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# English Channel 'harbours of refuge': a discussion on their origins and 'failures'

**Nigel William Henry Allsop** BSc, MICE, CENG
PhD student, School of Engineering, University of Edinburgh, Edinburgh, UK;
Principal, William Allsop Consulting, Abingdon, UK
(william.allsop51@outlook.com) (Orcid:0000-0002-2899-521X)

**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. This paper discusses the Cherbourg, Portland, St Catherine's, Alderney and Dover harbours (primarily their breakwaters) and outlines the extent to which these harbours/breakwaters failed or succeeded.**

## 1. Introduction

### 1.1 Harbours of refuge

Throughout much of the nineteenth century, Britain feared the growing strength of the French Navy. That fear was used by the UK government to justify construction of various coastal harbours. The 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 the Cherbourg Harbour, fuelled demands in the UK for 'harbours of refuge' (Figure 1). This need was debated at length throughout the 1840s.

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 the time of the design of these harbours (*c.* 1845, for most), most naval vessels were powered by sail. It was difficult for a sailing vessel to leave a harbour into an onshore wind without tugs. This limitation was understood in commercial operations. However, even as the harbours discussed here were constructed, propulsion and the form of vessels changed, with greater use of steam power and iron or steel replacing wooden hulls.

In the UK, a subtext of the debate on harbours of refuge was the development of new harbours for the Royal Navy (RN) for deterrence. Less commonly discussed was their 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. While developments around the channel might be termed 'harbours of refuge', these were primarily military enterprises.

### 1.2 Context of this paper

This paper considers the development of four harbours adjoining the English Channel: Cherbourg (seen as the main threat); Jersey and Alderney; Portland; and Dover. It discusses their origins, their construction and their 'success' or 'failure' in delivering the required access/shelter to the harbour users. It also comments on the recent life of these harbours. This paper does not analyse the structural performance of the breakwaters that formed these harbours, which is covered by two 'forensic' papers (Allsop and Bruce, 2020a, 2020b).

### 1.3 Sources

This paper draws primarily on historical books by Cachin (1820), Davies (1983) and Vernon-Harcourt (1885), on papers in the *Minutes of the Proceedings of the Institution of Civil Engineers* by King-Noel (1848), Scott (1859), Vernon-Harcourt (1874) and Wilson (1920), and on the discussions to those papers (Binns *et al*., 1920; Matthews *et al*., 1920; Winder *et al*., 1859). Material on Alderney and Dover was also derived from the author's previous studies (Allsop, *Old British Breakwaters – How Has History Influenced Their Survival?*, PhD thesis to be submitted summer/autumn 2020, University of Edinburgh; Allsop, 2009, 2010, 2019; Allsop and Bray, 1994; Allsop and Shih, 1990; Allsop *et al*., 1991; Bishop, 1951; Cuomo *et al*., 2010, 2011; Hall and Simm, 1995; Sayers *et al*., 1998). Supplementary material on Portland and Dover was condensed from the helpful websites by Sencicle (2019) and Smith (2019) and occasionally Wikipedia. An early version of this paper was discussed with French, English and Channel Island historians at the Henry Euler Memorial Trust on Alderney in 2019.

## 2. Cherbourg

The need for a harbour to protect La Manche against the British persuaded French military leaders to shelter the bay at Cherbourg

