ALDERNEY BREAKWATER - SCHEME EVOLUTION

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Abstract

Alderney is the northernmost of the Channel Islands, lying 13km off the Normandy coast. The main breakwater at Alderney, known as the Admiralty Breakwater, provides essential shelter to the commercial and fishing quays and swing moorings for fishing boats and visiting yachts. It also provides protection to the shoreline around Braye Bay.

Wave conditions at Alderney are frequently severe. In response to this severe wave attack the Admiralty Breakwater (constructed between 1847 and 1864) has required continual maintenance (costing £447,000 in 1998). Even with this level of investment, however, the long-term decay of the structure and occasional breaches continue.

This paper explores the history to the Admiralty Breakwater, why there is a need for works and how a range of disparate designs have evolved over time leading ultimately to a small number of viable solutions.

Introduction

Alderney Breakwater has been the subject of many studies since Vernon Harcourt gave an account of the construction of the Breakwater at the Institute of Civil Engineers in 1873 (Vernon Harcourt, 1873). In more recent times, HR Wallingford have been employed by successive owners of the Admiralty Breakwater to investigate its structural behaviour (see for example HR Wallingford 1963 and Allsop et al 1990) and latterly to propose an appropriate long-term solution for the protection of Alderney Harbour (Sayers et al, 1996a).

The complex history and structural of the Admiralty Breakwater combined with the severe wave climate at Alderney provides an interesting topic for study. This paper brings together some of the recent studies and discusses some of the options for solving the significant problems associated with providing a long-term solution at Alderney.

The history of Alderney Harbour

At the start of the last century Napoleon threatened to invade England. In response, the Royal Navy conceived the idea of a deep-water naval anchorage on Alderney, the northernmost of the Channel Islands, close to France (Figure 1).

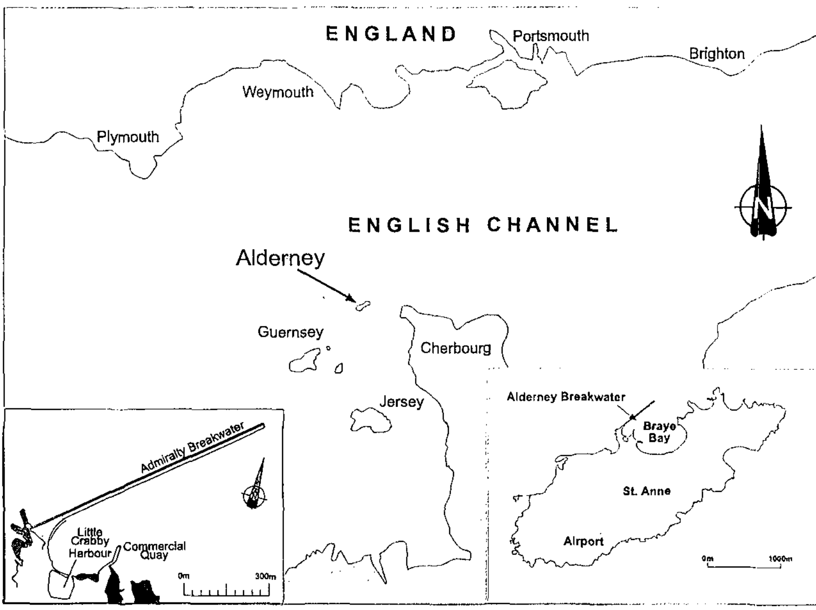

Figure 1 Location Plan

From here, the Admiralty claimed, they would be able to watch and, if necessary, blockade the French Port of Cherbourg and so repel French aggression. The Admiralty's original proposal was an ambitious plan enclosing all of Braye Bay (Figure 2). With a receding threat of invasion and escalating project costs however, construction of the planned second (east) breakwater was never realised.

