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SIR LEOPOLD HALLIDAY SAVILE, K.C.B.

PRESIDENT, 1940–41.

In ordinary years the Member upon whom you confer the privilege of election to the Presidency of this great Institution has some idea of the duties that lie before him and can console himself that where others have found themselves able to fulfil these duties with satisfaction to all concerned, he, with the guidance of Past-Presidents and the Council, and with the help of the Secretary and his staff, always so readily and so ably given, may hope to carry the great honour that you have entrusted to him in a manner that will not lower the high standard set and followed by his predecessors: but this is not an ordinary year, and nobody knows what part we may have to play in the struggle which we are waging against the forces of evil, as our share of the effort to bring about ultimate victory. All I can say is that we—and I know that I speak for the members as a body—will give without stint all of our energies, wherever required, to achieve that end. We have faced dangers in the past; we do not flinch from them now.

It is, however, perhaps a good thing during times of great stress occasionally to relax and to turn our thoughts right away from the present struggle. Therefore, when considering a suitable subject for my Address, I decided to follow the example set by Mr. W. J. E. Binnie in his Presidential Address 2 years ago and, leaving modern times, to touch upon ancient history. Since harbour engineering has been the branch of our profession with which I have been principally associated for most of my career, I propose to deal with harbours, from the dawn of written history to the early days of the Roman Empire.

The Four Harbours of Alexandria.

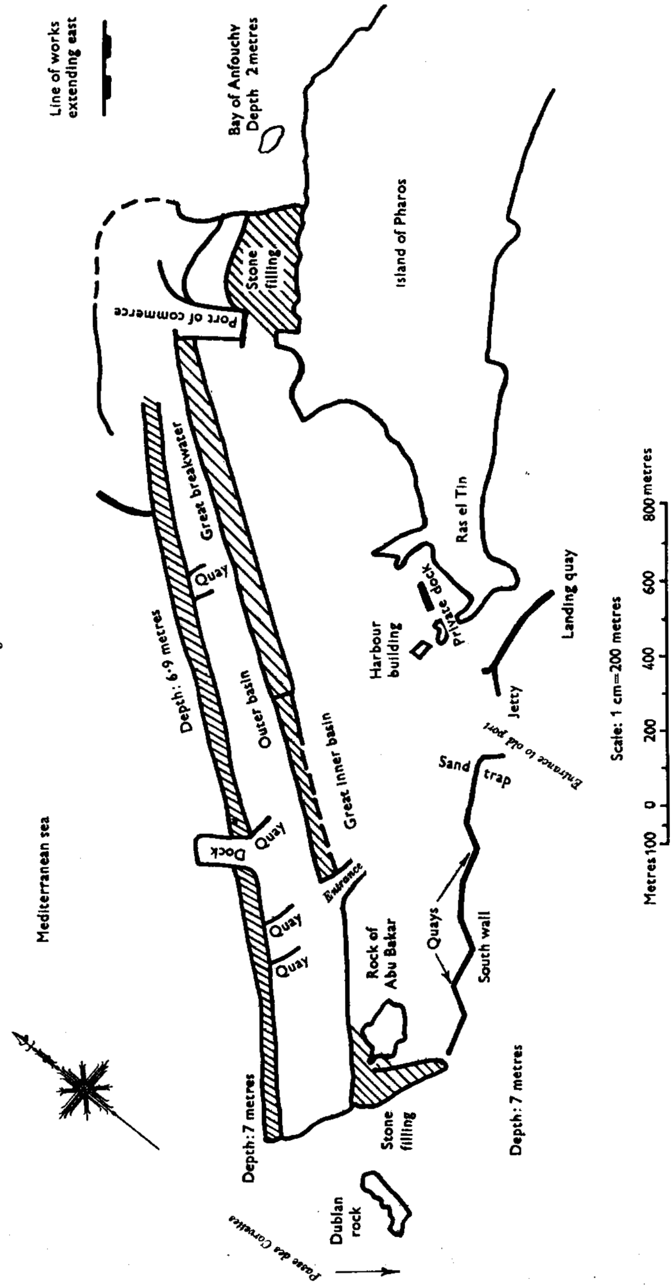
Shipbuilding and harbour engineering are two of the oldest branches of our profession. It is well established that before 3300 B.C. the

Egyptians built sea-going ships and that they made voyages to far lands to procure iron, lead, silver, and other materials; and it is recorded on the Palermo stone that about 3000 B.C. King Seneferu built sixty great ships to go to the Syrian coast to bring cedar-wood for his works. In the British Museum is a stone statue of Bedja, son of Ankhu, one of the great ship-builders of his days. The terminus of these voyages was on the Canopic branch of the Nile, where was situated A-ur or the Great Door, which Mr. P. E. Newberry calls "an ancient Alexandria of a period earlier than 3000 B.C." Little is known about this harbour, except that Narmer, one of the earliest kings of the First Dynasty, considered it of great importance and decided to conquer the petty kingdom of Harpoon, to which it belonged. It was an inland port and probably had the disadvantages of that type, especially as it lay on the banks of an arm of the delta. The actual site of the port is not known, but I refer to it because it is the earliest harbour of which I have found mention and because it marks the beginning of the harbour of Alexandria, which, I think, has the longest history of any harbour in the world. I propose to devote some of my time to a study of the great schemes adopted on the Alexandrian site over a period of nearly 5,000 years (Fig. 1, Plate 1, facing p. 10). There have been four distinct harbour building periods—the harbour of A-ur, about 3000 B.C.; the great harbour of Pharos, soon after 2000 B.C.; the harbour of Alexander the Great, begun in 332 B.C.; and the modern harbour, which dates from A.D. 1870.

The Great Harbour of Pharos (*Fig. 2*) was typical of the pre-hellenic form of massive structure, far more massive than some of the great harbours of modern times, and it is well worth study. Its layout and the skilful use made of the configuration of the bed of the sea might have been the work of a modern harbour engineer. "When," says M. Gaston Jondet, "one examines the largeness of the project and ponders on the boldness of its execution, it becomes obvious that it was conceived by a sovereign power of unequalled breadth of view, a realistic genius capable of conquering and keeping the mastery of the Mediterranean sea." Who the realistic genius was we do not know, for Egyptian history, curiously enough, has no record of this harbour. M. Raymond Weill attributes both its conception and its construction to the Minoan Cretans, who at that time were the greatest sea-faring power in the Mediterranean. It could not, however, have been made without the co-operation of the reigning Pharaoh, possibly Senusret of the Twelfth Dynasty, a famous builder of colossal buildings typical of the Egyptian, Minoan, and Mycenæan civilizations of those early times. This gives us a date somewhere between 2000 and 1800 B.C.

The harbour was based at its eastern end upon the island of Pharos, and at its western on the rock of Abu Bakar. It also took advantage of the submerged ridge running from Marabout point to the north of Pharos, and of the shelf which sloped from this towards the deep sea. From the bay of Ras el Tin at the western end of Pharos to the Abu Bakar rock there

Fig. 2.



Pre-Hellenic Port of Pharos, 1800 B.C.

is a deep pool, bounded on its northern edge by the submerged ridge. It was by surrounding this pool with breakwaters and piers that the great inner basin was formed. Seawards of this, another series of breakwaters, using the outer edge of the shelf, enclosed the outer basin. The two basins together formed a magnificent harbour about 300 acres in extent.

The entrance to the harbour was on the south, and the approach channel crossed the submerged ridge by the Passe des Corvettes between the Ikvan and El Dublan rocks. Between these rocks, the southern boundary of the harbour, and the island of Pharos, not then joined to the mainland of Egypt, was a sheltered roadstead for ships making the entrance against the prevailing north-west wind.

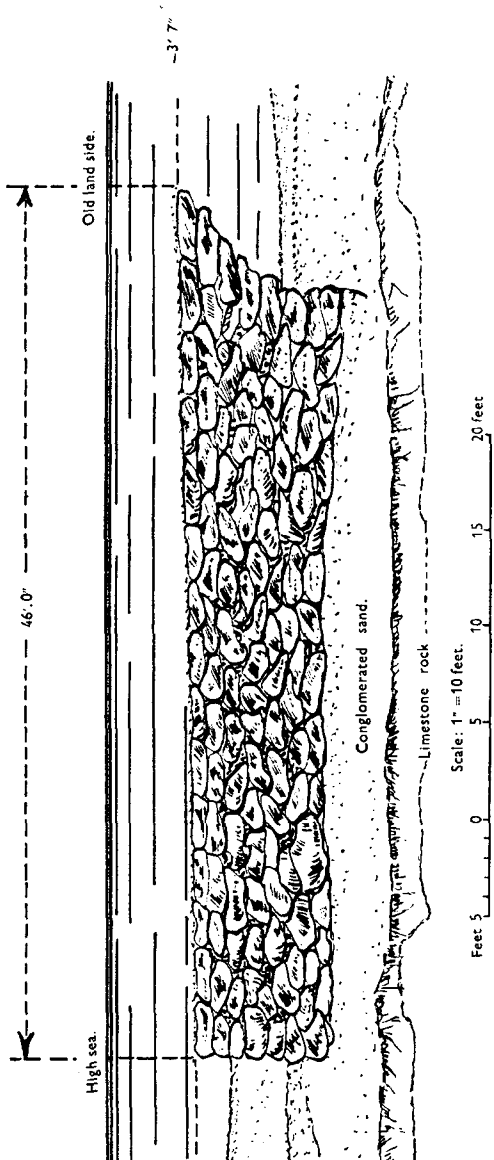
I will now try to give some idea of the construction of the works. On the right the entrance is flanked by a slightly-curved landing-quay (*Fig. 3*) running in a north-east—south-west line, founded on a firm mass of argillaceous sand in the shallow water off the end of Ras el Tin point. This quay was 525 feet long by 46 feet wide and 18–20 feet high, and was built of large rough-hewn blocks of limestone from the quarries at Mex on the mainland, carefully laid in courses and bonded with small aggregate and sand well tamped down. The top was paved with pentagonal flags 26 feet long by 23 feet wide, all of the same shape and forming a chequer-work. The walls were vertical, but the upper surface had a gradient of 3 per cent. No cement or mortar was used on this or on any of the quays or breakwaters.