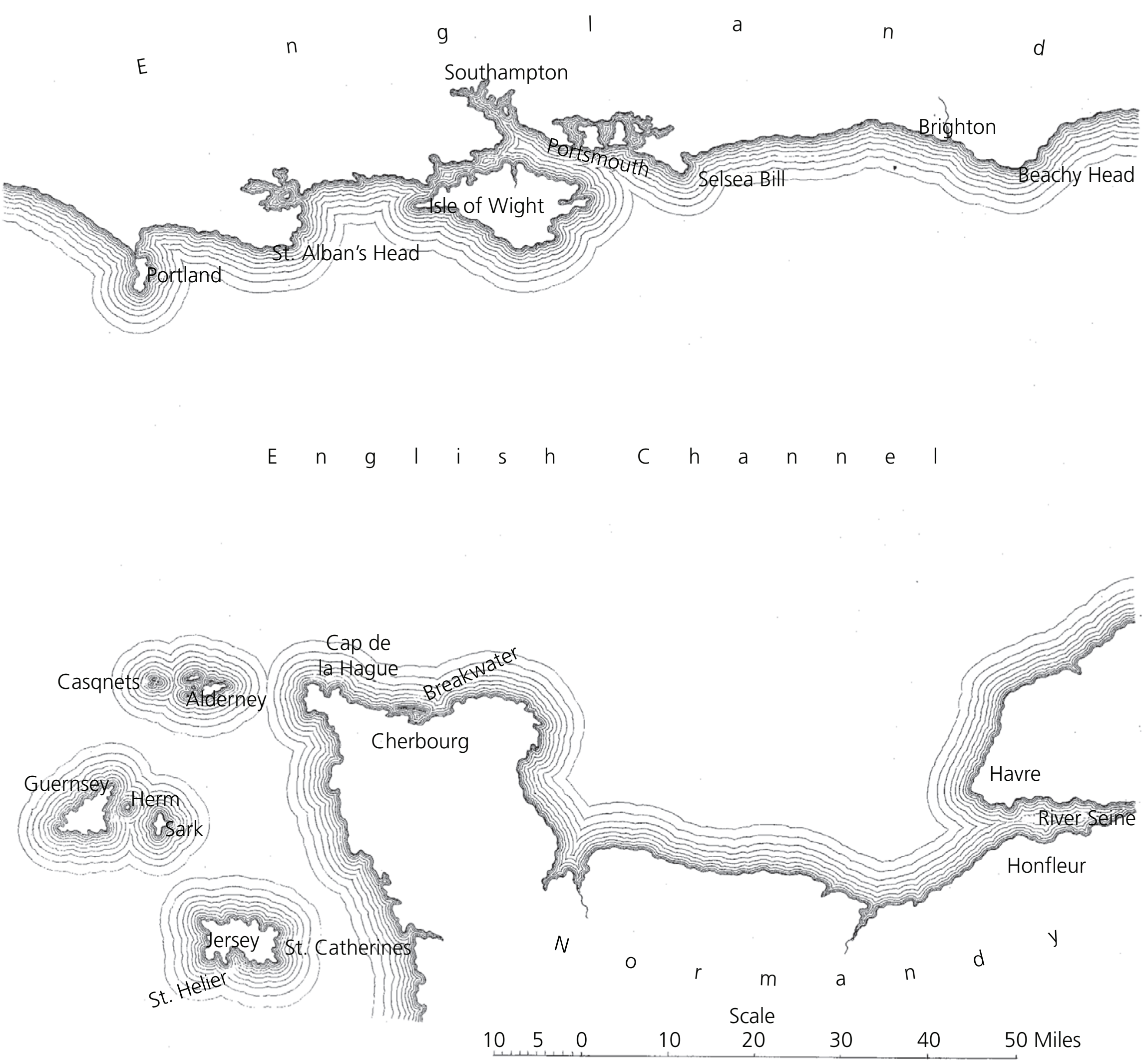


**Figure 1.** Map of Channel Islands and Cherbourg Peninsula (reproduced from Vernon-Harcourt (1874))

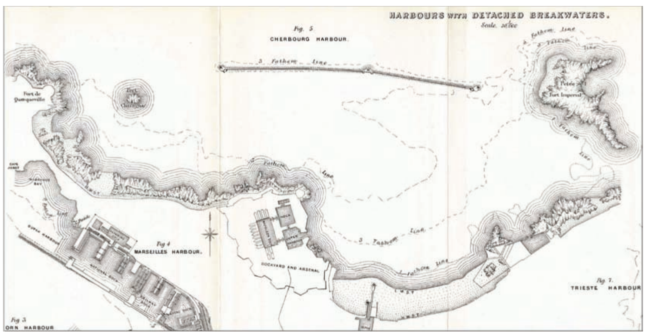


**Figure 2.** Cherbourg Harbour (reproduced from Vernon-Harcourt (1885))

as a roadstead harbour (Figure 2). (The term ‘roadstead’ implies a large area that is partly sheltered from waves but is less enclosed than a harbour. Cherbourg, Portland and Dover were all conceived as ‘roadstead harbours’).

At Cherbourg, three breakwaters were first mooted in 1665, but construction started only in June 1784 by the 4 km long central breakwater. The design by de Cessart used timber cones, each on 46 m in diameter at the seabed, 20 m in diameter at the top and 20 m 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 3 shows vessels depositing rock between the cones.

