaves, and therefore the sections of the air-passages are of a very unfavourable character as compared with

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those of the deeper workings. Under ordinary circumstances it draws 2·59 cubic mètres at 14 millimètres water-gauge per second, with a consumption of coal at the rate of 7·8 kilogrammes per hour per cubic mètre exhausted per second, or about half as much again as the Guibal fan. When the firing is forced, the quantity may be raised to 3·08 cubic mètres, at 17 millimètres water-gauge, but the expenditure of fuel is doubled. The conclusions drawn by the Author's experiments are as follow:—

1. The Guibal ventilator is by far the best contrivance of its kind, and could not be easily improved, the most favourable conditions of work being obtained, when drawing large volumes of air at a low water-gauge.

2. The Rittinger ventilator is less effective at lower than at higher pressures, but in every case its duty is far below that of the Guibal fan.

3. The Körting exhauster is only available as a reserve for emergencies, and then can only be used for small volumes of air.

4. The ventilating furnace is not uneconomical in working, and under certain conditions is capable of a high duty, notably in very deep shafts, and may be very useful in certain cases in combination with mechanical ventilators.

H. B.

Influence of Temperature in Tunnelling through High Mountains.

By Dr. F. M. Stapff.

(Revue universelle des Mines, 1879–80; vol. v., pp. 534–559; vol. vi., pp. 1–23, and 464–481; vol. vii., pp. 1–48.)

As the difficulties encountered from elevated temperature in tunnelling through high mountains require the adoption of appliances and resources very different from those hitherto employed, the Author, as Engineering Geologist of the St. Gothard Tunnel, Airolo, has during the past six years been collecting voluminous materials for the purpose of endeavouring to solve the two following questions:—

1st. What is the highest temperature at which men can work underground?

2nd. At what depth below surface is this temperature likely to be reached in tunnelling?

I.—*Temperature at which underground work becomes impossible.*—The limit of heat at which men can work depends upon the length of their exposure to it, the amount of exertion they put forth, their acclimatisation, the nature of the atmosphere, and most of all its degree of moisture. Omitting instances of momentary exposure to exceptional heat, it is certain that men cannot accustom themselves to stand for any length of time more than 60° to 75° Centigrade or 140° to 165° Fahrenheit, even when keeping perfectly still and in

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quite pure air. In the Author's experience on mining and railway works in Mexico and the south of the United States the temperature was as high as 40° C. or 104° F. In tropical seas the temperature in the stoke-holes of steamers occasionally reaches even 69° C. or 56° F., and is aggravated by the dust raised in the act of stoking. Unfortunately there is not sufficient information at present available as to the practicable limits of temperature in underground workings. In upcast shafts used for winding, and for raising and lowering the men, a temperature of from 27° to 32° C. or 80° to 90° F. is allowed for the air current in English collieries; and in Belgian from 22½° to 34½° C. or 72° to 94° F. At Fahlun copper mine in Sweden, in reopening some old workings that had been stopped by a fire twenty years previously, the clearing up was done at a temperature as high as 52° C. or 125° F.; but there the natural ventilation was excellent. In another mine, stoping was abandoned at a temperature of 33° C. or 91° F., where the dust from the decomposed pyrites was more intolerable than the mere heat, and dyed the miners as black as ink.[1] The highest temperature observed in the Mont Cenis tunnel was 30° C. or 86° F., at about 4 miles in from the south end. In the St. Gothard tunnel full work was carried on at about 31° C. or 87° F. on the south (Airolo) side, in air surcharged with moisture; and on the north (Göschenen) side at 29° C. or 84° F., in an atmosphere not quite saturated. The Author gives detailed particulars of the air-supply to each end of the tunnel, and of the number of men, animals, and lamps consuming it; and on the assumption that the dryness of the air is of equal importance with its purity, he deduces the ratio of 4 to 3 as about representing the superior ventilation of the northern section over the southern at the time of his observations, when each end had been driven about 4 miles in.

According to Professor Dubois-Reymond of Berlin, men can stand 50° C. or 122° F. when the air is as dry as possible, as in the case of blast-furnace workers; but in an atmosphere saturated with moisture even 40° C. or 104° F. would almost certainly prove fatal. Air feels very dry when only one quarter saturated, but becomes stifling before complete saturation is reached; hence a slight diminution of moisture may be of the utmost value, and the principal means of rendering high temperatures endurable would consist in drying the air. A wagon-load of quicklime, notwithstanding the heat evolved in quenching, he considers would even give a fresher feeling than one of ice, on account of the latter rendering the air

[1] In the last working of the United copper mines in Gwennap, Cornwall, a hot spring of water at 115° F. was met with in the bottom level about 1,500 feet below surface, and the rock was so hot that even with their thick clothing the miners could not lean against it. (See Proceedings Institution of Mechanical Engineers, 1873, p. 110.) In the Comstock silver mines, Nevada, the temperature averages 130° F. at about 2,000 feet below surface, and sometimes reaches 139° F., while in particular places even 157° F. has been observed. (See Transactions American Institute of Mining Engineers, vol. vii., pp. 45–76; and Minutes of Proceedings Inst. C.E., vol. lvii., p. 393.)

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still more moist. If at the working place there were both a wagon of lime and one of ice, and also a supply of fresh air direct from the tunnel mouth, he is of opinion that work could be carried on even where the temperature of the rock was as high as 50° C. or 122° F. The ice would indeed be far more efficacious if covered with a layer of common salt, whereby not only would the temperature be still further lowered, but also increase of moisture would be prevented. The men would have to work short shifts, and the heat of the body should not reach 40° C. or 104° F. the ordinary bodily temperature being from 36¾° to 38° C. or 98° to 100° F.

The Author goes minutely into the effects observed to be produced upon the health of the men employed in the St. Gothard tunnel. He also reports at length a number of observations he made, as to how hot the men got, and how much work they could do, according to the state of the air in the tunnel. The diminished effort instinctively exerted by them, in proportion as they get hotter from the heat and badness of the air they breathe in such situations, is shown to be in accordance with physiological principles. Taking as the unit of bodily exertion the amount of effort put forth in merely walking along the tunnel at an easy pace—say about 4,550 foot-lbs. per minute—the Author considers this is somewhat exceeded by the ordinary exertion of the workmen employed in the roomier portions of the tunnel, behind the advanced heading. Those engaged however in loading the broken rock into the wagons near the forebreast, in the confined space of the advanced heading itself, must in his opinion, judging from the shorter time they work and the higher rate of their wages, be working about twice as hard; and occasional intermittent efforts may be even four times as great. They have to fill the broken stone into baskets upon long narrow lorries running on temporary rails of 1 foot gauge, laid alongside the main rails of 3¼ feet gauge; the lorries have to be run back by hand through a distance averaging about 80 yards to the main trucks, into which the baskets have then to be emptied. A score of men formed the gang occupied in this heaviest work. The relative cost of the clearing per cubic yard of rock in the two headings is found to be represented by the very same ratio as the absolute moisture of the air in them, namely 1 to 1·18 in the Göschenen and Airolo ends respectively.

The highest limit theoretically possible for the air temperature in tunnel workings would be such as would induce fever heat, of 42° C. or 107° F. in the body; while the extreme practicable air temperature, still not free from the certain prospect of impaired health and premature death, would be that under which the heat of the body should not rise above 40° C. or 104° F. The latter limit being applied to the atmospheric conditions affecting the two ends of the St. Gothard tunnel, the Author calculates that the practicable limit of air temperature should not exceed 45¾° C. or 114° F. in the Göschenen end, and 37¾° C. or 100° F. in the Airolo end, for the labourers clearing the advanced headings. He

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adds in a tabular form the corresponding figures for assumed cases both of harder and of easier work than that of removing the spoil from the ends of these particular headings.

II.—*Limit to Depth of Tunnel below Summit of Ridge.*—The scale for increase of temperature with depth, which obtains in mines and bore-holes sunk below level ground,[1] is inapplicable to mountains, owing to the cooling effect of their exposed sloping sides. From Borelli's temperature observations[2] in the southern portion of Mont Cenis tunnel, Ansted deduced an increase of 1° C. per 50 mètres or 1° F. per 91 feet depth below the summit of the mountain profile over the line of the tunnel; but that rate did not hold good for lower elevations in the same profile, and was therefore not applicable as any guide for other tunnels. From his own observations in the St. Gothard tunnel, from 1873 to 1877, for distances of 4,800 yards in from the northern mouth and 4,500 yards in from the southern, the Author deduced[3] empirical formulæ for the temperature to be expected during the further progress of the work. These having been found to hold good for the 2,000 to 3,000 yards next driven, he now reproduces some of the principal. For the temperature of the rock itself, the general average result in its simplest form is an increase of 1° C. per 48·4 mètres or 1° F. per 88·1 feet of vertical depth below the surface of the mountain. This scale gives too low a temperature for parts of the tunnel that are under valleys and plains on the mountain sides, and too high for parts under peaks; the variations from the actual temperatures noted at individual points in the tunnel amount to nearly as much as 5° C. or 9° F. But, for the mean temperature throughout any considerable length of the tunnel, the calculated result agrees exactly with actual observation, however varied be the mountain profile overhead. In confirmation the Author reproduces from the St. Gothard company's eighth report a Table of observations made in 1878 through 1,500 yards' length of the southern half of the tunnel, between 5,000 and 6,500 yards in from the mouth.[4] The variations of mountain profile may even have the effect of producing a practically uniform temperature for miles of tunnel, notwithstanding hundreds of yards difference in the heights of rock overhead. For the temperatures to be expected at the middle of the tunnel, the minuter calculations are given which had been made last year by the Author at the time when each end had been driven about 7,700 yards in, leaving then about 1,000 yards intervening to be driven. His estimate, with a margin for error of ± 2½° C. or 4½° F. was 31¼° C. or 89° F. for the rock; the same for the air about 150 yards behind either forebreast,

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[1] See "Law of Geothermic Progression," Minutes of Proceedings Inst. C.E., vol. lviii., p. 394.

[2] Austrian Meteorological Society's Journal, vol. vii., No. 23, 1 Dec. 1872.

[3] "Studien über die Wärmevertheilung im Gothard." Berne, 1877.

[4] Earlier observations have also been previously recorded in the Minutes of Proceedings Inst. C.E., vol. xlii., p. 249; and vol. lvii., p. 246.

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prior to the two drivages holing through into each other; and 33¾° C. or 93° F. for the water issuing from the rock. In March 1880, after the holing through, the actual mean temperature of the rock for the middle length of 1,000 yards was found to be 30½° C. or 87° F.; and this was also the air temperature 150 yards behind the forebreasts prior to holing through. At the two forebreasts themselves the air temperature was brought down as low as 27¾° C. or 82° F. while boring, and 30° C. or 86° F. while clearing away spoil: which was about 3° C. or 5° F. lower than calculated, the reduction being due to an extra supply of compressed air during this last 1,000 yards' drivage. These several temperatures, though high enough to retard the progress materially in the middle of the tunnel, and render the work more laborious, were not so excessive as to entail either stoppage or danger.

General Remarks.—Having entered minutely and at great length into the various conditions affecting the execution of the work in the two ends of the St. Gothard tunnel, the Author refrains from attempting to lay down a fixed limit, either of temperature or of depth, for any future tunnelling operations which may enjoy the advantage of resources superior to those hitherto available. But the means to be employed for dealing with higher temperatures than have hitherto been encountered would have to be very carefully matured beforehand, both theoretically and practically.

Projected Simplon Tunnel.—The extent of guidance furnished by the light of present experience is illustrated by the Author's application of his calculations to the principal projects for tunnelling through the Simplon. Of the longer routes plotted, for piercing the mountain nearest its base, from near Brieg on the northern slope, those of MM. Favre & Clo, and M. Lommel, each nearly 12 miles, would appear to be impracticable of execution with the resources at present available. According to their mountain profiles, the depth of these tunnels below the ridge would be about 7,300 feet; whence the temperatures to be expected midway in the tunnels would be about 47° C. or 116° F. for the rock, and for the air 150 yards behind the forebreast; and about 53° C. or 127° F. for water issuing from the rock. In the shorter and higher tunnel proposed by M. Stockalper, about 10 miles long, piercing the range at about 2,560 feet above sea-level and beneath a rather lower portion of the ridge, the Author estimates the depth below the ridge at about 5,900 feet, and the rock temperature midway in the tunnel at about 40° C. or 104° F.; here therefore the extreme limit of practicable execution would be reached. In two still shorter and higher tunnels, each about 7½ miles long, proposed by MM. Clo & Venetz, and M. Jacquemin, the temperature encountered would be much the same as has been met with in the St. Gothard tunnel; but their greater height above sea-level would somewhat detract from the value of both these tunnels, as compared with those nearer the foot of the mountain.

Selection of Route.—Supposing its height above sea-level be

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already determined by commercial or political considerations, the route selected for a tunnel should be such as to offer the greatest facilities for its execution. In the case of the St. Gothard tunnel, it was pointed out by the Author in 1877 that, if the route had lain 1 mile or 1½ mile westward, it would have been attended with several advantages, which he here recapitulates. It is not so easy from surface indications to form an idea about the quantity of water likely to be met with, and the solidity of the rock to be driven through, as it is from the height and contour of a mountain to calculate the increase of temperature likely to be encountered. The principles long established by general mining experience may however be properly applied to tunnelling; and in the longitudinal sections compiled by the Author for the St. Gothard tunnel it is seen how the surface indications held good down to that depth: fissures, slides, and faults, noted on the mountain profile, severally made their appearance without fail in the tunnel, most of them in a very unwelcome manner. A recent illustration from near the middle of the tunnel is cited. The Author thinks it safer and easier to avoid difficulties of this sort by careful selection of route beforehand, than to try to get over them afterwards during the execution of the work. For the projected Arlberg tunnel in Austria, he is glad to find the route laid down with a view to avoiding, by a curved course, rock that seems likely to let out streams of water. Tunnels through high mountains should as far as possible be driven in places where they will have the least height and bulk of mountain overhead, and where they will be likely to be most free of water.

Mode of Driving.—The mode adopted for driving the St. Gothard tunnel is not considered by the Author, from the experience there gained, to be the most eligible for long tunnels, where not more than two ends can be driven, and these not faster than a certain limit of speed, and where it is impossible to foresee all the difficulties that may arise. In respect of the atmosphere pervading the working places, that mode of driving seems indeed decidedly objectionable. In the St. Gothard tunnel the long succession of trenches and steps, by which the small advanced heading was gradually widened and deepened to the full size of the finished tunnel, caused the working places to stretch back as far as a couple of miles behind the forebreast. Hence, even admitting the practicability of artificially supplying the advance heading itself with air so cold that, where the rock temperature was from 40° to 50° C. or 100° to 120° F., the men could work a hundred yards behind the forebreast, the Author considers the same means would be altogether inadequate for such a length as a couple of miles of tunnel, full of men at work and smoke from blasting. Moreover in the usual plan of driving the advance heading along the crown of the tunnel, the water issuing from the forebreast has to flow all along the heading, and then down along all the following steps and trenches of the successive enlargements, before reaching the completed culvert in the finished

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portion of the tunnel. The Author therefore suggests the desirability of proceeding by an inverted method, somewhat as in metalliferous mines: driving the advanced heading along the very bottom of the tunnel, and carrying the culvert forwards promptly with it, so that all water should drain at once into a narrow channel, presenting small surface for evaporation. Less moisture would thereby be imparted to the air, even when driving through very wet rock, than is evolved in drier rock from the vast extent of wet surface exposed by the puddles and mud that are inevitable with the ordinary mode of driving. Such an inverted method would doubtless present difficulties in regard to ventilation; but more attention might advantageously be paid in tunnelling to the improvements that have already been realised in mine ventilation by the adoption of systematic arrangements. For long tunnels that will take years to execute, instead of improvising foul-air outlets temporarily and at random, or opening cocks here and there on the compressed-air main, a regular system of ventilation should be carried out by means of brattices, air-doors and trunks, and should be pushed forwards continuously to follow up the progress of the work. A further suggestion for facilitating the execution of tunnels through hot rock is to complete each end to the full size as far in from the mouth as can be done without the heat becoming too oppressive, say up to 30° C. or 86° F.; and then to push forwards and complete the advance heading alone, without continuing the work of enlarging behind it. The practical difficulty would then be reduced to the efficient ventilation of the heading for a length of 100 yards back from the forebreast. As soon as the two headings met, a good current could be established right through from one end of the tunnel to the other, which would be largely efficacious in keeping down the temperature at the working places during the subsequent enlargement of the central length.

Haulage.—Manual or animal labour in the working places should as far as possible be replaced by mechanical power: though how to manage this practically for the most fatiguing portion of the work—the clearing away of the spoil—yet remains to be found out. Endless-rope haulage, as already carried out at collieries, would be more convenient for removing the stuff than the use of compressed-air locomotives, the size of which prevents their penetrating so far into the advancing end, and also interferes more with the ventilation.

Artificial Cooling.—This is the most difficult question of all, and is by no means solved by the use of extensive appliances for supplying compressed air. The heat from the rock is practically inexhaustible; and, whether all the air-cocks at the forebreast are open or all shut, the air temperature 200 yards back is practically constant and equal to that of the rock, and thenceforth gradually rises as the air travels further back along the working places. The utmost cooling at the forebreast, while four rock-drills are working together and discharging their exhaust air at 2½ to 4

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atmospheres pressure, does not exceed 4° C. or 7° F. at most, the average being only 1° C. or 2° F. below the rock temperature; and during the clearing away of the spoil the air may rise as high as 4° C. or 7° F. above the rock temperature, the average being 1½° C. or 3° F. above. A Table is given of periodical observations made by the Author at both ends of the St. Gothard tunnel while the drivage was suspended for surveying the line of driving, the working places being then deserted and the air-cocks left open. These records show that with a rock temperature of 47° C. or 116° F. it would be no easy matter to keep the air down to 35° C. or 95° F. in the working places while work was being carried on. There is no great difficulty in delivering highly compressed air in large quantities at the forebreast; the difficulty lies in arranging its distribution. Men cannot work within a distance of 5 or 6 yards in front of an aperture not more than 4 inches diameter; and often put a basket over it to break the blast. The most serious obstacle to the use of compressed air as the sole means of cooling lies in the low specific heat of air, whereby vast volumes become heated immediately to the temperature of the rock, without perceptibly cooling the rock itself. A jet of cold water has very little cooling effect on the air, and the mist thereby produced is decidedly objectionable; on the contrary indeed the compressed air should itself be supplied as dry as possible. To cool the air before delivering it into the tunnel is of little use, because its cooling effect depends much more on its sudden expansion; and also because, however cold it may have been at the tunnel mouth, by the time it reaches the inner end of a very long main the air is found to have acquired within 2° to 3° C. or 4° to 5° F. as high a temperature as the surrounding atmosphere in the tunnel. As a means of cooling in combination with other plans, the adoption of compressed air points to the use of compressing apparatus on a much larger scale than that at either Mont Cenis or St. Gothard. A further problem will be to devise better methods for drying the air. The air reservoirs at Mont Cenis and St. Gothard answered the purpose to a certain extent, and were supplemented by additional appliances at St. Gothard. For completely drying the air, Professor Dubois-Reymond's suggestion to employ quicklime might be adopted; and the Author points out that this mode of drying would be more efficaciously applied to the compressed air before its delivery into the tunnel, than by conveying the lime itself to the working places. The cooling mixture of ice and salt should however be conveyed in the spoil-wagons to the working places, and there discharged on the off side; as it gradually melted away, the water would run off, but without imparting so much moisture to the air as if there were no salt mixed with it. The combination of these two plans appears to the Author to offer the best means of enabling tunnels to be driven at high temperatures.