Jutting out from the end of this quay, and partly enclosing the harbour entrance, was a jetty about 426 feet long, consisting of two parallel walls just over 41 feet apart, closed at the end by a cross-wall. These walls were 7½ feet wide at the top, and were built with a slight batter on each face. The space thus enclosed was filled with rubble and sand, and had no paving on the upper surface.

The main entrance, of which this quay and jetty formed the eastern protection, was 650 feet wide. The south wall of the harbour was 2,300 feet long, in a general east to west direction, but its course was irregular because it was largely built up on a line of reefs which bordered the deep water of the inner basin. The upper parts of this wall were built of large, carefully-hewn blocks ranging from 8 feet to 16 feet in length, laid with great precision. Again no cement was used, but the joints were filled with small stones. At the main-entrance end of the wall was a short protective mole or spur, 360 feet long by 65 feet wide, the object of which appears to have been to form a sand-trap to prevent the drift of sand caused by the south and south-west winds from blocking the entrance to the harbour.

The pavement of the southern wall (*Fig. 4*, p. 6) is of interest because its pattern is typical of the pavements found in Minoan Crete and lends support to the view that the harbour was the work of Cretan engineers. It was composed of large slabs of stone, many 16 feet long, laid so that the joints radiated from a centre.

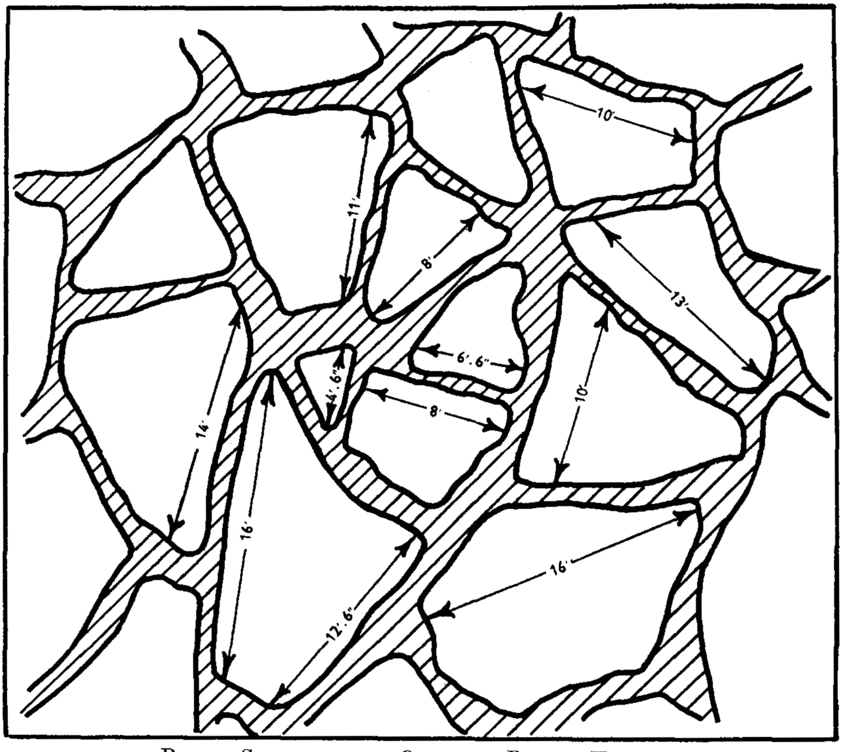
Fig. 3.



CROSS-SECTION OF LANDING QUAY, PORT OF PHAROS.

The southern wall ended at a point a short distance south-west of Abu Bakar. Thence ran two walls, each about 490 feet long, one in a north and the other in a north-west direction, enclosing between them a triangular area of about 28,000 square yards. This space was filled in by large blocks of limestone and formed an immensely powerful breakwater, much of which is still in existence and can be seen under water on a clear day.

Fig. 4.

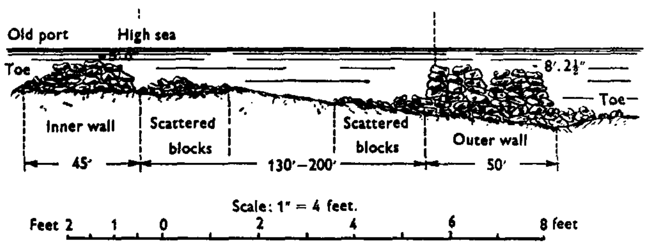


PAVING STONES OF THE QUAYS OF PHAROS HARBOUR.

The most marvellous works of this harbour were, I think, the two great breakwaters that guarded the inner basin and the outer basin. The first, which M. Jondet called the great breakwater, started from the northern end of the triangular mass just referred to and ran for 8,500 feet in a straight line to the western end of Anfouchy bay. For its first 2,000 feet it was built in the same way as the southern wall, except that the part bordering the Abu Bakar rock seems to have been filled in with dumped stone to form a solid mass. Then followed a length of 6,500 feet which needed to be very strongly made. Two walls founded on firm argillaceous sand overlying the submerged ridge already mentioned, were built 130–200 feet apart (*Fig. 5*). Each ranged in width at its upper surface from 26 feet to 40 feet, and had a batter of 1 in 30, and each was protected by a substantial toe. Their height, judged from the remains that have been found under water, appears to have ranged from 20 to 30 feet. The depth of water in the basin is unknown, but it may be estimated at 25–40 feet, with considerably deeper patches in the pool of Ras el Tin. The walls were built of enormous blocks of stone roughly hewn and coarsely laid. All of the space between the walls was filled with large blocks, forming a surface between 180 feet and 250 feet wide. The great width would enable defending parties to move rapidly to any part of the harbour during piratical attacks, whilst in normal times it was useful for drying and repairing sails and fishing-nets, weaving ropes, and so forth.

Running parallel to this breakwater, and about 650 feet distant from it, was another of similar construction enclosing the outer basin, the entrance to which was by a passage through the inner breakwater a little

Fig. 5.



TYPICAL SECTION OF GREAT BREAKWATER, PORT OF PHAROS.

to the north-east of Abu Bakar, between its single-wall and double-wall portion. Protection was afforded by two moles running in the same direction as the landing-quay and protective mole guarding the main entrance.

The whole of the inner breakwater formed an immense quay. Besides this, several jetties about 60 metres (197 feet) long ran out from the outer breakwater, and nearly the whole of the south wall of the inner basin formed a broad quay, giving a total length of quay of about 10,000 feet. There was also a kind of dock built out seawards from the outer breakwater, the purpose of which is not clear. It may have been another entrance to the harbour.

The remains at the eastern end of the harbour bordering on Anfouchy bay are not so easy to interpret. About 650 feet from its end the great breakwater of the inner harbour was pierced by an opening 160 feet wide and 525 feet long, to form what M. Jondet calls the commercial harbour. This small port had two entrances, one from the outer basin, and one direct from the sea, carefully protected by two incurving breakwaters. Beyond the commercial harbour the great breakwater continued for a short distance to the shallow water at the commencement of Anfouchy bay, where a north and south cross-wall closed the harbour. A very large area between the breakwater, the wall, and the shore of the island was filled in with large stone blocks, as at the west of Abu Bakar.

At the extremity of the point of Ras el Tin, near the main entrance to the inner basin, is a small island around which are the remains of other works, including a short mole which enclosed a small private dock—perhaps for the use of craft owned by the harbour authorities. This surmise is made the more probable by the fact that slightly to the north-west are the submerged ruins of a large building, more than 92 feet long by 46 wide, with approach channels and steps, which appears to have been the head-quarters of the port management, where pilots and the captains of ships would come to receive their orders.

To the east of the great harbour was a smaller one occupying the bay of Anfouchy. It also was protected by breakwaters and equipped with quays, but it afforded only a shallow depth of water and was used chiefly as a fishing-centre.

I have attempted to give a brief description of the ancient harbour of Pharos, as revealed by the researches of M. Gaston Jondet, carried out between 1910 and 1915; and when the science shown in its layout and construction is considered, we must, I think, agree with him that it was, indeed, the work of a realistic genius.

