Whitby Coastal Strategy

Further Investigations at Whitby Harbour

Scarborough Borough Council

April 2009

Final Report

9T0429

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HASKONING UK LTD.
COASTAL & RIVERS

Marlborough House
Marlborough Crescent
Newcastle upon Tyne NE1 4EE
United Kingdom
+44 (0)191 211 1300 Telephone
+44 (0) 191 211 1313 Fax
info@newcastle.royalhaskoning.com E-mail
www.royalhaskoning.com Internet

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Drafted by	Nick Cooper, Chris Grogan and Will Culley	
Checked by	Chris Grogan	
Date/initials check	………………….	………………….
Approved by	Nick Cooper	
Date/initials approval	………………….	………………….

SUMMARY

Background

The Whitby Coastal Strategy was completed in July 2002, covering approximately 5km of North Yorkshire's coastline from Sandsend to Abbey Cliff and extending approximately 2km upstream in the River Esk estuary.

The Strategy recognised the critical importance of the Whitby Harbour structures (main piers and extensions) to the overall flood and coastal defence system across the wider Strategy frontage, as well as directly to the harbour itself.

One of the most significant findings of the Strategy was the identification of the poor or very poor condition and performance of the main arms of the East and West Piers. The Strategy concluded that both main piers had a residual life of less than 10 years and made recommendations for a capital coastal defence scheme to significantly improve the coastal defence performance of the harbour.

The capital schemes were proposed to incorporate:

- major refurbishment of the West Pier, including upgrading and partial reconstruction of the bullnose;
- rock armour revetment on the outer face of the West Pier Extension coupled with repairs to the structure;
- rock armour revetment on the outer face of the East Pier coupled with repairs to fill voids and replace damage or missing blocks and replace/repair sheet piling; and
- rock armour revetment on the outer face of the East Pier Extension coupled with repairs to the structure.

Under the national funding prioritisation mechanisms that were current at that time, the capital schemes did not generate a sufficient priority score to enable implementation within the desired timescales. However, funding was made available in 2008/09 for undertaking the further investigations that were recommended in the Strategy to better characterise the extent and nature of the structural problems at Whitby Harbour and help better define the capital works required and associated costs and timescales for their implementation.

This report presents the findings from the further investigations that have now been undertaken on the Whitby Harbour structures. This information has also been used to re-evaluate the concept schemes that were proposed for the harbour structures in the original Whitby Coastal Strategy. The re-evaluation has also been undertaken in accordance with changes since the original Strategy was published in 2002, including new scheme prioritisation and assessment procedures, and changes in guidance relating to sea level rise.

The Role of the Whitby Harbour Piers

The present study has confirmed that the Whitby Harbour structures are essential in providing a coastal defence to the town of Whitby against erosion and essential in reducing tidal flood risk along the lower reaches of the River Esk estuary. They are also critical structures within the overall system of flood and coastal defence within the wider Strategy area.

In addition, the structures are essential for providing navigational shelter to vessels during storms and essential in retaining beach sediment along Whitby Sands and Upgang Beach that then provides natural protection to backing defences and sea cliffs.

Further Investigations of Structural Condition
In order to further investigate some of the defects associated with the main piers and pier extensions that were identified in the original Strategy, and to provide new, comprehensive and up-to-date information on the condition of these structures, a series of physical investigations was designed and undertaken between February and October 2008.

Firstly, existing surveys and associated reports were reviewed to highlight known problem areas and to identify gaps in data. An appropriate programme of investigations, using a range of both non-intrusive and intrusive techniques, was then designed to provide additional data. Specifications and contract documents were then written and used to procure suitable contractors, who were then managed in their execution of the investigations. The following investigations were undertaken:

- Topographic, digital measured and photographic surveys
- Dive survey and visual inspections
- Ground probing radar and microgravity surveys
- Ground investigation; and
- Hydrographic, geophysical and seismic surveys.

