



BUILDING IN UNCERTAINTY: THE CONSTRUCTION OF THE CHERBOURG BREAKWATER 1780-1853

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ABSTRACT

Cherbourg (1781-1853) was Europe's first modern offshore breakwater in exposed tidal waters, initiating an evolution of similar projects around the world. It was born of a perceived military imperative which attracted the necessary state funding, and a willingness on the part of state-sponsored engineers to undertake, and sustain, this unprecedented challenge in a climate of ongoing technical and logistical uncertainty.

The project to create a breakwater at Cherbourg represented a new phase in the C18th arms race; for it to be effective, the speed of completion of the project was the major success criterion, but the task was technically daunting - as the head of the Ponts et Chaussées was forced to admit in 1788, 'we have been continually obliged to carry forward both works and trials simultaneously'. The operation of these demands created a Catch-22 for engineers; the result was a hugely expensive and chronically inconclusive project, driven by priorities which tended at the outset to ignore, or reject, the existing knowledge bank and thus increase rather than decrease uncertainty.

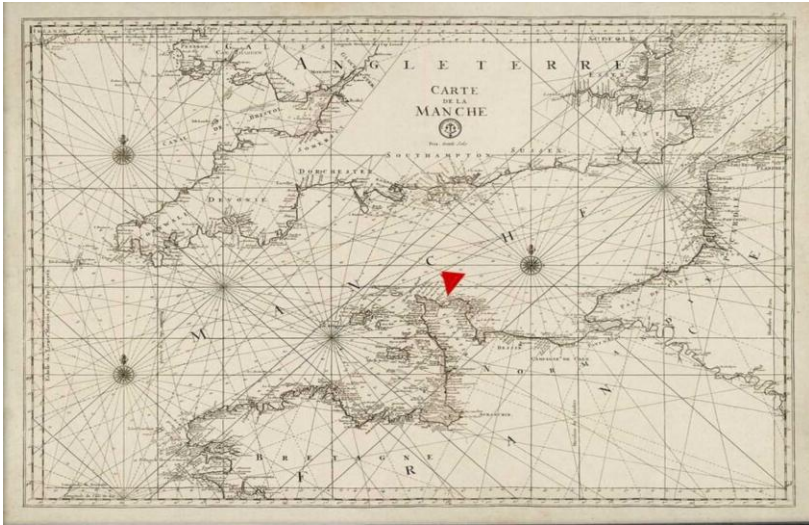
1. Introduction

Cherbourg, until the breakwater project began in the 1780s a small trading and fishing port, lies at the centre of the bay which forms much of the northern coast of the Cotentin peninsula in Normandy. The peninsula consists of a large outcrop of granite and associated stone types at its northern end, joined to the mainland by a low-lying area of wooded farmland and marshland which is protected by the existence to the west of the Channel Islands. (Figure 1a). The existence of a plentiful supply of stone was decisive in making Cherbourg the site for a protected roadstead and port in the 18th century.

The offshore breakwater was the first component of the plan to provide shelter for a naval fleet in the Channel, a military strategy which required completion in the shortest possible time and led the project managers into a less than rigorous process of decision-making, with a range of paradoxical results - including considerable delay. The breakwater slowly became the sum of its parts, including the mistakes made, which have affected the stability of the final construction in ways that are becoming difficult to ignore. The structure began to fail after only fifty years in ways which, to the historian of its construction, may not be overly surprising. The present paper summarises some important phases of construction

of this composite breakwater, which inevitably took the form of an experiment in real time with construction methods.

Figure 1a – French chart of 1773 showing location of Cherbourg



The wind at Cherbourg is predominantly westerly, with the strongest wind from the NW. Wind from the NE is also frequent; these two directions have the longest fetch (90 nm/170 km). Wave heights in N-sector gales can attain heights greater than 5m, depending on wind strength and direction. High and low water (spring tide) levels are abbreviated as MHWS and MLWS: maximum tidal current is between 2 and 4 knots (4-8kph) and maximum tide height is between 4 and 7 metres above MLWS (neap to spring tides) in the roadstead. At the time of building the average depth at MLWS at the breakwater site was sounded as approximately 12 metres.