It may seem strange that when Alexander the Great founded Alexandria and built his harbour in 332 B.C. he should have taken no notice of these wonderful works. The reason was that they had disappeared under the sea, and all that marked the site of the future city was a little village at Rhacotis and a small colony of fishermen. There is no more record of its fall than of its rise. Homer may refer to it in the fourth book of the "Odyssey," where he describes Pharos as an island in the troubled sea having within it a haven with fair moorings. If this is so, then its decline must be dated some time after 1000 B.C.

A few words as to the cause of its disappearance may be interesting, although "disappearance" is really a misnomer, because, as M. Jondet has shown, a very large portion of the works still exists and on a calm day parts of them can be seen clearly below the surface of the sea. The ridge of high ground upon which the harbour was built is formed of limestone similar to that exposed in the quarries of Mex. Overlying the slopes of this ridge is a thin layer of clay, upon which is a thick layer of river silt in various states of consolidation. Covering this on the higher slopes is the stratum of hard argillaceous sand, and it was upon this that the walls and breakwaters were built. M. Jondet considers that, as the silt consolidated, its bearing value weakened and the stratum of sand which rested upon it glided down the slopes in sudden subsidences, the underlying clay acting as a sliding surface. The process was purely mechanical, although earth tremors may at times have started the movement. In this manner whole portions of the works glided below water-level, often without any damage to their structure.

Fifteen hundred years after the foundation of the harbour of Pharos, Alexander the Great, returning down the Canopic branch of the Nile from his visit to the temple of Zeus Ammon in the oasis of Siwah, halted at the village of Rhacotis. Ever since his destruction of Tyre he had determined to build a harbour that should be her rival. At Rhacotis he had found the place he wanted. He, himself, is said to have traced the plan of Alexandria and its harbour, which his famous engineer, Dinocrates, was ordered to carry out (*Fig. 6*, p. 10). The main feature of the harbour was the great mole, 600 feet wide and 7 *stadia* (about 1 mile) in length, and hence called the *Heptastadion*, from the mainland to the island of Pharos, which divided the roadstead into two basins. It was built in a depth of water of 36 feet, and its construction entailed the excavation, transport, and deposition of about 2 million cubic yards of stone. The basin on the right of the mole formed the Great Harbour, and that on the left the *Eunostos* or Haven of Happy Return. Two openings through the mole connected them, thus conforming to the ancient rule that a harbour should have two entrances. The Great Harbour was bounded by the Lochias headland, the *Heptastadion*, and the eastern end of the island of Pharos. Seaward it was protected by a pier built out from Lochias and by a line of dangerous reefs, which made entrance to the harbour difficult. It was chiefly to remedy this that Ptolemy built the world-famous Pharos, or lighthouse, one of the seven wonders of the world, on the eastern point of the island. Alexander erred in putting his harbour in this place, since the depth of water was not so good as in the neighbouring haven, the reefs and Lochias pier did not provide sufficient protection against the winds, and the entrance was always difficult. Within the Great Harbour lies the small island of Antirrhodus, and between it, the mainland, and Lochias was formed a small *Portus Regius*, or Port Royal, for the king's ships. Between the *Portus Regius* and the *Heptastadion* the shore was lined with quays and storehouses. The public granaries were on the *Eunostos*, where also was a small inner harbour enclosed by piers. It was on this basin that the important canal connecting the harbours with lake Mareotis and the Nile, by its Canopic branch, opened. Alexandria partially fulfilled its founder's purpose of crippling the trade of Tyre; but this was due to the policy of Ptolemy Philadelphus (285–247 B.C.) who made a harbour at Berenice on the Red Sea, connected it with Coptos, on the Nile, by a road provided with water-places at proper stages, and reopened the canal between the Nile and the Red Sea at Suez. Thus he captured for Alexandria the important trade of the Indian Ocean and the Red Sea, which had hitherto passed by Eloth and Eziongebir to the coasts of Palestine, whence it was carried in Tyrian ships over the whole of the then known world. Alexandria's gain was Tyre's loss.

A period of more than 2,000 years passes (Fig. 1, Plate 1). In the meantime the sand, which the engineers of ancient Pharos had been so careful to fend from the entrance to their harbour, had passed along the roadstead

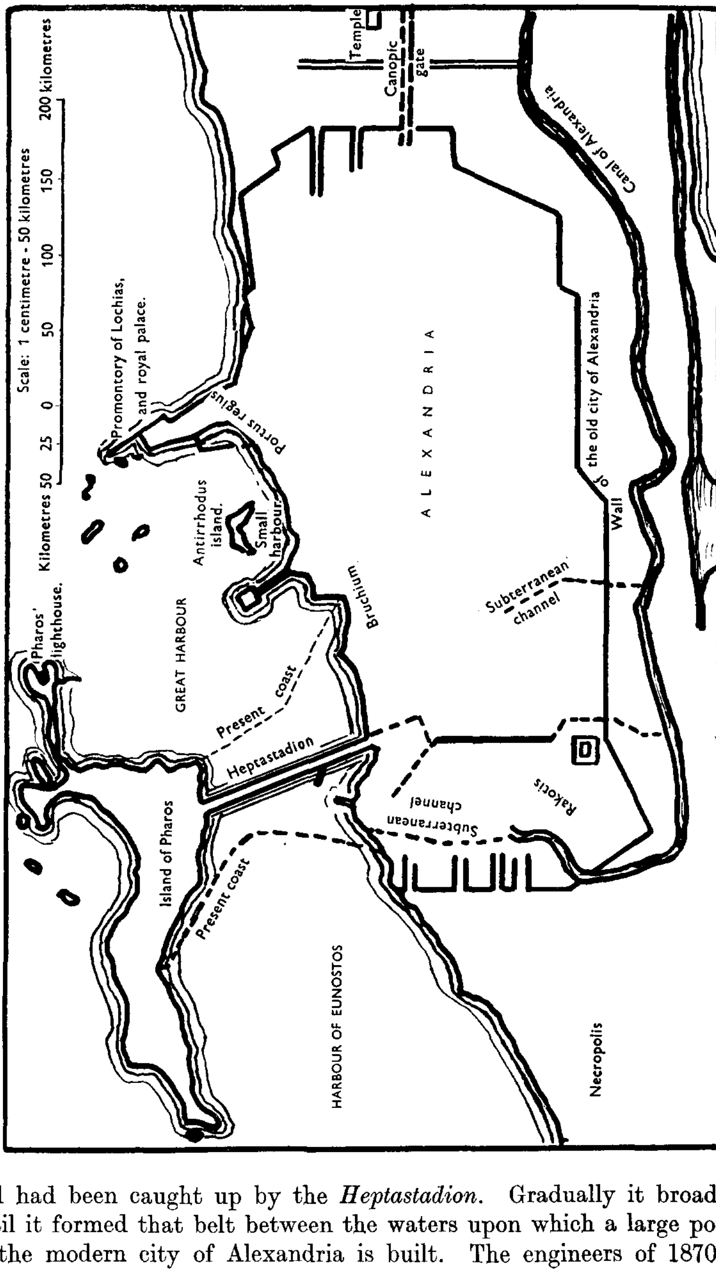


Fig. 6.

PLAN OF ALEXANDRIA AND ALEXANDER'S HARBOUR, 332 B.C.

and had been caught up by the *Heptastadion*. Gradually it broadened until it formed that belt between the waters upon which a large portion of the modern city of Alexandria is built. The engineers of 1870 dis-