Workmen, and Shifts.—Italians, used to a warm climate, and taking to mining with skill and perseverance, form as valuable a

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class of workmen for European tunnels as the Indians of Mexico or South America for tunnelling operations in those countries. Under such circumstances as obtained in the St. Gothard tunnel, the Author considers that, having regard both to economy and to health, the average duration of shift should not exceed eight hours. Two hours must be allowed for walking in to the working places, when at a distance of 4 to 4½ miles in from the mouth; then some rest is needed before commencing work; and two to three hours' work is all that can be managed before starting on the two hours' return journey, which should also be made leisurely on foot. The men at the boring-machines, and those clearing away spoil just behind, having the coolest and driest air, often remained fourteen hours in the St. Gothard tunnel. The men should strip themselves of clothing as far as possible, so long as the air temperature is lower than that of the body; if ever tunnelling came to be done at a higher temperature, it would of course be desirable to work with clothes on. Wherever artificial cooling of the air is required, the working places should also be followed up closely by suitable refuges or chambers, fresh and well ventilated, and even filled with dry air at a slight excess of pressure, where anyone overcome with exhaustion can be promptly restored, and where the men can dry and change before leaving work. Cooling beverages are recommended, for avoiding the danger of drinking too much cold water while at work.

In conclusion the Author points out that, from the nature of the work in long tunnels under high mountains and through hot rock, the question of cost, and even of time, may often become a consideration of secondary importance.

A. B.

Warming and Ventilation of the Monge School. By S. PÉRISSÉ.

(Mémoires de la Société des Ingénieurs civils, 1880, p. 661.)

The Monge school consists of four buildings 26 feet wide, so placed as to enclose a covered court 74 yards in length and 26 yards wide. Besides the basement, there are three floors. The class-rooms are 29 feet square and 13 feet high. It holds six hundred and seventy pupils. The building is warmed by means of hot water, in two groups of apparatus, each of which contains three vertical boilers placed underground. The pipes are carried up in recesses in the walls to the top of the house. Fresh air is admitted at the level of each floor, and passes upwards above the hot-water columns in the recesses in the walls. It is warmed as it ascends, and is discharged into each room at the ceiling. The air is withdrawn from the room through one or more grates near the floor, and ascends in flues to the attics, the temperature of which is maintained by the chimneys of the boilers

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which pass through them, and by the hot water expansion-cisterns. In summer, a special boiler is in action in the attics to ensure ventilation. The spent air is discharged at a height of 27 yards above the floor of the boiler-house.

The boilers are 3 feet 11 inches in diameter, and 13 feet high; the fire-box is 35½ inches in diameter, making a water-space of about 6 inches between the fire-box and the shell. The height of the fire-box is 12 feet, and the capacity of the boiler for water amounts, it is said, to 88 cubic feet. The products of combustion pass from the upper part of the fire-box, through the water-space, and wind round the exterior of the boiler downwards, whence they are led by a flue to the chimney. Each group of three boilers presents a heating surface of 807 square feet. The circulating pipes are of cast iron of from 8 inches to 6 inches in diameter, having a capacity of upwards of 800 cubic feet for the two groups together. During the month of December last, whilst the temperature externally was much below the freezing point, a temperature of from 56° to 59° Fahrenheit was maintained within the building.

During the school season 1878–79, the school was artificially warmed during two hundred and twenty-six days, with the consumption of 156 tons of Charleroi coal.

D. K. C.

Apparatus for Supplying Drinking Water at the Harbour of Flushing. By F. KAPAUN.

(Wochenschrift des österreichischen Ingenieur- und Architekten-Vereins, p. 149.)

The island of Walcheren is dependent for its supply of fresh water for drinking on the rainfall, all other water being brackish.

For the supply of ships leaving the harbour of Flushing it has been necessary to have recourse to the condensation of steam as being the only available source for fresh water independent of rain.

For this purpose an apparatus, patented by Dr. Normandy, has been erected, which is characterised, as compared with others of the same class, by its economy. Two main features distinguish this apparatus; the repeated utilization of the heat set free by the condensation of steam for the evaporation of the condensing water, and the application of a series of regulators for the continuously working pumps, which supply both the boilers and condensers with water.

Steam is generated from sea-water by a boiler of ordinary construction, from which a steam-engine driving six pumps is also supplied.

For the condensation and partial evaporation of steam there are three well-lagged receivers of about 3 mètres (9·84 feet) in height. These contain internally a series of tubes constituting the condensing surface.

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Condenser No. I. receives steam direct from the boiler, and also the exhaust steam from the engine; that from the boiler passes through a safety-valve loaded to 10 lbs. per square inch (English), and therefore only enters the condenser when the above pressure is exceeded. Two of the receivers are half, and the third entirely filled with water, which surrounds the tubes, and is supplied by four pumps. The condensed water finds its way through a number of small tubes for further cooling into a filter, and thence to the fresh-water reservoir. In condenser No. I. the heat from the condensed steam evaporates a portion of the circulating salt water, which then passes as steam through a connecting-pipe into the tubes of condenser No. II.; the same process is repeated as regards Nos. II. and III. The supply of water to the circulating and feed pumps is regulated by a series of floats acting on hydraulic valves.

The apparatus cost 28,000 florins (Dutch) (£2,339 3*s.* 7½*d.*). It produces an average of 1 cubic mètre of water per hour, or 18 kilogrammes per kilogramme of coal. The feed-water required is double the quantity of drinking water produced; the quality of the latter is satisfactory.

G. R. B.

Dervaux's Boiler Feeder. By Jules Henin.

(Revue universelle des Mines, vol. v., 1879, pp. 601–611.)

This contrivance is intended, besides maintaining a constant water-level in a steam-boiler, to heat the feed-water sufficiently for precipitating beforehand any deposit that would otherwise incrust the boiler plates with scale. It may be described as a large cast-iron tap or cock, the conical plug of which is vertical, with its bigger end downwards, and is continuously rotated by a worm-wheel. The plug is divided into two tiers or storeys; and each storey is furnished with four chambers, one in each quadrant. These communicate alternately, through ports in the body or casing of the cock, with external receptacles, of which the top pair are kept constantly supplied with the water employed for feed. As the plug rotates, its top chambers fill with feed-water, and carrying it round deliver it into an intermediate pair of receptacles, which communicate simultaneously with both the upper and the lower storey of the plug, thus allowing the water to enter from them into the lower chambers in the plug. These finally carry it round to two ports, one above the other, from each of which a pipe descends into the boiler; the pipe from the lower port reaches down to low-water level, while that from the upper port stops short at the higher or normal level to be maintained in the boiler. From the bottom chambers of the plug the feed-water runs down into the boiler through the lower or feed pipe, and is replaced in the plug by steam ascending through the

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upper or steam-pipe. The feeder being placed about 5 feet above the boiler, the downflow is produced by the column of water of that height in the feed-pipe; through the steam-pipe the full steam-pressure reaches the upper of the two ports in the feeder, while at the lower port the pressure is less by the amount of the 5-feet head of water. The feed continues until the water-level rises high enough to seal the orifice of the upper pipe; it then ceases until the orifice becomes again uncovered. The steam that gains access to the bottom chambers in the plug of the feeder follows exactly the reverse course to that already described for the feed-water; and in ascending through the feeder it heats the descending feed-water. Should the water-level ever fall so low as to unseal the orifice of the feed-pipe through the feed being too slow, the actuating head of water in the feed-pipe is lost, and the feed practically ceases, inasmuch as not more than a mere drop or two can now escape from the chamber of the plug during its rotation past the ports, because the pressure is now the same at both ports. If the feed-water is not pure, an intermediate closed settling vessel is interposed in the course of the feed-pipe, between the feeder and the boiler; in this vessel the deposit precipitated by the heating of the water becomes concentrated and subsides, while the feed passes considerably purer into the boiler.

The feeder can be arranged for feeding any number of boilers simultaneously or separately, whatever be the difference of their several water-levels, and without the aid of floats or regulators of any sort. This is accomplished by the lower storey of the plug being itself further subdivided into two or more tiers, each tier serving for two boilers. A double feeder was put up in Belgium about two years ago at the Hasard colliery, Tamines, where it continues in regular work, maintaining a constant water-level in the boilers. Another has also been working nearly two years at Boubier colliery, Châtelet, supplying a group of six boilers with complete success. Here the feed-water is so bad, possessing 27° (English)[1] of hardness, that each boiler had previously to be laid off for cleaning after every four weeks' work, and about 300 lbs. of mud was got out each time; the boilers also primed so heavily that the engine cylinders required frequent cleaning, and the safety-valves stuck every few days. With the Dervaux feeder the boilers were kept under steam from eight to ten weeks; one that

[1] In the English scale for the hardness of water, in accordance with Professor Clark's specification (No. 8,875, dated 8th September 1841), each degree represents 1 grain of chalk dissolved in 1 gallon (70,000 grains) of water. In the French scale each degree represents 0·01 gramme of chalk dissolved in 1 litre (1,000 grammes) of water. Hence 1 degree English = 1·43 degree French; and 1 degree French = 0·7 degree English. The hardness of the Boubier feed-water, given as 39 degrees French, is therefore 27 degrees English. Each French degree is also stated to represent 0·1 gramme of soap neutralised by 1 litre of water; whence chalk neutralises just ten times its weight of soap. [*See* Traité de Chimie, par J. Pelouze et E. Fremy, Paris 1865, tome I, page 246; Knight's English Cyclopædia, London 1861, vol. vii., pages 637–8; Wanklyn's Water Analysis, London 1874, pages 64–9 and 125–138.]

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was opened after ten weeks' working contained only about 6½ lbs. of mud, and there was no scale to speak of on the plates; the priming too was so far diminished that the cylinders required no cleaning, and the safety-valves continued in good order. Boilers also that have not been blown off before applying the feeder are found to be speedily freed from scum by its application. This is in consequence of the natural circulation that ensues, as soon as ever the water reaches its full level and seals the orifice of the steam-pipe; the dirty boiler-water then ascending through the steam-pipe to the feeder passes through a short channel that connects the upper port with the lower, and thence descending through the feed-pipe deposits its suspended impurities in the intervening settling vessel, whence it returns in a much cleaner state into the boiler. One of the Boubier boilers, that had been fired continuously for nearly six weeks before the feeder was applied, was opened twenty-four hours after its application, when it was found that the scum had disappeared, and the water was clear enough to see the bottom plates, which were no longer covered with mud. The Dervaux feeder is thus completely successful, not only in maintaining the water-level constant, but also in purifying the feed-water so thoroughly as practically to do away with all scale or deposit of any kind in the boilers, even with the worst water.

A. B.

Consumption of Steam in the Rolling of Steel Rails.[1]

By J. KRAFT, M. Inst. C.E.

(Revue universelle des Mines, 1879, vol. vi., pp. 451-460.)

At the Cockerill Co.'s Works at Seraing, Belgium, of which the Author is engineer-in-chief, the 10-yard steel rails for the Belgian State railways are rolled in double lengths of 20 yards. Each 10-yard rail weighs 760 lbs., and four hundred rails or 136 tons are turned out per day of ten hours. The ingot weighs 15 cwt., and is 3 feet 9 inches high, 13·6 inches square at bottom, and 11·8 inches at top. By eleven passes through the blooming rolls it is brought down to 7·7 inches square by 9 feet long. In the finishing train it passes six times through the roughing-down rolls, and then seven through the finishing rolls, from which it is delivered 64 feet long.

For calculating the total number of strokes the engine must make in rolling the original ingot down into the finished rail, the Author constructs the simple formula :—

$$N = \frac{2r}{c}\{L(m+1) + l(m-1)\},$$

in which N is the number of cylinders of steam theoretically neces-

[1] A translation of the greater part of this Paper is given in "Engineering," 20 August 1880, pp. 153-4.

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sary for elongating an ingot from an original length l to a final length L, by passing it m times through rolls of circumference c, driven through gearing in the ratio of r to 1 by a pair of cylinders coupled to right-angled cranks. With rolls driven and reversed by such an engine, the loss of steam at each starting ranges between a minimum of half a cylinderful and a maximum of one-and-a-half cylinder; to be on the safe side, the maximum loss is allowed for each reversal. Working out these calculations with the data which he furnishes of the steel-rail mill at Seraing, the Author shows that the blooming takes altogether 188 lbs. of steam, one-fifth of which is lost in the reversals; the engine is geared two to one to the rolls, and has a pair of cylinders 32 inches diameter and 4 feet stroke, with cut-off at 70 per cent. and 10 per cent. clearances; the steam pressure is 3 atmospheres effective. The roughing-down and finishing rolls are driven direct by an engine having a pair of cylinders 39⅜ inches diameter and 4 feet stroke, with the same cut-off, clearances, and pressure; the consumption of steam is calculated at 1,186 lbs., one-seventeenth of which is lost in the reversals. Hence the total consumption for the entire rolling of a double-length rail 20 yards long amounts to 1,374 lbs.; and to roll twenty of these per hour takes therefore 27,480 lbs. of steam per hour. Allowing 3·7 lbs. of steam per hour per square foot of heating surface, the total heating surface required is 7,430 square feet. A set of eight cylindrical boilers, including a spare one in reserve, is consequently employed, each having nearly 1,100 square feet of heating surface. Another set of six boilers of the same size supplies steam for blowing the Bessemer converters and cupolas, for driving the rest of the machines in the rail shops, and for other purposes.

A short calculation is added of the power lost by the friction in the bearings of the fly-wheel attached to a finishing train of rolls. With a 45-ton fly-wheel running at 75 revolutions per minute, the Author makes the loss 70 HP., when the coefficient of friction is taken as one-tenth.

A. B.

The most suitable Diameters for Steam-pipes.

By HERMANN FISCHER.

(Dingler's Polytechnisches Journal, vol. ccxxxvi., p. 353.)

The Author commences by remarking that, as a rule, the diameters of steam-pipes are chosen in a very arbitrary manner. When great precision is required, the diameter is fixed on the basis of the known velocity of the steam, it being taken for granted that this velocity remains unchanged throughout the whole length of the pipe. This supposition is false, for the sides of pipes absorb considerable quantities of heat, causing a partial condensation of the steam. If the quantity of steam which leaves the pipe is taken

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as a basis of calculation, then, through every cross-section of the pipe, a greater quantity of steam must pass than the final amount, and consequently the velocity will be everywhere greater than that calculated for. On the other hand, if the quantity of steam which enters the pipe is taken as a basis, the velocity will be everywhere less than that allowed for. In the first case, the diameter of the pipe will be too small, and in the last too large.

The Author next proceeds to construct an equation to represent the frictional resistance of pipes of various diameters and lengths to steam of various density; and also an equation to express the pressure of the steam at the beginning and the termination of its passage through the pipe.

On the basis of these formulæ he has computed four Tables, to be used in determining the dimensions of the steam-pipes for heating purposes.

Table I. applies to unlagged pipes of various diameters, and of the uniform length of 100 mètres, through which 120 kilogrammes of steam pass per hour, the terminal pressure being taken as 1·2 kilogramme per square centimètre. The Table gives the quantity of steam condensed in each case, together with initial pressure which it is necessary to maintain, and also the initial and terminal velocities of the steam.

Table II. gives similar data for the case of only 30 kilogrammes of steam passing hourly through the pipes, the terminal pressure being 1·08 kilogramme per square centimètre.

Tables III. and IV. give the corresponding data for well-lagged pipes.

A comparison of the Tables shows the great value to be attached to a proper covering for the pipes; for in the case of unlagged pipes, the ratios of the quantities of steam condensed and available vary between 0·26 and 3·93, while for well-lagged pipes the corresponding ratios vary between 0·1 and 0·98. The loss of pressure in the first case varies between 2·66 and 0·0028, and in the last case between 2·41 and 0·0006 kilogrammes per square centimètre.

The Author next proceeds to show how to use the Tables in order to determine the most economical diameter of pipes for particular cases, and gives it as a general conclusion that, in order to avoid waste, steam of considerably higher pressure, and pipes of considerably smaller diameter, than usual, should be chosen.

G. C. V. H.

Snow Clearing in Milan. By E. Bignami Sormani.

(Atti del Collegio degli Ingegneri ed Architetti in Milano, 1880, pp. 53–77.)

How greatly the labour and cost of snow clearing in a city are affected by variations in the density of the snow itself is shown by the results of observations made by Professor Clericetti and the Author, with the aid of a simple balance and compressing-box,

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both of which are described and illustrated. The range of density in fresh-fallen snow is found to be as great as eleven times, a cubic yard from one snowstorm weighing as much as 814 lbs., and from another only 71 lbs.; the records are furnished of a number of observations. Other circumstances affecting the labour and cost in different parts of a city are the northerly or southerly aspect of the streets, the amount of traffic through them, and the distance to which the swept snow has to be carted away.

In Milan the snow-carts are emptied into the navigable canals and numerous watercourses by which the city is intersected; and latterly also into the new sewers in the central portion of the city, which are promptly flushed whenever it snows. During the winter of 1879–80, the cost of clearing the 1,656,200 square yards total area of squares, streets, and lanes within the city walls averaged £200 per inch depth of snow fallen, and for the 502,800 square yards outside the walls the average cost was £62 per inch depth, equivalent in each case to about 1·05*d.* per cubic yard. Ordinarily the clearing of the more frequented streets is completed within eight or ten hours after it has stopped snowing; and of the rest within twenty-four hours, not reckoning night.

The organisation of the admirable arrangements by which this work is accomplished with such remarkable despatch and efficiency is ascribed by the Author to his predecessor in its direction, Signor Annibale Gafforini. The city is parcelled out into small districts, numbering 112 for last winter, of varying extent according to the importance of the work in each. An average rate of pay per inch depth of snow fallen is settled for the whole area of each separate district, according to its extent and the particular conditions affecting the several streets and squares comprised within it. Each district is allotted to a contractor, who usually associates with himself six to ten partners, besides the labourers whom he employs. He has to find carts, horses, and carters; the necessary implements—spades, shovels, brooms, scrapers, mattocks, barrows, &c.,—are furnished by the city, under suitable stipulations for ensuring proper care in their use. A copy is given of the complete form of contract now employed, comprising upwards of thirty clauses; the contracts are made annually, and the same persons almost always apply for them again year after year. The contractors come principally from the trades that are interrupted by winter—paviors, bricklayers and masons, and gravel quarrymen. For the direction and supervision of the work, the whole city is divided into four sections, over each of which is appointed an engineer with an assistant, who are aided in the general arrangements by the police surveillance.