Further Investigations of Defence Performance
In order to further investigate some of the defence performance and physical coastal process issues associated with the piers and pier extensions, a series of modelling and assessment investigations was designed and undertaken. These have informed an understanding of the present-day processes in the vicinity of Whitby Harbour, tested the vulnerability from structural failure of the harbour piers, and assessed the implications of different management options on overtopping discharges. This comprised the following components:

- Wave climate modelling and water level assessments;
- Beach behaviour and sediment budget analysis;
- Overtopping assessments; and
- Flood levels along the River Esk estuary.

Overview Assessment of Existing Structures
From the further investigations, the following assessments have been made of the harbour piers and their extensions:

Main West Pier – The overall condition is poor, with movement of sandstone blocks, opening of joints, scour at sea bed level, cracking and chipping of blocks, and voiding behind facing blocks. Overtopping discharges are in excess of target thresholds for serviceability and will worsen over time due to sea level rise.

West Pier Extension – The overall condition is poor, with opening of concrete joints and extensive voiding in the protective steel sheet piling. Overtopping discharges are likely to be in excess of target thresholds for avoidance of structural damage.

East Pier - The overall condition is poor, with cracking, chipping, displacement and settlement of sandstone blocks, opening of joints, and voids behind facing blocks. There is evidence of the onset of accelerated low-water corrosion to sections of protective sheet piling. There is also a series of three hollows in the sea bed adjacent to the pier wall which could lead to wall collapse. Overtopping discharges are in excess of target thresholds for serviceability and are greatest at the landward end of the pier. Overtopping will worsen over time due to sea level rise.

East Pier Extension – The overall condition is very poor, with a major void at the south-east corner that results in an entire section of concrete visible above water being suspended via a cantilevering action from the rest of the structure. In addition, there are numerous voids in the sheet piles caused through corrosion of the steel and loss of backing concrete. Overtopping discharges are great along this structure and well in excess of target thresholds for avoidance of structural damage.

Summary

The present investigations have highlighted that the existing piers are in poor condition and that the East Pier Extension particularly is at risk of failure and could possibly collapse in the short term. The probable failure and breach scenario is identified below:

1) The landward end of the East Pier extension is likely to collapse, due to the scouring of the supporting material under the landward end of the structure. This collapse would lead to increased exposure to the bullnose and seaward end of the main East Pier from tidal surges and wave attack.

2) The collapse would expose the core of the East Pier extension. The sea would continue to attack the remains of the outer sheet piles, scour the foundation to the next section of the structure and outwash the newly exposed core of the structure. This is likely to have been formed of the original weaker mass concrete construction and will erode faster than the reinforced concrete repair on the outer face. With time, further sections of the East Pier extension are likely to collapse in the same manner, propagating the breach.

3) The outer face of the main East Pier at the seaward end currently has damage to the stone block facing where scour has eroded the mortar from the joints and blocks are settled and cracked. The displaced blocks mean that seawater flushes the fill material out from the pier core from behind the blocks leaving cavities. This narrow section of pier is shown to have significant voiding behind the stone block faces on both sides and below the deck at present. These voids would increase in size at a greater pace than previously due to the increased exposure to sea conditions caused by the absence of protection from the East Pier extension.

4) As the worst conditions are from the north and northeast, the blocks would be dislodged into the voids by wave energy, causing the outer face to collapse taking away part of the pier deck. This would exposure the core of the main pier structure.

5) With the core exposed, the waves would further attack the core of the structure, dislodging the fill material and removing the support to the deck. This would reduce the pier height and eventually lead to a breach of the East Pier. With the breach, debris could disperse into the navigational channel presenting a hazard to vessels using the harbour.

6) The breach would continue to extend laterally during storm and high tide conditions as waves will propagate over and through the breach, causing it to enlarge. Eventually the whole of the northern section of the main East Pier would collapse into a mound with an ever decreasing defence height and effectiveness. This would allow larger waves to

enter the harbour and attack the inner face of the main West Pier and its extension. Waves may also begin to impact assets further upstream in the River Esk estuary.

