English Channel "harbours of refuge" – a discussion on their origins and 'failures'

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Abstract

In the mid-1800s, the threat of a resurgence of French naval power led the British to develop various harbours around the English Channel. The primary French threat was felt to be from Cherbourg. This perception drove harbour construction at Portland, Jersey and Alderney, and (later) at Dover.

The paper will discuss Cherbourg, Portland, St Catherine's, Alderney, and Dover harbours (primarily their breakwaters), and will outline the extent to which these harbours / breakwaters failed or succeeded.

1. Reasons for 'harbours of refuge'

Throughout much of the 1800s, Britain feared the growing strength of the French Navy. That fear was used by the UK government to justify the construction of various coastal harbours. The more explicit threat from France abated with the defeat of Napoleon Bonaparte's armies at Waterloo in 1815, and his death in 1821. Fears of a French resurgence however, emphasised by strengthening of Cherbourg harbour, fuelled proposals in the UK for 'harbours of refuge' (Fig. 1), debated at length through the 1840s.

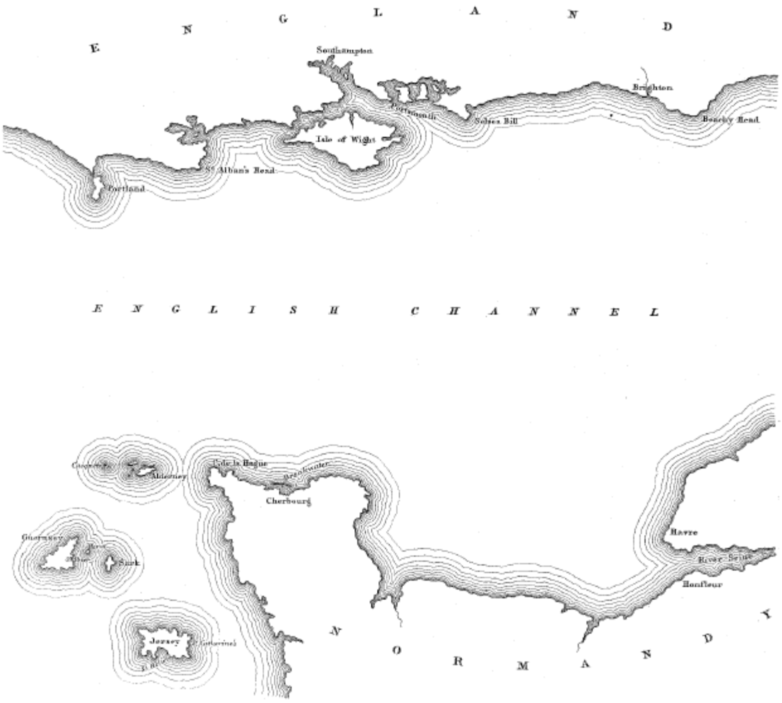

Figure 1 Channel Islands and Cherbourg peninsular (*source: Vernon-Harcourt, 1874)*

Harbours of refuge were notionally conceived to provide shelter from storms for commercial vessels, including mail packets, fishing and general trade. Naval use was often less explicit. At their design (~1845 for most) most naval vessels were powered by sail. It was difficult for a sailing vessel to leave harbour into an onshore wind without tugs. This limitation was understood in commercial operations. But even as the harbours discussed here were constructed, propulsion (and form) of vessels changed, with greater use of steam power, and iron (later steel) replacing wooden hulls.

In the UK, a sub-text of the 'harbours of refuge' debate was development of new harbours for the Royal Navy for deterrence. Less commonly discussed was potential use for offence. Possible 'harbours of refuge' were: Holyhead, Peterhead, Harwich, Dover, Seaford, Portland, Jersey and Alderney. The latter are close to the coast of France, seen as the major military threat. Whilst harbour developments here might be shrouded with the cloak of 'harbours of refuge', these harbours were simply military enterprises.

2. Cherbourg

The need for a harbour on their Channel coast persuaded French military leaders to protect the bay at Cherbourg as a roadstead harbour. Three breakwaters were first mooted in 1665, but construction only commenced in June 1784 by the 4km long central breakwater. The design by de Cessart used timber cones, each 46m diameter at the seabed, 20m diameter at the top, and 20m high. The timber cones were then filled by stone over the lower part, and masonry-faced concrete on the upper part. Gaps between adjoining cones were later filled by rubble mounds.

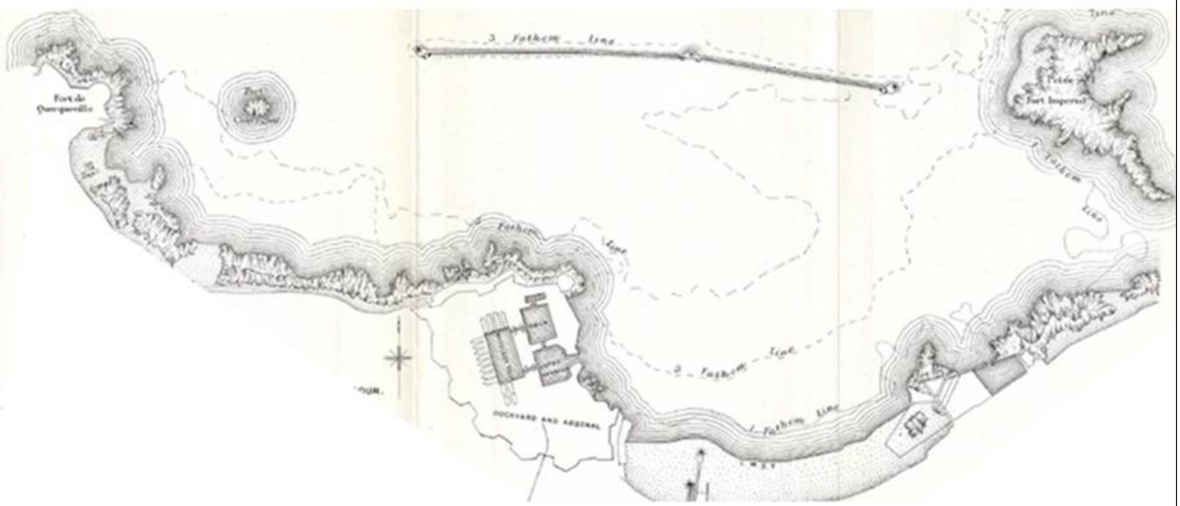

Figure 2 Cherbourg Harbour 1820 (*source: Vernon-Harcourt, 1885*)