Payment is made only for work effectually done. In each snowstorm the depth of snow falling, which is the basis of pay, is ascertained by means of a number of stone posts, fixed in suitable open spaces, clear of shelter from buildings, and each capped with a flat horizontal slab of stone. As soon as it stops snowing, or two or three times during a storm of several hours, the depth of snow

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caught on the slabs is measured by the engineer, in the presence of two of the contractors in his section.

The number of men ordinarily engaged in snow clearing on a winter's day is not less than two thousand, and has sometimes risen to three thousand. The stock of implements found by the city, representing a capital of about £1,600, is housed in two stores in opposite quarters of the city. In the winter of 1874–75 the total fall of snow amounted to 40¾ inches, and the whole expenditure for clearing it within the city walls exceeded £8,400; while in 1877–78 the fall was only 5¼ inches, involving an expenditure of less than £1,040 for a slightly larger area. Tables are given for the last ten winters, showing the depth of snow that fell in each, the extent of area cleared inside and outside the city walls, and the cost of clearing.

The Author concludes with some remarks upon sanding in frosts, and upon the advantages of amalgamating the several branches of the organisation necessary for the care of the streets in cities like Milan.

A. B.

Improvements in the Desilverising of Lead by Zinc.

By C. SCHNABEL.

(Zeitschrift für das Berg-, Hütten- und Salinen-Wesen, vol. xxviii., p. 262.)

Parkes' method of desilverising lead by means of zinc has been adopted in the smelting works of the Harz in preference to direct cupellation, or Patinson's process, since 1868, the desilverised lead being softened by Cordurie's plan of blowing steam through it at a red heat, which is found to succeed fairly well in practice, the risk of the production of explosive mixtures of air and hydrogen being avoided by the use of a steam jet aspirator in the chimney. The recovery of the silver from the zinc, or rather the mixture of zinc and lead containing it, has, however, always been the least satisfactory part of the operation, and various methods have been proposed for this purpose at different times, the principal ones being—

1. Extraction of the zinc by sulphuric acid.
2. Dry chlorination.
3. Fusion of the alloy with litharge on a test.
4. Liquation of part of the lead, and distillation of the zinc in retorts.
5. Decomposition of the alloy by steam, as in Cordurie's method.

The last of these gave the best results, but there was always considerable trouble in treating the zinc oxide produced, which kept back a notable proportion of the silver, and, from its infusibility, prevented the shots of argentiferous lead liquating properly from the mass. A new method, introduced by the Author, has been in use since the middle of 1879; this consists in softening

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the argentiferous lead and zinc alloy by blowing steam through it, when melted, until the bulk of the zinc is oxidised, leaving a metallic portion, consisting mainly of softened lead, with from 2½ to 3½ per cent. of silver, and an oxidised portion containing practically the whole of the zinc (about 20 per cent.), with from 60 to 65 per cent. of lead, and 1·2 to 1·8 per cent. of silver. This latter substance is treated in close vessels with a hot solution of carbonate of ammonia in caustic ammonia, which dissolves the oxides of zinc and copper as carbonates, leaving a residue of litharge and metallic lead, in which the whole of the residual silver is contained. The solution, when separated by filtration and washing, is treated with metallic zinc, which precipitates any copper that may be dissolved; the purified liquid is then subjected to distillation, when, in proportion as ammonia and carbonic acid are driven off, basic carbonate of zinc separates as an insoluble white powder. When the distillation is completed, the contents of the retort are blown out by a steam jet into a filtering vessel, where the zinc precipitate is separated, and the clear liquid, which is essentially water with only a minute quantity of ammonia, is utilized while still hot as feed-water for the steam boiler. The distillation is effected by the exhaust current of a steam-engine, and thus all the volatile products which can possibly contain ammonia are brought back to the condenser, so that there is very little possibility of any loss. The distilling apparatus, made by Wegelin and Hübner of Halle, has been in use for six months, and no sensible loss of ammonia has been experienced, the amount of zinc dissolved by a given volume of solution having been constant through the whole period. The solubility of oxide of zinc is greatest in solutions containing about 6·16 per cent. of ammonia and 10 per cent. of carbonic acid by weight, which, at a temperature of 30° Centigrade, take up about 10 per cent. of the oxide in twenty-four hours. When it is either more caustic, more carbonated, or more dilute, there is a sensible diminution in solvent power. The active solvent agent is sesquicarbonate of ammonia, which takes up its own weight of zinc oxide.

The precipitated basic carbonate of zinc is dried and calcined at as low a temperature as possible, producing zinc-white of a saleable quality. The carbonic acid lost by the precipitation is restored to the liquid by passing lime-kiln gas containing about 25 per cent. by volume of carbonic acid into the condenser with the ammoniacal steam. This is done by a force-pump driven by a small steam-engine.

As regards the economic results of the process, the Author goes into great detail as to the cost of the different operations. Taking the average of several years, the yield obtained from the furnace lead of the Upper Harz, averaging 99·4 per cent. of lead and 0·15 per cent. silver, was—

Lead	99·09 per cent.
Silver	104·72 „

on the apparent quantity contained by assay, the excess in the

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latter being due to absorption of silver by the assay cup and sundry allowances in weight, which together are computed as equal to a further amount of 0·48 per cent.; so that the apparent yield should be 105·2 per cent. if there were no loss of silver in the smelting process. Since the plan of extraction by ammonia has been introduced the yield has been brought up to 104·9 per cent., and the Author considers that it may be increased to 105 per cent.

The cost of treatment of 2·57 cwt. of oxide, resulting from 6·115 cwt. of zinc alloy, the quantity produced in the desilverising of 5 tons of ore furnace lead, is given as 9*s.* 3*d.* per cwt. of zinc-white produced. This assumes a loss of nearly ½ lb. of ammonia per cwt., which is, however, considerably above the real amount. Assuming the value of the zinc-white to be 15*s.* 6*d.* per cwt., there appears to be a small surplus of 2*s.* 3*d.* upon every 5 tons of lead desilverised by the method, after making allowance for interest and depreciation of plant.

The cost of the works is given at £2,000. About 8,000 tons of lead ore are desilverised annually, with a production of 1,630 cwt. of zinc-white, or about 7 cwt. daily. A principal advantage claimed for the process is the more complete recovery of the zinc—98-99 per cent. of the original amount—as compared with 43·8 per cent. which is obtained by the method of reduction and distillation in retorts.

II. B.

The Preparation of Salts of Uranium and Vanadium at Joachimsthal (Northern Bohemia). By C. LALLEMAND.

(Annales des Mines, 7th series, vol. xvii., p. 326.)

The pitchblende of Joachimsthal was first treated as a source of uranium salts in 1853, and since 1858 the manufacture has been carried on regularly, and the ore paid for to the mines at a special rate according to its richness.

The ore is delivered to the works in powder; its specific gravity is about 7, and it contains generally 40 to 55 per cent. of oxide of uranium ($U_3 O_4$) with smaller amounts of vanadium, arsenic, sulphur, molybdenum, tungsten, cobalt, nickel, copper, bismuth, lead, silver, iron, manganese, lime, magnesia, alumina, and silica. It is first sampled and assayed, to determine the percentage of uranium that it contains, and its consequent value. After the proportion of moisture in the sample has been ascertained, 3 grammes of it are heated with nitric acid for two hours. The uranium and most of the other metals are thus dissolved. The filtered liquid is treated with carbonate of soda in excess, which precipitates the vanadium, iron, lime, lead, copper, &c., while the uranium remains in solution. This is then thrown down as uranate of soda ($NaO\ 2U_2\ O_3$), mixed with excess of alkali, by

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neutralizing, boiling, and adding caustic soda; and after getting rid of the excess of soda, it is dried and weighed.

In treating the ore in the works, it is first roasted in a calcining furnace, heated with lignite. The temperature of the furnace is raised very gradually, in order to drive off as much as possible of the sulphur, arsenic, and molybdenum, without fritting the ore at all. At the end of eleven hours, when the temperature has been raised to dark red, the furnace is cooled a little, and a mixture of 4 per cent. of the weight of the charge of nitrate of soda and 15 per cent. of carbonate of soda is added. The roasting is continued after this addition for four hours more, the temperature being gradually raised to bright red.

The roasted ore is then washed for a day with hot water, which removes the soda salts that it contains of molybdenum, vanadium, tungsten, arsenious acid and sulphuric acid, while the uranium, iron, cobalt, nickel, copper and silver remain in the residue.

This is next treated with sulphuric and a little nitric acid, diluted with hot water. The solution contains uranium, copper, and some other metals, while silica, sulphate of lime, sesquioxide of iron, and silver, if present, remain undissolved. An excess of carbonate of soda is added to the clear liquid. This precipitates all the metals that it contains, except uranium. The filtered liquid is then boiled, by blowing in steam, to expel the dissolved carbonic acid, which retains in the solution traces of oxide of iron and of carbonate of lime, and finally, after the removal of these, the uranate of soda is thrown down, either by adding caustic soda to the acidified solution, to produce bright yellow (*jaune clair*) uranate ($NaO\ 2U_2\ O_3 + 6\ H\ O$) or by exactly neutralizing the original alkaline solution by sulphuric acid, to produce orange (*orangé*) uranate ($NaO\ 2U_2\ O_3$).

The selling price of the uranate of soda is fr. 57·50 per kilogramme. It is used in making coloured glass, and in painting on porcelain. Smaller quantities of oxide of uranium and of uranates of potash and ammonia, are also made. The annual output of uranium salts is now 4,500 kilogrammes.

Vanadium is extracted in small quantities at Joachimsthal from the liquor with which the roasted uranium ore has been washed, but the process by which it is obtained is still imperfect, and too complicated to be carried out by ordinary workmen. The crude ore contains by analysis about 0·1 per cent. of it. It is used in dyeing, to aid in the transformation of aniline into aniline black. The price of vanadate of soda at Joachimsthal is 90 francs per kilogramme. W. H.

Schwandorf Continuous Kiln with Gas Furnace.

(Annales du Génie Civil, 1880, p. 289.)

This kiln, for baking porcelain, pottery, cement, &c., designed by the Schwandorf Company, acts on the principle and the general

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arrangement of the Hoffmann continuous-furnace kiln; but it is heated by means of a gas-furnace. The gazogenes, to the number of one, two, or three, are usually placed at one end of the kiln, where the chimney is located between them and the kiln. They are commonly placed below the level of the ground to enable the gas to flow into the furnace without the aid of the chimney draught. The gas, on leaving the generator, is discharged into a semicircular flue, branching to the right and to the left of the kiln, and fitted with a valve, by means of which the current of gas may be turned either way, whilst the return current is diverted to the chimney. The gas is led into the interior of the kiln by a series of small flues under the floor, from which it emerges into the furnace through vertical tubes, one to each flue, perforated laterally by a series of holes, through which the gas escapes and burns with long flames. By this means uniformity of temperature is maintained through the furnace; and herein consists the alleged superiority of the furnace. The economy of fuel effected varies from 60 to 75 per cent. compared with the old furnaces.

D. K. C.

The Clearing of Coal Slack by an Air-blast.

(Berg- und Hüttenmännische Zeitung, vol. xxxix., p. 251.)

At the Rheinpreussen colliery, in the Ruhr basin, the separation of small coal from shale for coking purposes is carried out upon the plan due to the director of the works, Herr Hochstrate, in which the use of water, as in the ordinary Berard machine, is entirely avoided, the sized coal being exposed to a blast of air of sufficient velocity to remove the coal, the heavier shale being left undisturbed. The mixed coal as drawn from the pit is thrown on a riddle with 2-inch apertures, the lumps kept back being removed by a travelling band, which delivers them to the railway wagons. The stuff passing through is treated in a four-sieved drum classifier; the largest lumps made, from $\frac{7}{8}$ to 2 inches, are also taken by a band carrier to the loading-place, being partially hand-picked on the way. The four smaller sizes are, $\frac{7}{8}$–$\frac{3}{4}$ inch, $\frac{3}{4}$–$\frac{1}{2}$ inch, $\frac{1}{2}$–$\frac{1}{3}$ inch, and below $\frac{1}{3}$ inch. Each of these is passed by a special hopper into the separating apparatus, the admission being through a rapidly vibrating horizontal sieve plate, which allows the slack to fall in a thin layer upon a travelling band forming the bottom of the wind channel, whose motion is in the opposite direction to the current of air from a fan blower. The band is covered at intervals by laths, whose height varies in the different divisions, forming partitions within which the particles of shale deposit. In order to keep the material fully exposed to the air-current, a knocking apparatus is used to give a continuous vibratory motion to the band. The air-channel is divided by a series of horizontal sieves, placed one above the other, having alternately longitudinal and

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transverse bars. These perforated partition walls have the effect of diminishing the strength of the blast from above downwards. The coal fragments being, as a rule, more or less cubical, present a larger surface for the same volume than the heavier particles of shale, and are therefore more readily carried forward by the current, while the shale falling on the band is carried in the opposite direction to the waste delivery. The larger particles of coal are stopped by a sieve in the mouth of the air-channel, but the dust-laden air is carried into a chamber of large section common to all the divisions of the apparatus, where it is made to deposit the suspended coal by repeated changes in direction caused by numerous mid-feather walls. The clearing of the air is also facilitated by the injection of a small quantity of steam. The dust so deposited is removed by a screw creeper to a bucket elevator, which delivers it into the storage tower for coking coal. The depositing chamber has an air-tight casing of asphalted roofing paper. The passage through which the air escapes is covered with straw matting to keep back suspended matter as completely as possible.

In the month of April of this year, working seven hours daily, 6,585 tons were treated by this method with the following results:—

	Tons.		Per cent.
1. Lumps from the large riddle	1367·5	=	20·78
2. Nuts from the drum sieves	1614·0	=	24·33
3. Waste picked from 1 and 2	117·5	=	1·82
4. Nuts purified by air-blast	1020·0	=	15·51
5. Coking slack „	2018·5	=	30·76
6. Waste separated „	443·0	=	6·80
			100·00

The total amount of shale separated is therefore 8·62 per cent. The cost of the operation is given as follows:—

	£	s.	d.
Wages and management	30	9	4
Cost of steam power	6	8	9
Stoves and materials	3	2	8
Interest and sinking fund, 10 per cent. . . .	10	8	4
	50	9	1

Equal to about 2*d.* per ton on the clean coal obtained.

The unpurified slack below $\frac{1}{8}$ inch size contained 11 to 11$\frac{1}{2}$ per cent. of ash; and the dust coal from the chambers, as prepared for coking, 6 to 6·7 per cent., which, upon a 70 per cent. yield in the ovens, corresponds to a coke of 9 to 9$\frac{1}{2}$ per cent. ash. The ash in the different kinds of nut coal varied from 3·6 to 8·5 per cent.

In working this apparatus, it should be so arranged as to leave a little coal in the waste, in preference to recovering the whole of the coal in a less purified condition, as the mixture of coal and shale is sufficiently combustible to be used in raising steam. In the treatment of 500 tons daily, about 19 tons of waste with 50 per cent. of ash are obtained, which are burnt in the boiler furnaces.

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The total cost of a plant for the treatment of 15,000 tons monthly, or 600 tons per day, is given below—

	£
1. Coking coal stove and brickwork	240
2. Buildings for machinery. Wood with asphalt paper covering	260
3. Machinery	700
4. Transmission	115
5. 25-HP. steam-engine	165
	1,480

H. B.

On the Determination of Phosphorus and Silicon in Iron and Steel. By A. E. Haswell.

(Dingler's Polytechnisches Journal, vol. ccxxxvii., p. 315.)

The Author describes a new method of analysis, in which the whole of the electro-negative substances present in the metal are obtained in the insoluble residues, the iron being completely separated in solution as the first operation. The sample, in the form of filings or borings, is treated with a 7 per cent. solution of double chloride of copper and ammonium at the lowest possible temperature in a corked flask. About twelve hours are required to effect the solution, the flask being frequently shaken. If the proper equivalent quantities of the double copper-salt are taken, the iron will be completely dissolved as ferrous chloride, free, or nearly so, from copper, while the carbon, silicon, sulphur, and phosphorus will remain in association with the reduced sponge of metallic copper. This, when carefully washed, is dissolved in nitric acid, the silicon determined by evaporation to dryness and calcination, and the phosphorus by precipitation, first with molybdic acid, and then with magnesia in the usual way. The Author gives several examples showing that the molybdic acid precipitation is not affected by the presence of copper salts in the nitric acid solution, and that this method, while equally accurate with that of separation as basic phosphate of iron, can be carried out with greater rapidity.

H. B.

On the Weighing of Steel Ingots during Casting.[1] By F. Moro.

(Zeitschrift des Berg- und Hüttenmannischen Vereines für Steiermark, vol. xii., p. 265.)

The Author, after discussing the difficulties experienced in filling ingot moulds so as to regulate the weight of the ingots in such a manner that the finished object may be produced with as

[1] Since the above abstract was in type an illustrated account of this process has appeared in "Engineering" for October 1, 1880.—Sec. Inst. C.E.

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little waste as possible, describes a method, recently adopted at Kladno, for checking the weight at the moment of filling the mould. This is given in several modifications, the leading principle being, however, the same in all, namely, a platform lever weighing machine is mounted on a truck which may travel either in a straight or curved path according to the form of the casting pit. The machine overhangs the truck on one side, and may be pushed still further out by a rack-and-pinion motion. The bottom of the ingot mould is supported upon two parallel pieces of]-iron, leaving an open space between them sufficient to admit the passage of the platform of the machine, which is brought into position by three turns of the traversing pinion. This platform is supported at the four corners by small hydraulic presses, worked by a hand-pump on the carriage, and these when put into action lift the mould off its bearings, so that it is entirely supported by the weighing machine. The stopper of the ladle is then opened, and the steel flows in until the required quantity, as indicated by the scale beam, has been admitted, when the supply is stopped, the mould lowered on its bearings, and the platform withdrawn, to be placed under the next mould, and so on. It is not found necessary to have the machine in place before pouring, and there is, therefore, no greater delay experienced than in the ordinary method of filling to a chalk line on the side of the moulds. The different modifications of the method refer principally to the substitution of lever movements for the hydraulic machinery. The method actually in use at Kladno is adapted to the plan of casting from a fixed ladle, the moulds being movable upon a railway, and therefore the weighing machine is fixed, and the lifting arrangement formed by placing the fulcrum of the scale upon the ram of a hydraulic press.

H. B.

On the Mechanical Equivalent of Heat, with Subsidiary Researches on the Variation of the Mercurial from the Air Thermometer, and on the Variation of the Specific Heat of Water.

By Professor H. A. ROWLAND.