7) With the increased exposure to the main West Pier on its inner faces this structure too would eventually collapse and breach in a similar manner described for main East Pier. This is demonstrated by the defects recorded along the inner face of the main West Pier which leave it vulnerable to such processes. The analogue can be further extended to the West Pier extension, due to the scour action on the inner landward end, which could extend to collapse part of this structure.

8) If the structures receive no capital investment, they will continue to erode, collapse and disintegrate until only the ruins remain. This will expose the town and estuary to increase wave and tide conditions.

9) With the loss of the main West Pier and its extension, the beach deposits shift and deplete from the current profiles on the Whitby Sands beach. The sediment would block the navigation channel and drift further along the coast to cover the bedrock foreshore to the east of the harbour.

Management Options

To address the present condition and performance problems of the piers and pier extensions, there are three principal categories of options, namely:

Do Nothing - this is considered here primarily for the purposes of assessing a base case against which other options will be compared. It would involve no further management or maintenance of the piers or pier extensions.

Do Minimum – this is considered to be the ‘continue present practice’ option, whereby relatively modest maintenance is undertaken annually. This mainly focuses on visual inspection and local reactive repairs for operational and health and safety purposes.

Do Something – this covers a wide range of potential options aimed at improving the present condition and/or performance situation through some formal intervention. There are various means of implementing this option, with different types and standards of improvement that can be attained through implementation of each.

The strategic management options for Whitby Harbour that have been considered are summarised in the following table.

Strategic Management Options

<table>
<tr><th colspan="2">Option</th><th>Description</th></tr>
<tr><td colspan="2">1</td><td>Do Nothing – the ‘walk-away’ base case against which other options are compared.</td></tr>
<tr><td colspan="2">2</td><td>Do Minimum – continue with present practice involving modest reactive maintenance, primarily for reasons of harbour operations and health and safety.</td></tr>
<tr><td rowspan="8">Do Something</td><td>3</td><td>Advance the Line - protect the existing harbour structures through construction of a new structure(s) to seaward.</td></tr>
<tr><td>4</td><td>Managed Realignment – changes in harbour plan form alignment to reduce exposure.</td></tr>
<tr><td>5</td><td>Modify existing structures to improve present structural condition.</td></tr>
<tr><td>6</td><td>Modify existing structures to improve present defence performance (especially with respect to overtopping discharges).</td></tr>
<tr><td>7</td><td>Modify existing structures to improve present structural condition and present defence performance.</td></tr>
<tr><td>8</td><td>Managed Removal - removal of harbour structures and management of flood and erosion risk through other means.</td></tr>
<tr><td>9</td><td>Managed Relocation of vulnerable assets – relocation of properties, businesses, infrastructure and other assets at risk of erosion and flooding.</td></tr>
<tr><td>10</td><td>Demolish and Rebuild – the existing piers and extensions would be demolished and rebuilt on their existing alignment.</td></tr>
</table>

Following an initial screening process against technical, economic and environmental criteria, options 1, 2, 5 and 7 were short-listed for more detailed consideration.

This process has identified a preferred option of modifying the existing structures to improve present structural condition and present defence performance (Option 7). This will involve:

- Pointing, grouting and partial sheet pile protection to the main piers;
- Sheet piling and concrete fill to the pier extensions;
- Reducing overtopping risk along the piers and extensions.

The above approach will have some undoubted adverse impacts as well as the intended positive impacts associated with its implementation. In particular, further consideration will need to be given to the optimum method of reducing wave overtopping along the piers and their extensions, given the rates of sea level rise that will be experienced and the key amenity, aesthetic and heritage value of the main piers and their iconic setting.

Next Steps

1. Due to the urgency of the capital works needed at the south-east corner of the East Pier extension, a Project Appraisal Report should immediately be produced to seek funding to prevent a collapse and breach in this area in advance of the main works.