In 1802, Napoleon I restarted work on the central breakwater, reinforcing the centre to accommodate cannons. Large stones

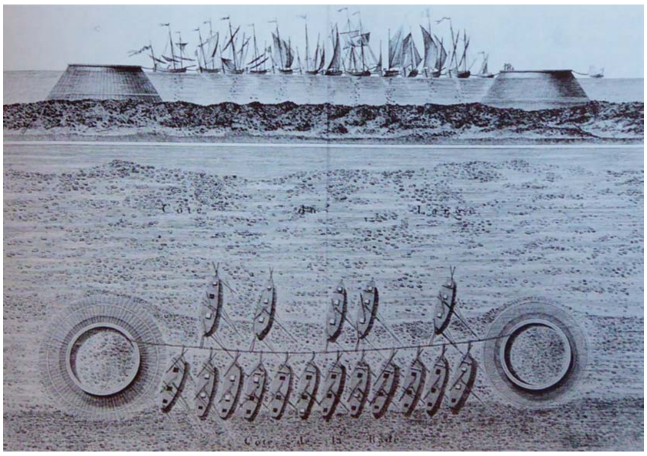

Figure 3. Use of timber cones at Cherbourg (courtesy of Alderney Museum)

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 low water. Some 13 300 $m^3$ of 'the largest stone procurable' was placed in 1811 (Vernon-Harcourt, 1885). (Sadly, Vernon-Harcourt did not identify the rock size needed.)

By 1813 the works were stopped, restarting some 11 years later. Raising the breakwater crest above water restarted in 1830. Concrete blocks that were cast in place on the rubble mound to form a toe/foundation (Figures 4(a) and 4(b)). The lower slope was protected by large stones down to −5 m above low water (mLW) 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' (Vernon-Harcourt, 1885). The central breakwater superstructure was completed in 1846 under Louis Philippe I, and the pier head forts were completed in 1853. From 1846, work continued on the two side breakwaters Digue de Querqueville and Digue de l'Est, which were completed by 1895, enclosing the then largest harbour in the world.

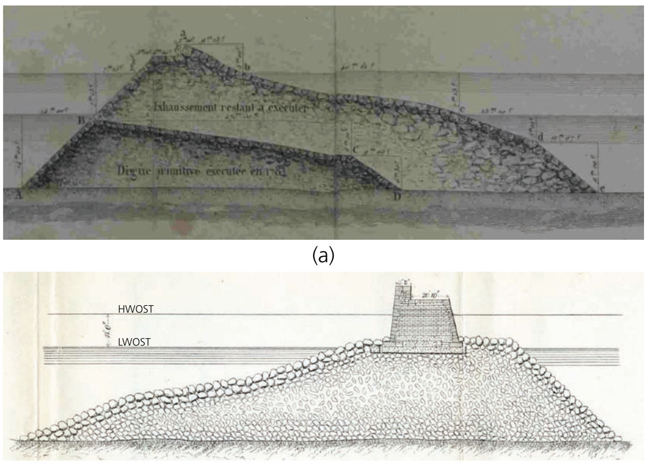


Figure 4. Rubble mounds at Cherbourg: (a) reproduced from Cachin (1820); (b) reproduced from Vernon-Harcourt (1885). 1′ = 1 foot = 0·305 m; 1″ = 1 inch = 25·4 mm. HWOST, high water of ordinary spring tides; LWOST, low water of ordinary spring tides

The full potential for docking and shipbuilding were, however, never fully realised, apart from specialised submarine construction and maintenance (which continue). The harbour became a major transatlantic terminal from the late 1800s, remains a significant ferry port and continues to accommodate a fishing fleet and submarine maintenance. So, while the original 'cone' breakwaters were a substantial failure, the overall harbour with the later rubble mounds may be deemed a success, although at the cost of some recurrent maintenance expenditure.

## 3. Portland

The 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 120 m wide entrance. Construction began in July 1849, designed by J. M. Rendel, and supervised by John Coode as resident engineer. Both breakwaters were simple rock-armoured rubble mounds (Figure 5) 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 10 m apart and surmounted by creosoted cross-beams ~5·5 m above high water) were founded on iron screws into the clay bed. Stone was dumped in ridges from the staging, 'the waves gradually levelled these ridges' (Vernon-Harcourt, 1885). Large stones (3–7 t) were dumped at an average of 500 000 t/year from 1853 to 1860, reducing to 140 000 t/year in 1866, giving a total of 5 800 000 t. The outer (eastern) breakwater was then completed by two pier heads formed in masonry founded at −7·3 mLW.