(Proceedings of the American Society of Arts and Sciences, vol. xv., pp. 75–200.)

The Author commences by stating that the only determination of the mechanical equivalent of heat which has been made with anything like modern scientific accuracy is that of Joule, thirty years ago. This philosopher experimented with water at one temperature, and did not reduce his results to the air thermometer, whereby an error of perhaps 1 per cent. is occasioned. The variation of the specific heat of water with temperature is an important factor in the determination of the equivalent, and this matter has hitherto received but little attention. The Author has sought

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firstly to measure with great accuracy temperatures by the air thermometer, and to note the deviation from ordinary thermometers, and, secondly, to determine the mechanical equivalent of heat by so accurate a method that the variation of the specific heat of water should follow from the experiments alone. He finds this to decrease from 0° to 30° or 35° centigrade, and then to increase, which he believes to be an entirely unique fact in nature, seeing that there is apparently no other substance hitherto experimented upon whose specific heat decreases on rise of temperature without change of state.

The apparatus employed by the Author consists of a Joule's calorimeter, attached to a movable axis, the whole suspended by a torsion wire. The shaft of the calorimeter comes out below, and receives uniform motion from an engine by means of bevel wheels; a chronograph recording the number of revolutions. The axis carries a diametral arm, having sliding weights attached by means of which the moment of inertia can be varied, and also an accurately-turned horizontal torsion wheel, around the circumference of which passes a silk thread supporting torsion weights over friction wheels. The moment of force was measured by these and the torsion of the suspension wire. To the shaft of the calorimeter is fixed a copper tube supporting four rings, to each of which is attached eight paddles, so arranged that no one paddle is over another; the lower paddles are turned backwards to throw the water outwards. Round the movable paddles are five rows, each containing ten stationary paddles. The cover contains a perforated cylinder, supporting the thermometer within the copper tube, and a tube for supplying the water. The water flows up in the space between the outer shell and the fixed paddles, and down through the central tube of the revolving paddles. The whole is surrounded by a water-jacket.

The action of the apparatus is as follows: The revolution of the inner paddles causes the water to strike the outer paddles, and thus tends to turn the calorimeter with a force which is balanced by means of the torsion weights acting on the torsion wheel. Any slight variation in the velocity of the engine will cause the calorimeter to revolve in one direction or another, until the torsion wire brings it into equilibrium again. The amount of torsion can be read off upon a scale on the edge of the torsion wheel.

The application of the apparatus to the estimation of Joule's equivalent is in this wise: The calorimeter receives heat by friction, and gives it out by conduction and radiation. So long as there is radiation, there will never be a theoretically stationary condition of temperature; but as the heat capacity of the apparatus is only 4 per cent. of that of the apparatus with the contained water, and as the latter is thoroughly stirred, the temperature may be assumed to be practically constant. The work done is equal to the continued product of the combined weight of the torsion weights, W, the diameter of the torsion wheel, D, π, and the total number of revolutions of paddles, N, within an error of 1 in 5,000 due to vibration.

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The heat capacity of the calorimeter alone is equal to 0·347 kilograms of water, and hence its total heat capacity is A + 0·347, where A is the weight of the contained water.

As the chronograph makes one revolution for every one hundred and two revolutions made by the paddles, each revolution of the former is $n = \frac{N}{102}$, and Joule's equivalent is

$$J = \frac{102\,\pi\,n\,W\,D}{(A + 0{\cdot}347)\,(t - t')}\,g,$$

where $t - t'$ is the rise of temperature, and g the force of gravity.

The Author's results at 15°·7 Centigrade agree with those of Joule's to within one-quarter per cent.

The Author observes, "A series extending over from one-half to a whole hour, and recording a rise of 15° Centigrade, to perhaps 25° Centigrade, and in which a record was made for perhaps each tenth of a degree, would thus contain several hundred observations, from any two of which the equivalent of heat could be determined, though they would not all be independent. Such a series would evidently have immense weight; and, in fact, I estimate that, neglecting constant errors, a single series has more weight than all Joule's experiments of 1849 on water put together.[1]

"The correction for radiation is inversely proportional to the ratio of the rate of work generated to the rate at which the heat is lost; and this, for equal ranges of temperature, is only $\frac{1}{30}$ as great in my measures as in Joule's, for Joule's rate of increase was about 0°·62 Centigrade per hour, while mine is about 35° Centigrade in the same time, and can be increased to over 45° Centigrade per hour."

E. F. B.

Sensitive Thermometer for Small Measurements.

By M. Thouvenot.

(La Nature, 7 August, 1880, p. 151.)

This instrument, devised by M. Dufour, is intended for measuring minute differences of temperature. It has a range of only between 1° and 2° (C.). It is so sensitive that the presence of any one near it causes a deflection of the index needle of from

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[1] "Forty experiments, with an average rise of temperature of 0°·56 Fahrenheit, equal to 0°·31 Centigrade, give a total rise of 12°·4 Centigrade, which is only about two-thirds the average of one of my experiments. As my work is measured with equal accuracy, and my radiation with greater, the statement seems to be correct."

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5 to 6 centimètres ($1\frac{2}{3}$ to $2\frac{1}{3}$ inches), and the immediate neighbourhood of the hand deflects the needle through its entire course. The thermometer is composed of a spherical bulb of glass, with a tubular neck about twice the length and one-sixth the diameter of the bulb, which latter is coated outside with lamp-black. The tubular neck is bent so as to form an inverted siphon, and filled with mercury sufficient to keep it upright when swung in its normal position. A long index needle is attached to the upright leg of an inverted ⅄ of brass, either arm of which terminates in a sleeve inclosing the tube. The whole is balanced on a tempered steel knife-edge, passing through the middle of the brass ⅄ at right angles to the plane of the arms, and resting on supports. The system is kept in equilibrium by a short vertical bar fixed to one end of the knife-edge, and carrying a horizontal arm on which slides a small weight. Two studs serve to limit the amplitude of oscillation. The action of the instrument is as follows. When the temperature rises, the heat absorbed by the blackened bulb causes the confined air to expand, thereby forcing the mercury to rise in the open limb of the siphon. The centre of gravity being thus disturbed, the needle immediately inclines to the right. In experimenting, the weighted arm is adjusted until the needle indicates 0, to give the normal heat of the surrounding air; the observations are then made by attaching the substance to be experimented upon to hooks fixed near the bulb of the thermometer.

It is suggested that this simple apparatus may, in certain cases, advantageously replace the thermo-electric pile.

F. G. D.

On Telephonic Effects Resulting from the Percussion of Magnetic Substances. By T. du Moncel.

(La Lumière Electrique, vol. ii., p. 277.)

In 1878 M. Desportes published accounts of experiments made by himself, which showed that in a telephone deprived of its diaphragm, percussion on the end of the magnet resulted in currents being generated in the bobbin sufficient to cause sounds in another telephone. M. Ader, in experimenting in the same direction, has made the following discoveries. If the metallic core is of soft iron or nickel, the sounds are remarkably clear; if of steel, hardened but not magnetised, no sounds are transmitted, however powerful the blows, and similarly if of copper or other non-magnetic substance. If the core is a magnetised bar, then sounds were heard, but if the wire was wound direct on the core, and all the coils cemented together, so as to prevent actual movement of the core within the wires, then in the latter case no sounds were heard. From these results it appears that the core to produce

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such effects must be of a substance very conductive of magnetism. Further experiments showed that mere displacement of unmagnetised cores inside the bobbins was not sufficient to cause sounds, but the shock must be molecular; and also that these effects were not due to terrestrial magnetism. These results seem to be the converse of those that M. Ader recently obtained,[1] as telephonic currents were obtained from a core which was suddenly released from compression. These results are therefore probably due to some species of molecular motion, and analogous to those observed in mercury, as described in M. Lippman's researches; and they also in some way explain the cause by which magnetised bars lose their magnetism by repeated percussion, though the actual theory of the subject is still beyond the reach of our present knowledge.

F. J.

A New Form of Constant Electric Battery without Acid.

By EMILE REYNIER.

(La Lumière Electrique, vol. ii., p. 289.)

In this, a modification of the "Daniell" battery, the copper plate is surrounded by a solution of sulphate of copper, and the zinc by a solution of caustic soda, the porous diaphragm being made from parchment paper folded into the required shape so as to avoid seams, two or three thicknesses being used, according to the resistance required. The zinc and copper plates are formed from the commercial sheet metal, with two longitudinal slits extending two-thirds the length of the plate which is bent to form three sides of a parallelopiped; the centre part between the two slits is turned back and upwards, so as to reach above the liquid and form the connections of the cell, and thus all waste in cutting out the plates, and at the same time soldered connections, are avoided. As the zinc plate is not attacked when the battery is on "open circuit," it does not require to be amalgamated. Its electromotive force varies from 1·47 to 1·35 volt, the latter value being reached after the cell has been for a considerable time on short circuit, and its internal resistance, for a cell 20 centimètres (7·87 inches) high and 3 litres (2·64 quarts) capacity, is about 0·075 ohm.

The subjoined Table gives the comparative values of the batteries in ordinary use, when employed for the production of mechanical work through an external resistance equal to that of the battery, from which it will be seen that this battery holds

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lxi., p. 402.

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almost the first place, besides possessing the considerable advantage that no noxious fumes are generated therefrom.

Description of Battery.	Electrical Constants.		Useful Effect.	
	E.M.F. in Volts.	Resistance in Ohms.	Kilogram-metres.	Calories (Gramme-degrees).
Bunsen, ordinary cylindrical form, 9 inches high	1·80	0·24	0·344	0·796
Bunsen, Ruhmkorff's form, 9 inches high	1·80	0·06	1·378	3·189
Daniell, large cylindrical form, 9 inches high	1·06	2·80	0·010	0·023
Thomson's Tray, electrodes 14 × 14 inches surface	1·06	0·20	0·143	0·331
Carré, cylindrical form, 2 feet high	1·06	0·12	0·238	0·551
Reynier, rectangular form, 9 inches high	1·35	0·075	0·619	1·440

At a meeting of the Physical Society of Paris, fifty of these cells were employed to light the hall by electric arc, to work a powerful induction coil, and, after being some hours in use, to raise a platinum wire to red heat. This cell seems likely to supplant the "Bunsen" for laboratory use.

F. J.

Comparison of the Power of Hollow and Solid Magnets.

By W. Holtz.

(Annalen der Physik und Chemie, vol. x., p. 694.)

The Author's experiments on the magnetising of steel during the process of hardening (Wied. Ann. vol. vii., p. 71) led him to the conclusion that the core of a solid magnet acted as an armature joining the two poles, and so caused a great absorption of magnetising force; which deduction resulted in the experiments forming the subject of this Paper. Comparing by the method of oscillations a solid bar-magnet of 12·5 centimètres (4·92 inches) length and 13 millimètres (0·512 inch) diameter with a hollow one of the same dimensions and 1·75 millimètre (0·069 inch) thick, both being magnetised to saturation, the tube was 60 per cent. stronger; and with the dimensions increased to 32 centimètres (12·6 inches) length and 35 millimètres (1·378 inch) diameter, the thickness of the tube remaining as before, the tube was 50 per cent. stronger. When a soft-iron core was inserted in the tube, the magnetism was very small. This experiment perhaps shows most convincingly the disadvantageous effect of the interior of a solid magnet. After half a year the magnets were again com-

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pared; the hollow magnets were 2·5 and 2·9 times as strong as the solid, for the larger and smaller sizes respectively; proving that the hollow magnets were more retentive of their magnetism than the solid. It is not necessary that the surface of the tubular magnets be closed, and they can therefore be easily manufactured from steel plate.

Nobili, in 1835 (Pogg. Ann. xxxiv., p. 270), gave the relative power of a solid and tubular magnet as 28·5 to 16, but no dimensions are given in the Paper referred to above.

F. J.

Improvement of Siemens Armature. By G. Trouvé.

(Comptes rendus de l'Académie des Sciences, vol. xci., p. 48.)

If the ordinary armature of the Siemens form be caused to revolve, the power developed is almost nil during two periods of a revolution, amounting to about 30° each, and corresponding to the times during which the cylindrical poles of the armature are passing those of the fixed magnet; the reason being that the distance between the reacting faces of the poles remains then unaltered. The Author has effected the removal of these "dead-points" by altering the sectional form of the faces of the armature from circular to spiral, so that the distance between the fixed and movable faces gradually decreases during the revolution of the armature, until the minimum is reached just when the poles are quitting each other and mutual repulsion commences. A considerable increase of power developed has thus been obtained. The Author prefers that the armature should work in the field of an electro-magnet which is in the same circuit, as an alteration of the intensity of the current circulating in the coils does not then affect the ratio of the magnetic intensities. A motor formed of one of these armatures excited by a current from 3 elements of the Reynier form, is sufficient to drive a sewing machine; thus constituting an economical engine for domestic purposes.

F. J.

On Electrical Expansion. By G. Quincke.

(Annalen der Physik und Chemie, vol. x., pp. 414 and 513.

The Author has made a long and careful series of experiments on the alteration of volume of dielectrics when subjected to electrical stress similar to that which the glass of a Leyden jar undergoes when charged with electricity. The results obtained may be summarised as follow:—

For solid and fluid substances the alteration in volume is in general expansion, but in some cases, *e.g.* of fatty oils, is con-

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traction, this being due neither to increase of temperature nor to mechanical compression. No alteration, or at the most an increase of $\frac{1}{3.000.000.000}$ of the original volume has been observed in gases. In flint glass the increase is instantaneous, but German glass, which is a better conductor, reaches its maximum after a definite time, and the behaviour is similar in the return of the substances to their original volume after the electricity is discharged. The length of a tubular condenser alters in the same direction, but not always in the same ratio, as the volume, and both increase with the potential of the charge and the diminution of the thickness of the dielectric nearly in the ratio of their squares; the actual coefficients of expansion being a function of the substance. After the electricity is discharged, the substance does not return exactly to its original volume, the difference varying with the electrical polarisation of the material. In the case of flint glass the electrical expansion is equal in all directions, and is independent of the sign or direction of the electrical charge, but varies with the electrical conductivity of the material. When submitted to electrical stress the elasticity of the substance decreases in the case of flint glass, German glass, and india-rubber, but increases in the case of mica and gutta-percha. The passage of the electric spark through glass and other substances is due to the unequal electrical expansion at different points of the body. By being subjected to a variable electrical stress, solid and liquid substances can be unequally expanded, resulting in their temporary reception of the property of doubly refracting optical rays; if submitted to a uniform electrical stress no such property is developed. The behaviour of substances as regards the "positive" and "negative" double refraction—to which attention was first directed by Dr. Kerr—can be explained by the way in which the index of refraction, together with the density and volume of the substance, alter under electrical stress.

F. J.

Martelli's Altiplanimetrograph.

(Giornale dei Lavori Pubblici e delle Strade Ferrate, an. 7, p. 304.)

This instrument is intended to define graphically the plan and vertical profile of any given area of ground. It is principally constructed of metal, and is accompanied by two tablets, which may be made partly in metal and partly in wood. The operative part of the instrument carries a powerful telescope, provided with a scale for indicating distances. By referring the indications afforded by this scale to one of the tablets, results are obtained of geodesic accuracy. A regular horizontal movement is given to the telescope by means of a vertical wheel, which acts on the teeth of a horizontal wheel; and a corresponding arrangement gives a vertical movement to the tube. Indices are attached to each

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system of movement, by which the horizontal and vertical angles may be read.

When the angular readings, both horizontal and vertical, of any object are thus obtained, and the distance of that object from the instrument is taken from the scale on the telescope, the ordinate and abscissa of each point are readily to be found by reference to the first of the tables accompanying the instrument. The second table is calculated for the purpose of using the instrument for triangulation.

F. R. C.

Novel Domestic Motor.

(Engineering and Mining Journal, [New York], August 7, 1880, p. 91.)

This motor, invented by Capt. John Ericsson, depends for its action upon the alternate expansion and contraction of a given volume of air confined in a cylinder and subjected to rapid alternations of high and low temperature. The cylinder, cast in a single piece, is mounted vertically, and is heated at the bottom either by a small coal fire, or from several gas jets (by preference from three burners consuming 5 cubic feet per hour). A length of one-third of the cylinder at the top is provided with a water-jacket for cooling the expanded and heated air. The top of the cylinder is open, and into it is fitted a piston whose stroke is confined to the space surrounded by the water-jacket. There is also provided a solid plunger, of slightly smaller diameter than that of the cylinder, and which is operated by a rod passing through the piston and its rod. The mechanism controlling the relative motions of the piston and the plunger consists of a walking-beam, to which the piston-rod is attached by suitable links, and which converts the rectilinear motion into circular motion by means of a connecting-rod and crank acting on a fly-wheel. The plunger is operated by a bell-crank and link from the connecting-rod; its motion is the reverse of that of the piston; as the latter rises the plunger falls, and *vice versâ*. Its function is the displacing of the confined air from direct contact with the heated bottom of the cylinder at each stroke. A feed pump keeps up a regular supply of cold water. The action of the machine is as follows. The confined air being heated forces the piston to the top of the cylinder. As this occurs the expanded air is exposed to the continually increasing cooling surface of the water-jacket, and at the same time the solid plunger, actuated in the direction opposite to that of the piston, has descended, and interposes itself between the air and the source of heat. Thus the air contracts as quickly as it had previously expanded. The piston, which is exposed on the whole of its upper surface, is forced down by atmospheric pressure, thus making one complete revolution of the crank and fly-wheel. The lowest point reached by the piston is about one-third the distance from the top

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of the cylinder, where the water-jacket terminates, so that it is cushioned on the confined air. The descent of the piston is accompanied by the rise of the plunger; this displaces the air and again exposes it to heat, when the foregoing operations are repeated. The apparatus has therefore no valves or air-pumps, but uses a confined body of air over and over again. It occupies a floor space of about 24 inches by 30 inches, and is about 4 feet high. With a 6-inch cylinder, consuming about a scuttle of coal a day, or 15 cubic feet of gas per hour, it will pump 200 gallons of water per hour to a height of 50 feet. Once started, it requires no further attention.

A Ballistic Apparatus for Registering the Law of Motion of a Projectile in the Bore of a Gun, or in a Resisting Medium.

By M. SEBERT.

(Comptes rendus de l'Academie des Sciences, vol. xc., p. 1468.)

An apparatus for registering the law of motion of a projectile in the bore of a gun has long been sought for by artillerists, in order that the pressures developed by the combustion of the charge may be deduced correctly, with the view to improving the construction of the piece, and the powder. Hitherto, the means employed have been inconvenient to use, and unsatisfactory in the results obtained, and quite inapplicable to heavy guns.

The Author has succeeded in automatically recording the spaces passed over by a projectile in successive periods of time, which can be made as small as $\frac{1}{600}$ part of a second. The instrument consists of a metal rod of square section, placed in the axis of the projectile, and capable of revolving on its own axis. This rod serves as a guide for a movable weight, which carries a small tuning-fork, the vibrating ends of which carry two small metal tracers which bear lightly against one of the faces of the guide-rod, which has been previously smoked so as to be covered with a thin layer of lamp-black.