2. A solution to this defect must then be designed and implemented with urgency because if a collapse or breach were to occur, gaining access to temporarily or permanently construct remedial works would be extremely difficult, especially as the breach is likely to form during winter storm conditions. Therefore prevention of collapse and breaching is essential.

3. In parallel with implementation of the East Pier extension urgent works, a Project Appraisal Report should be produced in support of an application to the Environment Agency (as funding body) for Grant-in-Aid for subsequent stages of development of the main works.

4. Following allocation of funding by the Environment Agency, detailed design and assessment shall be undertaken. This will involve physical and/or numerical modelling of overtopping, preparing an Environmental Impact Assessment, obtaining licences and consents, preparing Tender Documents, and procurement of Contractors.

5. Once the scheme has been designed and assessed in detail, it will be delivered by the preferred Contractor through construction works.

It is vital to note that consultation with the public and with statutory regulatory bodies will continue to be undertaken throughout the next steps of the project to investigate opportunities for minimising concerns and impacts through a considered detailed design and environmental impact assessment process.

CONTENTS

Appendices

List of Tables

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1 BACKGROUND TO THE FURTHER INVESTIGATIONS

1.1 Background

The Whitby Coastal Strategy (the Strategy) was completed in July 2002, comprising three main volumes and seven supporting appendices as follows:

Volume	1	Text and Figures
	2	Aerial Photographs
	3	Management Units
Appendix	I	Wave Climate, Coastal Processes and Flood Risk
	II	Condition Assessment of the Coastal and River Defences
	III	Coastal Slope Condition and Management
	IV	Environmental Studies
	V	Economic Assessment
	VI	Beach Survey
	VII	Factual Report on Ground Investigation at Metropole Cliff

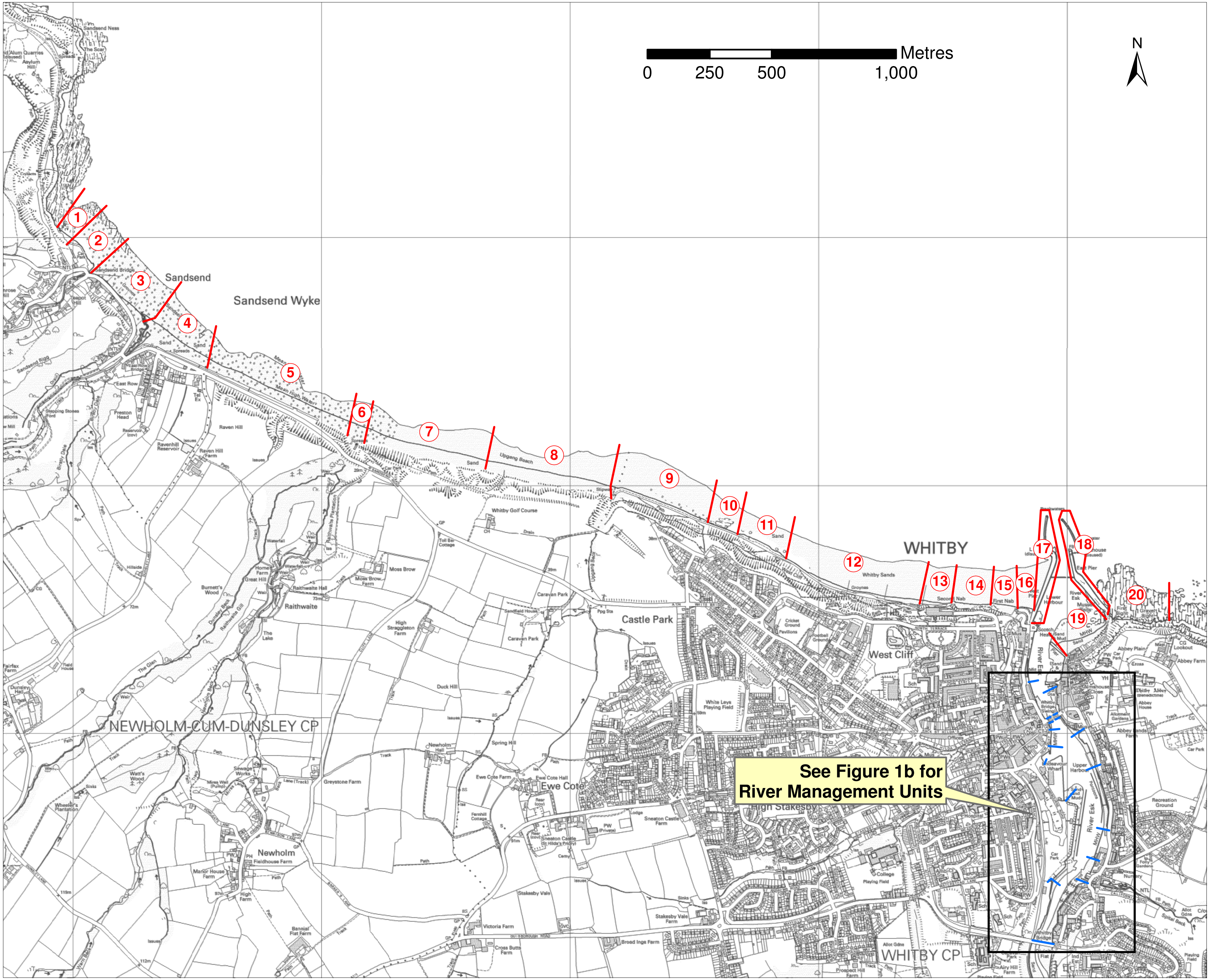
The Strategy covered approximately 5km of North Yorkshire's coastline from Sandsend to Abbey Cliff and extended along approximately 2km of the lower reaches of the River Esk estuary, upstream to the high-level road bridge. The Strategy frontage is shown in Figure 1.