In 1802, Napoleon 1 restarted work on the central breakwater, reinforcing the centre to accommodate cannons. Large stones were used to raise and protect the crest in 1802 – 1803 for these gun batteries, but this rock was still moved by storms. In 1811 it was decided to take the battery foundations down to LW. Some 13,300m^3 of "*the largest stone procurable*" was placed in 1811. By 1813 the works were stopped, recommencing some 11 years later. Raising the breakwater crest above water re-started in 1830. Concrete blocks were cast in place on the rubble mound formed a toe / foundation, Figs. 2 & 3. The lower slope was protected by large stones down to -5mLW at a slope of 1:5. The new superstructure suffered uneven settlement in the somewhat variable mound, so the final part was delayed "*3-4 years to allow the mound to consolidate*". The central breakwater superstructure was completed in 1846 under Louis Philippe I, and the pierhead forts in 1853. From 1846, work continued on the two side breakwaters Digue de Querqueville and Digue de l'Est, completed by 1895, enclosing the largest harbour in the world.

The full potential for docking and ship-building were however never fully realised, apart from specialised submarine construction and maintenance (which continue). The harbour became a major transatlantic terminal from late 1800s, remains a significant ferry port, and continues to accommodate a fishing fleet.

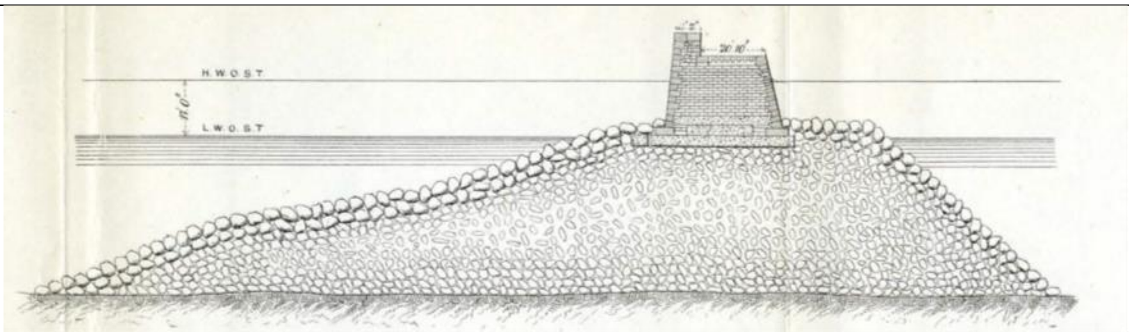

Figure 3 Section through Cherbourg breakwater (*source: Vernon-Harcourt, 1885*)

3. Portland

Portland Harbour is another 'roadstead' harbour like Cherbourg, formed in the shelter of Chesil Beach and the Isle of Portland. The harbour was created initially by two breakwaters: the short inner or southern breakwater connected to the island; and a detached breakwater to the north-east with a 120m wide entrance. Construction began in July 1849, designed by J.M. Rendel, supervised by John Coode as resident engineer. Both breakwaters were rubble mounds with superstructures from low water. Portland stone was quarried from the island quarries by convicts, run-out onto the breakwaters over timber staging extending over the gap between inner and outer breakwaters, Vernon-Harcourt (1885). Timber piles (spaced about 10m apart and surmounted by creosoted cross-beams ~5.5m above HW) were founded on iron screws into the clay bed. Stone was dumped in ridges from the staging, "*the waves gradually levelled these ridges*". Large stones (3-7t) were dumped at an average of 500,000t per year from 1853 to 1860, reducing to 140,000t per year to 1866, giving a total of 5,800,000t. The outer (eastern) breakwater was then completed by two pierheads formed in masonry founded at -7.3mLW. The harbour was declared complete by the Prince of Wales in 1872. As part of works against torpedo attack, two further breakwaters were added between 1893-1906 (Fig. 4).

Figure 4 Portland Harbour showing original southern and later northern two breakwaters,

(source: Bing Maps / Ordnance Survey

Portland Harbour was initially important for the Channel and later Home Fleets providing coaling and oiling depots. The harbour also became a base for the Admiralty's Underwater Weapons Establishment, and a factory and pier for torpedo testing. The harbour was active in both World Wars. The docks closed in 1959. The Naval Base continued for officer-training until RN operations at Portland ceased in 1995. The helicopter base closed in 1999. Portland Port was founded in 1996 as a private company to provide commercial and leisure uses, accommodating cruise ships and hosting sporting activities, including the 2012 Olympics.

4. Alderney

Alderney (Figure 1) is just to the west of Cherbourg in an area of high velocity where tides running up the Channel are compressed by the Cotentin peninsular giving: the Swinge to the west, and the Alderney Race to the east, The western coast of Alderney is exposed directly to Atlantic storms. As a possible harbour of refuge, Alderney is well south of any coastal traffic along the south coast of England. Almost no civilian vessels would require a refuge harbour on Alderney, and in any case they might prefer to shelter on the less wave-exposed east of the island, although tidal currents there are more severe.

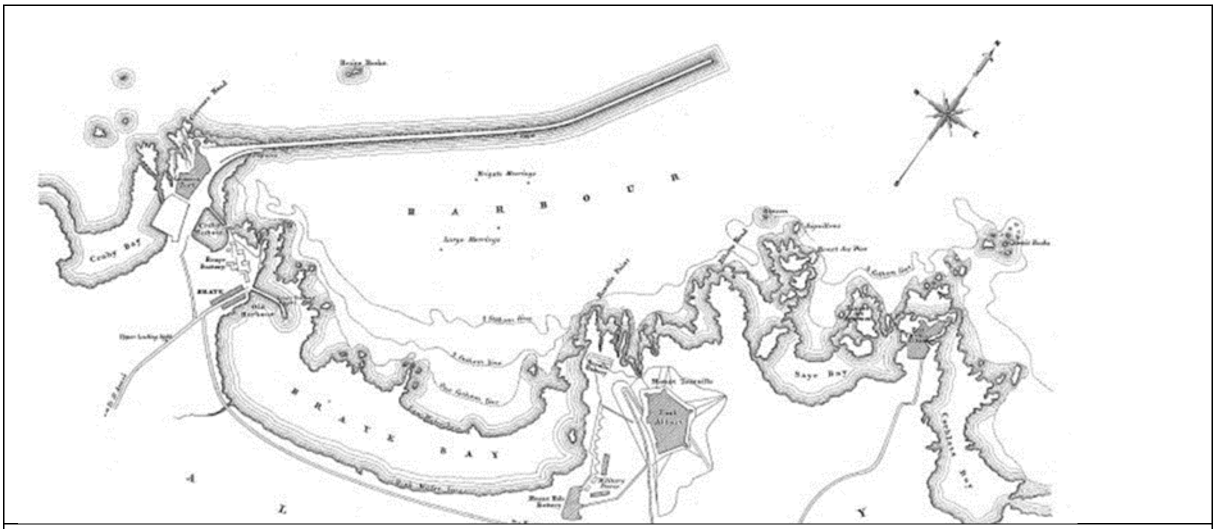

Figure 5: Braye Bay and Alderney Breakwater (*source: Vernon-Harcourt, 1873*)

In the age of sail, a major naval tactic was to blockade one's enemy's fleet in its own harbour, why Cherbourg and Dover each have two entrances. But with the age of steam, fuelling a blockading fleet became complicated, so a convenient harbour from which to observe the enemy's harbour was needed.