Figure 5. Portland Harbour (© of Google Earth 2020)

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 and 1906. The present layout is shown in Figure 5.

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 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.

Being constructed in the shelter of the Isle of Portland, wave attack on these breakwaters is relatively mild, certainly substantially less than at Alderney. Damage to the rubble mounds has been similarly moderate. The main naval need for the harbour lasted until 1959, so about 100 years of useful life. Portland may therefore be deemed a success.

## 4. Alderney

Alderney Island is just to the west of Cherbourg in an area of high-velocity flows where tides running up the Channel are compressed by the Cotentin Peninsula, 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 they might certainly prefer to shelter on the less-wave-exposed east of the island.

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

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. However, by locating the harbour on the wave-attacked west side, Admiralty planners effectively sealed the fate of the harbour and certainly of the breakwater.

A background to the selection of these sites is discussed by Vernon-Harcourt (1874) in the *Minutes of the Proceedings of the Institution of Civil Engineers* and by Vernon-Harcourt (1885) and Davies (1983). Admiral Sir Edward Belcher explained to Vernon-Harcourt that he had been summoned 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 relocating the harbour to Longy on the south-east side of the island (but that could have made the tidal velocities even higher!). Belcher's advice to the Admiralty was that a harbour at Longy would cost £1 500 000 (Redman *et al*., 1874).

Even so, construction of the Admiralty breakwater at Alderney (Figure 6) started in 1847 to a design by James Walker, second Institution of Civil Engineers (ICE) president. The initial design included a rubble 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. Almost immediately, the weakness of Walker's design became apparent with frequent breaches of the breakwater wall. By 1849, sections of 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 125 m, steepening the wall; masonry was set in Medina cement; and the seaward foundation was started lower. The foundation had been lowered after the first 46 m as far as was practicable without divers. Having used end tipping hitherto, the new lower mound level allowed use of hopper barges, but those required a construction harbour.

In the revised design, the rubble mound was not disturbed lower than about −3·7 m low water of ordinary spring tides (LWOST) in the absence of the superstructure. Work to the revised design (Figure 7) proceeded 'as soon as diving apparatus and the hopper barges were procured' (Vernon-Harcourt, 1874). Construction continued to 823 m by 1856. The design was then revised again, further lowering the wall foundation, now easier with the availability of divers. Construction of the outer section was nominally completed in 1864, giving a total length of 1430 m.

However, following repeated breaches and substantial cost increases, Sir Francis Baring summoned Sir Edward Belcher back to the Admiralty in 1852 to tell him that '… the former Commission was still in force … 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

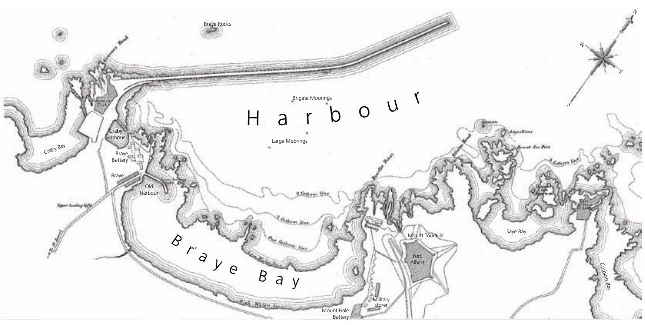


Figure 6. Braye Bay and the Admiralty breakwater (reproduced from Vernon-Harcourt (1874))

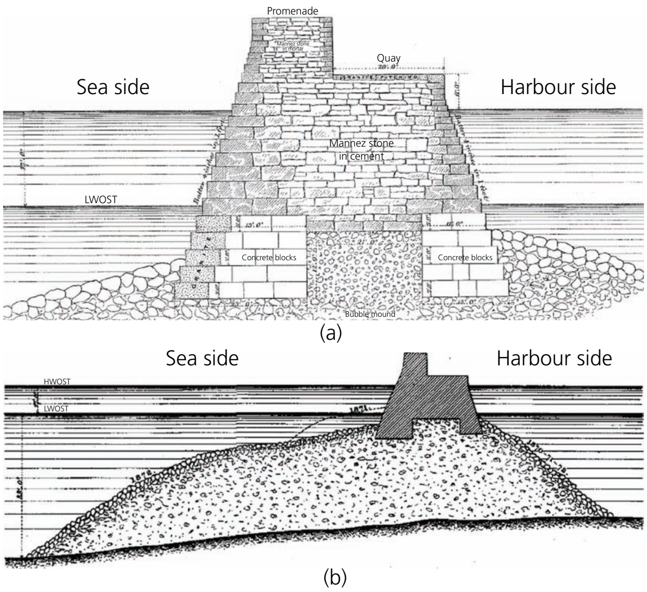


Figure 7. Alderney breakwate: (a) breakwater superstructure; (b) breakwater mound (reproduced from Vernon-Harcourt (1885)). 1′ = 1 foot = 0·305 m; 1″ = 1 inch = 25·4 mm

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 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 1874 *Minutes of the Proceedings of the Institution of Civil Engineers* discussion with the following 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' (Redman *et al*., 1874).