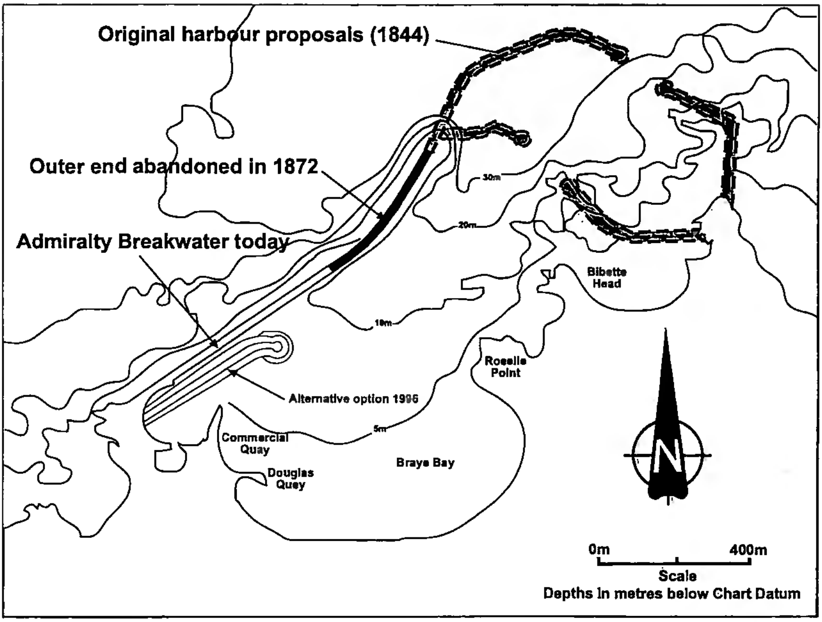

Figure 2 Alderney Harbour: The original harbour proposals

The overall length of the Admiralty Breakwater at completion in 1864 was 1430m. By 1872, however, continual storm damage, in some instances complete breaches, had led to unsustainable maintenance costs. To limit their financial commitment, the Admiralty abandoned the outer end of the Breakwater and chose to maintain only the first 871m where a temporary head, which had served to protect the 'scar end' of a seasons work during construction, formed a suitable point for termination. It is this remaining length that continues to provide shelter to Alderney Harbour today (Plate1).

Plate 1 The existing Admiralty Breakwater

The existing structure

A review of the original construction method reveals the Admiralty Breakwater to consist of two distinct sections: a rubble mound foundation which had been placed on the seabed (in water depths frequently greater than 40m) to a formation level near low water (+0.8mCD); and a masonry superstructure constructed on top of the rubble mound to +12.1mCD (Figure 3).

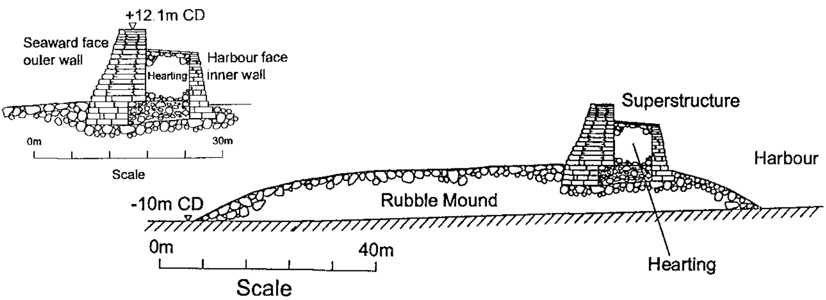

Figure 3 Section through the existing breakwater

The failure mechanisms of the existing structure have been analysed by a number of authors (Hall J et al (1995), Allsop et al (1990)). Based on this analysis, an event tree of the likely failure mechanisms was developed (Figure 4). From this analysis it is clear that any attempt to rehabilitate the existing structure will need to ensure stability of the masonry superstructure and protect it from aggressive abrasion by the highly mobile rubble mound and undermining of its toe.

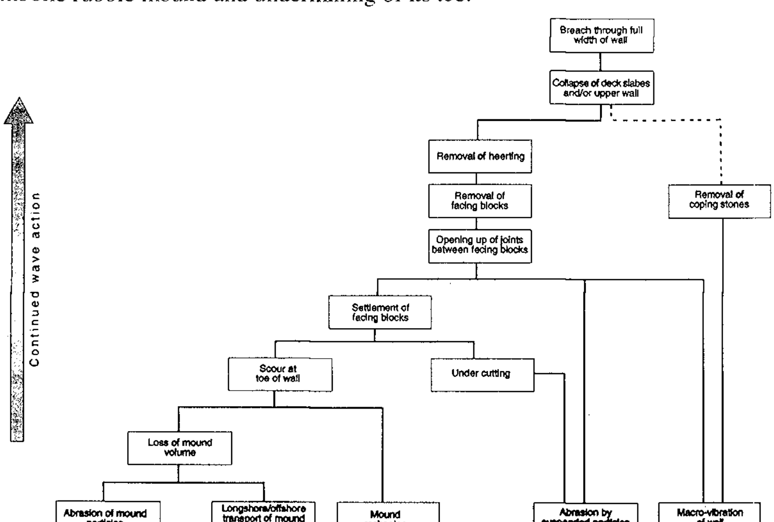

Figure 4 Likely failure mechanisms of the Admiralty Breakwater

The severe wave and tidal climate

Wave and tidal conditions at Alderney are frequently severe. The large open fetch to the north-west of the island exposes the island to the full force of Atlantic swell and the large tidal range drives notoriously strong tidal currents through The Swinge and the Alderney Race (5.5m tidal range on Mean Spring Tides and tidal currents up to 3.0m/s – see Table 1).