But why site this harbour on the most exposed coast? Again the reason was military, to hide British warships from French telescopes on the Cotentin cliffs. But by locating the harbour on the wave-attacked west side, Admiralty planners effectively sealed the fate of the harbour, and certainly of the breakwater.

Background to the selection of these sites is discussed by Vernon-Harcourt (1873) in ICE proceedings, by Vernon-Harcourt (1885), and Davies (1983) mainly St Catherine's, but also Alderney. Admiral Sir Edward Belcher explained to Vernon-Harcourt (1873) that he had been summoned by Government in August 1842 to examine (military) defences in the Channel Islands and advise on "*… what guns should be added or withdrawn, and what harbours should be made…*" He was asked to report early to allow estimates to be laid before Parliament. At Alderney, they found the tidal race across "*the mouth of the proposed harbour…*" [probably Braye Bay] "*… would render it utterly impossible for any disabled vessel to get in…*". He suggested re-locating the harbour to Longy on the south-east side of the island, (but that could have made the tidal velocities even higher!) His advice to the Admiralty in September 1842 was that a harbour at Longy would cost £1,500,000.

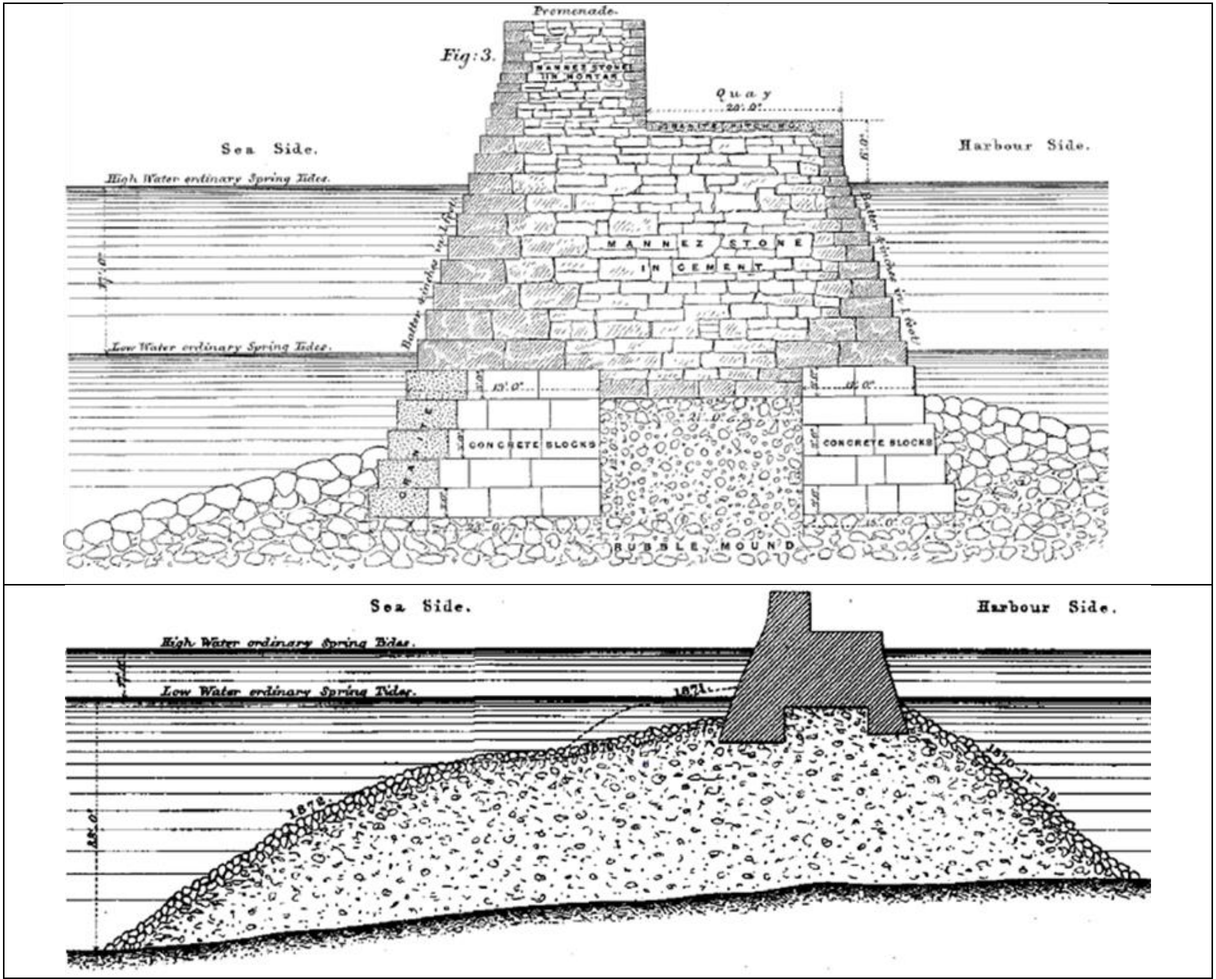

Figure 6: Alderney - Sections of mound and breakwater wall. Note extended mound from addition of stone dumped down the seaward face of the wall. (*Source: Vernon Harcourt, 1873*)

Even so, construction at Alderney started in 1847 to a design by James Walker, 2nd ICE President. The initial design included a mound to low water, surmounted by blockwork walls with rubble infill. Stone for mound and walls was quarried from Mannez quarry on the opposite side of Alderney. But almost immediately the weakness of Walker's design became apparent with frequent breaches of the breakwater wall. By 1849, the rubble mound had been disturbed and washed into the harbour, and considerable damage had been done to the walls. The design section was amended after 125m steepening the wall, masonry was set in Medina cement, and the seaward foundation started lower. [The foundation had already been lowered after the first 46m length as far as was practicable without divers.] Having used end-tipping hitherto, the new lower mound level allowed use of hopper barges, which required a construction harbour.