Vernon-Harcourt (1874) noted that the idea of a further eastern breakwater had not been abandoned until 1862. While 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 had 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 (15 and 40 m) through the superstructure. Another breach occurred in January 1866, a smaller one in February 1867 and another 18 m 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 of the ICE) and Colonel Sir Andrew Clarke were requested by the Board of Trade, who had reluctantly inherited the harbour, 'to visit Alderney and to report on the best measures for securing permanently', either the whole (1740 m) or the inner (870 m) portion of the breakwater. Hawkshaw and Clarke noted the 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 (Vernon-Harcourt, 1874).

The wall toe had been partially protected by stone dumped onto the foreshore. About 300 000 t was 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 870 m. The outer portion was abandoned to the sea, and the wall quickly collapsed, leaving a mound crest about −4 mLW (Figure 8). For the shortened section, approximately 20 000 t of stone was dumped annually, and further work was still required to repair breaches in the superstructure. Dumping of foreshore rock continued until 1964 except during the German occupation (1940–1945).

Waves at Alderney are frequently severe. Depths off the breakwater generally exceed 15–20 m, and waves reach the breakwater with little reduction, with the 1:50 year storm condition of $H_s$ = 11·0 m offshore corresponding to $H_s$ = 8·0–8·5 m 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.

Up to 1990, the maintenance cost was around £500 000 per annum, excluding the cost of 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 1 m. 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.

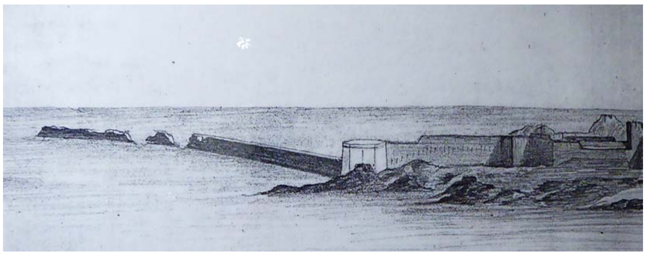

Figure 8. Alderney breakwater in 1883, by Lt Farmar RA (courtesy of Alderney Museum)

### 4.1 Recently

In 1989/1990, storms battered the breakwater for 6 weeks. At its peak on 25/26 January 1990, the storm had a return period of about 1:25 years, with offshore conditions of $H_s$ = 10·0–10·5 m. During the next 6 d, the storm subsided slowly and then rose again to $H_s > 7$ m. On 11 and 12 February, storm conditions again exceeded $H_s$ = 9 m. This cracked the masonry facing, and a large cavity was formed in the wall, which was 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 d. Repair costs was estimated at £1·1 million. Studies by Coode & Partners and HR Wallingford explored potential solutions (see the paper by Allsop *et al*. (1991)). Later work on alternative approaches to protecting this breakwater is described by Jensen *et al*. (2017).

The breakwater design at Alderney was certainly a failure, suffering numerous failures and losing one-half of its length. The harbour itself was misconceived and rushed and was quickly of no use to the Admiralty, so it was also a failure. However, in recent years, the States of Guernsey's repair/maintenance has significantly reduced the occurrence of damage, and trade and leisure use makes quite full use of the harbour – so perhaps it is a success.

## 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 Davies (1983) (Figure 9) 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 and has recently been refurbished (Hold, 2009). 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. However, 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 a state Archirondel to that when it was abandoned.