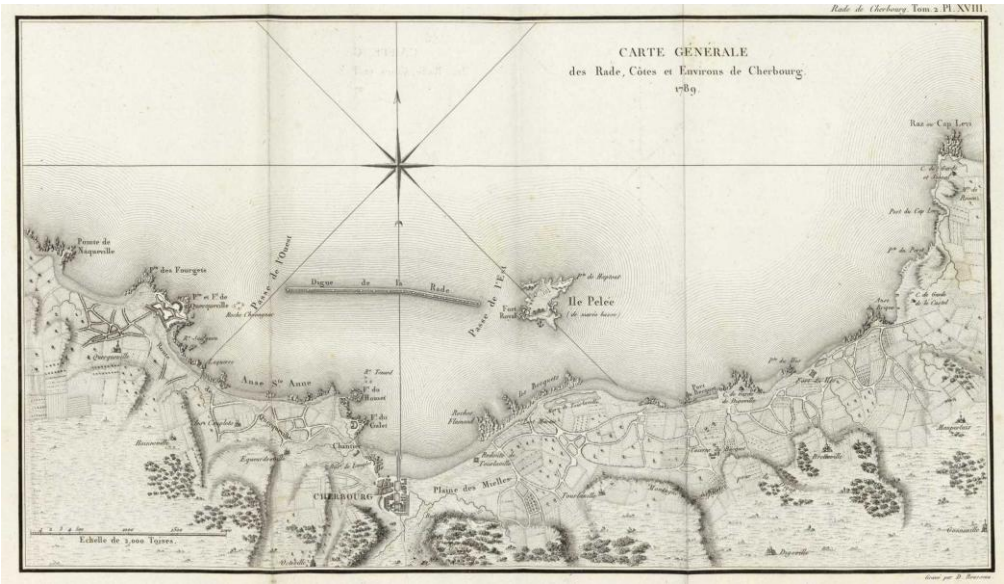
At various moments between 1680 and the present, disastrous storms have been recorded on the Cherbourg coast, notably that of 12 February 1808 - or 11 January 1866, after the completion of the breakwater, when numerous ships were nonetheless still carried on to the beach at Chantereyne. Much later, serious breaches in the breakwater in 1893 and 1978 show that the problem has not changed much in character.

2. Political context

France's slow recovery from the disasters of the Seven Years War (1756-1763) included a developing awareness of the need to restore the power and prestige of the country's navy. One important focus became the desire to implement the long-dreamt-of project of

building a port to challenge British naval hegemony in the waters of the English Channel. The success of France’s involvement in the American War of Independence (1778-1783) offered an opportunity to begin the project, which, in the first instance, became to construct a breakwater which would protect a naval fleet both from the weather and from enemy attack, as the first stage in the creation of a permanent base in the Channel. The breakwater needed to be finished before the next outbreak of war with Britain; a window of 10 years was envisaged for implementation.

Figure 1b Chart showing the layout of the Cherbourg roadstead protected by the breakwater, 1789



Military engineers were traditionally responsible for the defence of ports, though the rise of the state civil engineering corps of the Ponts et Chaussées provided increasing competition during the 1770s and 1780s, of which Cherbourg was the most important example. Cooperation, and information transfer, between the two corps was limited. A centralised pyramidal culture of competitiveness bred fear of failure, prevarication and a rigid conservatism which did little to encourage technical innovation - in marked contrast to the situation of British engineers of the same period.

Table 1 - Project chronology

1781	breakwater project at Cherbourg proposed
1782	first trial of cone at Le Havre

1784	first cones sunk at Cherbourg, first cone damaged by storm
1785	first intermediary breakwater between cones
1786-8	cones increasingly damaged by storms, breakwaters continued
1791	project halted by lack of funds, 4 km breakwater complete to MLWS
1803	central breakwater section and excavation of military port begun
1808	storm damage to raised section, 200 workers killed
1813	work abandoned on breakwater, first basin of military port opened
1830	work begins on masonry wall to complete breakwater
1853	wall completed
1858	final basin of military port opened

3. A rubble mound breakwater to MLWS level

The military engineers, in charge of building the forts at Cherbourg from 1778, proposed an underwater rubble mound, first in one section, then in three, as the project evolved in 1780 to a more ambitious plan to enclose the whole of Cherbourg bay to shelter a full battle fleet. The plan eventually reverted to a single breakwater over the whole bay as construction progressed (Figure 1b). It was assumed that this/these mound(s) would eventually support a superstructure on the lines proposed by Belidor (Figure 4).

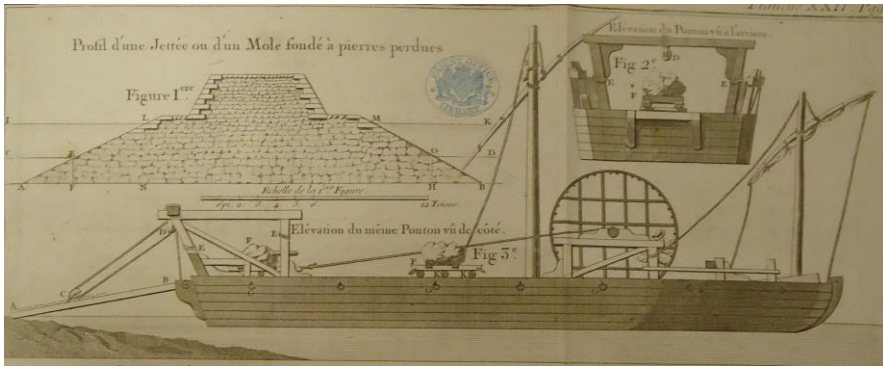
The default construction solution was the method of *pierres perdues*, or tipped stone, as prescribed in Belidor's *Architecture hydraulique* (1753), a work much in demand among engineers throughout Europe in the second half of the 18th century. Cherbourg was the first attempt to implement the theoretical propositions of Belidor in a major offshore project; his ideas echo throughout the more than two centuries of the project's existence.