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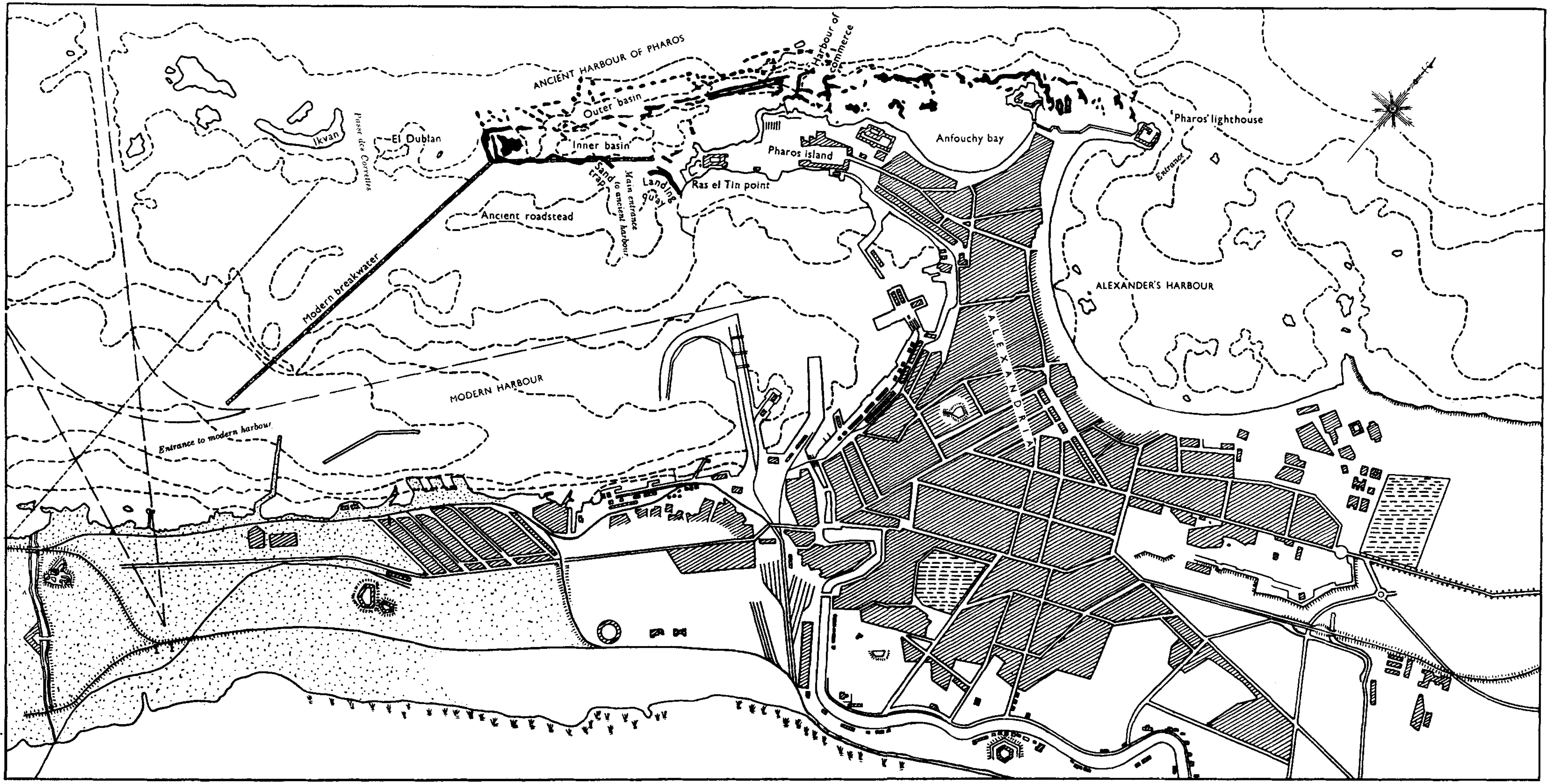
FIG: 1.



ALEXANDRIA, SHOWING THE ANCIENT HARBOUR OF PHAROS, ALEXANDER'S HARBOUR, AND THE MODERN HARBOUR.

carded Alexander's Great Harbour, which had been for many years too difficult and shallow for shipping, and the entrance to which was still dangerous and difficult to make. They returned to the western side of Pharos and their great breakwater, like the south mole of the ancient harbour, was based on Ras el Tin. The modern harbour occupies what was the roadstead of its predecessor of 4,000 years ago.

TYRE.

Tyre was another famous pre-hellenic harbour (*Figs. 7* and *8*, pp. 12 and 13), but it is only a few years ago that a true plan of its works was published by Père A. Poidebard. As a result of 3 years' research, from 1934 to 1936, in which he made brilliant use of aerial observation and photography, coupled with submarine observation and photography, Poidebard was able to demonstrate the incorrectness of all previous plans and the unreliability of any plan made of ancient works unchecked by careful research and observation on the spot.

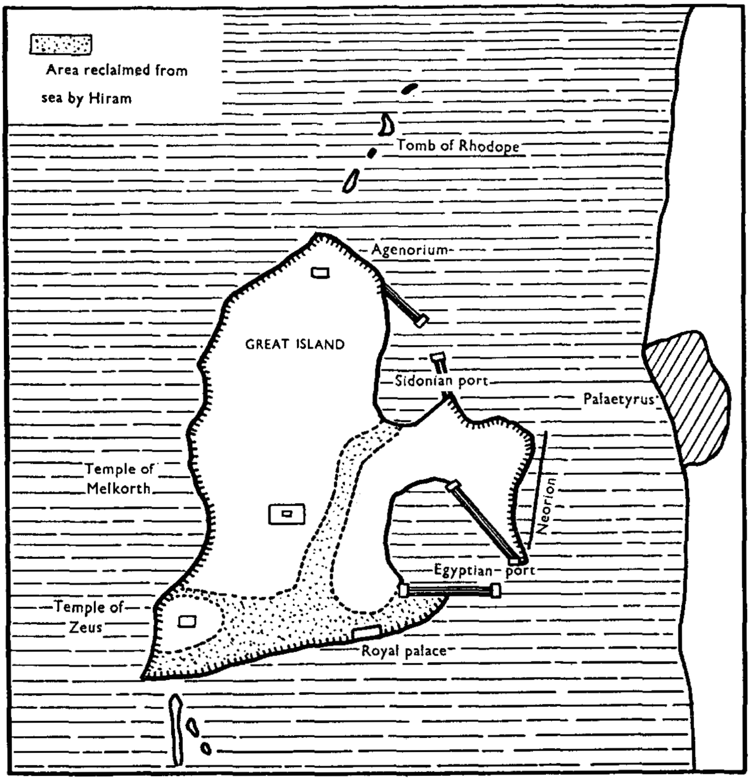
History has given the Phœnicians a reputation as builders and engineers. A delightful story is told by Herodotus in his description of the cutting of the Canal of Athos, which illustrates their skill as engineers. "When the trench grew deep," he writes, "the workmen at the bottom continued to dig, while others handed the earth, as it was dug out, to labourers placed higher up upon ladders, and these taking it, passed it on further, till it came at last to those at the top, who carried it off and emptied it away. All other nations, therefore, except the Phœnicians, had double labour; for the sides of the trench fell in continually, as could not but happen, since they made the width no greater at the top than it was required to be at the bottom. But the Phœnicians showed in this the skill which they are wont to exhibit in all their undertakings. For in the portion of the work which was allotted to them they began by making the trench at the top twice as wide as the prescribed measure, and then as they dug downwards approached the sides nearer and nearer together, so that when they reached the bottom their part of the work was of the same width as the rest." As builders they are, as everyone knows, renowned for the work they did for Solomon in building the temple of Jerusalem, whose "great stones," "wrought stones," and massive brass pillars 18 cubits high, modelled on those in the temple of Melkart, at Tyre, so impressed the Jews.

Tyre had two harbours (*Fig. 8*), the Sidonian on the north of the island and the Egyptian on the south, and like Pharos, a spacious roadstead to protect ships from the stress of the open sea when making the entrances. The Sidonian was what the ancients called a closed (*kleistos*) harbour; that is to say, it was within the circumvallation of the city and its entrance could be blocked by suspending a chain from one side to the other. The Egyptian was an open (*aneimenos*) harbour, outside the fortifications but adjoining them.

Tyre was a very old city, dating back, according to Herodotus, to

2750 B.C. This is probably incorrect, but at all events by 1400 B.C. its renown was widespread, and by 1100 B.C. its seamen had passed Gibraltar and had dared the Atlantic. It was probably about this time that the Sidonian harbour was built. Hiram, king of Tyre (970–936 B.C.) friend and ally of Solomon, was a great builder and engineer. When he came to the throne Tyre was separated into three islands by arms of the sea full of reefs. Hiram filled these channels and on part of the land so reclaimed

Fig. 7.



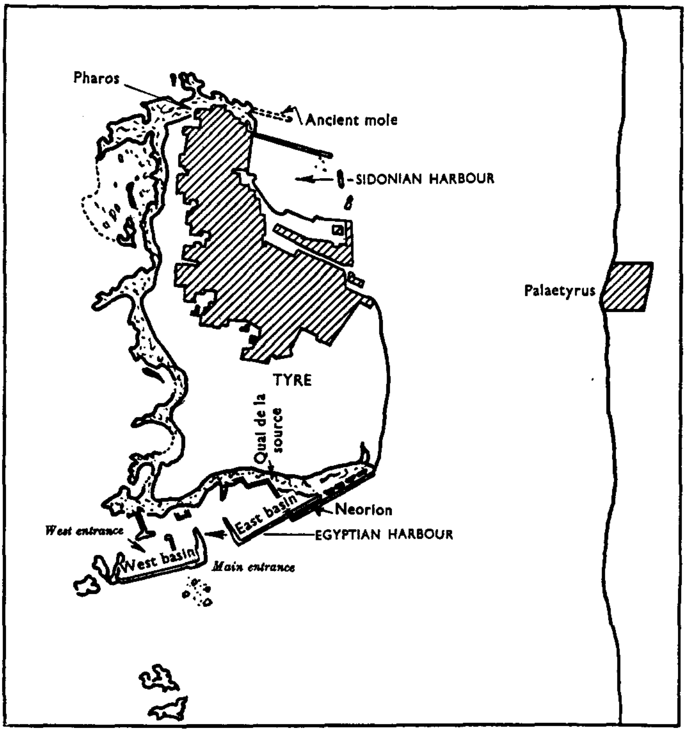
TYRE.
Note incorrect position of Egyptian harbour.

built the Egyptian harbour, not as Maspero and others have asserted, on the south-east of the island (*Fig. 7*), but, as Père Poidebard's discoveries have shown, along its south coast (*Fig. 8*). A massive mole, 2,500 feet long, runs from the south-east corner to a large exposed rock lying off the south-west corner. Two similar moles, one running northwards from the rock at the end of the south mole, and the other running southwards from the shore of the island, enclosed the harbour on the west. The ends of these walls overlapped so as to form a protected entrance from the open sea to the western basin.