Davies argued that siting a harbour of refuge on Jersey made no sense. This is an island of 12 m tides. It is close to (but separate from) France, to which it is nearly 'joined' by submerged rocks east–south-east 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) rehearsed 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 (White, 1846). 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',

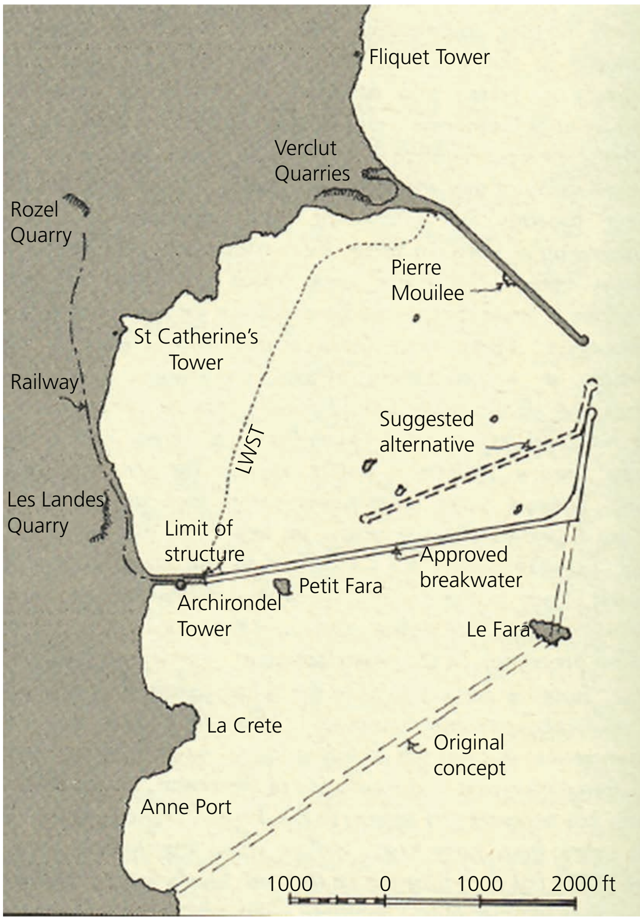


Figure 9. Layout of the proposed harbour at St Catherine's (reproduced from Davies (1983)). 1 ft = 1 foot = 0·305 m

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 and Captain Sheringham (surveyor), some later involved in the Harbours Commission of 1844.

However, by 1842, the 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 noted that the national Harbours Commission of 1844, set up by the Treasury, did not mention the Channel Islands, yet in only 3 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' (Davies, 1983). 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 obituary in the

*Minutes of the Proceedings of the Institution of Civil Engineers* includes '… he had, at least, as much skill "in the engineering of men as of matter"' (Anon, 1863)).

Walker's breakwater design for St Catherine's (Figure 10) is very similar to that for Alderney, and its construction was relatively straightforward. Even if St Catherine's harbour could have been maintained, its utility would, however, have been severely limited by tidal conditions for which it could be accessed and by the 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 the cancellation of Archirondel breakwater. The stub of that breakwater probably remains much as it was left (Figure 11).

By 1866, St Catherine's breakwater had been handed to the Board of Trade (Harbours and Lighthouses Department) whose Captain Bedford commented, '[I]t 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 Her Majesty's Receiver-General concluded in 1877 when it became the responsibility of the States of Jersey.

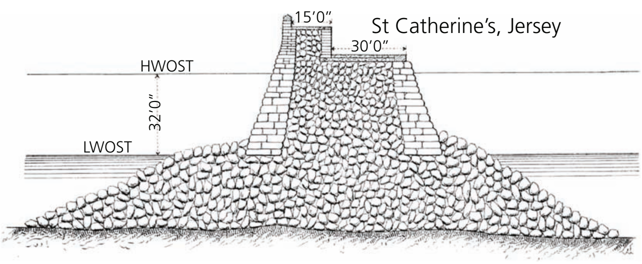


Figure 10. Section of the breakwater at St Catherine's (reproduced from Vernon-Harcourt (1885)). 1′ = 1 foot = 0·305 m. HWOST, high water of ordinary spring tides; LWOST, low water of ordinary spring tides

Figure 11. Archirondel breakwater stub in 2014 (author's own photograph)

The failure of the St Catherine's harbour was primarily of utility, compounded by insufficient depth and lack of interest 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 2 years.

## 6. Dover

The Royal Commission of 1840 favoured a deep-water harbour in Dover Bay to enclose 450 acres (18·2 $km^2$), costing £2 000 000. The 1844 Royal Commission re-considered whether a harbour of refuge was desirable here, requiring it, in order of precedence, to

(*a*) provide ease of access for vessels 'requiring shelter from stress of weather'
(*b*) provide for armed vessels in event of hostilities, both offensive and defensive
(*c*) 'possess facilities for ensuring its defence' against attack.