In the new works, the rubble mound was not disturbed lower than about -3.7m LWOST (in the absence of the superstructure). Work to the revised design proceeded "*as soon as diving apparatus and the hopper barges were procured*". Construction continued to 823m by 1856. The design was then revised again, further lowering wall foundation, now easier with the availability of divers. Construction of the outer section was nominally completed in 1864, giving a total length of 1430m.

But following repeated breaches and cost increases, Sir Francis Baring summoned Sir Edward Belcher back to the Admiralty (1852) to tell him that "*… the former Commission was still in force … ordered to go to Alderney harbour and report upon it*." Further "*… you are not to entertain any of the opinions that you entertained before; you are to examine the place and tell us what has been done, and whether it is worthwhile to expend £600,000 more on the eastern arm*." James Walker (designer of the Alderney breakwater) was also instructed to go "*… in order that he might be there in a gale.*" Walker and Belcher advised against an additional eastern arm, perhaps convinced that the concentration of tidal flows across the breakwater heads would scour their foundation mounds. Belcher concluded his contribution to the ICE discussion with the barbed comment: "*The present works were certainly a credit to British engineers, and showed what Englishmen could do when they were determined – whether right or wrong*."

Vernon-Harcourt (1873) noted that the idea of a further eastern breakwater had not been abandoned until 1862. Whilst agreeing with Sir John Coode and Colonel Jervois that the eastern arm should be added " *… if the harbour was to be rendered perfect …*" He felt that it was little use as a 'harbour of refuge' being away from the main shipping routes, and it was "*… a bad harbour in easterly gales*." He disagreed with Sir Edward Belcher on the 'rapid scouring' fear "*… as the harbour area was not large and the rise of tide at Alderney was not peculiarly great*".

Following breakwater completion in 1864, a storm in January 1865 forced two breaches (15m and 40m) through the superstructure. Another breach occurred in January 1866, a smaller one in February 1867, and another 18m wide in January 1868. There were further breaches in December 1868, and in February and March 1869. By early January 1870, there remained two breaches of the superstructure along the outer part, and five other locations of damage. Sir John Hawkshaw (President ICE) and Col. Sir Andrew Clarke were requested by Board of Trade (reluctantly inherited the harbour) *"to visit Alderney and to report on the best measures for securing permanently*", either the whole (1740m) or the inner (870m) portion of the breakwater. Hawkshaw and Clarke noted instability of the mound and suggested removal of the (upper) promenade wall, and deposition of a large additional foreshore of rubble or concrete blocks. The government did not however consider that the costs were merited, so no significant actions were taken.

The wall toe had been (partially) protected by stone dumped onto the foreshore. About 300,000 tons were tipped between 1864 and September 1871, after which it was decided to abandon the outer length. From 1873, repair and maintenance covered only the inner length of 870m. The outer portion was abandoned to the sea and the wall quickly collapsed leaving a mound crest about -4mLW (Figs. 7 & 8). For the shortened section, approximately 20,000 tons of stone were dumped annually, and further work was still required to repair breaches in the superstructure. Dumping of foreshore rock (interrupted during the German occupation, 1940-1945) continued until 1964.

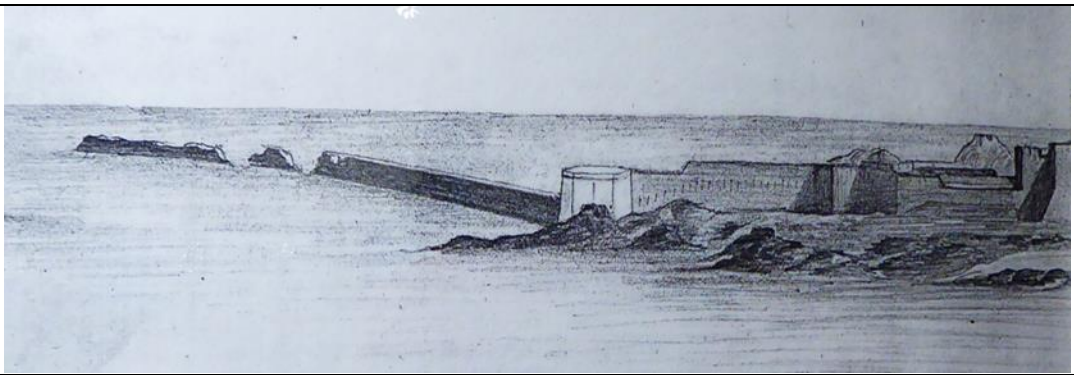

Figure 7: Alderney breakwater in 1883, Lt Farmar RA (*courtesy Alderney Museum*)

Waves at Alderney are frequently severe. Depths off the breakwater generally exceed 15 - 20m and waves reach the breakwater with little reduction, with the 1:50 year storm condition of H_s=11.0m offshore corresponding to H_s=8.0 to 8.5m at the breakwater. The severity of wave impact on the wall is increased by waves shoaling over the mound, causing impulsive breaking. Storms usually persist for many hours, so the breakwater is exposed to the range of wave and water level combinations that allow waves to break directly against it.

Figure 8: View of the reduced-length breakwater from St Anne, 1885 (*source: wikiVisually*),

In 1987 responsibility for the 870m long Alderney breakwater transferred to the States of Guernsey. Maintenance to 1990 cost around £500,000 per annum, excluding storm damage. That damage takes two main forms. Direct wave impact on the wall shakes the breakwater, and cracks mortar joints. Impact pressures force water into joints, and voids behind. Loose rock from the mound is thrown against the wall, abrading the wall by up to 1m. Over time, the typical size of rubble on the mound has reduced, and the process has generated considerable quantities of gravel and sand on Little Crabby and Platte Saline beaches.

Recently

During 1989/90, storms battered the breakwater for six weeks. At its peak on 25/26 January 1990, the storm had a return period of about 1:25 years, with offshore conditions of H_s=10 to 10.5m. During the next six days the storm subsided slowly, then rose again to H_s > 7m. On 11 and 12 February, storm conditions again exceeded H_s = 9m. This cracked the masonry facing, and a large cavity was formed in the wall which breached by an explosive failure audible around Braye. Other sections of the structure also suffered damage. An emergency procedure was in place, and repair work was underway within 10 days. Repair costs was estimated at £1.1 million. Studies by Coode & Partners and HR Wallingford explored potential solutions, see Allsop *et al* (1991). Later work on alternative approaches to protecting this breakwater are described by Jensen (2017).