Belidor proposed a project in two parts: first a rubble mound built preferably in courses, with the largest stone possible used near the surface, and allowed to settle; then, on this mound a foundation of concrete, established as low as possible (eg MLWS) would support a masonry wall. Belidor may have been thinking of an example such as de Mari's composite breakwater at Genoa, although his account of the works there is very general. Certainly, Cherbourg engineers in 1787 acknowledged their need to study Italian hydraulic techniques. De Mari's 'Molo Nuovo' is a candidate for Europe's first modern (non-tidal) offshore breakwater (Franco (1996)).

The default profile of 1:1 or 1: 2 for the proposed profile at Cherbourg was based on Belidor (1753); time constraints meant that the submerged rubble-mound to MLWS level was all that was proposed at this stage, with considerable uncertainty remaining about the effects of the sea on the loose stone in the mound. Research into sea states at Cherbourg was confined to the experience of military engineers building the forts in exposed locations at Hommet and Ile Pelée.

Peer review by a senior military engineer, René-Michel Bouillard, who applied Dutch practice to the problem, concluded that the profiles proposed were naive; a seaward slope of 1:7 would be necessary, and such a stable slope would anyway be created in time by the action of the sea. This conclusion doubled the estimate for stone from 5 to 10 million m^3 while the implementation time rose from 8 to 14 years; the effect of this was to stall the project, which now evidently required an experiment on a vast scale, for which engineers were reluctant to assume responsibility.

Figure 2 Breakwater profile and stone transport from Belidor (1753)



6. Caissons (wooden cones) filled with stone sunk base to base in a line

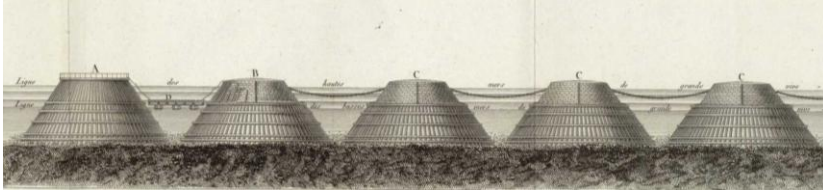
In 1781 the Ponts et Chaussées capitalised on this uncertainty with an alternative, modular project, proposed by experienced hydraulic engineer Louis-Alexandre de Cessart, which also aimed to bypass the recognised problem of building the superstructure on the rubble mound. One hundred huge truncated wooden cones (20m high with a 45m base diameter) would be sunk and filled with stone to create the 3 sections of breakwater. This would solve problems of stone movement, and in theory reduce the quantity of stone needed to some 1.7 million m^3 . To build each cone required 700 m^3 of prime timber, held together with 5000 hand-forged bolts. According to Cessart, a cone's mass was 900 tonnes, and 8500 tonnes when filled with stone.

The cones would in theory be able to support the construction of forts or batteries on top to solve the problem of defence from enemy attack. An ambitious claim that 10 cones (or more) a year would be built and sunk, giving a total implementation time of 10 years, led to an extended experiment at Cherbourg being authorised.

Apart from a brief flotation trial, using barrels attached around the base, at Le Havre in November 1782, the cones were untested. The modular programme appears innovative, even though caissons, in use from classical times, and developed in Italy in the 16th

century, were now beginning to be widely experimented with in hydraulic projects - particularly by naval engineer Antoine Groignard, who acted in a consultative capacity at the beginning of the Cherbourg project.

Figure 3 The breakwater made up of cones according to Cessart's original plan



Cessart's design shows a number of obvious weaknesses. The cones, based on a standard pier design, were designed to solve the less important issue of stone movement by current, and their mass was calculated merely in relation to displacement, and the effect of surging rather than breaking waves; the wooden container and the stone were also considered as one mass. This led to a radical underestimation of the complexity of forces which wave action would bring to bear; once a cone had been sunk on site only superficial repair would be possible.

The 75 ft long *montants* or uprights were made up of straight trunks 20-30ft (8-9m) long, squared to 12 x 12in (30cm x 30 cm). The horizontal *moises* varied from 215ft (65m) to 500ft (151m) in total length, built up from 12-20ft lengths, also 12 x 12in square.