While 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 (21 $km^2$) out to 7 fathoms (12·8 m). 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 noted the shortage of experience in concrete. However, given the chalk bottom, absence of local rock 'and a moderate depth, the upright wall was the best system to adopt' (Vernon-Harcourt, 1885).

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' (Wilson, 1920). A contract was let in October 1847 for 244 m of Admiralty Pier. Subsequent contracts in 1854 and 1857 covered a further 305 m, so that the work extending Admiralty Pier was essentially complete in 1871 to 640 m from the shore.

Admiralty Pier was formed by 7–8 t concrete blocks with outer stone facings. The main wall was 'surmounted by a high parapet, overhanging considerably to the seaward'. However, on 1 January 1877, about 300 m of this parapet at the outer end was swept away down to quay level. Wilson (1920) ascribed the blame to the curved overhang, although the slender nature of the up-stand wall and the absence of any tensile reinforcement must surely have contributed substantially. The damaged section that was rebuilt with a significantly thicker (about 3·3 m) vertical face 'proved perfectly satisfactory' (Wilson, 1920).

This single pier did not, however, give adequate shelter from easterlies, and a contract was let by Dover Harbour Board (DHB) in 1892 to Sir John Jackson to construct the Prince of Wales Pier to some 503 m, supervised by Coode, Son & Matthews. Then, in late 1895, Coode was requested to prepare drawings to facilitate expansion to the full Admiralty Harbour (Figure 12) by

- extension of Admiralty Pier by a further 610 m
- a detached breakwater, the south breakwater, of 1284 m
- the eastern arm of 1012 m.

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 was let in November 1897 to S. Pearson & Son.

The new walls were formed almost entirely by concrete blocks (generally 2·3 m wide and 1·8 m high, depth from 2·4 to 4 m 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.

Figure 12. Dover Harbour layout (© Google Earth 2020)

For the foundation layers, underwater blocks were set by divers, placed tightly without mortar. Above the low water course (a band 1·8 m high centred on LWOST), four courses were grouted by 2:1 Portland cement mortar. The eastern arm 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 7·5 m above high water of ordinary spring tides (HWOST) (+13·3 m LWOST).

The east arm breakwater projects south for 900 m. The section is similar to the Admiralty Pier extension, although the parapet wall was lower with the harbour cope at +8·8 m LWOST) (Figure 13). Foundation blocks for the east arm were laid direct on the chalk or the chalk marl/flint matrix down to −16·2 m LWOST. The east arm was intended to provide berthing, so the harbour face was vertical with timber fenders and had an L-shaped head to shelter the inner face.

The south breakwater (the island breakwater) runs 1284 m 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 Wouldham Company) delivered by barge in 160 t loads was derived from

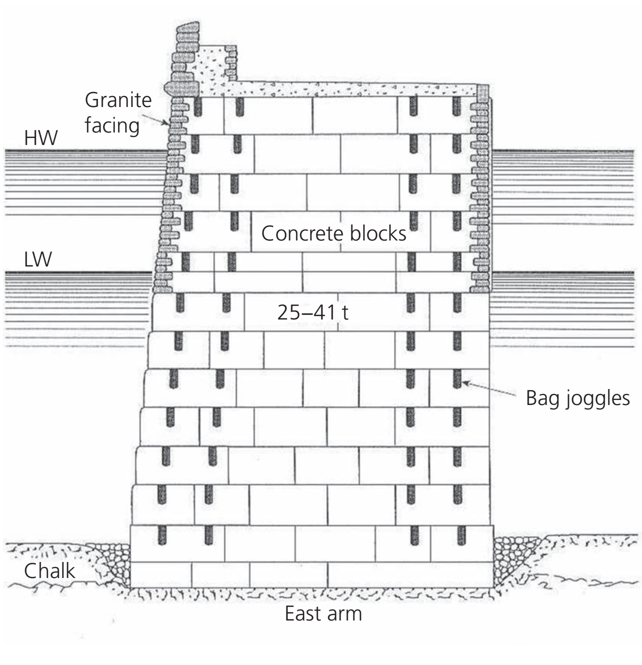


Figure 13. Concrete block construction of the Dover east arm. HW, high water; LW, low water

'ordinary- and rotary-kiln' production. Wilson (1920) noted 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 yard$^3$ (0·765 m$^3$) capacity. Output averaged 100 yard$^3$ (76·5 m$^3$) per mixer per day. Blocks were lifted after 7 d 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 42 t 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 Goliath travelling cranes (Figure 14). The rail level for these cranes was generally above +8·2 m HWOST. Tasmanian blue gum piles were heavier than water, but Oregon pine required weighting by old iron rails to sink them. Staging piles were reused 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.