5. St Catherine's, Jersey

Two issues affect the utility of any 'harbour of refuge' on Jersey: whether that is a useful location at all. If so, where on Jersey might a harbour be useful? The plan by Hold (2009) and by Davies (Figure 7) shows two breakwaters, both of which were started in 1847: St Catherine's to the north; and Archirondel to the south. The St Catherine's breakwater exists to this day (Fig. 9), and has recently been refurbished Hold (2013). The Archirondel breakwater was planned to be 2.5 times longer, protecting the harbour from southerly and south-east waves, and from the northerly running tidal currents. But in July 1849 Walker instructed the contractor to divert effort to completing the northern breakwater, perhaps as the putative harbour started to silt up as the breakwater trapped sediment in the northerly drift. A stub of the Archirondel breakwater exists today, probably in similar state to when it was abandoned.

Davies argues that siting a harbour of refuge on Jersey made no sense. This is an island of 12m tides. It is close to (but separate from) France to which it is nearly 'joined' by submerged rocks ESE to Coutances. Together with the substantial tidal flows between Jersey and France, these rocks significantly limit any trading vessel traffic along the east side of Jersey.

What about military use, even if not so declared? Again Davies (1983) rehearses the convoluted discussions. In 1831, Sir William Symonds favoured Bouley Bay on the north coast, although this had been countered by (Admiral, Rtd) Martin White (Jerseyman and navy surveyor) who "*unmistakably showed up the defects*" of that option. In early 1840s, Sir William Napier, Lieutenant-Governor of Guernsey, was requested by Whitehall "*to prepare a military appraisal of the Channel Islands as a whole*", for which "*he personally inspected Jersey, Guernsey, Alderney, Sark and Jethou*". Sir William was not impressed by the civilian administrations of either Jersey or Guernsey, and "*crossed swords* *with everybody who did not agree with his point of view, whether they be military or civil* ". The UK government then set up a Commission to revisit Sir William's work, including Admiral Belcher, Colonel Cardew, Lieutenant-Colonel Colquhoun, supported by James Walker, Captain Sheringham (surveyor), some later involved in the Harbours Commission of 1844.

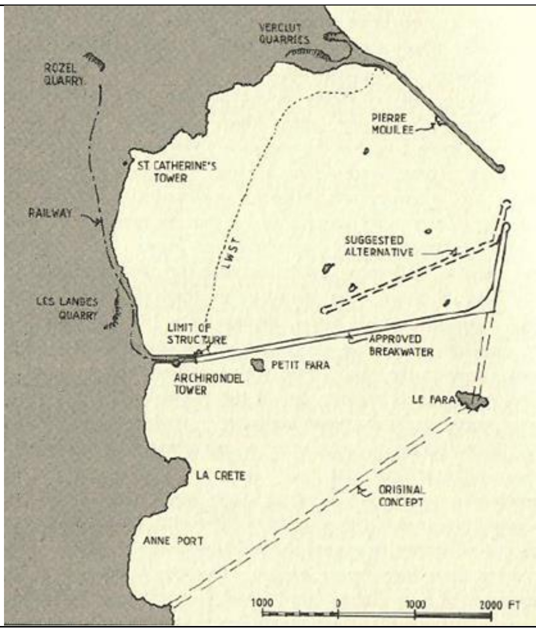

Figure 9: Intended harbour layout at St Catherine's (*after Davies, 1983)*

But by 1842, Government was ready to act. There were competing claims for Noirmont Point on the south-west coast of Jersey, or Bouley Bay towards the north-east corner. Davies notes that the national Harbours Commission of 1844, set up by the Treasury, did not mention the Channel Islands, yet in only three years, both "*the St Catherine's and Alderney projects had been proposed, authorised and commenced. No sound reason can be found for such a hasty decision, and this aspect must remain a mystery*." It is likely that James Walker exercised his considerable 'networking' skills within Whitehall in favour of St Catherine's on the north-east coast. (Walker's ICE obituary includes: *"…he had, at least, as much skill 'in the engineering of men as of matter*.")

Figure 10 St Catherine's, top; and remains of Archirondel, bottom (*the author, 2014*)

Even if St Catherine's harbour could have been maintained, its utility would have been severely limited by tidal conditions for which it could be accessed, and by sailing space between Jersey and France. The second threat was siltation, particularly sand driven by the northward-running tidal flows, depositing over slack water, made worse by cancellation of Archirondel breakwater (Figs. 9 & 10).

By 1866, St Catherine's breakwater had been handed to the Board of Trade (Harbours and Lighthouses Department) whose Captain Bedford commented: "*it is anything but agreeable to take up and deal with the cast-off works of another Department – cast off too because they can find no use for them.*" There were various attempts to shift the problem, War Office, Home Office, back to Board of Trade, but the best option was to pass the problem to States of Jersey, despite their reluctance to take on an unwanted maintenance liability. The stand-off continued to February 1876 when the States passed a proposition to accept the breakwater, together with a 'dowry' of sufficient land to balance the anticipated maintenance liability. Negotiations with HM Receiver-General concluded in 1877 when it became the responsibility of the States of Jersey.

The failure of this harbour was primarily of utility, compounded by lack of depth, and disinterest of the States of Jersey, and the Admiralty. The breakwater itself has suffered little damage, most being confined to the outer end described by Hold (2009). Siltation of the harbour area was accelerated by constructing the breakwaters in the wrong sequence, capturing the sediment-laden northerly current, rather than deflecting it by Archirondel breakwater. No records exist of the changes of depth, but they must have been rapid to cause doubts on continuing construction beyond the first two years.

6. Dover

The Royal Commission of 1840 favoured a deep-water harbour in Dover Bay to enclose 450 acres (18.2km^2), cost £2,000,000. The 1844 Royal Commission re-considered whether a harbour of refuge was desirable here, requiring it to deliver, in order of precedence:

a) Ease of access for vessels "*requiring shelter from stress of weather*";
b) For armed vessels in event of hostilities, both offensive and defensive;
c) Should "*possess facilities for ensuring its defence"* against attack.