Before firing the gun, the movable weight with its attached tuning-fork is moved along the guide-rod, till it bears against the forward face of the hollow of the shell. The two tracers thus mark out two parallel straight lines on the blackened side of the guide-rod. When it reaches the end of the guide, the prongs of the tuning-fork are pressed apart by a small wedge which forms part of the guide-rod. When the charge is fired, the projectile travels quickly forward, but the movable weight being quite free, remains fixed in space. The guide-rod and wedge of course travel with the projectile, thus liberating the prongs of the tuning-fork, which commences vibrating at a known rate. While vibrating, the tracers mark out two wavy lines on the blackened surface of the guide-rod, which is travelling past them. The intersections

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of either of these wavy lines with the previously traced straight line, mark off successive spaces, exactly equal in length to the successive spaces passed over by the projectile during the successive vibrations of the fork. Each of these vibrations may be made to correspond to the $\frac{1}{600}$ of a second. From the diagrams thus obtained, a curve of spaces passed over by the projectile may be drawn, and from this may be deduced curves of velocities acquired, and of the accelerating forces. Supposing the resistances due to friction and the rifling to be known—and these resistances can be ascertained by separate experiments—the law of the development of the powder pressures on the base of the projectile can be determined. Of course the length of flight of the projectile which can be experimented on in this manner is limited by the length of the hollow part of the shell; but it is precisely this short piece of the commencement of the flight which is the most interesting to examine.

It is easy to prove that, in consequence of the great rapidity of the motion of the projectile, the movable weight remains so nearly absolutely fixed in space during the motion of the guide-bar through it, that the small forward movement which it experiences in consequence of the friction between it and the guide may be neglected. Also, as the whole instrument is free to turn on its axis, the effect of the rotation due to the rifling may be disregarded.

The first experiments with this apparatus were made on the 25th of March this year, at Sevran-Livry, where the projectiles can be fired into sandbanks, which permit of their easy recovery. The experiments were carried out on a 24-centimètre naval gun, with service projectiles weighing 144 kilogrammes. The tuning-forks employed vibrated 3,000 times in the second, and the charges used weighed 14, 21, and 28 kilogrammes, giving initial velocities of 300, 370, and 440 mètres, the last-named being the regulation charge. The curves obtained were very clear and regular.

If the apparatus, instead of being placed against the forward end, be placed in contact with the base of the hollow of the shell, it will move forward through space with the projectile, until the latter meets with a sudden resistance such as an armour plate, when the inertia of the apparatus will cause it to fly forward, and register the retardation of the projectile by means of a wavy line as before.

G. C. V. H.

Note on Stability, considered from the Point of View of the Duration and Amplitude of Rolling. By L. DE BUSSY.

(Revue Maritime et Coloniale, vol. lxvi., July 1880, p. 66.)

When a ship is under the influence of waves alone, the circumstances which may lead to a dangerous angle of heel are when it is crossing a swell, the waves of which have the same period from

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crest to crest as the double roll of the ship, for the coincidence of successive impulses communicated by the waves, with the successive rolls of the ship, tends to increase the angle of roll indefinitely. The resulting danger is only great when the periods of the ship's rolls are isochronous, *i.e.*, when the time of great and small oscillations is the same. Such is not the case with those vessels the dead wood of which have a pronounced "tumble home" in the neighbourhood of the line of flotation. Such vessels are far from having an isochronous period. In their case the period of roll increases with the amplitude, and when the angle of roll approaches the angle of vanishing stability, the duration of the roll is extremely great. Hence it follows that when a ship of this type commences to roll among waves, which have a period exactly the same as that of the ship for a certain angle of roll, the coincidence ceases as soon as the angle of roll is sensibly increased. Hence it is clear that those conditions of stability which are most effectual in causing the time of the oscillations to increase with their amplitude are also those which will best limit the extent of the rolling of a vessel in a swell.

The Author then proceeds to show how the law which connects the period of the oscillations and their amplitude depends on the curve of stability of the ship, and then examines what this law is for a vessel with a considerable "tumble home," and what this law would become if the "tumble home" were so diminished as to reduce the inclination which any given upsetting force would cause. When the curve of the moments of stability of a ship is a curve of sines, the law which connects the duration with the amplitude of the oscillations is derived from the similar law for a simple pendulum, which Legendre has shown to be expressed by an elliptic function. According to this law, if unity be the time of a very small oscillation, then the times of oscillations from the vertical of

	30°	60°	90°	120°	150°	180°
are	1,017	1,073	1,183	1,373	1,762	infinity.

When the curve of stability is a curve of sines, the law connecting the duration and the amplitude of the oscillations is the same for the ship as for the pendulum, for in each case the moving force is equal to a constant multiplied by the sine of the inclination. Hence the times of oscillations from the vertical of 30°, 60°, 90°, &c., will be the same as those above given.

If the ordinates of the curve of stability be proportional to the sines of the angles, which represent the products of the abscissæ and a constant coefficient, the durations of the oscillations still increase according to the law given above for a simple pendulum; but the amplitudes, instead of being represented by the abscissæ which measure the oscillations, of which the comparative durations have to be evaluated, are represented by the products of these abscissæ and the constant coefficient. The difference between the

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times of the two oscillations depends upon the difference between the forces in play during the two oscillations.

The Author next proceeds to apply the above considerations to the case of a ship having a given curve of stability, and traces the injurious effect on the stability caused by a suppression of the "tumble home."

G. C. V. H.

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INDEX

TO THE

MINUTES OF PROCEEDINGS,

1879-80.—PART IV.

A.P., or Dutch standard level, account of, 4, 32.
Abbey, J. B., elected associate member, 66.
Achard, M., continuous electric railway brake, 394.
Adie, P., his cement-testing machines described, 114.—Remarks as to Portland cement, 200.—Ditto as to testing and testing-machines, 200.
Air-blast, use of for clearing coal slack, 419.
—— engines. *Vide* Power.
Aitken, R., remarks as to the Amsterdam canal, 56.—Ditto as to the causes of the breaches in breakwaters, 56.—Ditto as to the parapet of Dover breakwater, 56.
Alexandre, M., repair of the sill of the Duquesne lock at Dieppe harbour, 372.
Altiplanimetrograph, Martelli's, 429.
Amsterdam canal. *Vide* Canal.
André electric light, description of the, 347.
Armature, Siemens, improvement of the, 428.
Arrowsmith, —, table of results of experiments on small vertical boilers, 297.
Aspdin, J. and W., their connection with the Portland cement manufacture, referred to, 67, 68.
Austrian rules for testing Roman cement, 210, 357.

Bailey, W. H. and Co., machine for testing Portland cement made by, referred to, 82.
Baker, B. "The Practical Strength of Beams," 251.
Ballistic apparatus for registering the law of motion of a projectile in the bore of a gun, or in a resisting medium, 431.
Barba, J., on the extension of metals under tensional stress after rupture, 360.
Barlow, E. S., elected associate member, 66.
———, W. H., President, conversazione given by, 250.
Battery, electric, constant, a new form of, without acid, 426.
Bauschinger, Prof., remarks as to Portland cement, 208.—Ditto as to testing, 208.
Baynes, C. C. C., remarks as to Portland cement, 197.—Ditto as to some advantages inherent in the old system of manufacture in obtaining uniform quality, 197.
Beams. "The Practical Strength of Beams," 251.—Present state of the theory of transverse stress, 251.—Strength of rails considered as beams, 252.—Determination by template of the moment of resistance of different sections of rail,

Digitized by Google

256.—Behaviour of a rolled joist under transverse strain, 263.—Failure of riveted girders through lateral deflection of the web, 263.—Influence of the width of flange, 264.—Influence of thickness of web, 265.—General conditions laid down by Mr. Chanute for riveted girders for the Erie railway, 267.—Elastic deflection of a beam of any type, 268.—Discrepancies between observed and actual strength of rail due to unskilled tests, 270.—Difficulty of establishing a general theory of transverse strength universally applicable, 271.

Belgian public works. *Vide* Public Works.

Belk, W., remarks as to Portland cement, 208.—Ditto as to a sea-wall at Hartlepool composed entirely of concrete blocks, 208.

Bell, I., remarks as to the Amsterdam canal, 57.—Ditto as to the expenditure on the works, 57.—Ditto as to the "Titans," 57.—Ditto as to the discrepancy between the estimated and the actual tide-levels, 57.

Berg, Hr., the pumping machinery for the new waterworks at Hanover, 382.

Bernays, E. A. "Portland Cement Concrete and some of its Applications," 87.—Remarks as to ditto, 205.—Ditto as to the free use of water in concrete mixing, 205.—Ditto as to loam in cement, 206.—Ditto as to cement mortar, 206.—Ditto as to the danger of using Portland cement fresh from the casks, 206.—Ditto as to some quicker test than that of twenty-eight days being a necessity, 207.—Ditto as to some experiments to determine the variations in the tensile strain recorded by testing machines due to the form of briquette adopted, 207.

Bigg, J. G. S., admitted student, 66.

Birch, R. W. P., transferred member, 250.

Blackmore, G. F., admitted student, 66.

Boiler, Davy-Paxman, referred to, 295.

——— feeder, Dervaux's, 409.

Boilers, steam, on the causes of the internal corrosion of, 384.

———, ———, vertical, table of experiments on, 297.

Boissay, C., surmountable gradients, 388.

Bömches, F., remarks as to Portland cement, 209.—Ditto as to the hydraulic lime used at the Trieste harbour-works, 209.—Ditto as to the Austrian recommendations for securing a uniform nomenclature and testing of hydraulic limes, 210.

Brake, railway, continuous electric, 394.

Breakwater, Dover, cause of the failure of the parapet of, referred to, 56.

———————, Hartlepool, constructed entirely of concrete blocks, described, 208, 216.

———————, North Sea. *Vide* Canal, Amsterdam.

Bridge, swing, over the Liffey, cofferdams for central pier and north abutment, referred to, 60.

Bridges, iron railway, piers of, the most suitable dimensions for, and number of the, 389.

Briquettes for testing cement, forms of, 116 *et seq.*

Brotherhood, P., his three-cylinder steam engine, described, 299.

Brown, O., transferred member, 250.

Brush dynamo-electric machine for lighting purposes, description of the, 342.

Buenos Ayres improvement works, use of cement concrete in the, 220 *et seq.*

Bussy, L. de, note on stability [of ships], considered from the point of view of the duration and amplitude of rolling, 432.

Butler, J. S., admitted student, 250.

Byers, T. B., admitted student, 250.

Digitized by Google

Canal. "The Amsterdam Ship Canal," 1.—History of the various plans for improving the navigation between Amsterdam and the North Sea, 1.—Constitution of the Amsterdam canal company, 3.—Physical features of the country traversed by the canal, 4.—Earthworks, 5.—The dam across Lake Y, 8.—Zuider Zee locks, 9.—Cofferdam for constructing the Zuider Zee locks, 11.—North Sea locks, 16.—Land reclamation, 16.—Pumping machinery, 17.—North Sea harbour, 19.—Cost of the works, 25.

———, North Holland ship, referred to, 1.

———, Panama, Count F. de Lesseps' project of, 377.

Canalisation of the Meuse between Namur and the French frontier, 375.

Carey, E. G., admitted student, 66.

Cay, W. D., remarks as to the Amsterdam canal, 58.—Ditto as to the North Sea piers, 58.—Ditto as to the form of the harbour, 58.—Remarks as to Portland cement, 210.—Ditto as to the Portland cement used at Aberdeen harbour, 210.—Ditto as to a table showing the relative strength of concrete made with fresh and with salt water, 211.—Ditto as to testing cement, 211.

Cement. "Portland Cement; its Nature, Tests, and Uses," 98.—Great development in the employment of the material of late years, 98.—Influence of the German and Austrian standard rules on the manufacture in those countries, 99.—Manufacture of Portland cement, 100.—Weight, 103.—Specific gravity, 103.—Setting, 104.—Hardening, 105.—Various conditions which affect its ultimate strength, 106.—Mixing concrete, 110.—Concrete in blocks and in mass, 111.—Testing apparatus and appliances, 113.—Form of briquettes, 116.—Moulds, 119.—Measures, 121.—Testing cement, 122.—Appendices: I. Form of specification for Portland cement, 126.—II. Guillot's apparatus, 127.—III. On the specific gravity of Portland cement, 127.—IV. Mr. Keates's double bulb bottle for ascertaining specific gravity, 129.—V.-L. Tables giving the results of experiments, 130.—LI. Memoranda, 179.

———. "The Manufacture and Testing of Portland Cement," 67.—History of the Portland cement manufacture, 67.—Authors who have brought the material into prominence, 69.—Components, 70.—Manufacture, 71.—Treatment of the slip, 71.—Drying, 73.—Cost of drying by Johnson's process, 76.—Fuel expenditure, 76.—Treatment of the clinker after its withdrawal from the kiln, 81.—Grinding and sifting, 81.—Testing, 82.—Machines of W. H. Bailey & Co., and Frühling and Michaëlis, 82.—German practice, 83.—Value of fine grinding, 85.

———, concrete, Portland. *Vide* Concrete.

———, Roman, regulations for the uniform testing and nomenclature of, 210, 357.

———, testing, experiments with appliances for, 359.

Cette, port of, note on the, 370.

Chanute, O., specification of, for riveted girders for the Erie railway, referred to, 267.

Chatham dockyard extension works, Portland cement concrete used at. *Vide* Concrete.

"Chimborazo," s.s., electric lighting of the, 347.

Chorlton, J. S., elected member, 250.

Clarke, T. C., transferred member, 250.

Cleminson, J., transferred member, 66.

Clip calliper for lifting waste weir planking, 373.

Clow, J. G. H., elected associate member, 66.

Digitized by Google

Coal slack, the clearing of, by an air blast, 419.
Cofferdam for constructing the Zuider Zee locks, Amsterdam canal, description of the, 11.
——————————— swing bridge over the Liffey, referred to, 60.
Colliery ventilation, a comparison of different methods of, 396.
Colson, C., remarks as to Portland cement, 211.—Ditto as to fine grinding, 211.—Ditto as to the weight test, 213.—Ditto as to the desirability of superseding the bushel as a measure, 213.—Ditto as to the sand test, 214.—Ditto as to concrete mixing, 214.—Ditto as to the proportion of sand in cement mortar, 215.
Compound engine. *Vide* Steam engines.
Concrete. "Portland Cement Concrete, and some of its Applications," 87.—Increasing importance of the material in engineering works, 87.—Concrete made with cements other than Portland used at the Chatham dockyard works, 88.—Specification of Portland cement concrete at Chatham, 89.—Mode of mixing at Chatham, 91.—Mode of laying in mass, 92.—Characteristics of the Thames and Medway shingles, 92.—Applications of concrete at Chatham, 93.—Special concrete for facing walls, 94.—Advantages of laying concrete in mass over the employment of blocks, 95.—Applications of concrete other than for dock walls, 96.—Cost at Chatham, 97.
Conversazione of the President, 250.
Coode, Sir J., remarks as to the Amsterdam canal, 33.—Ditto as to the dam in Lake Y, 33.—Ditto as to pile-driving, 33.—Ditto as to the North Sea jetties, 33.—Ditto as to the latter period of gales being more destructive than the former part, 33.—Ditto as to the bond of the breakwater, 34.—Ditto in explanation of previous remarks, 40.
Cooper, C. H., elected associate member, 250.
Copperthwaite, H. "Earthwork Slips on the Leeds and Wetherby Branch Railway," 285.
Cordner, R. A., elected member, 250.
Costobadie, W. P., elected associate member, 66.
Craig, J., B.A., elected associate member, 66.
Cuttings and embankments, railway, earthwork slips in. *Vide* Slips.
Cyprus, island of, report on the, 362.

Davey, H., steam-engine for small power, invented by, 302.
Davy-Paxman boiler, referred to, 295.
Dervaux's boiler feeder, 409.
Dirks, J., appointed resident engineer of the Amsterdam canal, 3.
Dockyard, Chatham, extension works, Portland cement concrete used at, 87 *et seq.*
————, Portsmouth, extension works, Portland cement concrete used at, 226 *et seq.*
Doherty, W. J., remarks as to the Amsterdam canal, 58.—Ditto as to fascine foundations, 58.—Ditto as to the circular cofferdam, 59.—Ditto as to safeguards for maintaining large cofferdams intact, 59.—Ditto as to leakage through the bolt-holes, 60.—Ditto as to the cofferdam constructed in connection with the swing-bridge over the Liffey, 60.—Ditto as to excavations inside the dam, 60.
Domestic motor, novel, 430.
Doruing, H., elected associate member, 250.

Digitized by Google

Douglass, J. N. "The Seven Stones Light Vessel," 288.
Dredging plant employed on the works of the Amsterdam canal, 7.
Dufour, M., his sensitive thermometer for small measurements, 424.
Dunsmure, J. P. H., admitted student, 250.
Düsing, Hr., ice-breaking in the Vistula, 379.
Dyke, T., remarks as to Portland cement, 215.—Ditto as to the breakwater at Hartlepool composed entirely of concrete blocks, 216.
Dynamo-electric machines, different systems of, 339 *et seq.*

Earthwork slips. *Vide* Slips.
Edison, T. A., description of his incandescent electric light, 346.
Edwards, W. C., admitted student, 66.
Electric battery, constant, a new form of, without acid, 426.
——— intercommunication in trains, 394.
——— light. "Notes on the principal Systems of Electric Light in use in England and in the United States, 339.—Recent progress in electric lighting, 339.—Gramme system, 339.—Siemens system, 340.—Brush system, 342.—Single and multiple system, 345.—Lighting by incandescent substances, 346.—Edison lamp, 346.—Werdermann lamp, 347.—André lamp, 347.—Electric light on board the ss. "Chimborazo," 347.
——— railway brake, continuous, 394.
Electrical expansion, on, 428.
Electricity as a motive power, 321 *et seq.*
Embankments, railway, slips in. *Vide* Slips.
Engines, domestic. *Vide* Power.
Ericsson, Capt. J., his original hot-air engine, referred to, 309.—Novel domestic motor, 430.
Extension of metals under tensional stress after rupture, 360.