Table 1 Indicative tidal current speeds (measured by HR Wallingford, 1989a)

1km offshore	Upto 3.0 m/s
In the Harbour Approaches	Upto 1.0 m/s
Adjacent to the Admiralty Breakwater	Upto 0.5 m/s

Swell is an important component of the wave climate at Alderney and needs to be included in prediction of the design wave conditions. Therefore, the extreme offshore wave climate has been derived using data from the Meteorological Office Wave Model[1] of the Atlantic Ocean. Using a wave refraction model (PORTRAY, HR Wallingford, 1995) which includes the refracting effects of the strong tidal currents at Alderney, the predicted offshore waves were propagated inshore to the -10mCD contour close to the face of the Admiralty Breakwater (Table 2).

Table 2 Wave conditions at the –10mCD contour

Inshore Return Period (years)	H_s(m) (offshore wave direction 330°N)	T_m(s)	Still water level SWL(mCD)
0.1	4.0	9.6	3.6 (mid ebb)[2]
1	5.2	10.7	3.6
10	6.2	11.8	3.6
100	7.6	12.8	3.6
2000	9.5	14.2	3.6

Why is there a need for rehabilitation or replace works

The States of Guernsey, Board of Administration (the body responsible for the maintenance of the Breakwater since 1987) currently spend approximately £500k per annum (£447,000 in 1998) on maintenance of the superstructure. Even with this level of investment however, the long-term decay of the structure and occasional breaches continue (Plate 2).

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[1] This data has the distinct advantage over the more usual method of deriving an offshore wave climate from a wind-wave prediction model based on local winds in that it includes the effects of swell.

[2] Interestingly, the most severe waves impact on the Breakwater at approximately normal incidence, and originate from the 255°-285° N offshore sector; not the expected north-west direction (the largest fetch). The reason for this is the strong wave-current interactions that cause significant wave refraction. It was also found that wave-current interactions cause the largest waves occur at the ebb mid tide condition.

Plate 2 Storm attack and damage - 1962

Studies by HR Wallingford in 1990 (Allsop et al, 1990 and 1991) and more recent analysis (Sayers et al, 1996b) confirms that the rubble mound upon which the superstructure is founded continues to erode. If this trend continues, future maintenance costs are likely to increase as toe support to the super-structure is lost and breaches become more frequent.

In addition to these long-term changes in the level of the mound the level at the toe of the super-structure is highly volatile in the short-term (Figure 5). In combination the long term processes and short-term volatility of the toe level lead to considerable uncertainty as to when the mound will reach a level that critically undermines the super-structure.

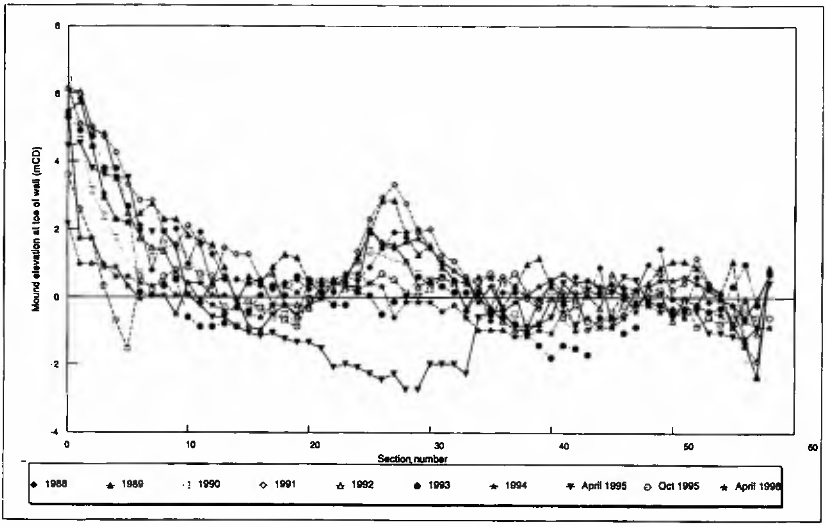

Figure 5 Toe level of the Admiralty Breakwater superstructure from dip measurement

Evolving a solution: Study terms of reference

In 1995 the States of Guernsey Department of Engineering on behalf of the Board of Administration, commissioned HR Wallingford to undertake studies to assess and design in outline the most appropriate long term solution for providing shelter to Alderney. The Terms of Reference for this study were:

"To assess the viability of alternative solutions for replacing or upgrading the Admiralty Breakwater based on the need to satisfy the following requirements:

- Minimise maintenance commitment
- Maintain access to a commercial quay
- Maintain mooring facilities for fish storage
- Maintain small craft moorings
- Limit impact on the coastline
- Minimise financial risk"

It should be noted here however, that the States of Guernsey have responsibility for protecting a harbour on the Island of Alderney and providing the financial backing (subject to financial constraints) for any capital project undertaken (if and when necessary). Therefore, not surprisingly, their objective is to minimise expenditure without compromising (but not necessarily improving) existing operations in Alderney Harbour. The objective of the States of Alderney however, is to seek an improved Harbour facility and one that provides potential for future development. These are somewhat disparate viewpoints and are not easily reconciled by a single solution.

This paper largely addresses the needs and solutions based on the Terms of Reference set out by the States of Guernsey (the Client). The arguments developed in terms of structural performance, navigation and other operational issues for the various options are however, generic to any solution proposed.

Design criteria

An important precursor to any study to propose remedial or replacement works is to understand the design criteria against which the 'solutions' are to be judged. Below is an outline of the main design criteria set for this study.

Cost limits

For the construction of a new breakwater to be viable it will need to be justified in economic terms. For the States of Guernsey this means that the primary cost of any given solution should be justified based on reduced maintenance of the Admiralty Breakwater. Based on an annual present expenditure by the States of Guernsey on maintenance of £0.5 million and a 50 year design life the capital expenditure that may be directly justified is approximately £8 million (based on a discount rate of 6%). Continued loss in the volume of the rubble mound and the known volatility of its level at the toe of the super-structure are expected to increase the frequency of major breaches in the Admiralty Breakwater. Hence, the annual maintenance cost may be expected to rise. To avoid the repair and maintenance becoming uneconomical and unsustainable it is, therefore, appropriate to consider options for rehabilitation or replacement of the Admiralty Breakwater with present day values in excess of £8 million.

Navigation issues
At present the largest vessel conducting commercial operations at Alderney is the Ariante (79.15m LOA x 13.1m beam). It is noteworthy that although there is a marked trend for smaller vessels (such as the Ariante) to be difficult to source, as they become increasingly uneconomic to operate, the Ariante has been defined as the 'design vessel' for a number of locally applicable reasons. For all designs therefore a nominal navigation channel of about 60m in width has been set (based on five times the beam of the Ariante). (Note: If it does become necessary then it is accepted that any design developed using the Ariante may require significant alteration.)

Wave disturbance at the Commercial Quay
Wave disturbance at the Commercial Quay is a function of wave transmission through the Harbour entrance and over/through the breakwater. The wave disturbance criterion adopted is that any proposed solution should provide the same standard of shelter at the Commercial Quay as is afforded at present. Based on more detailed study of the operational limitations at the Commercial Quay the limiting wave height for safe mooring at the Commercial Quay has been set as approximately 0.45m (Thoresen (1988), PIANC (1995), Iceland Harbour Authorities (1987), Brattleland (1974) and 3-dimensional physical model tests by Sayers et al, 1996a). This wave height is expected to cause total horizontal movements in the Ariante of up to 1.5m in surge and in sway, and angular movements of 2 to 5 degrees.

Small craft moorings
A total of 135 multi-point moorings are laid and maintained in Braye Bay by the Harbour Authorities. If some or all of the facilities for small craft moorings in the lee of the Admiralty Breakwater are lost a small craft marina may be required as an integral part of any solution considered.

Wave overtopping
No limit on wave overtopping for serviceability in terms of safety of access has been imposed. When overtopping is expected to represent a high risk to persons on the breakwater an overtopping hazard warning will be issued and access to the breakwater prevented. The design criterion in terms of wave overtopping was, therefore, based only on the protection afforded against wave disturbance. The criteria was set such that wave heights in the lee of the structure should be no more than that experienced at present.

Armour layer stability
Any solution proposed is likely to involve the use of rock or concrete armouring. The required performance of any armour layer is to:

- Require no more than limited maintenance in the aftermath of a 1:100 year return period storm (i.e. a storm that has a 63% chance of being exceeded during any 100 year period).

- Be able to resist `failure` (defined as a total breakdown of the form of the design) during a 1:2000 year return period storm (i.e. a storm that has a 5% chance of being exceeded during any 100 year period).