Whilst this harbour was in theory to be for civilian vessels, military purposes were clear from the start. The 1844 Commission accepted the proposed site and general plan layout of the new outer harbour. A third Commission in 1845 considered plans by eight engineers for a harbour of some 520 acres (21km^2) out to 7 fathoms (12.8m). The outer breakwater was to be aligned with tidal flows to reduce siltation. The Commissioners reported in 1846 in favour of Mr Rendel's design. In comment, Vernon-Harcourt (1885) noted damage to sloping solutions at Cherbourg and Plymouth, and the lack of suitable stone at Dover. He also notes the shortage of experience in concrete. But given the chalk bottom, absence of local rock, "*and a moderate depth, the upright wall was the best system to adopt*".

The issue of siltation was again of significant concern, although this commission commented rather testily: '*… if liability to silt were deemed an objection, it would be idle to attempt such works on any part of our coasts'*. A contract was let in October 1847 for 244m of Admiralty Pier. Subsequent contracts in 1854 and 1857 covered further 305m, so that the work extending Admiralty Pier was essentially complete in 1871 to 640m from the shore.

Admiralty Pier was formed by 7-8ton concrete blocks with outer stone facings. The main wall was 'surmounted by a high parapet, overhanging considerably to the seaward'. But on 1 January 1877 about 300m of this parapet at the outer end was swept away down to quay level. Wilson (1919) ascribes the blame to the curved overhang, although the slender nature of the up-stand wall, and absence of any tensile reinforcement must surely have contributed substantially. The damaged section rebuilt with a significantly thicker (about 3.3m) vertical face "*proved perfectly satisfactory*".

This single pier did not however give adequate shelter from easterlies, and a contract was let by Dover Harbour Board in 1892 to Sir John Jackson to construct the Prince of Wales Pier to some 503m supervised by Coode, Son & Matthews. Then in late 1895, Coode was requested to prepare drawings to facilitate expansion to the full Admiralty Harbour (Fig. 11) by:

a) Extension of Admiralty Pier by a further 610m;
b) A detached breakwater, the South Breakwater, of 1284m;
c) The Eastern Arm of 1012m.

This revised layout altered the length and overlap of the Admiralty Pier extension, and the position / width of the Eastern entrance, with the aims of improving accessibility to vessels, and reducing siltation. The Coode design was approved by the Admiralty, and a contract let in November 1897 to S Pearson & Son.

The new walls were formed almost entirely by concrete blocks (generally 2.3m wide and 1.8m high, depth from 2.4 to 4m to accommodate the 12:1 batter and ensure adequate bonding. Jointing was strengthened by half-height joggle joints, filled by 4:1 concrete rammed into canvas bags. At outer ends, tensile strength was increased by bull-headed rails turned down at the ends, and let into chased channels / holes filled by 2:1 cement mortar.

For the foundation layers, underwater blocks were set by divers, placed tightly without mortar. Above the low water course (a band 1.8m high centred on LWOST) four courses were grouted by 2:1 Portland cement mortar. The Eastern Pier and Admiralty Pier Extension carried parapet walls, but such additional overtopping protection was not needed on (most of) the South Breakwater as mooring against its inside face was not envisaged. Mass concrete and granite pavers completed the crest. The parapet wall on the Admiralty Pier Extension reached 7.5m above HWOST (+13.3m LWOST).

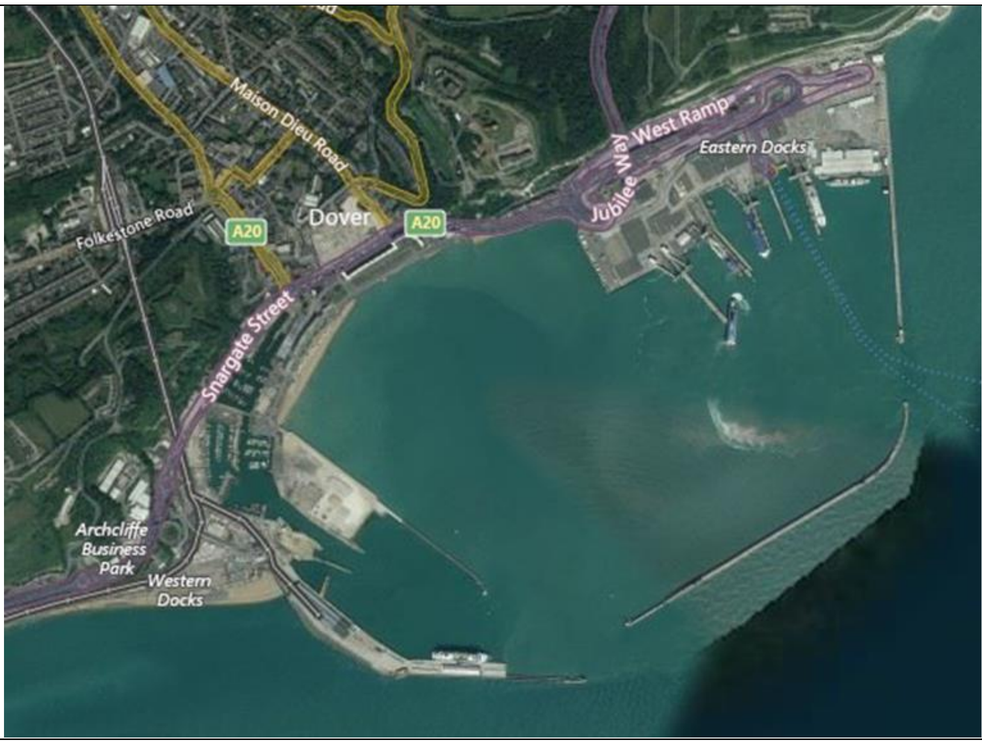

Figure 11 Dover Harbour, present day (*courtesy Bing Maps)*

The East Arm breakwater projects south for 900m. The section is similar to Admiralty Pier Extension, although the parapet wall was lower with the harbour cope at +8.8m LWOST). Foundation blocks for the East Arm were laid direct on the chalk or the chalk marl / flint matrix down to -16.2m LWOST. The East Arm was intended to provide berthing, so the harbour face was vertical with timber fenders, and an L-shaped head to shelter the inner face.

The South Breakwater (the Island Breakwater) runs 1284m parallel to the shoreline. Placement of blocks for this wall started short of the eastern end, allowing a later adjustment of the width of the eastern entrance guided by wave penetration and flows during construction. A curved section connected the eastern end to the main run of wall using curved blocks to maintain block tightness. No parapet wall was used along the main section of the South Breakwater, simply being added at the ends to provide shelter to buildings close to the roundheads.