Two marked advances had occurred in constructional methods since the days when the harbour of Pharos was built, namely, the use of concrete in making sea-walls, and the use of iron dowels run in with lead. Both of these methods were used at Tyre.

The moles were very solid structures (*Figs. 9* (*a*) and (*b*), facing p. 14). They had foundations of large, hewn, rectangular blocks, all laid as headers. The middle was composed of hard concrete divided at intervals into com-

Fig. 8.



TYRE.
Showing correct position of Egyptian harbour.

partments by transverse bonding. The side bordering the sea was faced with squared slabs, 10 feet long by $4\frac{1}{2}$ feet thick, laid as stretchers. The south mole varied in width from 24 feet to 26 feet, whilst the two western moles, which had to face the full force of the sea, were $7\frac{1}{2}$ feet wider.

In the middle of the south mole was the main entrance to the harbour, and from each side of it two large wharfs, built of concrete and faced with stone, were built across the interior for about two-thirds of its width. The narrow passage thus formed was commanded by a fortified post on the island. This passage was the boundary between the Western and Eastern basins.

A concrete wharf, the *Quai de la Source* on Père Poidebard's plan, cut the eastern basin into two, the farther and smaller one of which appears to have been paved throughout with flagstones and to have been used as a *neorion*, or shipbuilding and repairing yard, equipped with slips and storehouses. Père Poidebard thinks that it may have communicated with its neighbouring basin by means of an inclined plane, but M. Bertou thought it had direct access to the sea. Possibly both methods existed. At the northern corner of the outer eastern basin, where the *Quai de la Source* abuts the island, was a small basin which accommodated a drinking-water tank for replenishing ships—an important item, for water was precious in Tyre, nearly the whole supply of the island having to be brought across by boat from springs on the mainland.

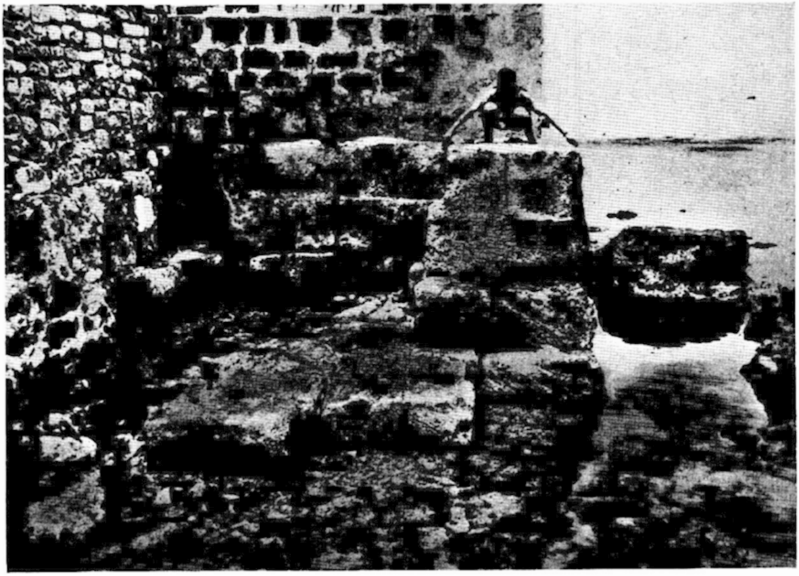
The Sidonian harbour made use of a small bay at the north-east side of the island and was partly surrounded by the city. Two jetties, one jutting out from the ancient tower near the modern lighthouse and the other coming from the opposite side in a northerly direction to meet it, protected its entrance. Père Poidebard was able to trace the northern jetty, and thus to prove that it lay some distance beyond the existing jetty of Sur and that the ancient harbour was larger than the modern. The construction of the jetties was similar to that of the moles in the Egyptian harbour.

Old authorities record that the two harbours were connected by a canal, and many old plans show this canal, but it is not shown on Père Poidebard's plan, or on Berthou's, made in 1846. It is, however, possible that there was communication through the arm of the sea said to have been reclaimed by Hiram. It was a common custom in ancient harbours to have two separate but interconnected basins, and Sidon, which also belonged to the Phœnicians, was laid out on this plan, which had obvious advantages. Vessels could enter one of the basins when a contrary wind prevented them from entering the other ; if one basin was made unsafe by a storm, ships could move through the canal and take refuge in its neighbour ; whilst if an enemy attacked he would have to split up his fleet or risk being surprised by the defenders who, having escaped through the other entrance, might attack him in the rear.

In addition to its harbours, Tyre took care to protect its roadsteads (*Fig. 10*, p. 15). North and south of the island ridges of rock, partly submerged and partly exposed, stretched parallel to the coast and formed a natural barrier against the waves. That they were not, however, considered sufficiently effective has been made clear by Père Poidebard's discovery of traces of two separate lengths of wall based on the southern line of reefs, one about 1,000 feet and the other 1,650 feet in length. These walls were of massive structure, 100 feet wide, and were faced with rocks, some of which were 10 feet square by 2½ feet thick and weighed about 15 tons (*Fig. 11*, facing p. 15). Probably, although sufficient evidence is not yet available, there was a similar reinforcement of the north reef. Traces seem still to have been in existence when Maundrell visited Tyre in 1697, for he reports that

Figs. 9.

(a)



(b)

FOUNDATIONS OF THE MOLES OF THE SIDONIAN HARBOUR.

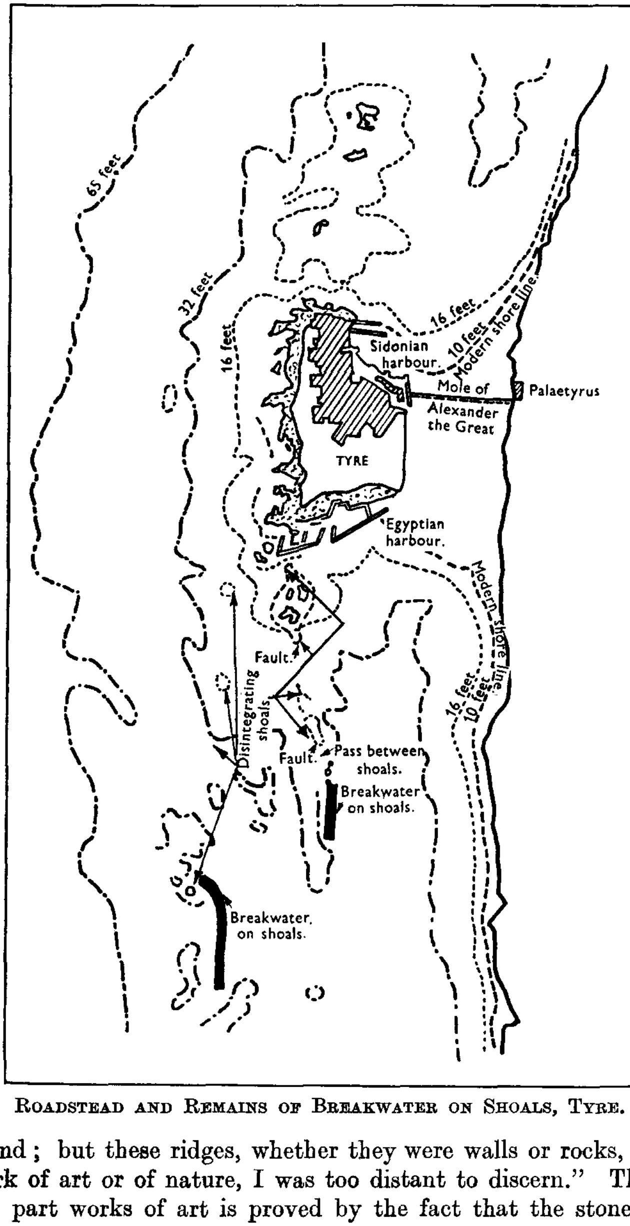
Pres. Address.

Fig. 11.

FOUNDATIONS OF BREAKWATER AT TYRE.

the harbours were, "in part defended from the ocean, each by a long ridge resembling a mole stretching directly out on both sides, from the head of

Fig. 10.



ROADSTEAD AND REMAINS OF BREAKWATER ON SHOALS, TYRE.

the island; but these ridges, whether they were walls or rocks, whether the work of art or of nature, I was too distant to discern." That they were in part works of art is proved by the fact that the stone used is different from the rocks upon which it is laid, and that it must have come from quarries on the mainland where a similar stone is found. One cannot help wishing that more information was available as to how these immense masses of stone were conveyed to the spot and laid with such accuracy. M. Henri Watier, whom Poidebard consulted, considered the construction of such works perfectly practicable in antiquity. "Several divers could," he says, "easily push stones of nine tons weight into place as they were being let down by ropes." The divers of Tyre, who were accustomed to collect the shellfish *murex* for the famous purple dye, would be ideal for such work. It is known that they could remain below water for 1½ minute.