Impact on coast protection in Braye Bay and swing moorings
Wave activity in Braye Bay will be an issue when selecting the most acceptable option. The acceptability of the design proposals in terms of the impact on wave activity within Braye Bay has been based on the relative increase when compared to the existing situation and the significance of that increase. A prescriptive criterion has not, therefore, been set.

Scheme options and design

A number of solutions have been proposed:

- Rehabilitation/protection of the existing structure
  - Improved maintenance
  - Rock / concrete armouring, **Option A**
  - Grouting
- Offshore breakwaters
- Abandonment and construction of a new breakwater in the lee of Admiralty Breakwater, **Option B**

Some of the above form part of the studies undertaken by HR Wallingford and others have been investigated by independent consultants and those employed by the States of Alderney. This paper focuses on the detailed studies undertaken in the investigation of the performance of two of these options: Option A and Option B.

Option A

Option A consists of a shortened length of the existing Admiralty Breakwater armoured using a composite structure of concrete armour units (Accropodes) and rock. A 'spur' breakwater is then 'returned' through the superstructure of the Admiralty Breakwater to afford protection against wave penetration up to the Commercial Quay (Figure 5 and 6).

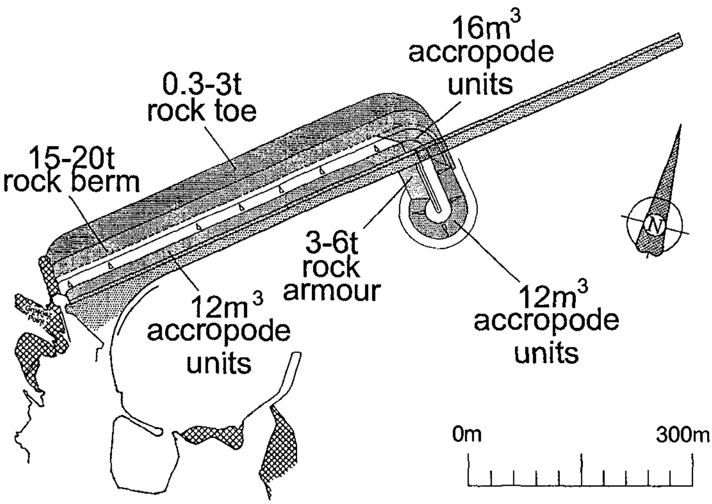

Figure 5 Plan view: Option A

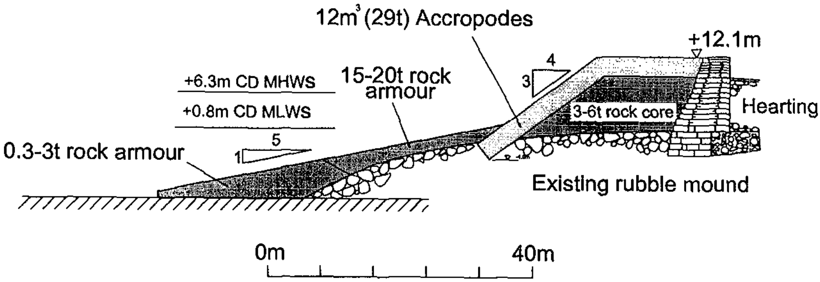

Figure 6 A typical cross-section: Option A

Option B

This option abandons the Admiralty Breakwater and proposes the construction of a new breakwater within Alderney Harbour. The new breakwater is set back 70m landwards of the Admiralty Breakwater. Its construction uses concrete armour units (Accropodes) and rock armour (Figures 7 and 8).