Faija, H., remarks as to Portland cement, 185.—Ditto as to wet grinding, 185.—Ditto as to the proper amount of water to use in mixing cement concrete, 186.—Ditto as to weight *v.* specific gravity as a test, 186.—Ditto as to the sand test, 186.—Ditto as to the seven-day test, 187.—Ditto as to the form of briquette, 187.—Ditto as to the worthlessness of crushing tests, 187.—Ditto as to the effect of using salt water for gauging samples, 187.—Ditto as to testing-machines, 187.
Ferry-boat. The Central Pacific Railroad Company's transfer boat "Solano," 393.
Fischer, H., the most suitable diameters for steam-pipes, 412.
Flatt, B. W., elected associate member, 250.
Fletcher, L. E., transferred member, 66.
Fogerty, J., remarks as to the Amsterdam canal, 34.—Ditto as to the dam across Lake Y, 34.—Ditto as to the North Holland canal, 34.—Ditto as to the position of the locks, 35.—Ditto as to the lock gates, 35.—Ditto as to the pumping machinery, 36.—Ditto as to the effect of the works in increasing the difficulty of dealing with the sewage of Amsterdam, 37.—Ditto as to the probable large amount of dredging that will be required to keep the harbour open, 38.
Frühling and Michaëlis, Messrs., machine for testing Portland cement, made by, referred to, 82.
Fry, —, table of experiments on small vertical boilers, 297.
Funk, Hr., on the durability of railway sleepers, 390.

Digitized by Google

Gamble, J. G., a storage reservoir in the Achterfeld (South Africa), 380.
Gas-engines. *Vide* Power.
Gibbons, R. A., his improvements in the manufacture of Portland cement, referred to, 74.—Remarks as to Portland cement, 198.—Ditto as to Goreham's process, 198.
Giles, A., remarks as to the Amsterdam canal, 45.—Ditto as to the cost of dredging, 45.—Ditto as to the position of the breakwaters, 45.—Ditto as to the circular dam, 46.—Ditto as to Portland cement, 197.— Ditto as to loam in concrete, 197.
Girders, strength of. *Vide* Beams.
Goreham, W., his cement patent of July 1870 referred to, 72 *et seq.*
Gostling, W., remarks as to Portland cement, 216.—Ditto as to the desirability of having a uniform specification for cement used for concrete, 216.—Ditto as to the German standard rules, 217.—Ditto as to some specifications exhibiting great divergence in the tests, 218.
Gradients, surmountable, 388.
Gramme dynamo-electric machine for lighting purposes, description of the, 339.
Grant, J., his experiments on the strength of cement, referred to, 69.—"Portland Cement; its Nature, Tests, and Uses," 98.—Remarks as to ditto, 240.—Ditto as to fine grinding, 241.—Ditto as to the sand test, 244.—Ditto as to loam in concrete, 244.—Ditto as to the tensile strength of cement and the mode of testing it, 244.—Ditto as to the German and Austrian standard rules, 245.—Ditto as to the time test, 246.—Ditto as to the effect of the market price on the mode of manufacture, 247.—Ditto as to the specific gravity of Portland cement, 247.—Ditto as to cement mortar, 248.—Ditto as to the effect of salt water on the strength of cement, 248.—Ditto as to the objects of his experiments, 248.
Grawitz, G., remarks as to Portland cement, 188.—Ditto as to the sieve test, 188.—Ditto as to the German standard rules, 188.—Ditto as to German opinion on the advisability of severer tests than those at present exacted, 189.—Ditto as to setting, 189.—Ditto as to public testing establishments, 190.—Ditto as to testing machines, 190.—Ditto as to a uniform scheme for testing cement, 191.
Gregory, C. H., C.M.G., remarks as to the Amsterdam canal, 33.—Ditto as to the amount of dredging necessary to keep open the canal and entrance harbour, 33.
Griffin, J. G., elected associate member, 66.
Gunyon, T. P., elected associate member, 250.

Haddan, J. L., memoir of, 352.
Hall, J., admitted student, 66.
Hallauer, O., comparative experiments on Woolf-engines and marine compound engines, 385.
Hanover waterworks, pumping machinery for the new, 382.
Hans, M., canalisation of the Meuse between Namur and the French frontier, 375.
Harbour, Cette, note on, 370.
———, Dieppe, repair of the sill of the Duquesne lock at, 372.
———, Hartlepool, sea wall of concrete blocks at, described, 208, 216.
———, Lowestoft, dredging sand in, 44.
———, North Sea, of the Amsterdam canal, 19.
———, Trieste, hydraulic lime used at, 209.
Hardy de Beaulieu, M. le, report on public works made to the Belgian Chamber of Representatives, 367.
Hastie's water engine, description of, 319.

Digitized by Google

Haswell, A. E., on the determination of phosphorus and silicon in iron and steel, 421.

Hawkshaw, Sir J., appointed consulting engineer of the Amsterdam canal, 3.—Remarks as to ditto, 40.—Ditto as to the effect of the canal on the commerce of Amsterdam, 40.—Ditto as to the reason for adopting an embanked canal through the Zuider Zee, 41.—Ditto as to the bond of the breakwater, 41.—Ditto as to the position of the locks, 41.—Ditto as to the sewerage of Amsterdam, 42.—Ditto as to the effect of shutting out the Zuider Zee from Amsterdam, 42.—Ditto as to silting in the harbour, 43.—Ditto as to a certain amount of dredging being inevitable, 44.

Hayes, A., clip calliper for lifting waste weir planking, 373.

Hayter, H., "The Amsterdam Ship Canal," 1.—Remarks as to ditto, 27.—Ditto as to the lock gates, 27.—Ditto as to Mr. D. Hutton's apparatus for lowering concrete blocks, 29.—Ditto as to silting in the North Sea harbour, 48.—Ditto as to the position of the locks, 49.—Ditto as to the guide moles, 49.—Ditto as to the non-use of grooves for caissons in the locks, 50.—Ditto as to the reasons which determined the level of the canal, 50.—Ditto as to the circular dam, 51.—Ditto as to scour at the extremity of the South breakwater, 51.—Ditto as to the recession of the contour lines on sandy coasts by the construction of outside piers and breakwaters, 52.—Ditto as to the duty of the Zuider Zee pumping engines, 52.—Ditto as to the expenditure on the breakwater, 53.—Ditto as to the cost of land reclamations, 53.—Ditto as to the dredging operations, 54.—Ditto as to the success of the undertaking, 55.—Ditto as to the action of waves on an upright wall, 63.—Ditto as to the cost of dredging, 63.—Ditto as to the difference between the estimated and the actual tide level, 64.—Ditto as to the reasons for not using concrete in mass, 64.—Ditto as to fascine foundations, 64.—Ditto as to dredgers *versus* sand pumps, 65.—Ditto as to the adoption of iron for the lock gates, 65.—Ditto as to the breaches in the North Sea piers, 65.—Ditto as to the erroneous opinions attributed to Sir J. Hawkshaw in reference to the Amsterdam canal, 65.

Heat, on the mechanical equivalent of, 422.

Hedges, K. W., "Notes on the Principal Systems of Electric Light in use in England and in the United States," 339.

Heintzel, Dr. C., remarks as to Portland cement tests, 220.

Henderson, D. and W., description of the light-draught passenger steamer 'Terranora,' constructed by, 334.

Henin, J., Dervaux's boiler feeder, 409.

Hervey, M. W., elected associate member, 66.

Hesketh, E., elected associate member, 66.

Higgin, G., remarks as to Portland cement, 220.—Ditto as to the use of cement concrete in the Buenos Ayres improvement works, 220.

Hill, W., elected associate member, 250.

Holmes, P. H., elected associate member, 66.

Holtz, W., comparison of the power of hollow and of solid magnets, 427.

Hot-air engines. *Vide* Power.

Howard, J., tests of iron and steel shafting, 361.

Hownam-Meik, S., elected associate member, 250.

Hudson, F., elected associate member, 66.

Hutton, D., his connection with the Amsterdam canal, 3.—Self-liberating levers, devised by, for lowering concrete blocks, 27.—Table of cost of dredging by ordinary dredger and by sand pumps, 55.—Remarks as to Portland cement, 195.

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—Ditto as to some experiments on the strength of cement and sand briquettes made at Plymouth Breakwater, 195.—Ditto as to the strength of the concrete blocks used for the Amsterdam canal harbour works, 196.
———, R. J., B.A., transferred member, 250.
Hydraulic engines. *Vide* Power.
Hydro-carbon engines. *Vide* Power.
Hydrotrophe for feeding steam boilers, referred to, 305.
Hyndman, P. K., elected member, 66.

Ice-breaking in the Vistula, 379.
Iron railway bridges. *Vide* Bridges.
——, strength of. *Vide* Beams.
—— and steel, on the determination of phosphorus and silicon in, 421.
Irrigation, South Africa, a storage reservoir in the Achterfeld, 380.
Italy, public works in, expenditure on, 365.

Jäger, —, concession to, for the construction of the Amsterdam canal, 3.
Johnson, I. C., his employment of cylindrical settling tanks for making Portland cement, referred to, 72 *et seq.*—Remarks as to Portland cement, 194.—Ditto as to utilizing the waste heat from the kilns, 194.—Ditto as to tests, 195.—Ditto as to the origin of the Portland cement manufacture, 195.
Johnston, H. D., elected associate member, 66.
Johnstone, W., memoir of, 354.
Jones, E. D., admitted student, 250.
Joseph, T., elected member, 250.

Kapaun, F., apparatus for supplying drinking water at the harbour of Flushing, 408.
Keates, T. W., his apparatus for determining the specific gravity of cement described, 104, 129.
Kidd, W., admitted student, 66.
Kiln, Schwandorf continuous, with gas furnace, 418.
Kraft, J., consumption of steam in the rolling of steel rails, 411.

Lake Y, construction of the Amsterdam canal through, and reclamation of shores of, 1 *et seq.*
Lallemand, C., the preparation of salts of uranium and vanadium at Joachimsthal (Northern Bohemia), 417.
Land reclamation in connection with the Amsterdam canal, 16.
Lang, E. T., memoir of, 355.
Langley, A. A., remarks as to the Amsterdam canal, 44.—Ditto as to the best appliances for dredging sand, 44.—Ditto as to dredging in Lowestoft harbour, 44.
Latham and Bradley, small steam engines made by, referred to, 295.
Lavalley, A., remarks as to the Amsterdam canal, 46.—Ditto as to the means adopted for delivering the dredgers in the Suez Canal, 46.—Ditto as to the cost of sand dredging at Dunkirk and elsewhere, 47.
Lead, improvements in the desilverising of, by zinc, 415.
Lee and Sons, Messrs. H., appointed contractors for the Amsterdam canal, 3.
Lehmann's hot-air engine, referred to, 311.
Lenoir's gas engine, referred to, 305.
Lesseps, Count F. de, G.C.S.I., elected honorary member, 66.—His project of an interoceanic canal at Panama, 377.

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Lewis, Prof. T. H., remarks as to Portland cement, 201.—Ditto as to the works of the Romans in concrete, 201.—Ditto as to the formation of the cement in mortar and concrete, as shown by the microscope, 202.
Light-vessel. "The Seven Stones Light Vessel," 288.
List, G. H., Jun., transferred member, 66.
Llewellin, D., memoir of, 356.
Lock, Duquesne, Dieppe harbour, repair of the sill of the, 372.
Locks, North Sea and Zuider Zee, of the Amsterdam canal, 9 *et seq.*
Locomotive engines, balancing, 386.
Lodin, M., on the causes of internal corrosion of steam boilers, 384.
Longridge, M., M.A., transferred member, 250.
Luiggi, L., report on the island of Cyprus, 362.
Lyons, J., elected associate member, 66.

Macdonald, R. M., admitted student, 66.
Mackay, J. C., elected associate member, 66.
Magnets, hollow and solid, comparison of the power of, 427.
Mann, I. J., remarks as to Portland cement, 222.—Ditto as to testing, 223.—Ditto as to the moderate requirements of the specification for the cement used at Chatham, 223.—Ditto as to liquid concrete, 223.—Ditto as to excess of water in concrete, 223.—Ditto as to the specific gravity test, 224.
Martelli's altiplanimetrograph, 429.
Mayer, J., a comparison of different methods of colliery ventilation, 396.
Mear, W. T. M., admitted student, 250.
Meik, P. W., transferred member, 66.
——, S. H., elected associate member, 250.
Memoirs of deceased members, 349.
Menneer, R. R., admitted student, 66.
Messent, P. J., remarks as to the Amsterdam canal, 60.—Ditto as to the hire of the Tyne dredgers, 60.—Ditto as to the relative efficiency of dredgers and sand-pumps, 60.
Metals, extension of, under tensional stress after rupture, 360.
Meyer, C. H., remarks as to Portland cement, 224.—Ditto as to the history of the material, 224.—Ditto as to fine grinding, 225.—Ditto as to English tests being as a rule too lenient, 225.—Ditto as to using cement directly it was made, 225.—Ditto as to the question of uniform rules for testing, 226.—Ditto as to the adoption of Portland cement for the Government works at Portsmouth and at Chatham, 226.—Ditto as to the mode of applying concrete at Portsmouth, 227.—Ditto as to cracks in concrete, 228.—Ditto as to loam in shingle, 229.—Ditto as to the quantities used in the Portsmouth Dockyard works, 229.
Michäelis, Dr., remarks as to Portland cement, 229.—Ditto as to the sand test, 229.—Ditto as to the weight test, 230.—Ditto as to the German standard rules, 231.—Ditto as to accurate comparative tests being only possible with cements ground in the same way, 232.—Ditto as to time tests, 233.—Ditto as to fine grinding, 233.—Ditto as to printed articles on the subject, 234.
Michele, V. de, his improvements in the manufacture of Portland cement, referred to, 72.—Remarks as to Portland cement, 198.—Ditto as to the Michele mills, 198.—Ditto as to excessive strength in the briquette not necessarily implying a safe cement, 198.—Ditto as to some suggested rules for judging the quality of cement, 199.—Ditto as to the best form of briquette, 200.—Ditto as to the concrete used at Chatham dockyard, 200.

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Michell, T., elected associate member, 66.
Moncel, Count du, on telephonic effects resulting from the percussion of magnetic substances, 425.
Monckton, M. J., elected associate member, 66.
Monge school, warming and ventilation of the, 407.
Monson, G. J., admitted student, 250.
Morin, General A. J., memoir of, 349.
Moro, F., on the weighing of steel ingots during casting, 421.
Motive power. *Vide* Power.
Motor, domestic, novel, 430.
Mulatière, the, weir on the Saône, at Lyons, 374.
Munday, B., admitted student, 250.

Noble, A., experiments with appliances for testing cement, 359.

Oldie, H. J., elected associate member, 250.
Otto and Langen's gas-engine, referred to, 305.

Pape, W. A. H. de, elected associate member, 250.
Parker's cement. *Vide* Cement (Scott and Redgrave).
Parkes, W., remarks as to the Amsterdam canal, 47.—Ditto as to the silting-up of harbours only involving a small annual outlay owing to the low cost of dredging, 47.—Ditto as to the wave-breakers, 48.
Paterson, R. O., elected associate member, 66.
Pauling, H. J., elected member, 66.
Peache, J. C., elected associate member, 66.
Périssé, S., warming and ventilation of the Monge school, 407.
Phipps, G. H., remarks as to the Amsterdam canal, 61.—Ditto as to the lock-gates, 61.
Phosphorus, determination of, in iron and steel, 421.
Piers of iron railway bridges, the most suitable dimensions for, and number of the, 389.
Pihl, C., elected member, 66.
Pile-driving for cofferdams. *Vide* Canal, Amsterdam. Discussion, p. 33 *et seq.*
Port of Cette, note on the, 370.
Porter, W., remarks as to Portland cement, 234.—Ditto as to testing, 234.—Ditto as to the superiority in the strength claimed for cement made of late years being more apparent than real, 235.—Ditto as to the prejudicial effect of too much chalk, 235.—Ditto as to the high standard exacted by modern specifications being only met by a mode of manufacture prejudicial to the lasting qualities of the cement, 236.—Ditto as to what constitutes strength, 236.—Ditto as to improved testing apparatus probably indicating an increased breaking strain in cement, 236.
Portland cement. *Vide* Cement and Concrete.
Portsmouth dockyard extension works, Portland cement concrete used at, 226 *et seq.*
Power. "Small Motive Power," 290.—Definitions, 290.—Steam engines, 294.—Single-acting engine, 299.—Double-acting engine, 300.—Rotary engines, 302.—Steam action on fluid surfaces, 303.—Gas engines, 305.—Hydro-carbon motors, 308.—Air-engines, 309.—Water-engines, 314.—Electricity, 321.—Conditions of application of the foregoing motors, 328.—Conclusions, 332.

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President's conversazione, 250.
Projectile, law of motion of a, in the bore of a gun, ballistic apparatus for registering the, 431.
Public works, Belgium, report on, 367.
——— ———, Italy, state and communal expenditure on, 365.
Pulsometer pump, description of the, 304.
Pumping machinery employed at the Amsterdam canal, described, 17 *et seq.*
——— ——— for the new waterworks at Hanover, 382.
Purcell, G., B.A., elected associate member, 66.

Quillot, —, his machine for testing cement, referred to, and described, 116, 127.
Quincke, G., on electrical expansion, 428.

Rails, strength of. *Vide* Beams.
Railway, Ashby and Nuneaton, earthwork slips on the, 276.
———, brake, continuous electric, 394.
———, Castle Eden and Stockton, earthwork slips on the, 280.
———, Chatburn and Hellifield, earthwork slips on the, 277.
———, gradients, table of, 388.
———, Leeds and Wetherby branch, earthwork slips on the, 285.
———, Meltham branch, earthwork slips at Dungeon Wood and at Netherton tunnel, 272.
———, Shawforth branch, earthwork slips on the, 274.
——— sleepers. *Vide* Sleepers.
———, West Lancashire, earthwork slips on the, 278.
Ramsbottom, J. (Leeds), his water engine described, 317.
Redgrave, R., and Scott, Major.-Gen. H. Y. D., C.B., R.E. "The Manufacture and Testing of Portland Cement," 67.—Remarks as to ditto, 203.—Ditto as to the necessity of reducing the cost of manufacture, 204.—Ditto as to German cement, 204.—Ditto as to fine grinding, 204.—Ditto as to the nature of the action which produced cement from lime and clay, 205.—Ditto as to microscopic tests, 205.
Redman, J. B., remarks as to the Amsterdam canal, 38.—Ditto as to the outfall of the canal, 39.—Ditto as to the preference for a canal over an open tidal cut connecting the Zuider Zee with the North Sea, 39.—Ditto as to the circular dam, 39.—Ditto as to Mr. Rendel's dam at Grimsby, 39.—Ditto as to the rising of gauge-piles, 40.—Ditto as to the position of the entrance to the Amsterdam canal, 40.
Reichenbach, O., transferred member, 66.
Reid, H., remarks as to Portland cement, 191.—Ditto as to German Portland cement, 191.—Ditto as to the possible misuse of the waste heat, 191.—Ditto as to Johnson's kiln, 192.—Ditto as to the Stern cement, 192.—Ditto as to the form of mould, 192.
——, W. F., remarks as to Portland cement, 237.—Ditto as to the form of kiln used for burning, 237.—Ditto as to the German custom of hourly testing during manufacture, 237.—Ditto as to the possibility of making Portland cement at the site of works abroad and thus saving freight, 238.—Ditto as to grinding, 238.—Ditto as to the German and Austrian standard rules, 238.
Reservoir, storage, in the Achterfeld (South Africa), 380.
Reynier, E., his electric lamp, referred to, 347.—A new form of constant electric battery without acid, 426.
Rider's hot-air engine, description of, 311.