To form the concrete blocks, cement (mostly from the Wouldham Company) delivered by barge in 160t loads was derived from '*ordinary- and rotary-kiln*' production. Wilson notes that the rotary-kiln cement was "*usually far quicker setting*", so the two types were mixed. Concrete was mixed in two electric 'Messent' mixers of 1 yd^3 capacity. Output averaged 100yd^3 per mixer per day. Blocks were lifted after 7 days and stored for 3+ weeks. Two lifting holes ran through each block for the T-headed lewis bars. Blocks within the storage yard were moved by two 42t travelling Goliath cranes, then on stripped-down steam locomotives. Facing blocks included granite cast into the rest of the overall block. Granite was supplied from a Pearson-owned quarry in Cornwall, supplemented from Sweden, requiring special permission from the Admiralty.

Pearson eschewed the use of Titan block placing cranes that would run along the constructed works in favour of temporary staging above and beyond the works, supporting steam powered travelling cranes. The rail level for these cranes was generally above +8.2m HWOST. Tasmanian Blue Gum piles were heavier than water, but Oregon pine required weighting by old iron rails to sink them. Staging piles were re-used as the work progressed, extracted by winch from a floating hulk. After use, piles were spliced to ensure availability of an undamaged head for driving.

Figure 12 Goliath crane on staging (*courtesy Dover Harbour Board)*

Ahead of block placing, the seabed was prepared by excavating 1.5m of surface material, most by a 'Hone grab'. The final 0.3m of excavation was removed by four men using picks and shovels within a 35t diving bell which excavated a 4.6m wide strip across the running face, sufficient for two rows of blocks. The bell passed over each strip to give a coarse levelling, "*within a few inches*", and then a second pass for final levelling. Working under compressed air continued day and night in 3 hour shifts.

Block-setting was supervised by two helmet-divers, blocks being placed hard against their neighbours. Significant effort was devoted to checking and regularising these courses to ensure an even base for the subsequent blocks. Bag joggles were placed by the divers, or from within the bell returned to deal with several blocks, and to regularise any unevenness in the completed surface. Helmet-diver working was limited to tidal velocities below 1 knot, restricting operations to about 4-5 hours each tide, during which 6 blocks were placed per hour at best.

Trimming / filling the 'Low-water course' compensated for any errors in lower layers. Blocks above were set by masons during the 2-3 hours of low water on spring tides. All the upper courses were set / bedded in 2:1 Portland cement mortar. All lower joints were caulked by sacking / rope, pointed in neat (quick-setting) cement, to avoid any loss of jointing / bedding mortar downward.

Toe protection blocks were laid along the seaward face using essentially similar procedures with a smaller diving bell operated from a luffing-jib crane running along the wall. As these protection aprons were completed, so the parapet walls were added above. A capping layer of in-situ concrete with granite paving completed the deck, allowing for rails, gas / electric / telephone cables and water pipes.

On declaration of war in 1914, ferry and commercial activities moved to Folkestone, Dover reverting to naval use. After the war, the harbour remained with the Admiralty but the Commercial Harbour was managed by Dover Harbour Board (DHB) who had to deal with years of neglect and adaptations. Ferrry and commercial trade increased, and in September 1923, Admiralty Harbour was transferred by Act of Parliament to DHB, with the Admiralty reserving that the harbour would revert to the Admiralty should Defence of the Realm require.

In 1931, Southern Railway launched a car-ferry, their first designated cross-Channel car-carrying ferry. From the mid-1930s cross-Channel passengers and cars increased rapidly, as did freight. Plans were made to increase the number of berths to use the Eastern Dockyard. In September 1939 Admiralty Pier with the rest of the harbour, came under the Admiralty as part of Fortress Dover.

After the war, in November 1949, DHB promoted a Parliamentary Bill to create a car ferry terminal at the Eastern Dockyard for the bulk of passenger services. Previously railway ferries from Admiralty Pier had dominated ferry traffic. Most such traffic has since moved to the Eastern Docks. Dover Harbour now remains the main route for UK ro-ro trade.

7. The generality of harbours of refuge

In considering the harbour of refuge options, it is worth noting that developments of steamships were in their infancy in 1830-40 (Barnes, 2014), but that over the following years requirements for harbours (particularly naval harbours) were significantly altered by new forms of propulsion, particularly reducing mooring and swinging space, and improving the ability to depart under adverse winds. This was potentially of significant benefit to the French ports at St Malo and Granville (perhaps also at Cherbourg) where the new steamships could more easily depart under westerly winds than would sailing vessels.

The often-heated discussions at ICE on 'harbours of refuge' may have been fuelled in some part by struggles for prominence, and the apparent proximity of a large pot of money. In the discussion on Blyth by Scott (1858), Bidder (ICE Vice President) discussed the Government supervision of Holyhead, Portland, Dover, and Alderney. Bidder had examined " *the Parliamentary Blue Books… which confirmed his own previous observations …these great works were being executed without any efficient responsible supervision or control* ", asserting further that "*… the Government itself had been kept utterly in the dark… The time had now arrived when these matters should be brought before the bar of public opinion … the Institution of Civil Engineers appeared to be the most fitting arena for the discussion of the question*." Bidder referred to several Reports of the Committee on Harbours of Refuge from 1845, noting that they could not agree on the preferred form of breakwater, "*…chiefly arisen from the Committee not having arrived at a clear understanding of the terms used, and of the basis of the various arguments employed*." He continued [somewhat acidly] " *… facts derived from the Blue Books … appeared to contain everything except the specific information sought for*."

Considering Alderney, it "*appeared to be of a disadvantageous form … the effect of the waves upon this wall must be very prejudicial … and greater than upon any other form which could be devised*." Bidder continued in an attack on James Walker (past President of ICE, and designer of both breakwaters at Alderney and St Catherine's) who had signed the report of 1845 stating that the costs of a vertical wall or rubble mound "*would be nearly identical*". Yet the vertical pier at Dover was costing £415/ft, whilst the rubble mounds at Portland less than half that. Bidder is however ignoring the rather different wave exposures. Of four works recommended, three had been commenced, and two "*had been intrusted* (sic) *to Mr James Walker, himself one of the Commissioners*". Bidder continued "*… it seemed that the Government authorised works …without any idea being given of the cost of such works, or of the time that would be occupied in their construction, or even of the mode in which they were to be executed*."