Cessart tried to economise as much as possible on the timber used in the construction of a cone, for two reasons: first, the finished mass of the cone had to be kept to a minimum for the purposes of flotation and towing, and second, the necessary timber was of shipbuilding grade and therefore the maximum economy was required.

The cone was thus designed as a timber shell, with no internal structure to be damaged by stone being tipped into it, and without a base other than a network of ropes under tension joining the ends of the uprights, so that the cone would sit upright even if the seabed was uneven. This also meant that the structure could flex under pressure, before and after sinking, imposing aleatoric stress on connecting bolts (Figures 9, 11).

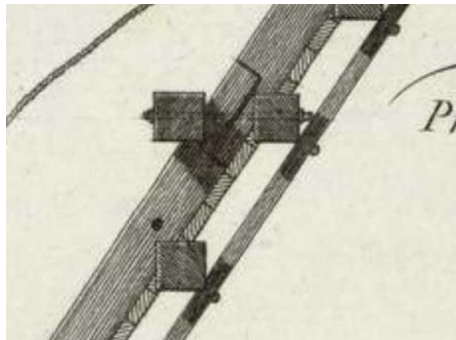
In 1784 the second cone to be sunk broke up in a NE gale only a few weeks after launching; this cone had already been trialled at Le Havre, dismantled, transported to Cherbourg and rebuilt in 1783 but then left over the winter on the beach when bad weather had prevented its launch. The damage to the cone led to a strengthening of the uprights by doubling them throughout their whole length; this required even more timber per cone and a later evolution of the design was a compromise which still left the upper section of the cone vulnerable.

Figure 4 Sinking a cone by releasing the flotation barrels



The major weakness of this construction method lay in the amount of drilling and bolting required to join the sections of upright, and to link them by means of the horizontal members, both internal and external. A further problem lay in the fact that these horizontals forming a circle around the cone would not lie flush to the uprights, being only curved in one dimension, which made securing them more difficult (Figure 5).

Figure 5 Detail of horizontal members bolted through upright



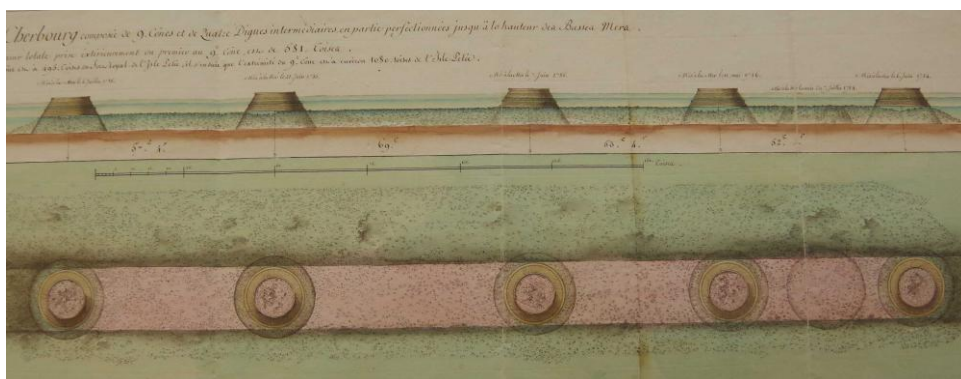
These details show how flawed both the design thinking and the reviewing process were; it comes as no surprise to learn that the cones were systematically destroyed by the weather, often very soon after launching.

7. The ‘système mixte’: cones and breakwaters

After the second cone was damaged, Cessart, with breathtaking inconsistency, (but following a tense private meeting with project committee members come hotfoot from Paris), countered accusations about timber consumption, and delays to the programme, by proposing a drastic reduction in the number of cones from 100 to 38, spacing them out and infilling with tipped stone (Figure 6) - in direct contradiction of his earlier stated belief that tipped stone would simply be carried away by currents. A change of system was not accompanied by any technological development, however. The cones had to be filled by hand from boats transporting the stone; for reasons of speed and continuity, the same method of stone delivery, and thus size of stone, was used for the intermediary breakwaters, instead of developing, for example, Belidor’s proposal for delivering larger masses of stone with purpose-built barges (Figure 2).

The cones were proposed as a means of countering attack both by the sea and by an enemy, which required their elevation above MHWS as the basis for batteries, and thus provoked an immediate, wholly unresearched, confrontation with wave action; waves breaking on the exterior surface of the cone and then falling vertically into it emptied out the stone to the point that the force of breakers could then easily attack the upper woodwork. In 1787 all five cones sunk were soon irreparably damaged, and the last three, sunk in 1788, had their woodwork above MLWS cut off after sinking.