Ahead of block placing, the seabed was prepared by excavating 1·5 m of surface material, mostly by a 'Hone grab'. The final 0·3 m of excavation was removed by four men using picks and shovels within a 35 t diving bell, which excavated a 4·6 m 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 h 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 (1·85 km/h), restricting operations to about 4–5 h each tide, during which six blocks were placed per hour at best.


Figure 14. Construction of the south breakwater using a Goliath crane on staging (courtesy of DHB)

Trimming/filling the 'low-water course' compensated for any errors in lower layers. Blocks above were set by masons during the 2–3 h 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 downwards.

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 DHB, who had to deal with years of neglect and adaptations. Ferry and commercial trade increased, and in September 1923, Admiralty Harbour was transferred by an act of Parliament to DHB, with the harbour reverting to the Admiralty should Defence of the Realm require it.

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. Given the age of the breakwaters and the high volume of traffic using the harbour, the maintenance requirements of the Pearson structures have been very moderate. The harbour layout has been significantly modified over the years to respond to new vessels and traffic requirements. Taken overall, this harbour, and the breakwaters that protect it, should be deemed significant successes.

## 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

1830–1840 (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 Saint-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 (1859) and Winder *et al*. (1859), 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' (Winder *et al*., 1859). 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' (Winder *et al*., 1859). 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' (Winder *et al*., 1859). Bidder continued in an attack on James Walker (past president of the 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' (Winder *et al*., 1859). Yet the vertical pier at Dover was cost approximately twice that of the rubble mounds at Portland. Bidder, however, ignored the rather different wave exposures, and the simple nature of the Portland mounds, and the proximity of the rock supply.

Of four harbours recommended, three had been started and two 'had been intrusted [sic] to Mr. James Walker, himself one of the Commissioners' (Winder *et al*., 1859). In the 1858 discussion, Bidder continued, '… it seemed, that the Government authorized 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' (Winder *et al*., 1859).

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' (Winder *et al*., 1859). 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 …' (Winder *et al*., 1859). At this remove, it is difficult to disagree.

### 7.1 Cherbourg, Portland and Dover

Each of these (initially) military harbours has continued to be 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. The 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 the 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 823 m by 1856. The section design was then revised again, and construction of the outer section was completed in 1864, giving a total length of 1430 m.

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 was needed to get 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 (*c.* 1845), breakwater design was by trial and error with no calculation of loads or resistance. Designs advanced by experience. 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) remarked, '… 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 Shield (1895) might have been helpful had they been available in 1845–1847. 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 Bidder in the discussion to Scott (1859) (Winder *et al*., 1859).

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 ~12 m is one of the greatest in the world (a few sites reach ~14 m), but the general tidal currents are not focused here, except in local flows around the roundhead. Thus, 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 5·2 m, but currents may exceed 7–8 knots (3·6–4·1 m/s). Modelling of waves and currents discussed by Allsop *et al*. (1991) shows that waves are refracted by currents in a 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 the greatest. Modelling in 1989 (see the paper by Allsop *et al*. (1991)) gave a 1:50 year condition of $H_s$ = 11·0 m offshore, reducing to $H_s$ = 8·0–8·5 m at the breakwater. However, 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 reminded 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…' (Shield, 1899) (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' (Shield, 1899), while being somewhat oblique, does illustrate a growing appreciation of these effects. Shield then used work by Airy (1845) 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 (1899) noted, 'As the tide recedes, however, they are quickly transformed into angry waves of translation by being tripped up by the foreshore…'. He then drew 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' (Shield, 1899). He noted that rubble may be washed away at the outer end of a breakwater down to depths >12 m. At Alderney, with a bed depth of −14 mLW at 300 m from the root, the mound at −1 mLW 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.

### 8.1 Construction practicalities

However, not only did the lack of clear understanding on wave forces severely hamper the design, but also key technologies that would greatly assist construction at the end of the century were yet to be developed. Ordinary Portland cement (OPC) had been patented by Aspdin in 1823 but was not available in commercial quantities until 1840–1850. 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 the discussion to Vernon-Harcourt (1874), 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 seaside and two on the harbour side, working in 4 h 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 one part cement to two parts sand to bed the blocks.

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