Bidder then turned to the harbours on Alderney and Jersey, the former being "*nearly valueless*" and that at St Catherine's offering "*scarcely shelter for a few fishing boats*". In conclusion, Bidder criticised [in fairly immoderate language] the shortage of independent members in the Commissions, the prevalence of "*foregone conclusions*" and "*hocus pocus*" in decision-making. He called for "*the attention of some independent Member of the House of Commons … pertinaciously attacking and exposing the present objectionable system …*"

Cherbourg, Portland and Dover
Each of these (initially) military harbours have continued in use, although only Cherbourg retains any naval use. Breakwaters at Cherbourg still require an annual supply of large rock. Portland (facing essentially away from any significant wave action) has required relatively little remediation. Dover harbour is probably one of the most successful harbours anywhere, substantially due to the large volumes of cross-channel ferry traffic. There have been many changes to the internal harbour structures, but the main breakwaters have required remarkably little repair work given their 110+ year age!

8. Breakwater design and construction

Despite radically different wave exposures, the Walker designs for Alderney and St Catherine's were essentially the same, a mound of quarried stone to low water surmounted by blockwork walls with rubble infill. Most stone for mound and walls was from the Mannez quarry on Alderney, or from Verclut on Jersey, although both required imported granite facings.

Shortly into construction, the design at Alderney was revised. The mound level was reduced to improve stability of foundation stones. Those, until then simply placed tightly, were now laid using cement mortar. The batter of the wall itself was steepened to give a greater 'pinching force' on the lower blocks. This continued to 823m by 1856. The section design was then revised again and construction of the outer section was completed in 1864, giving a total length of 1430m.

At both sites, the main construction was from above (as adopted by Pearson at Dover), supported on timber staging with steam power to assist. At Alderney, an innovative rock chute carried rock into the barges without punching a hole through them! Rock slid down the chute was slowed by a reversal of direction at part-height. Mound rock at St Catherine's was simply tipped from the staging where the greater tidal range and lower wave exposure made placement of the wall blocks in the 'dry' far easier.

At the time of the design of these breakwaters (~1845), breakwater design was by trial and error with no calculation of loads or resistance. Designs advanced by experience. Scott Russell (1847) remarked: "*Perhaps it may be considered rather hard by the young engineer, that he should be left to be guided entirely by circumstances, without the aid of any one general principle for his assistance.*", In discussing his wave dynamometer, Stevenson (1849) remarks*:"… the engineer has always a difficulty in estimating the force of the waves with which he has to contend… The information … derived from local informants … is not satisfactory*." Those uncertainties were substantially compounded by significant misunderstandings on wave behaviour over submerged mounds, although not for want of trying many different descriptions. Here the books by Stevenson (1874), Vernon-Harcourt (1885), and more particularly that by Shields (1895), might have been helpful had they been available in 1845-47. Even without formulae on near-structure wave transformations, it is still a little surprising to modern eyes that the designs were so similar when the exposure was so different, perhaps also to more perceptive contemporaries, see comments by GP Bidder above.

The site at St Catherine's on the lee side of Jersey is sheltered from major storm waves. Waves from the Atlantic are substantially reduced by refraction and diffraction along the north coast of Jersey, so when reaching St Catherine's they are strongly oblique to the breakwater. The only direct attack on this breakwater is by waves from north and east which are strongly fetch-limited. The tidal range at Jersey at ~ 12m is one of the greatest in the world (a few sites reach ~14m), but the general tidal currents are not focussed here, except in local flows around the roundhead. So this breakwater is very lightly attacked, as evidenced by the significant lack of damage or demand for repair until very recently.

Conditions at Alderney are very different. The tidal range is less at 5.2m, but currents may exceed 7-8 knots (3.6 to 4.1m/s). Modelling of waves and currents discussed by Allsop *et al* (1991) show that waves are refracted by currents in somewhat surprising fashion. Tidal currents are generally greatest at mid-tide, with slack water at high and low tide levels. At Alderney the contrary is true with tidal velocities being greatest around high and low water. Those high currents reduce wave heights at the breakwater at high and low water, but no wave-current refraction applies at mid-tide so wave attack is greatest. Modelling in 1989 (see Allsop *et al*, 1991) gave a 1:50 year condition of H_s=11.0m offshore reducing to

H_s=8.0 to 8.5m at the breakwater. But combining direct wave attack at mid-tide, and the effect of shoaling over the submerged mound, causes waves to break impulsively over the mound onto the breakwater wall.

The debate on wave behaviour is discussed particularly by Shield (1899) who reminds his reader of *"…one or two leading points … generally accepted as the theory of waves*", discussing the change from circular wave orbits to ellipses as waves move into shallow water. He notes that waves "*break on entering water of a depth which but little exceeds their height…*" [implying that the effects of steep bed slopes, and (perhaps) wave period on wave breaking limits were little appreciated]. The following comment *"… swell waves however … are often transformed into waves of a dangerous character*" whilst being somewhat oblique, does illustrate a growing appreciation of these effects. Shield then uses work by Airy (1848) to derive relative particle displacements for various depths below the water surface, concluding that, for all depths in which it is practical to construct breakwaters, storm waves will (mostly) have transformed to "*waves of translation* ". In discussing wave action at a vertical quay with an approaching bed slope of 1:10, Shield noted "*As the tide recedes, however, they are quickly transformed into angry waves of translation by being tripped up by the foreshore…".* He then draws the similarity with Alderney, noting that the returning wave often causes damage to the foundation, and that high parapets "*greatly intensify this action… and are objectionable*". He notes that rubble may be washed away at the outer end of a breakwater down to depths >12m. At Alderney, with a bed depth of -14mLW at 300m from the root, the mound at -1mLW was not stable even at a slope of 1:6.5, foundation stones being eroded, removing support from the wall foundation, in turn weakening the wall and leading to breaching.

Construction practicalities

But not only did the lack of clear understanding on wave forces severely hamper the design, but key technologies that would greatly assist construction at the end of the century were yet to be developed. Ordinary Portland Cement (OPC) had been patended by Aspedin in 1823, but was not available in commercial quantities until 1840-50. Perceptively, Pearson ensured the supply needed for Dover by buying the cement works beforehand, and then sold it afterwards (at a profit).

Cement mortar (initially Medina, later OPC) and helmet divers were however both included in the design revisions at Alderney. In discussion to Vernon-Harcourt (1873) John Jackson (the contractors' agent 1857-1866) described using helmet divers to excavate holes to receive support piles. Six divers operated at any one time, four on the sea-side, and two on the harbour side, working in four hour shifts, three shifts per day. Jackson discussed the operation of delivering blocks to the divers, and then to the masons once the blockwork emerged above LW. Medina cement mortar brought fresh from the Isle of Wight so that its setting was not impaired was used in 1 part cement to 2 parts sand to bed the blocks.

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