Figure 6 The cones spaced with intermediary breakwaters at the end of 1786 (note the broken cone 2nd from right)



By this time, the method of tipped stone was already proving to be less problematic than feared; it was becoming clear to engineers that because of wave action the breakwater sections, increasingly viewed as a single breakwater, were approaching the stable state

predicted by Bouillard of around 1:7, though this naturally required more stone to maintain its height at MLWS level. Stone tipping continued until funds ran out after 1792, as the economic crisis of the Revolution deepened, by which time around 2.5 million cubic metres of stone had been tipped. The 4km rubble mound, nominally at MLWS level, also had eighteen cones buried in it, which would cause problems later in the project.

The head of the Ponts et Chaussées, Chaumont de la Millière, wrote in his defence of the corps in 1791 that, given the prevailing atmosphere of prevarication, without the cones the project would never have got started. While the cones did not solve the perceived problem of stone movement, they brought about the compromise conditions whereby the behaviour of stone slopes could be examined in real time within a context of limited risk.

8. A missed opportunity? Nicolas Céard's concrete blocks

In 1785 Ponts et Chaussées engineer Nicolas Céard, who had proposed using masonry to complete the cones (as in Figure 3), then proposed making large concrete blocks to build the whole breakwater. This required the use of volcanic *pouzzolane* to make concrete which would last underwater; until alternatives were developed, the limited supply of this material from Italy restricted upscaling of its use in large projects such as Cherbourg - the first cargo of pouzzolane to arrive at Cherbourg in 1786 was ironically nearly lost by shipwreck on the breakwater. Essentially Céard created the method which Poiré would reinvent at Algiers in the 1830s, and which would be used at Cherbourg from the 1840s. His proposals were however rejected; Céard later achieved fame as the engineer of the road over the Simplon Pass in the Alps.

9. Armouring the rubble mound: the policy of 'big blocks'

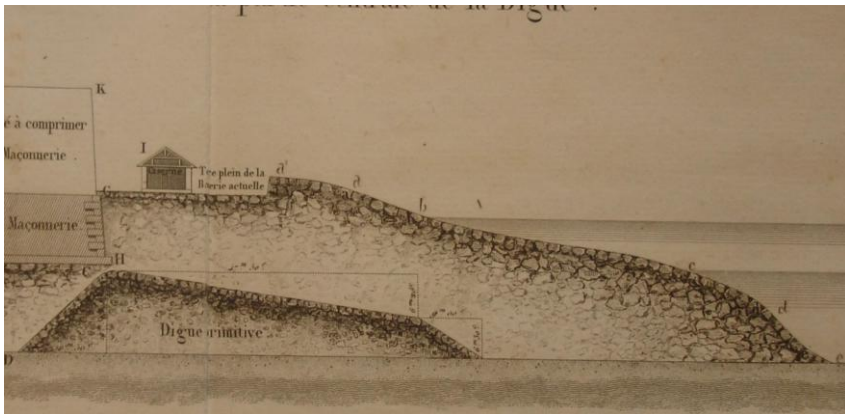
After the failure of the cones, the Ponts et Chaussées were under pressure to come up with a method for finishing the breakwater or run the very real risk of having to give up the project. In 1787 inconclusive trials were undertaken with natural stone blocks measuring some 0.5-0.8m³ and weighing 1-2 tonnes, in the hope that they would create a stable armoured surface which could be raised above MHWS. This was an attempt to arrive at a cheaper and quicker solution than Belidor's masonry wall (Figure 2). The failure to develop a technology to mechanise the transport of larger blocks, such as that implemented successfully at Plymouth, limited their size; the transports at Plymouth were designed from the outset to carry stones of 5 tonnes.

A Commission of 1793, led by Cessart's protégé and successor Joseph Cachin, nonetheless proposed the use of 'large' blocks of stone for the whole breakwater, including a second breakwater to reduce the width of the western entrance. A further Commission of 1799, which included both Cessart and Cachin, recommended implementing in full the proposals of 1793. The Ponts et Chaussées thus survived the Revolution in full command of the Cherbourg project, though the retention of the method of using loose blocks of stone was to lead to another extended period of technical failure.

When work definitively resumed at Cherbourg in 1803 under Cachin, the elevation of a 200 metre section at the centre of the breakwater to 3m above MHWS, as the base for a battery or fort, formed the first part of the overall plan to implement the 1793 Commission's proposals to raise the whole breakwater to that level. It can be seen how much stone would need to be added to the original mound to complete the project by this means (Figure 7a). The problems of using large blocks of loose stone occupied the following twenty years, during which not even the central section was completed.

Stone blocks piled up in front of the battery were repeatedly removed by storm-driven wave action. In spite of this, large numbers of workers were still lodged on the platform under construction, and on 12 February 1808 over 200 people lost their lives in an exceptionally fierce storm graphically described by Pierre François Trigan, a naval officer on duty on the breakwater that night. Trigan's heroic account may be the first to provide data from inside a terminal civil engineering experiment.