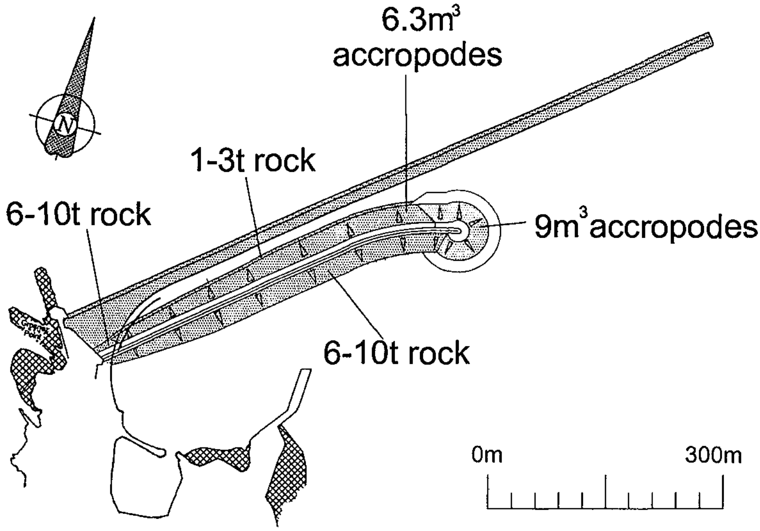

Figure 7 Plan view: Option B

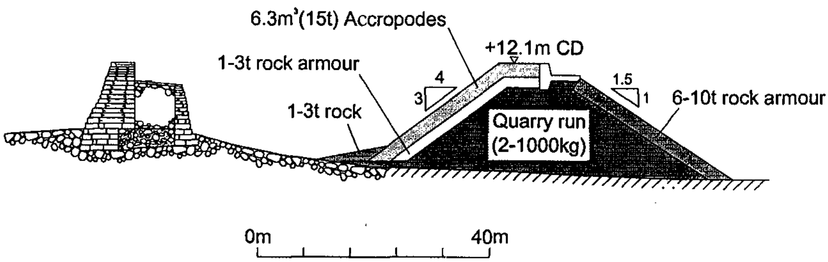

Figure 8 A typical cross-section: Option B

Comparing Options A and B

Based on detailed 2 and 3-dimensional physical modelling, numerical modelling of waves and currents, engineering design, investigation of construction risks and cost estimates it has been possible to compare the performance of Options A and B and comment on their ability to satisfy the study terms of reference. A discussion of this comparison is given below.

Impact on the coastline of Braye Bay
Physical model tests suggest that when the Admiralty Breakwater is replaced with either Option A or B wave activity within the Bay is increased. This will adversely impact on the tenability of present swing moorings within the Bay and can be expected to accelerate coast erosion in the east of the Bay. Increased coastal erosion will, in the medium term, result in the need for remedial measures. There is, however, no significant difference between the two Options A and B in terms of their likely impact on the coastline of Braye Bay.

Impact on navigation
Navigation simulations were undertaken to establish the feasibility of continuing to navigate into Alderney Harbour using the Ariante following construction of the proposed breakwater Option B.

Prior to these studies two principal concerns regarding the approach and berthing of a ship if the Alderney Breakwater was shortened were raised. These were:

- The ability of the ship to counter the strong cross currents in the existing approach.
- The ability of the design ship to slow its approach to a near zero speed in a controlled manner in the distance from the end of a new breakwater to the Commercial Quay.

To investigate the validity of these concerns comprehensive navigation simulations were undertaken in the HR Wallingford simulator[3] (Sayers et al, 1996a).

[3] The mathematical model used in the HR Wallingford simulator is of a standard type, using Newtonian equations in three degrees of freedom, and having a modular structure. The effects on the hull of all the influences due to the hydrodynamic, effect or and disturbance forces are added, and the accelerations found in three degrees of freedom, i.e. in the surge, sway and yaw directions. Integration and transformation will yield the position of the ship in the playing area. Once the ship position is known, this position can be used to access the databases for current and depth, so as to produce new currents and depths for use in the next iteration of the model equations. The outputs of the model are the position and heading of the ship as a function of time, taking account of the effects of wind, current, depth of water and tugs (as necessary). The mathematical models used to represent the Ariante must also behave in such a way that the position, swept path and heading of the simulated ship are always representative of real behaviour (including the combined influence of wind, waves and currents).

Prior to undertaking the simulations it was important to reliably predict the strong tidal currents and include them in the simulations. To obtain the required variable resolution, with a finer mesh in the area of the Admiralty Breakwater and a coarser grid further away, the numerical model TELEMAC-2D (developed by LNH, Paris and HR Wallingford) was selected as the most suitable.

Once calibrated (against various existing sources of current data and specially commissioned surveys) TELEMAC-2D was used to predict in detail the existing flow regime and the likely future changes if the Admiralty Breakwater was abandoned and Option B constructed (Figure 9).