Tyre enjoyed many centuries of fame as the finest and richest city in the world. All will recall the three vivid chapters in which the prophet Ezekiel describes the city and foretells its fall—"thy riches, and thy wares, thy merchandise, thy mariners and thy pilots, thy calkers, and the exchangers of thy merchandise, and all thy men of war, with all thy company which is in the midst of thee, shall fall into the heart of the seas in the day of thy ruin." Even in the bitterness of his scorn he cannot refrain from a note of admiration; "by thy wisdom and by thine understanding thou hast gotten these things."

Five hundred and eighty years after the death of Hiram came Alexander the Great. Tyre, unconquered still, was too great a danger to leave behind him while he was away subduing the East. Alexander's fleet was too weak to fight her at sea. Nothing daunted, he attacked from the land, and for this purpose he built a colossal mole 100 feet wide and ½ mile long in 3 fathoms of water, so that Tyre ceased to be an island and became a peninsula. He demolished the old city of Palætyrus for stone and robbed the forests of Lebanon for timber to accomplish his purpose. In 9 months he completed his task and captured the city. The laws of nature asserted themselves; coastal drift completed what Alexander began, and now Sur, the ancient Tyre, is connected to Syria by a broad neck of land.

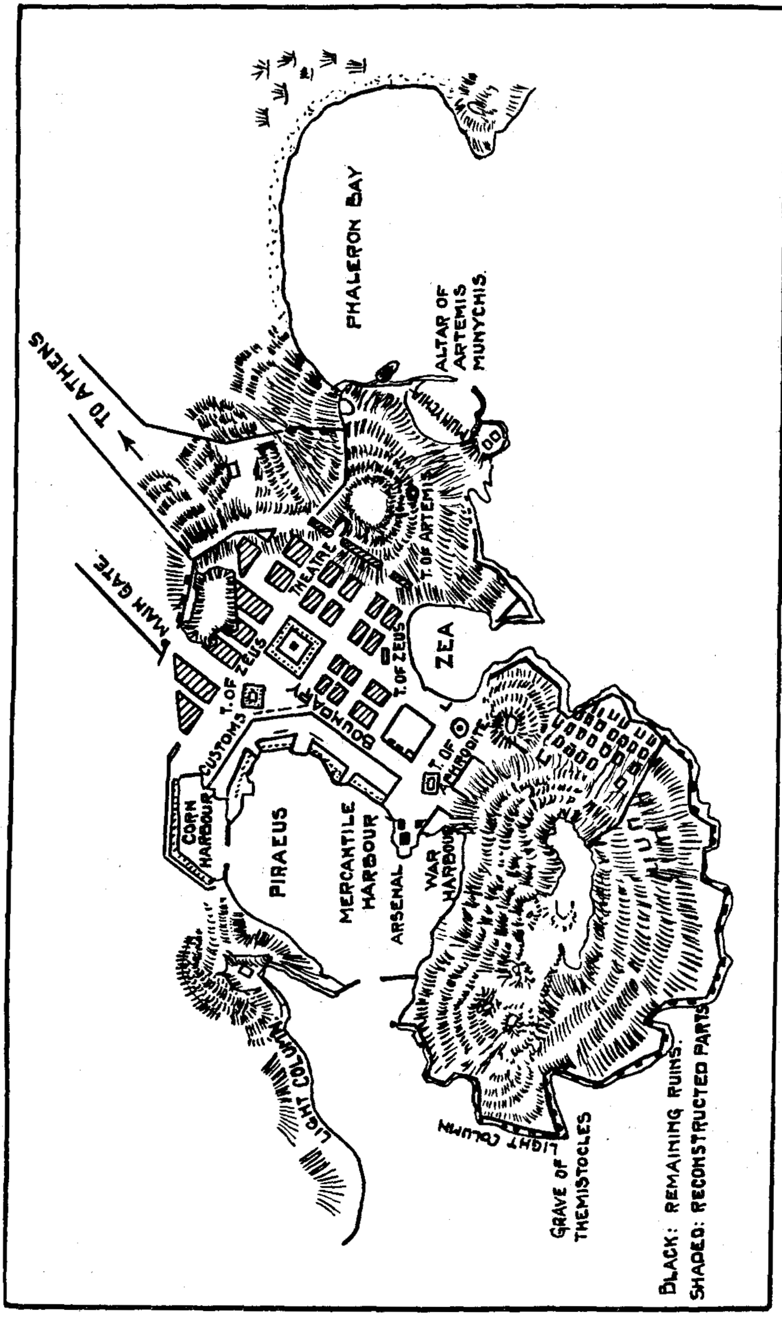
The following interesting example will illustrate the efficiency of the ancient harbour engineer. Some years ago a friend of mine went out to advise on the construction of a harbour in the Black sea. After careful study, he recommended a plan for a rubble stone breakwater protecting a deep-water pier. On his return journey his ship called at Samsoun, the ancient colony of Amisus. As he had never been at Samsoun before, he went ashore, and was interested to find the ruins of a rubble breakwater sheltering a massive quay-wall, made of great blocks of masonry, which might almost have been built to the plans he had just drawn up. The ruins dated back to the days of Darius, say about 500 B.C. and I am very tempted to see in them the "wisdom and understanding" of a Tyrian engineer, for it is known that the Phœnician interests extended thus far. Perhaps there is a powerful *genius loci* in the Black sea; be that as it may, it is interesting that a Phœnician engineer (if my surmise is right) and a British engineer, separated in time by 2½ millenna, should have solved a problem in almost exactly the same way.

Grecian Harbours.

When we come to Grecian times a rather different state of things is found. The shores of Greece and those of most of her colonies abounded in deep bays and long arms of the sea stretching inland, forming excellent natural harbours that required little in the way of artificial works to make them safe refuges. Moreover, Greece was divided into many small states, each of which, except Doris, Arcadia, and a few others with no seaboard, had its own port. Great harbours of cyclopic stonework like Pharos and Tyre were, therefore, unnecessary. Generally all that their natural harbours needed, apart from quays and wharfs, were short moles to narrow the entrance.

In the early days Athens used the broad open bay of Phalerum, where ships were beached in sight of the city. That arrangement had several disadvantages. In a surprise attack the enemy might land and paralyse the defenders before they could get down from the city and launch their ships; a more serious and permanent objection was that vessels had to lie out in the open exposed to the elements, an important fact when it is remembered that no voyages were undertaken between November and March. When the Persian danger arose, Themistocles, in 493 B.C., persuaded the Athenians to transfer their shipping to the fine natural harbour of Piræus and its two small neighbouring land-locked bays of Zea and Munychia (*Fig. 12*, p. 18). The works initiated by Themistocles and completed by Pericles gave Athens one of the safest and most convenient harbours in the ancient world. All three harbours were enclosed in one circuit of fortifications and connected to the city by the two famous long walls. The natural entrances to Piræus and Munychia were reduced in width to 55 yards and 40 yards respectively by the construction of solid breakwaters. Zea needed no narrowing. Apparently those breakwaters were constructed by heavy rubble thrown into the water and allowed to assume a natural slope. When the mound thus formed reached water-level a superstructure of huge blocks, some of them 10 feet square, fastened together with iron cramps, run in with molten lead, was built. This was the usual type of Grecian pier. Piræus, the main harbour, was divided into three chief basins, the mercantile harbour, in the centre, which occupied most of the area, the small corn harbour on the north, and the war harbour in the south. In the centre was the *agora*, or market, of Hoppodamus; on the western margin of the War Harbour (the *Kantharos*) extended the emporium or *deigma*, flanked by a series of porticos, the centre of commercial activities; near the entrance to the corn harbour was another large *agora*. Around the three harbours shipsteads were built, in which vessels could lie high and dry. They formed an essential part of the dockyard, especially for warships, which put to sea only on active service. If the triremes were left lying in the water they soon became leaky and unseaworthy, and also were liable to be attacked by the *teredo*. Their wooden fittings were stored alongside the vessels in the shipsteads; hanging tackle, sails, and ropes

Fig. 12.

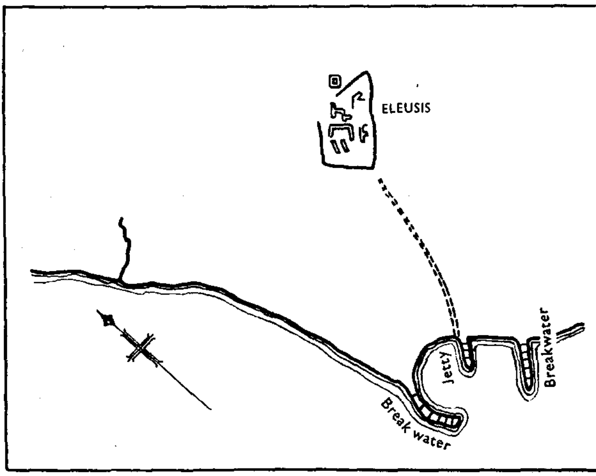


Plan of Piræus, Zea and Munychia.

were kept in the large arsenal at the entrance to the War Harbour. Traces of such buildings in Zea and Munychia are still in existence; those around Zea were roofed by low gables supported on stone columns, each gable sheltering two triremes.