Figure 7a Section of Cachin's battery from his 1820 memoire

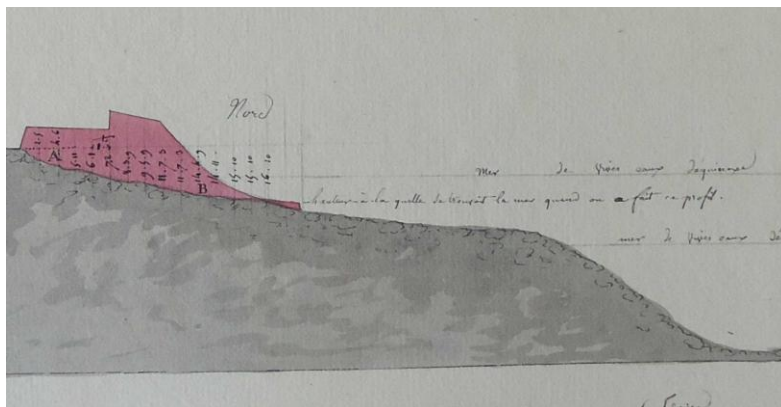


According to Trigan's description the conditions on the breakwater were appalling; the sea was breaking heavily right over the site; at 4am, just after low tide, 60cm of water already covered the platform with a 3-knot (6 kph) current setting to the east. The parapet of big blocks (5-20 cu ft) was swept away, and nearly everything that had been built on the platform was destroyed. Of the various sorts of people on the site that night – officers, soldiers, workers, even children - Trigan's resourcefulness managed to rescue around fifty. A profile made just after the storm, however, shows the extent of the damage, where everything coloured pink was removed (Figure 7b).

Further storms merely undid the annual repair work, though engineers noted that any element of masonry walling survived more or less intact. This supported a growing preference for the idea of building any superstructure in solid masonry; Cachin himself

had acknowledged this as an ideal by 1807, but one which would require a step-change in logistical support to deliver the necessary quantity of materials to the breakwater fast enough to create a structure each season solid enough to withstand subsequent storms.

Figure 7b – Profile of the battery (in grey) after the storm of February 1808



10. Building the monolith

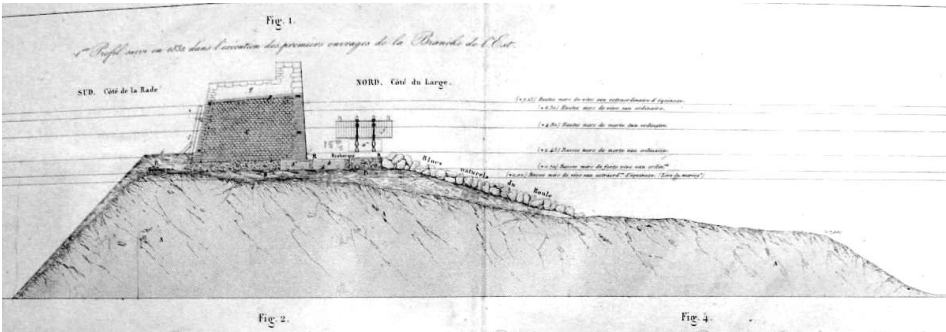
When the works were restarted in 1831, the new project director, Cachin's former assistant Fouques-Duparc, followed Cachin by insisting that the solution to the problem of wave action was to build 'a simple wall, all of whose parts, closely connected together, would make a single indivisible object'. His proposal was for a concrete base on the rubble mound, some 0.8m thick, carrying a solid masonry wall faced in granite freestone on both sides; this more or less followed Belidor's prescription. The wall would be 8m high with a parapet 2.5m thick and 1.6m high running along its northern edge; it would be 11m wide at its base and 9m wide at the top. Its seaward batter would be 1:20 and its inner batter 1:5. On the southern side a berm 5m wide would be raised to 3m above MLWS (Figure 8).

Aspects of this new construction remained as experimental as the earlier phases of construction. Stability calculations gave a resistance of 16 tonnes/m² to overturning, and 12 tonnes/m² resistance to sliding on its base, although it was later recognised that these were underestimated, as was true of Duparc's early calculation of breaking wave pressure at 3 tonnes/m². The effect of masses of water falling vertically was also undervalued, as it had been with the cones.

Owing to the difficulty and cost of obtaining pozzolane from Italy, experiments were conducted on hydraulic mortars using a range of local materials; albeit successful, these

were eventually replaced by Medina and Parker ‘Portland’ cements in the early 1840s. Different mortars were used in the construction of the inside and outside of the wall.