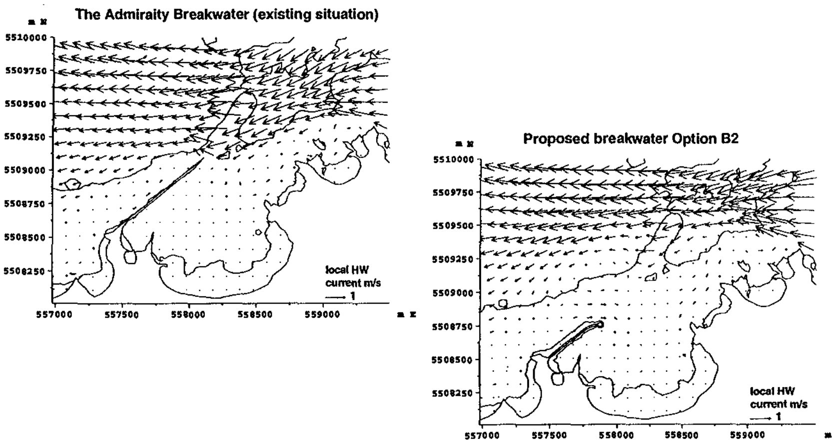

Figure 9 Tidal flows: Existing and future conditions

It can be observed that in the existing situation an eddy current is generated offshore of the Admiralty Breakwater during the late flood (generated as the strong tidal currents in the Swinge flow past the Admiralty Breakwater). This leads to a strong cross current at the head of the Admiralty Breakwater. This current flows westward at about 1 m/s causing difficult for vessels approaching the existing harbour.

With Option B the eddy is affected by changed breakwater location and is generally significantly reduced with the proposed scheme when compared with the existing condition[4].

4 For most of the runs it was assumed that the existing Breakwater had totally collapsed, so that there was no protection beyond the head of the Option B breakwater. For many years this is unlikely to be the case, and the entrance channel will be afforded some additional protection from waves, particularly for winds from north through to west. The condition of an Admiralty Breakwater in a partially collapsed condition was not considered.

The simulations confirmed that at present it is not practicable to start to slow the ship significantly from its approach speed of about six knots until the ship is in the shelter of the Admiralty Breakwater. Once in shelter, the Ariante at present needs around five ship lengths to slow in a controlled manner. However, when the Admiralty Breakwater is replaced, the improved tidal conditions in the approach to the Harbour facilitate a slower approach speed past the head of the new breakwater. Consequently, the distance required for the ship to slow once inside the shelter of the breakwater is reduced.

In summary the navigation simulations concluded that the adopted position of the head of the proposed breakwater, Option B2, is an optimum compromise between the two conflicting requirements, of shelter and ease of approach, given above. When combined with approach navigation aids Option B allows satisfactory access to Commercial Quay.

Provisions for small craft moorings
The disadvantage both Options A and B is loss of harbour space and the restricted flexibility for future harbour.

To minimise encroachment into the existing harbour space of Option B concrete armour units (15t Accropode units) are used as the primary armour layer. This enables a steep seaward face of 3 in 4 to be used to minimise the breakwater footprint without compromising structural stability. Even so, in the case of Option B seventy moorings are lost, including twenty local, service and store box moorings. A slightly reduced number are lost if Option A is constructed.

To offset the loss of moorings it was shown that it would be possible to relocate the majority of moorings in to the space just outside of Little Crabby Harbour. (Further details of the proposed new anchorage / marina development may be found in Sayers et al, 1996a)

Interaction with a decaying Admiralty Breakwater
The unpredictable decay of the Admiralty Breakwater may adversely affect the performance of Option B. However, the physical model investigations allay many of the early concerns. The potential for wave energy to be focused through breaches in the Admiralty Breakwater causing structural damage to Option B has been explored and discarded. In addition, fouling of the navigation approaches by mound material and abrasion of the Accropode units by mound material carried landwards by incoming waves have both been considered and discounted as a significant risk.

Construction risks and costs
The novel idea of constructing a new breakwater 'set-back' in the lee of the Admiralty Breakwater (Option B) has two distinct advantages over construction on the seaward side of the Admiralty Breakwater (Option A). Firstly, the existing breakwater could be used as shelter to the construction, significantly reducing construction risk and lengthening the safe construction working period. Secondly, it is predicted that the rubble mound foundation of the Admiralty Breakwater will remain in place in the long-term, albeit at a reduced level, providing partial shelter to the completed works

during the worst of the Alderney storms. In-turn this eliminates the need for the very heavy armour rock required if construction were to take place on the seaward face of the Admiralty Breakwater, material that is often difficult to source.

For each of the main breakwater Options A and B the estimated construction costs are given below in Figure 10.