Piræus, Zea, and Munychia were typical examples of the Greek natural harbours. At some places, however, artificial harbours had to be constructed, of which that at Eleusis (*Fig. 13*) may be regarded as typical, as the others were planned on a similar general principle. Two breakwaters were built out from the shore, curving inwards to form a narrow entrance between their ends, the space enclosed being an obvious imitation of a natural bay. Within the harbour was a jetty. This jetty and the break-

Fig. 13.



ELEUSIS HARBOUR.

water were constructed in the same way, with a foundation of dumped stone and a superstructure of large blocks held together by iron dowels. In all cases the material used was stone, probably because the art of pile-driving was not yet sufficiently developed to make the use of piles safe in harbour engineering, although piling had already been used in house-building for many centuries, and probably, also, because piles were liable to attack by *teredo*.

ROMAN HARBOURS.

"Italy," wrote Mr. H. Stuart Jones, "is not furnished by nature with many good harbours. The estuaries of her greater rivers—the Po and the Tiber—are subject to rapid accumulation of alluvial deposit, and some of her natural roadsteads, such as Antium, are rendered unfit for remunerative harbour-works by reason of their shifting sands. Few are the harbours such as Brundusium, where a safe anchorage is provided by natural spits and promontories. The Romans were therefore obliged to face technical problems of no small difficulty when their growing commerce demanded effectual shelter in the ports of Italy." The Romans were essentially practical people, and in dealing with those technical problems they introduced many new methods, among which the most outstanding were the use of the arch, the cofferdam, hydraulic cement (pozzuolana) and the driving of piles in deep water. The discovery of pozzuolana in the 3rd century B.C. brought about a radical change in building and civil engineering structures. " Mixed with lime and rubble " wrote Vitruvius, " it not only furnishes strength to other buildings, but also when piers are built in the sea, they set under water and can be dissolved neither by the waves nor by the power of the water." The Egyptians, as I have shown, used the cyclopic dry-stone structure; the Greeks used large ashlar masonry held together by iron dowels and lead; the Romans used their famous, almost everlasting concrete made of pozzuolana, lime, and stone; and it was pozzuolana that rendered possible the erection of those gigantic vaulted structures found all over the Empire. Piles were used in bridgework and foundations; but the great importance of pile-driving, so far as we are concerned at the moment, was that it enabled the engineer to make cofferdams for pier-building.

Vitruvius, in his treatise on architecture and civil engineering, *De Architectura*, written at the beginning of the 1st century A.D., has at the end of the fifth book a short chapter on harbour engineering. His object was to deal with the methods by which ships could be protected against storms and tempests. After a reference to the usefulness of natural harbours, he explains the technique of building breakwaters by means of cofferdams (*arcae*). In the last section of the chapter he states that shipyards should have a northern aspect whenever possible, because southern aspects, owing to their warmth, generate dry rot, *tinea*, *teredo*, and other kinds of noxious creatures. In any case, he says, wood should be used as little as possible on account of its inflammable nature. His remarks on the construction of breakwaters are of considerable interest. Four different methods are described. In the first case, where a masonry dam had to be made in the sea, he advised a cofferdam made of oak piles bound firmly together with chains. When this was finished the bottom was to be levelled and cleared, and a platform of beams laid upon it. The whole space above this was to be filled with stones embedded in a mortar composed of 2 parts of hydraulic cement to 1 part of lime. Next he discusses what should be done in places where hydraulic cement is unobtainable. In this case a double cofferdam should be built and the spaces between the walls of each cofferdam filled with clay in wicker baskets, tightly rammed down to make them watertight. The interior was then to be pumped dry by means of water-screws and water-wheels, and, if the bottom were hard ground, a concrete wall composed of stone, lime, and sand was to be built upon it, the lower portion being made wider than the upper. If, however (and this is his third method) the ground at the bottom was soft, the foundation had to be prepared by putting down a layer of piles of charred alder and olive-wood filled in with charcoal. On this the outsides of the walls were built of squared stone, with the longest possible joints, so that the middle stones might be well tied together by the bedding. The middle was filled with rubble or masonry work. In a very difficult passage, he describes a fourth method, to be employed when it was not possible to use cofferdams owing to the violence of the sea. A mound was built out as far as possible, at the end of which small walls, springing from just below the water, were built up to the level of the top, forming an empty space between themselves and the slopes of the mound. This space was filled with sand, and formed what he called a margin. On this margin a large pillar of masonry was built and was left for 2 months to dry; after that period the walls were cut away, and when the sand was scoured by the action of the waves the pillar fell into the sea as a solid monolith. "In this way" says Vitruvius, "as often as is necessary, the pier is carried further into the water." It must, however, have been a very slow process.

The Roman ideal plan of a harbour is clearly expressed by Virgil in the first book of the "Æneid":

> "*Est in secessu longo locus: insula portum*
> *Efficit objectu laterum; quibus omnis ab alto*
> *Frangitur . . .*"

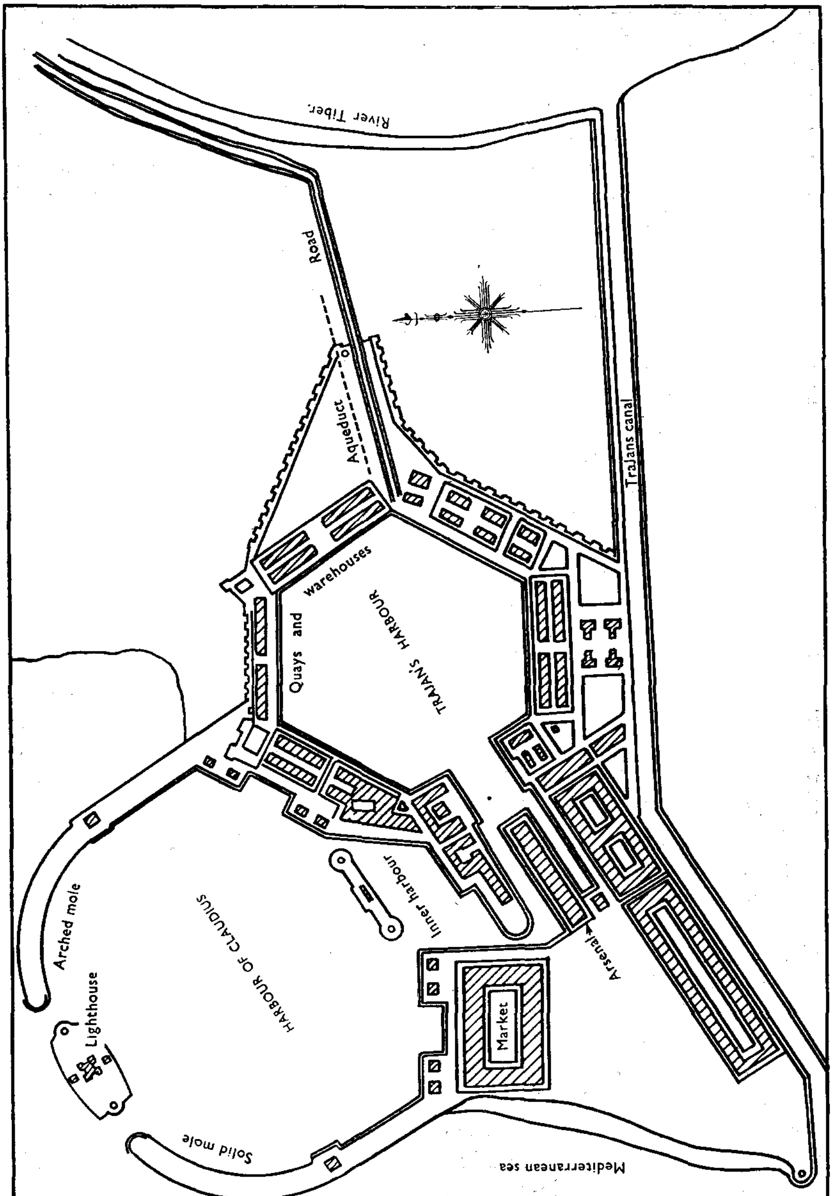
("There is a deep bay in a roadstead; an island forms it into a harbour by the shelter of its sides, which break every wave from the open sea.")

This, translated into an artificial harbour, presents us with the two incurving breakwaters of the Greeks, but with the Roman addition of a short protecting mole or island breakwater in front of the entrance, a type found in the important harbours of Antium, the Claudian harbour at Ostia, Centum Cellæ, etc. (*Fig. 14*, p. 22).

There were, however, exceptions to this rule. At Puteoli, on the bay of Naples, one mole originally protected the harbour. It was of a peculiar type introduced by the Romans, consisting of an arcade of fourteen arches resting on fifteen piers, each about 50 feet square. The foundations of the piers were built of pozzuolana concrete, as laid down by Vitruvius, the upper portions being filled with fragments of tufa and brick. In addition to the mole there are also remains of a number of basins protected from the sea by a double row of piers; those in the outer row were rectangular and probably carried arches, whilst the inner piers, opposite the open archways, are trapezoidal in section. Caligula built a floating bridge from the end of the main pier across the bay to Cumæ, a distance of 2–3 miles, which probably had also the military object of protecting the upper end of the bay of Naples against attack by sea.