Figure 8 Profile of Duparc’s proposed wall on the rubble foundation



The rubble mound would need restoring to MLWS level; this took 97 000m³ for the eastern section and 357 000m³ for the western section. Work began on this in the summer of 1831. Each subsequent season ended with measures to leave the work in a state capable of resisting winter gales. The length of concrete foundation created each summer needed to have been covered with two courses of granite, with armouring in front of it, while further courses were staggered back and capped with concrete, before the winter. This created another problem, that of the strength of the jointing between old and new work.

Uneven settlement showed itself in damage laterally and longitudinally. Engineers were aware of the hard spots where the cones were buried (Figure 9), which created unevenness which had to be levelled as the wall rose; the evidence of this can be seen today in the split courses of the wall at various points (Figure 10).

Settlement, especially between the remains of the cones, created problems of cracking. In onshore gales during 1836 breaking waves rose vertically to 30 or 40 metres above the wall. A severe NE gale on 25 December 1836 opened up an 80m longitudinal crack in the stonework and threw more than 200 armour blocks, weighing 3 tonnes and more, over the wall on to the inner berm.

The storm also caused a 15m breach across the wall, which was already 6 courses high. This was on a high point over a cone, where transversal cracks had opened up the joints between the granite blocks. In 1839, on its completion, it was found that the eastern section of the wall had effectively broken into five sections, with 20mm cracks between them.

Longitudinal settlement on the landward side of the western section was caused by the fact that much of the stone had been tipped relatively recently; the line of this section of

the wall had to be moved slightly seawards as a result. As the wall increased in size, minor adjustments continued to be made to compensate for any further settlement.

Figure 9 Chart of the completed breakwater, showing GPS positions of cones along its length.



Concrete blocks were used to protect the toe of the wall, and later as an apron around the forts. These were made ashore and towed out, then when circumstances permitted, made on site which reduced towing costs. Such blocks required constant monitoring and renewal; the remains of some of them can be seen today.

Figure 10 Sites of cones 14 and 15 revealed by the stonework of the wall, western section



11. Maintenance – 1860 to present

A total of 5 million cubic metres (8 million tonnes) of stone was used for the breakwater, about half of which was tipped before the Revolution, the other half being equally divided between the second and third phases. After the completion of the breakwater in 1853, a series of contractors were employed to supply further armouring to the breakwater, and a pattern evolved whereby around 10 000 tonnes of stone a year were supplied - but always of stone of a size which remained vulnerable to movement and eventual destruction by the

sea. A major breach in the upper wall at the western end of the breakwater in November 1893 (Figure 11) made it clear that even more substantial maintenance was required. The addition of the eastern and western breakwaters during the 1890s added to these demands.

In 1898 the engineer Paul Minard worked with a contractor called the *Société anonyme des carrières de l'ouest* to change the method of transport of stone from Roule to the port des Flamands, using a branch of the railway system which was already quite complex at Cherbourg. From 1900 to 1910, 57 600 tonnes of blocks were added to the armouring of the seaward slope. A further 57 200 tonnes were added between 1931 and 1941; some of these blocks weighed up to 40 tonnes. Later inconclusive experiments were conducted with tetrapods and other forms of artificial armour.

Figure 11 Breach in the parapet of the breakwater, November 1893



On 11-13 January 1978, a storm created waves estimated to have been 9m high, which broke to 50 m above the breakwater. The sea caused several breaches in the revetment and severely damaged the parapet, while the paved surface of the top showed a renewal of longitudinal fissures; the damage cost 9 million francs (Figure 12).

The report written by Minard in 1893 is interesting to compare with that written by scientists commissioned to investigate the damage in 1978. Minard found that while the layers of white mortar above and below it were intact, the red mortar of layer B (Figure 13) to be in a state of ‘complete decomposition’, which for him explained the depth of the breach. In 1978 a central layer of mortar was found to be similarly decomposed, by the conversion of ettringite into thaumasite, which caused the mortar to lose its consistency and power of adhesion.

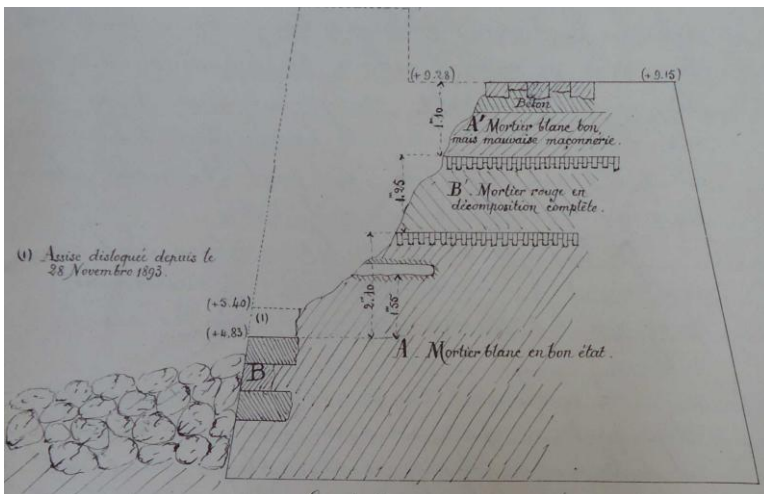
This decomposition was used to explain the ‘bellying’ outwards of the breakwater surface on both sides and the fissuring of the upper surface. Minard saw ‘no other palliative measure than to repoint joints to the greatest depth possible’ to slow down this process.