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River Meuse, canalisation of the, between Namur and the French frontier, 375.
—— navigation in Australia, light-draught passenger steamer for, 334.
—— Vistula, ice-breaking in the, 379.
Rock-drill, Schram's, description of, 313.
Rolling of ships, duration and amplitude of, 432.
Roman cement. *Vide* Cement.
Ross, A., elected member, 250.
Rotary steam-engines. *Vide* Power.
Rowland, Prof. H. A., on the mechanical equivalent of heat, with subsidiary researches on the variation of the mercurial from the air thermometer, and on the variation of the specific heat of water, 422.

Sanford, Lieut.-Col. G. E. L. S., R.E., elected associate, 250.
Saunders, H. J., elected associate member, 250.
——, R. J. H., elected associate member, 250.
Schmid's portable water engines, referred to, 317.
Schnabel, C., improvements in the desilverising of lead by zinc, 415.
Schram, R., description of his rock drill, 313.
Schwandorf continuous kiln with gas furnace, 418.
Scott, H. H., elected associate member, 250.
——, Major-Gen. H. Y. D., C.B., R.E., remarks as to Portland cement, 202.—Ditto as to the sand test, 202.—Ditto as to the sieve test, 203.—Ditto as to German researches on Portland cement, 203.—Ditto as to the most suitable proportion of lime to clay in the raw materials, 203.—Ditto as to 'underclayed' cement, 240.—Ditto as to fine grinding, 240.—Ditto as to 'double' tests, *i.e.* neat cement and cement and sand, 240.
—— and Redgrave, R. "The Manufacture and Testing of Portland Cement," 67.
Seaton, G., elected member, 66.
Sebert, M., a ballastic apparatus for registering the law of motion of a projectile in the bore of a gun, or in a resisting medium, 431.
Seven Stones light vessel. *Vide* Light Vessel.
Sewerage of Amsterdam, present condition of the, 36 *et seq.*
Shafting, iron and steel, tests of, 361.
Sharp, F., elected associate member, 66.
Shaw, H. S. H. "Small Motive power," 290.
Ships, stability of, 432.
Shoolbred, J. N., remarks as to the Amsterdam canal, 31.—Ditto as to the tides at the North Sea entrance of the canal, 31.—Ditto as to the various standards of tidal measure used by countries bordering on the North Sea, 32.
Siemens armature, improvement of, 428.
—— system of electric lighting, description of the, 340.
Silicon, determination of, in iron and steel, 421.
Simon's gas engine, referred to, 305.
Sleepers, railway, the durability of, 390.
Slips. "Earthwork Slips in the Cuttings and Embankments of various Railways, with their causes and modes of treatment," 272.—Slips on the Meltham branch railway at Dungeon wood and Netherton tunnel, 272.—Ditto Shawforth branch railway, 274.—Ditto Ashby and Nuneaton railway, 276.—Ditto Chatburn and Hellifield railway, 277.—Ditto West Lancashire railway, 278.—General conclusions as to the causes of slips, 278.

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Slips. "Earthwork Slips on the Castle Eden and Stockton Railway," 280.—Nature of the ground traversed by the line, 280.—General form of the slips, 280.—Mode of treatment, 281.—Conclusions, 283.
—— "Earthwork Slips on the Leeds and Wetherby Branch Railway," 285.—Nature of the slips, 285.—Treatment, 287.
Smith, C. A., balancing locomotive engines, 386.
——, J. Thorneloe, elected member, 250.
Snow clearing in Milan, 413.
"Solano," Central Pacific Railroad Company's transfer boat, 393.
Sormani, E. B., snow clearing in Milan, 413.
Squire, J. B. "Earthwork Slips in the Cuttings and Embankments of various Railways, with their causes and modes of treatment," 272.
Stability, note on, considered from the point of view of the duration and amplitude of rolling, 432.
Stapff, Dr. F. M., influence of temperature in tunnelling through high mountains, 399.
Steamer, light draught, for ocean and river navigation, 334.
Steam boilers. *Vide* Boilers.
——, consumption of, in the rolling of steel rails, 411.
—— engine, three-cylinder, Brotherhoods, described, 299.
—— engines, small. *Vide* Power.
—— ——, Woolf, and marine compound, comparative experiments on, 385.
—— pipes, the most suitable diameters for, 412.
Steel ingots, on the weighing of, during casting, 421.
—— rails, consumption of steam in the rolling of, 411.
——, strength of. *Vide* Beams.
"Stern" brand of Portland cement, referred to, 188 *et seq.*
Stewart, J. T., elected member, 250.
Stirling's hot-air engine, referred to, 309.
Strength of materials. *Vide* Metals; Shafting.
—— rails, of rolled and of riveted beams. *Vide* Beams.
Studt, —, his apparatus for testing cement, referred to, 116.—Drawing and description, 239.
Synge, R. A., B.A., admitted student, 66.

Telephonic effects resulting from the percussion of magnetic substances, 425.
Temperature, influence of, in tunnelling through high mountains, 399.
"Terranora," light draught paddle steamer, description of the, 334.
Tests of Portland cement, cement mortar, and cement concrete, 67 *et seq.*
Thermometer, sensitive, for small measurements, 424.
Thermometers, variation of different varieties of. *Vide* Rowland.
Thomas, J. D., elected associate member, 66.
Thompson, J. A. "Light draught Steel P.S. 'Terranora' for Ocean and River Navigation," 334.
Thomson, Prof. J., his inward flow turbine, referred to, 316.
Thouvenot, M., sensitive thermometer for small measurements, 424.
Trouvé, G., improvement of Siemens armature, 428.
Tunnel, Netherton, Meltham branch railway, referred to, 274.
Tunnelling through high mountains, influence of temperature in, 399.
Tylor, L. E., admitted student, 66.
Tyrrell, L. G., elected associate member, 66.

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Uranium and vanadium, the preparation of salts of, at Joachimsthal, 417

Vachell, T. I., admitted student, 66.
Vanadium. *Vide* Uranium.
Ventilation, colliery, a comparison of different methods of, 396.
Vernon-Harcourt, L. F., remarks as to the Amsterdam canal, 61.—Ditto as to the cofferdam in Lake Y, 61.—Ditto as to the locks, 61.—Ditto as to the action of winds on the North Sea coasts, and their effect on the concrete blocks, 62.—Ditto as to the maintenance of the piers, 63.—Ditto as to erroneous opinions attributed to Sir J. Hawkshaw respecting the Amsterdam canal, 63.—Ditto as to Portland cement concrete, 192.—Ditto as to dock walls constructed wholly of concrete, 192.—Ditto as to the price of concrete, 193.—Ditto as to the new Victoria and Albert docks on the Thames, 193.—Ditto as to loam in concrete, 193.—Ditto as to bridges constructed wholly of Portland cement concrete, 194.

Walters, H. E., admitted student, 66.
Warming and ventilation of the Monge school, 407.
Water, drinking, apparatus for supplying, at the harbour of Flushing, 408.
Waterworks, Hanover, pumping machinery for the new, 382.
Watson, J. W. M., transferred member, 66.
———, T. C., his connection with the Amsterdam canal, referred to, 3.—Remarks as to ditto, 30.—Ditto as to the cofferdam, 30.
Weir, Mulatière, on the Saône at Lyons, 374.
Weirs, waste, clip calliper for lifting the planking of, 373.
Welch, E. F., elected associate member, 66.
Werdermann system of electric light, referred to, 347.
White, G. F., remarks as to Portland cement, 180.—Ditto as to the frequent superfluous strength of cement concrete, 180.—Ditto as to the proper proportions of chalk and clay in the raw cement, 180.—Ditto as to the Goreham process of mixing, 181.—Ditto as to drying the slip, 181.—Ditto as to the Hoffman kiln, 182.—Ditto as to the asserted superiority of Johnson's mode of applying the heat to one surface of the slip only, 183.—Ditto as to testing, 184.
Whitley, H. M., "Earthwork Slips on the Castle Eden and Stockton Railway," 280.
Wijker Meer, construction of the Amsterdam canal through the, 1 *et seq.*
Willcox, J. E., admitted student, 250.
Winter, G. K., electrical intercommunication in trains, 394.
Woolf-engines. *Vide* Steam engines.
Wyld, R. S., jun., elected associate member, 66.

Zuider Zee. *Vide* Canal, Amsterdam.

END OF VOL. LXII.

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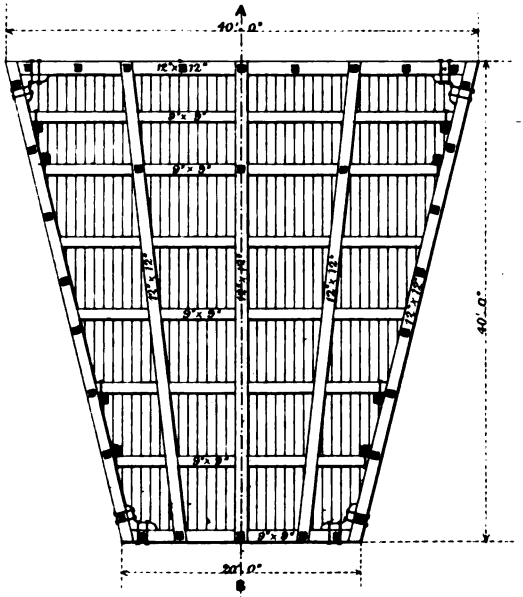

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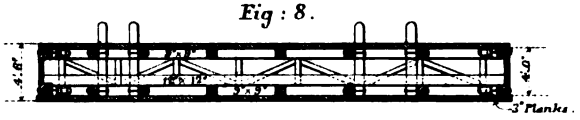

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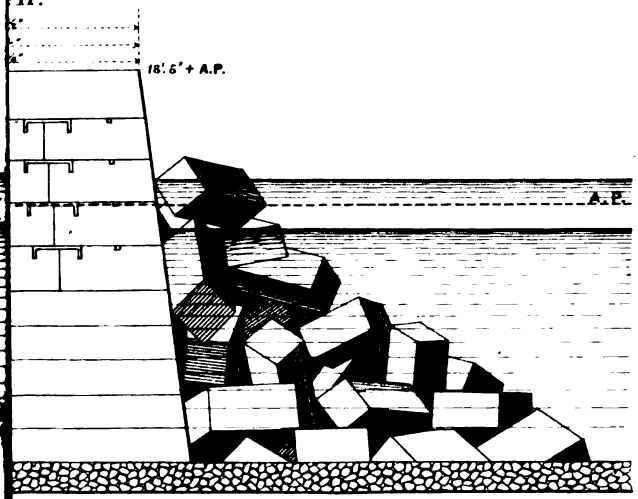

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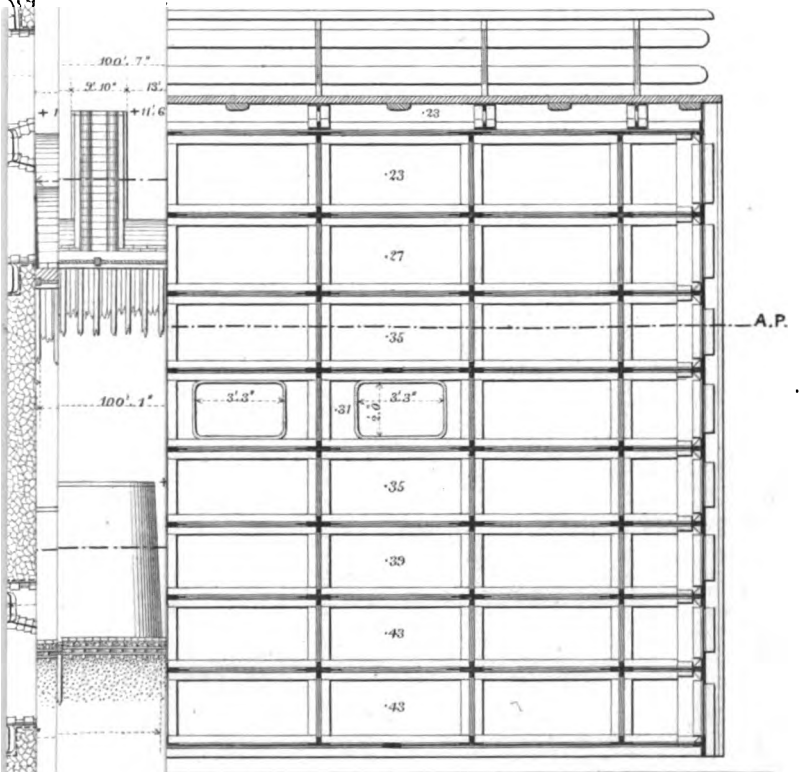

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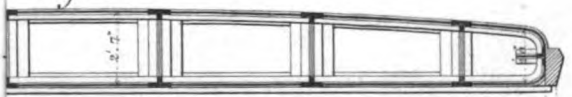

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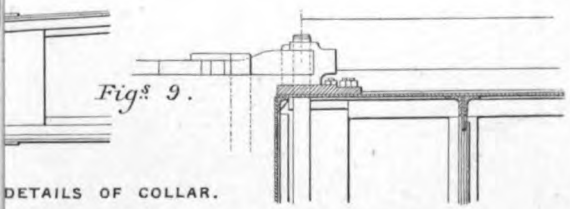

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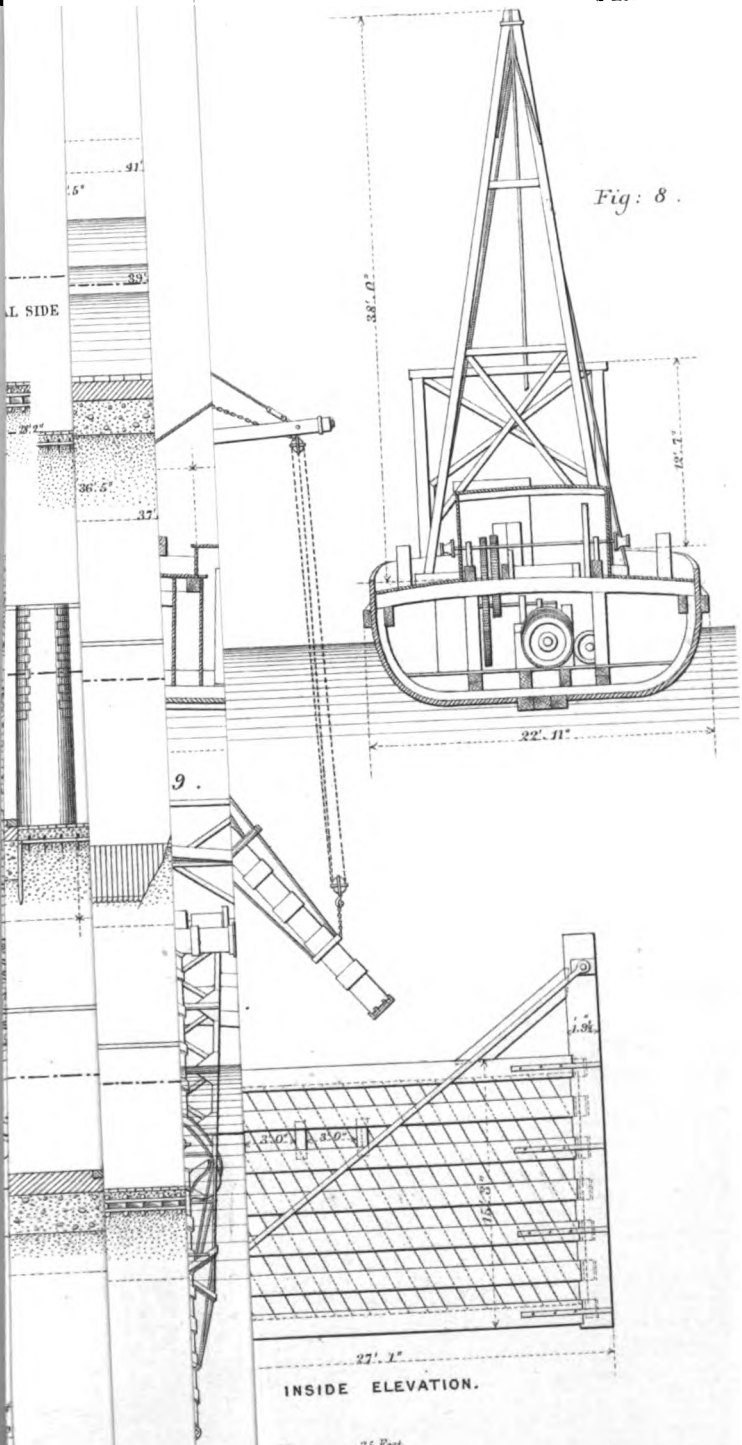

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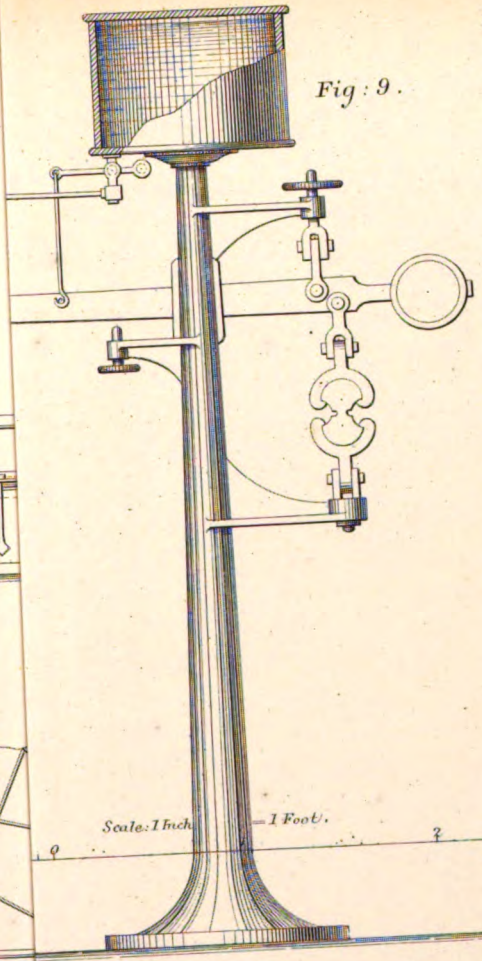

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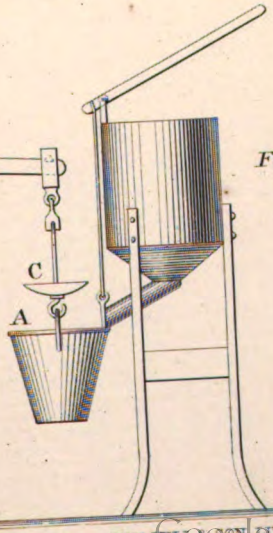

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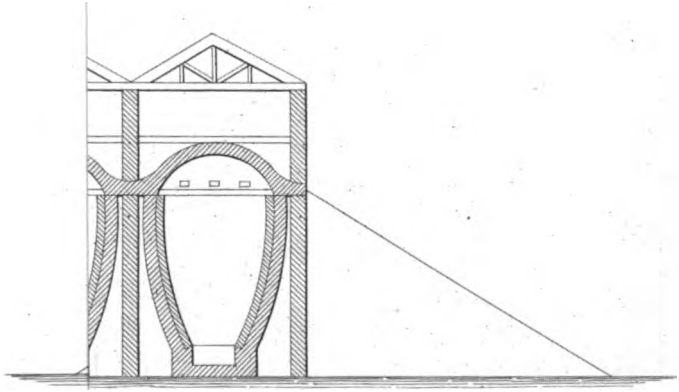

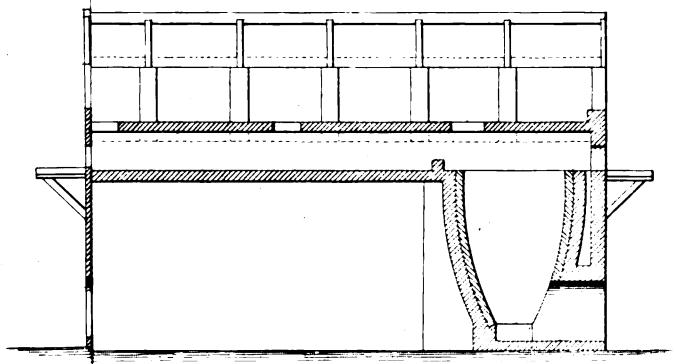

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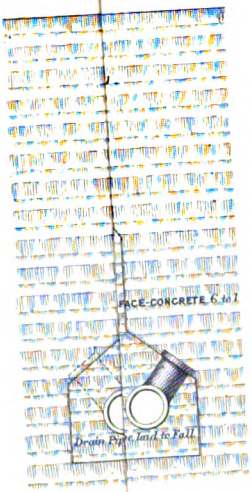
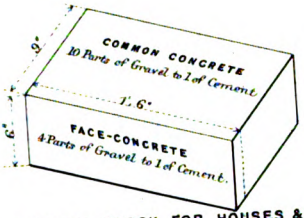
AT CHATHAM DOCKYARD E



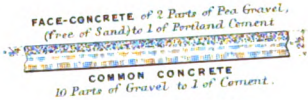
TRANBASINS.