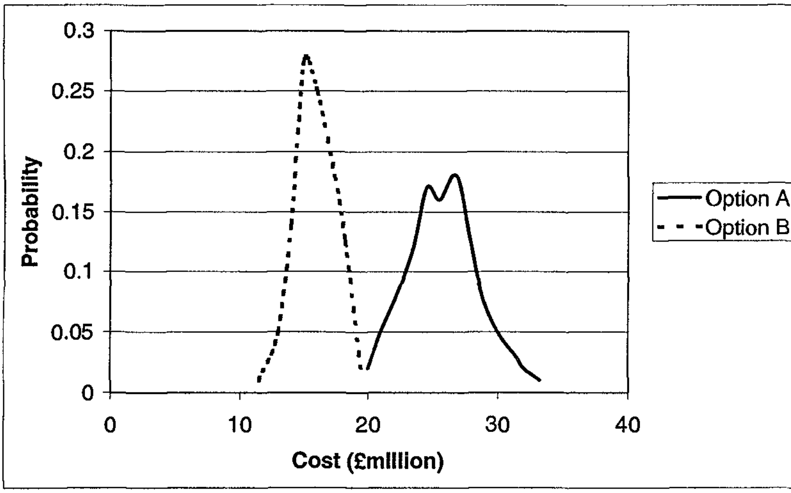

Figure 10 Estimate construction costs: Options A and B

These cost estimates have been developed based on detailed dialogue with would-be contractors and reflect the higher construction risks associated with Option A. For example, potential future increases in price of rock would add considerable cost to Option A due to the large quantities of large armour rock required (an increase of £10/m³ placed would add £0.9 million to the total construction cost). Option A is further disadvantaged by severe construction risks; heavy downtime during a necessarily long construction period spread over several seasons is also expected to add considerable cost to the project. The difficulty in excavating the existing mound to secure the toe of the Accropode slope and the susceptibility of part-completed structures to storm damage will add further risk, and hence cost, to the project. In addition, Option A requires large volumes of heavy armour rock (87056m^3 of 15 to 20t rock). This will be difficult to source and may have a slow rate of supply.

Option B however is less sensitive to fluctuations in the price of large amour rock and has no significant risk attached to construction due to its sheltered position in the lee of the Admiralty Breakwater (giving a high degree of certainty to the cost estimates). It can also be constructed in one year (assuming sufficient lead in time is given to facilitate pre-casting and stockpiling of the Accropode units and rock).

To over-come some of these issues a procurement route involving a design and construct package is recommended.

Summary: Options A and B
Option A partially retains the visual appearance of the Admiralty Breakwater from the Harbour side and maintains an area for swing moorings to the north of the 'Safety Fairway' (albeit for a reduced number of vessels). In addition, existing access to Little Crabby Harbour is maintained. However, Option A involves the abandonment of the outer 365m of Admiralty Breakwater. Therefore, a considerable number of swing moorings will be lost.

Following the demise of the Admiralty Breakwater and the construction of Option B, it is predicted that the tidal current regime in the approaches to the new Harbour will be generally improved over that experienced at present. This facilitates access to the Commercial Quay under similar environmental restricts to those applied at present. In addition, access to Little Crabby Harbour is also maintained. the historic value and appearance of the Admiralty Breakwater is, however, lost..

Both Options A and B lead to the loss of protection to majority of swing moorings currently available in Braye Bay and Harbour space. Most of these, could, however to relocated. Effective protection to the east coastline of Braye Bay is also lost together and the likely erosion will have to be management appropriately.

What are the alternatives to Options A and B

The rehabilitation or replacement of Alderney Breakwater has caused considerable interest; both in Alderney and Guernsey. As a result, various consultants have been engaged by the States of Alderney to propose ameliorative works that attempt to address the Terms of Reference as given by Alderney (as opposed to those defined by the States of Guernsey). The "solutions" proposed range from armouring the full length of the Admiralty Breakwater (at an estimated cost of at least £40million) to the use of salvaged ship hulls as offshore reefs.

Some of the "solutions" proposed by the various consultants offer little in the detailed understanding of the existing Breakwater and how any future works may perform. Others, however, are more interesting and worth of further investigation. Due to the present status of this project (currently in the hands of the Board of Administration, States of Guernsey) it is, unfortunately, outside the scope of this paper to discuss the details of these "alternative" proposals.

Conclusions

Options A and B provide well-engineered and robust solutions to the problems perceived by Guernsey. The costing exercise associated with Options A and B has however, demonstrated that due to the harsh physical environment at Alderney the cost of construction is sensitive to the method adopted and the availability of the required sizes and volumes of rock. In particular the construction risks associated with undertaking works on the seaward side of the Admiralty Breakwater (for example Option A) are vast.

This study has clearly demonstrated that if different questions are posed different solutions will result. At present the States of Guernsey (would-be funders of any scheme) have differing requirements to the States of Alderney (would-be users of any scheme). It is clear therefore, that until consensus is achieved on the ultimate objectives of the project there will be continued debate over the selection of the most appropriate solution for rehabilitating or replacing the Admiralty Breakwater.

Acknowledgements

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