Figure 12 Breach in the parapet and longitudinal fissure, 1978



In 1978 the study concluded that the mortar inside the breakwater was in a state of 'permanent evolution', and that sooner or later chemical action would cause the decomposition of mortar which was then still in good condition.

Figure 13 Cross-section of wall by Minard showing construction detail



Between 1980 and 1986 nearly 60 000 tonnes of armour blocks were added; in 1993 a 'new' method was used (albeit one mentioned in Belidor) locating blocks precisely in

position so as best to resist waves. In spite of this in 2002 a 12 metre breach opened near the central fort.

The fine summer of 2003 permitted the repointing of 130 km of joints, and the addition of 13 250 tonnes of granite. It was reckoned that a block of granite would last *in situ* for around 20 years, and on that basis annual maintenance required 3500 tonnes of blocks, with regular repointing of joints. This has not been strictly maintained, especially since the permanent maintenance team was disbanded some ten years ago.

At present the main breakwater is still owned by the *Marine nationale*, together with the western breakwater, while the eastern breakwater and Ile Pelee are owned by PNA (*Ports Normands Associés*), who have built the new industrial zone to the NE of the commercial port.

In 2018 the reinforcement of some 110 m of the eastern breakwater with 3750 tonnes of stone was carried out by contractors for PNA, who have allocated an annual budget of 120 000 euros. The current maintenance budget for the remainder of the breakwaters is set by the Ministère des Armées at more than half a million euros, comprising a biennial programme of reinforcement involving 4000 tonnes of stone to cover 200m of breakwater.

Armour blocks were added to the central section of the main breakwater in the summer of 2019, and in September 2020 the *Service d'infrastructure de la Defense at Rennes* offered a similar contract for the supply and placing of around 5000 tonnes of blocks, together with the repointing of 1.5 km of masonry joints divided between the exterior and interior walls.

Figure 14 Cracks are beginning to appear in the south face of the wall



A rough calculation gives around 170km of mortar joints for the two sides of the main breakwater; a large proportion of the joints on the outer face are covered by armour blocks, making it difficult to monitor their condition. Analysis of pictures of the damage in 1893 and 1978 suggest that the thickness of the revetment layer of granite is less than appears in construction drawings, making it vulnerable to removal if damaged.

According to François Zoonekyndt of the Service historique de la Défense at Cherbourg, the present state of the breakwaters is acknowledged to be of concern, though considered to be of a sensitivity such as to preclude the publication of a detailed report at present. The present condition of the breakwater reveals the progressive internal damage mentioned above, causing cracks to appear on the S face (Figure 14).

Conclusion

The Cherbourg breakwater experiment stands as the foundation of modern breakwater practice worldwide, a monument to the engineers who had the courage and resilience to persist with what must have seemed at times like continuous failure, and to the generations of workers whose anonymous sacrifices were essential to the success of the project.

The political urgency which drove the Cherbourg experiment was also responsible for the collective error that authorised the first construction method of the cones, whose ‘innovative’ aspects might have been interrogated more closely. That urgency was, at the same time, the reason the project got under way at all, in a toxic climate of rivalry and competition which undermined the possibility of developing a collective knowledge base.

Engineers were aware from the outset, from their reading of Belidor, of the fundamental issues: the effects of wave action in a zone starting some 15ft (5m) below MLWS and ending at the highest point reached by waves in storm conditions at MHWS; the need to create an indestructible bond between a rubble mound foundation and the superstructure to be built on it; and the need for the superstructure to be built as solidly as possible. Belidor also implies a process of construction without delays, other than to allow for the preliminary settlement of the rubble mound. For reasons largely of expediency, alternatives to this default method were tried and, in their failure, helped to focus attention back on it, while adding to the technical challenges; it is clear that the experiment of the Cherbourg breakwater is by no means over.

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Sources for illustrations

- 1a – Author's collection
1b, 3, 5 – Cessart (1808) vol 2.
2 – Belidor (1753) part 2, vol 2.
4, 6, 7a 7b, 8, 1, 12, 23 – SHD Cherbourg, reproduced by kind permission
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