12 6 7 Feet.

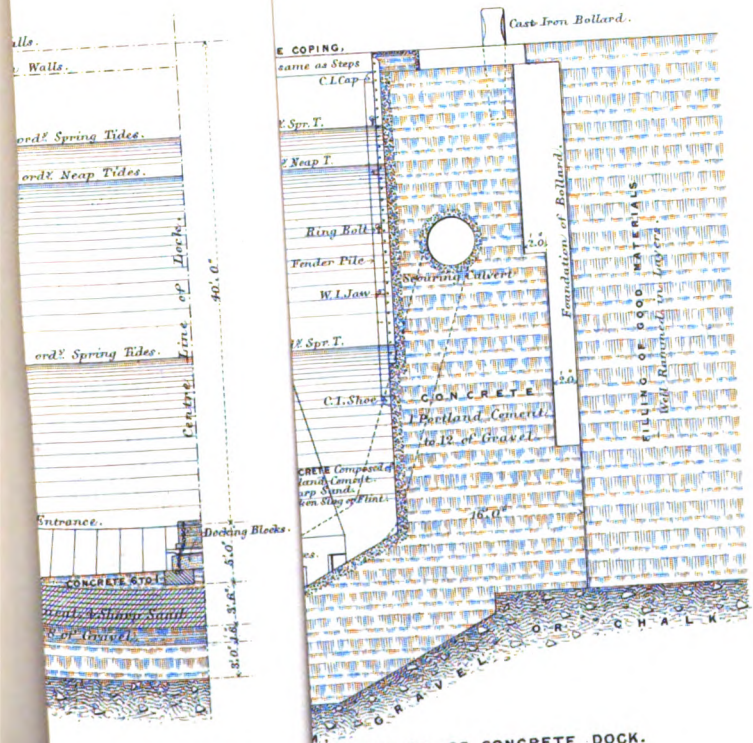


BUILDING BLOCK FOR HOUSES &c.

TRANSVERSE SECTION.



SURFACE PAVING.



Scale: 16 Feet = 1 Inch.

ALF SECTION OF CONCRETE DOCK.

For Discharging of Steam Colliers.

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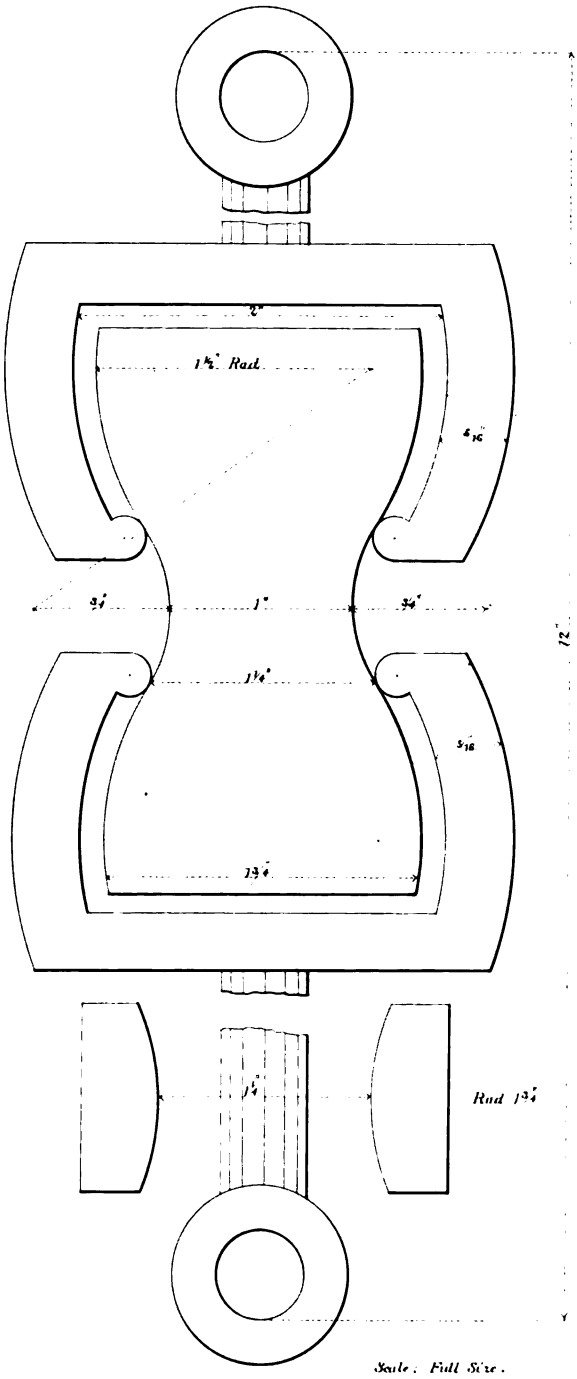
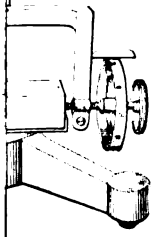
Fig: 6.





ING EXPANSION BRIQUETTES.

PRESENT CLIPS AND BRIQUETTE.

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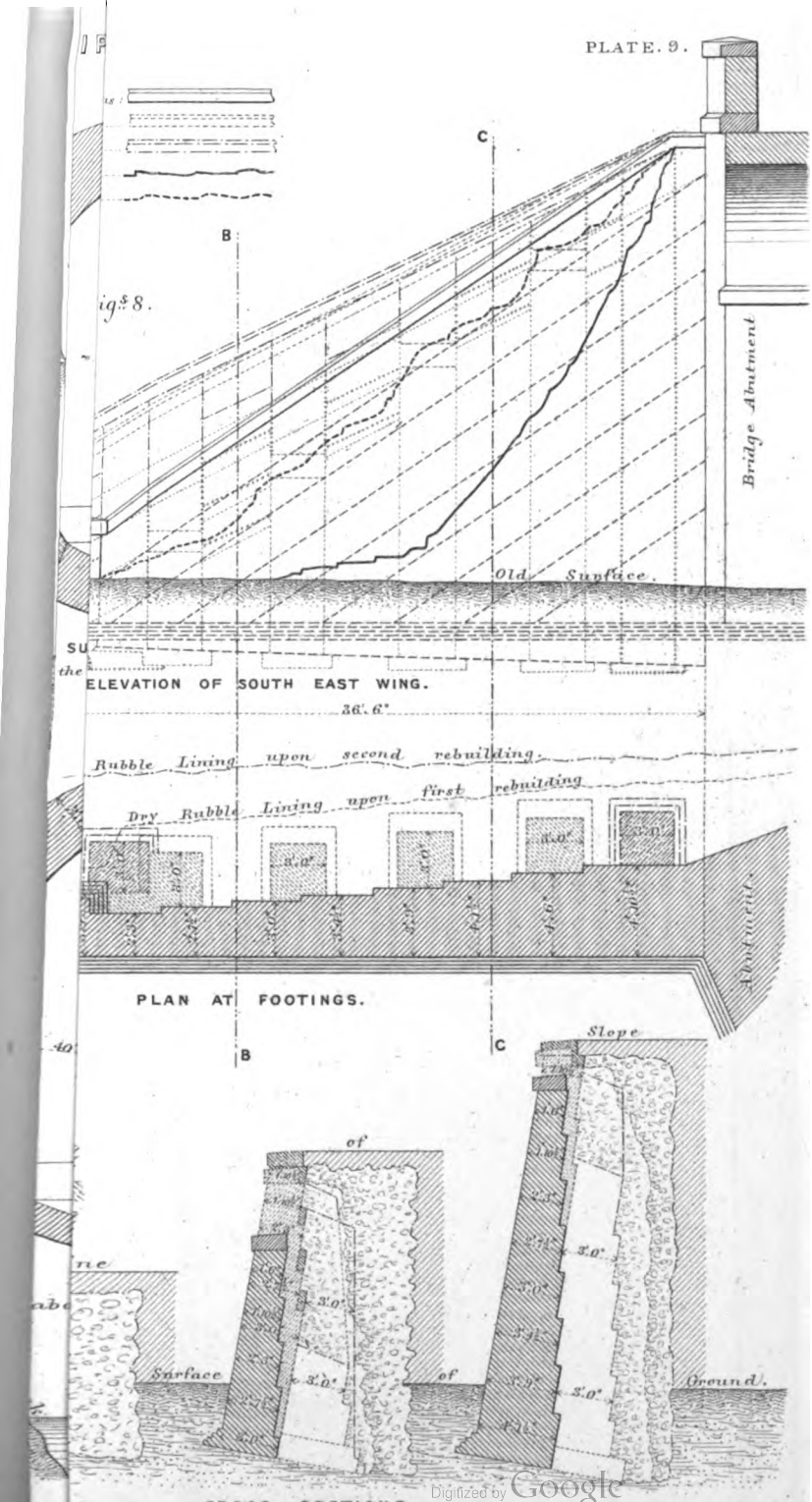
PLATE. 9.



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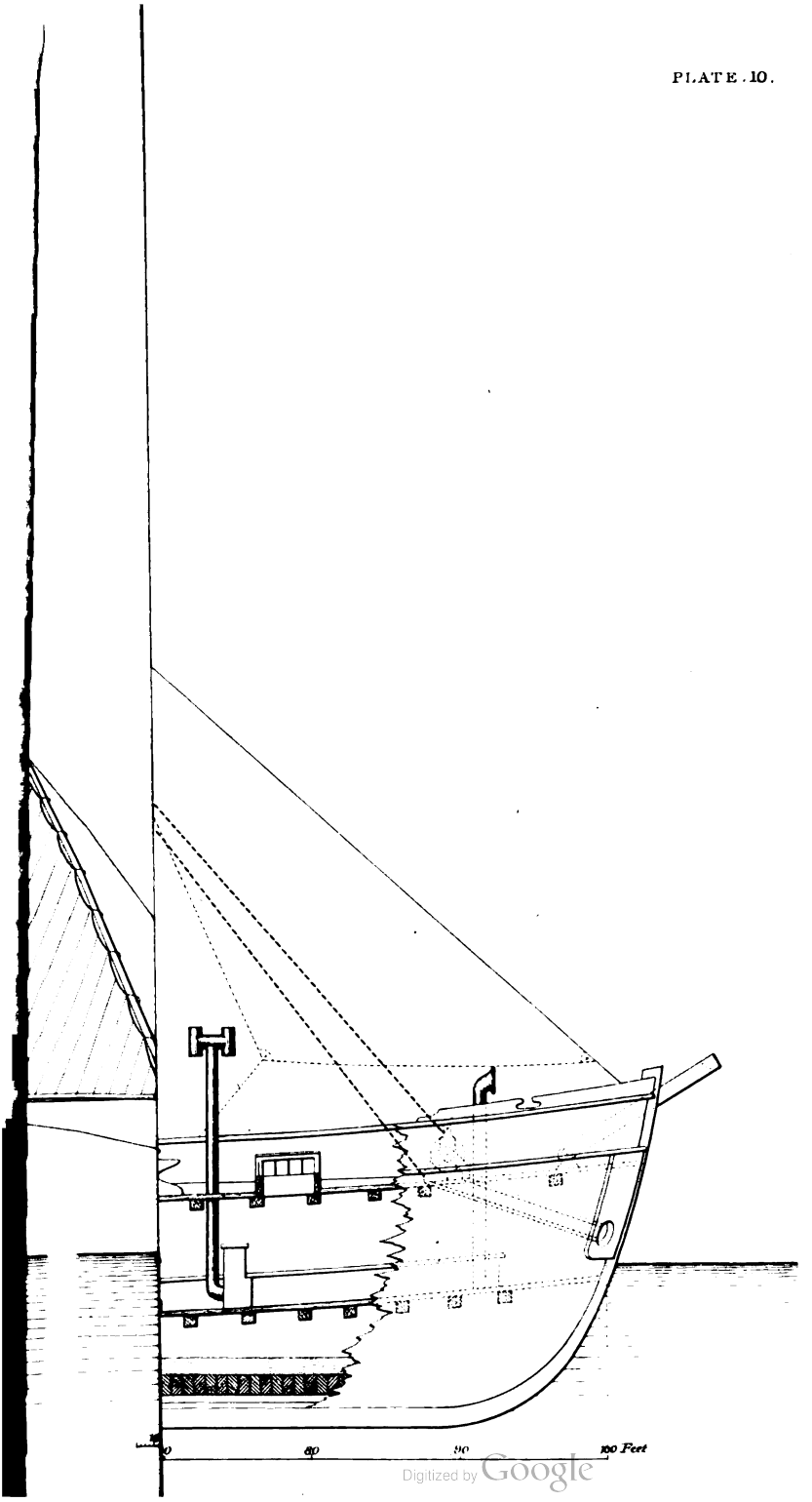

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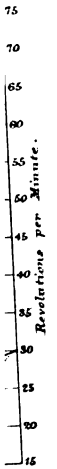

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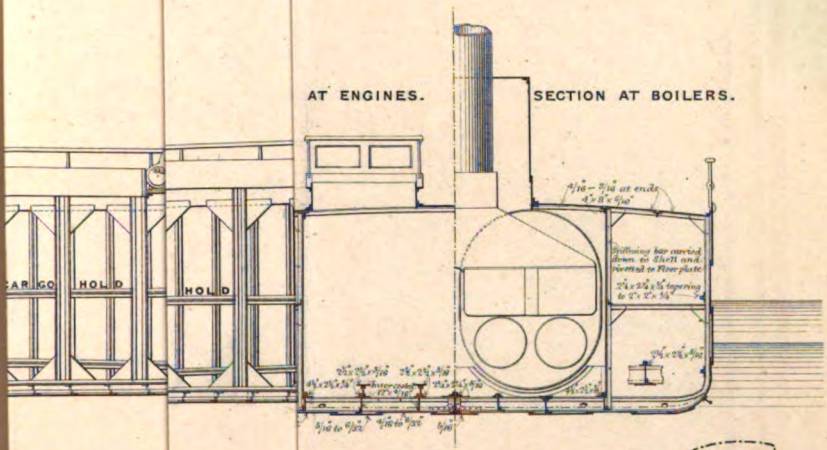
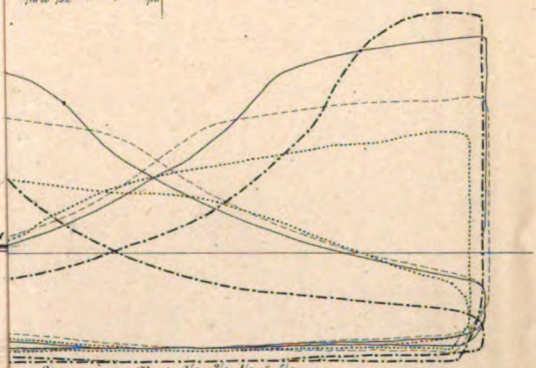
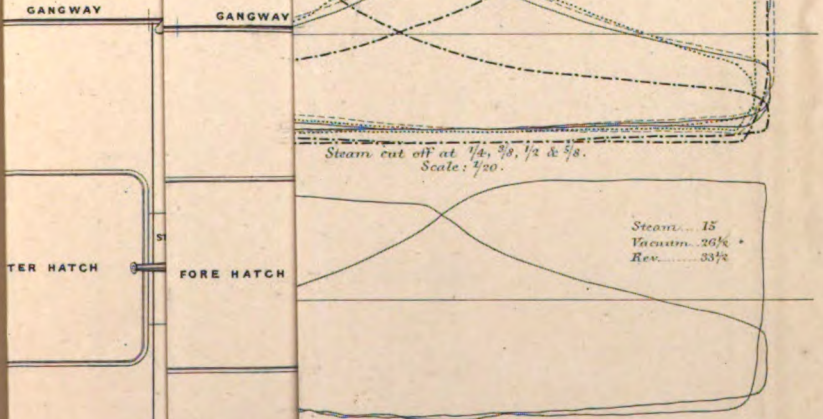
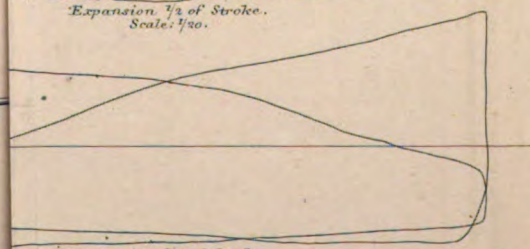




Steam cut off at 1/4, 3/8, 1/2 & 5/8.
Scale: 1/20.



Expansion 1/2 of Stroke.
Scale: 1/20.



Expansion 5/8 of Stroke.
Scale: 1/20.

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