The sand problem caused the Romans considerable trouble. Although some form of dredging is said to have been practised by the ancients in maintaining and deepening their irrigation channels, no record exists that it was ever developed sufficiently to enable them to use it to deal with

Fig. 14.

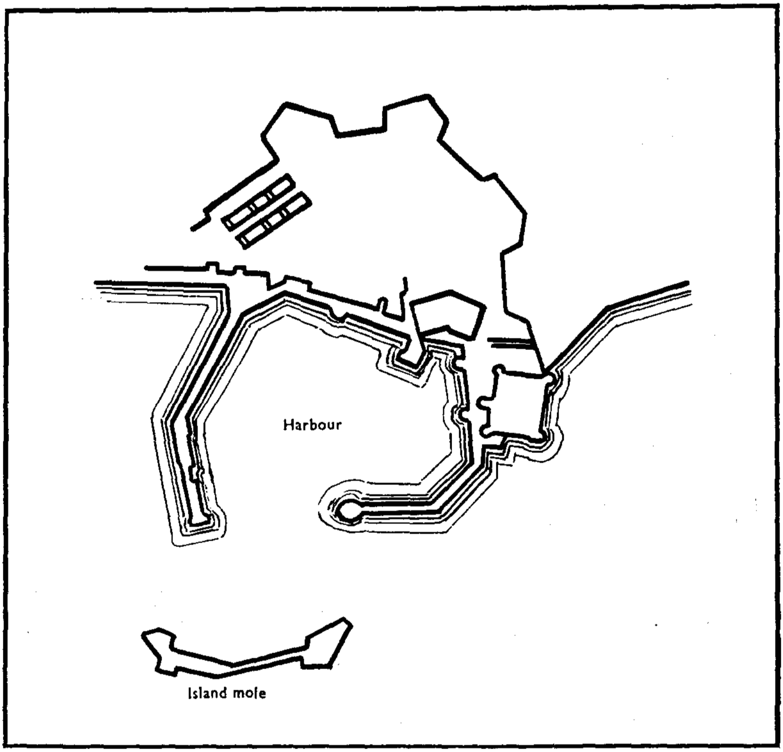


THE CLAUDIAN AND TRAJAN HARBOURS OF OSTIA.

silting in river-channels and harbours. The arcade form of breakwater was an attempt to use the tidal current to scour harbours, but usually failed in its purpose. The problem remained and silting drove the Romans from the harbour at Antium, and from the Tiber, and turned the magnificent harbour at Ostia into a failure. Speaking of the problem at the mouth of the Tiber, Sir John Rennie wrote, "Upon referring to the history of the shore, at the mouth of the Tiber we find that from the foundation of Ostia by Ancus Martius in 634 B.C. to the end of the Commonwealth in 82 B.C. the line of shore had advanced about 1,100 yards in 552 years; again from the Commonwealth to the end of the Empire in A.D. 364, a period of 446 years, it had advanced also about 1,100 yards, and from the Empire to the present time, being a period of about 1,400 years, it has advanced 2,550 yards, making a total distance of about 3 miles 600 yards in 2,480 years; and a projecting delta is formed at the mouth of the Tiber."

Many efforts were made to keep the Tiber open below Rome by revetting the banks and controlling the channel to induce scour, but all in vain. Gradually all shipping, except boats of the shallowest draught, was forced down to the lower part of the estuary, whence goods had to be transferred by barge to Rome. A great deal of the trade was transferred to Puteoli, which came to be regarded as the port of Rome and rose to the position of the premier commercial harbour of Italy; but its distance of about 140 miles from the metropolis, along the Via Appia, formed a serious inconvenience in view of the slowness of transport in those days. Moreover a safe harbour nearby was needed to accommodate the fleet which had the duty of guarding the mouth of the Tiber. Cæsar realized the urgency of the problem and proposed to build a new port, but he was prevented from doing so by the objections of his engineers. In A.D. 43 Claudius overruled these objections and gave orders to proceed with the work (*Fig. 14,* p. 22). A spot was chosen on the sea a short distance north of the river-mouth, and the place was called Ostia, after the town which had been the centre of the port works of the river harbour. This harbour had two basins. The outer was formed by two artificial moles, each 1,900 feet long and 180 feet wide. Both moles ran out almost at right angles from the shore for nearly half their length, and then curved inwards, leaving a space of 1,100 feet between their extremities. Immediately in the centre, and between the extremities, was an isolated mole, 780 feet long by 400 feet wide, leaving an entrance of 160 feet on either side. To form this mole the ship which had conveyed a huge obelisk from Alexandria to Rome for Caligula's Circus was filled with concrete and sunk. Great concrete masses were then piled on the top of it until the mole reached the surface. A lighthouse after the model of the famous Pharos of Alexandria was built on this island mole. The circular part of the main northern breakwater was constructed upon arches, in the hope that the current would prevent accumulations of sand The southern breakwater was solid throughout, to prevent the entrance of drifting silt and sand from the mouth of the Tiber. The depth of water in the basin is unknown, but Sir John Rennie estimated that it would range from 15 feet to 20 feet at low water. The area was about 130 acres. At the upper end of this main basin was a smaller one 1,200 feet long and 520 feet wide, covering an area of about 7 acres. It was separated from the main basin by an island mole similar to that in the main entrance. A very large portion of the harbour was dug from the mainland, and it is said that this involved the excavation of 80 million cubic feet of earth. In

Fig. 15.

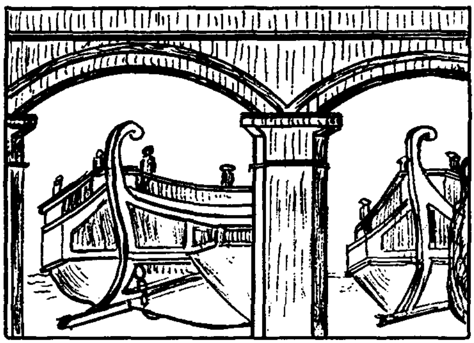


CENTUM CELLAE HARBOUR.

spite of the vast amount of money and care expended on this work the harbour was not a success. Tacitus reports that 200 ships were sunk in the harbour itself during a storm in A.D. 62. Trajan (A.D. 92–117) added an inner basin, hexagonal in shape, with an area of about 70 acres. Claudius had dug two canals, running parallel to each other, connecting the harbour with the sea and the Tiber. To remedy this, Trajan took up part of one of these canals in creating his new basin and filled up the other. He then dug a fresh canal, which has since become the mouth of the Tiber, the river having deserted its old course. The harbour was well provided with quays, transit-sheds, and store-houses, some of which were finished, regardless of expense, with marble tiling.

The Roman engineers were right when they advised against building this harbour. The forces of nature were against it from the beginning, and to-day the remains of the great port of Ostia lie buried in sand a mile from the shore. The tendency must have begun to become obvious even in the reign of Trajan, for he took measures to provide a new harbour for Rome a little higher up the coast. The result was the harbour which, under its modern name of Civita Vecchia, is now the principal port of Rome. Centum Cellae (*Fig. 15*), to give it the name by which it was then called, was planned and built on precisely the same principles as those employed

Fig. 16.



CELLAE AT CENTUM CELLAE.

at Ostia, except that in it the island mole overlapped the ends of the main breakwater, instead of lying between them. The harbour, as its name implies, was provided with one hundred covered *cellae*, or docks for warships (*Fig. 16*).

Pliny the Younger, nephew of the naturalist, when staying with Trajan in the locality, visited the new port while construction was going on, and wrote a description of it in a letter to his friend Cornelianus.

> "The house is most beautiful," he wrote; "it is surrounded by green fields and overlooks a bay where, at this very moment, a harbour is being built. The breakwater on the left side is already finished and is a work of great solidity. The one on the right is still under construction. In front of the entrance to the harbour an island is being formed, which by opposing the storm breaks the force of the waves and forms a safe passage for ships on each side. The construction of this island is a work of art that is well worth seeing. Enormous blocks of stone are brought in great barges and tipped, one on top of the other, into the water. Their immense weight and mass keep them steady and gradually they heap up and form an embankment.

> Already a ridge of rocks, which breaks the driven waves and throws them skywards in a cloud of spray, is beginning to appear above sea level. The crash of the foaming sea is tremendous. Piers will afterwards be built on the rocks and in the course of time the impression will be that of a natural island rising from the waters. This port will be named after its maker, indeed it has already been so named, and it will save, one may say, a multitude of lives; for this coast, which for a long stretch is without a harbour, will now have this one as a refuge for ships."

The Roman Empire was followed by a period of more than a thousand years of quiescence, or even retrograde action, in harbour engineering. I know of no great harbours, such as those which I have described, that were built during the dark periods of the Middle Ages. We have to wait till the great engineering revival that began about the middle of the 18th century before we find such ambitious schemes again attempted.

It is, however, interesting to study the debt we owe to the ancients. The similarity of their treatment of problems to the methods of the modern engineer is, as I have tried to show, in many cases very remarkable. I have touched only the fringe of the subject, but that has been sufficient to convince me that it is one well worth deeper study and research.

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