Within this overall stretch of coastline there are several important environmental designations, including Heritage Coast, Sites of Importance for Nature Conservation (SINC) and a Site of Special Scientific Interest (SSSI) which has been designated on the basis of internationally important geological strata located to the immediate east of Whitby Harbour. The harbour itself is vital to the economy of the town of Whitby, particularly in relation to tourism, fishing and the marina, and the whole frontage has a dramatic landscape and highly aesthetic appearance. Much of Abbey Plain is scheduled as an ancient monument of national importance and the main piers at Whitby Harbour are Grade II Listed Structures.

In the Strategy the coastal frontage was sub-divided into 20 coastal Management Units, with the River Esk frontage sub-divided into 9 Management Units on the west bank and 9 on the east bank. These Management Units are also shown in Figure 1.

Of the coastal Management Units, one (MU17) covered the Whitby Harbour West Pier and Extension and one (MU18) the East Pier and Extension. Figure 2 shows the different elements of the harbour structures, identifying the West and East main piers, bullnoses and extensions. The Strategy recognised the critical importance of all these harbour structures to the overall flood and coastal defence system across the wider Strategy frontage, as well as directly to the harbour itself.

One of the most significant findings of the Strategy was the identification of the poor condition and performance of the main arms of the East and West Piers. The Strategy concluded that both main piers had a residual life of less than 10 years and made recommendations for a capital coastal defence scheme to significantly improve the coastal defence performance of the harbour.



Title:
Strategy Frontage -
Coastal Management Units

Project:
Whitby Coastal Strategy Further Investigations at Whitby Harbour

Client:
Scarborough Borough Council

Date:	Scale:
January 2009	1 : 20,000

Figure:	Drawn:	Checked:
1a	TC	NC

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Management Unit boundary

RW1 Management Unit number

Title:
Strategy Frontage -
River Management Units

Project:
Whitby Coastal Strategy Further
Investigations at Whitby Harbour

Client:
Scarborough Borough Council

Date:
January 2009

Scale:
1 : 7,800

Figure:
1b

Drawn:
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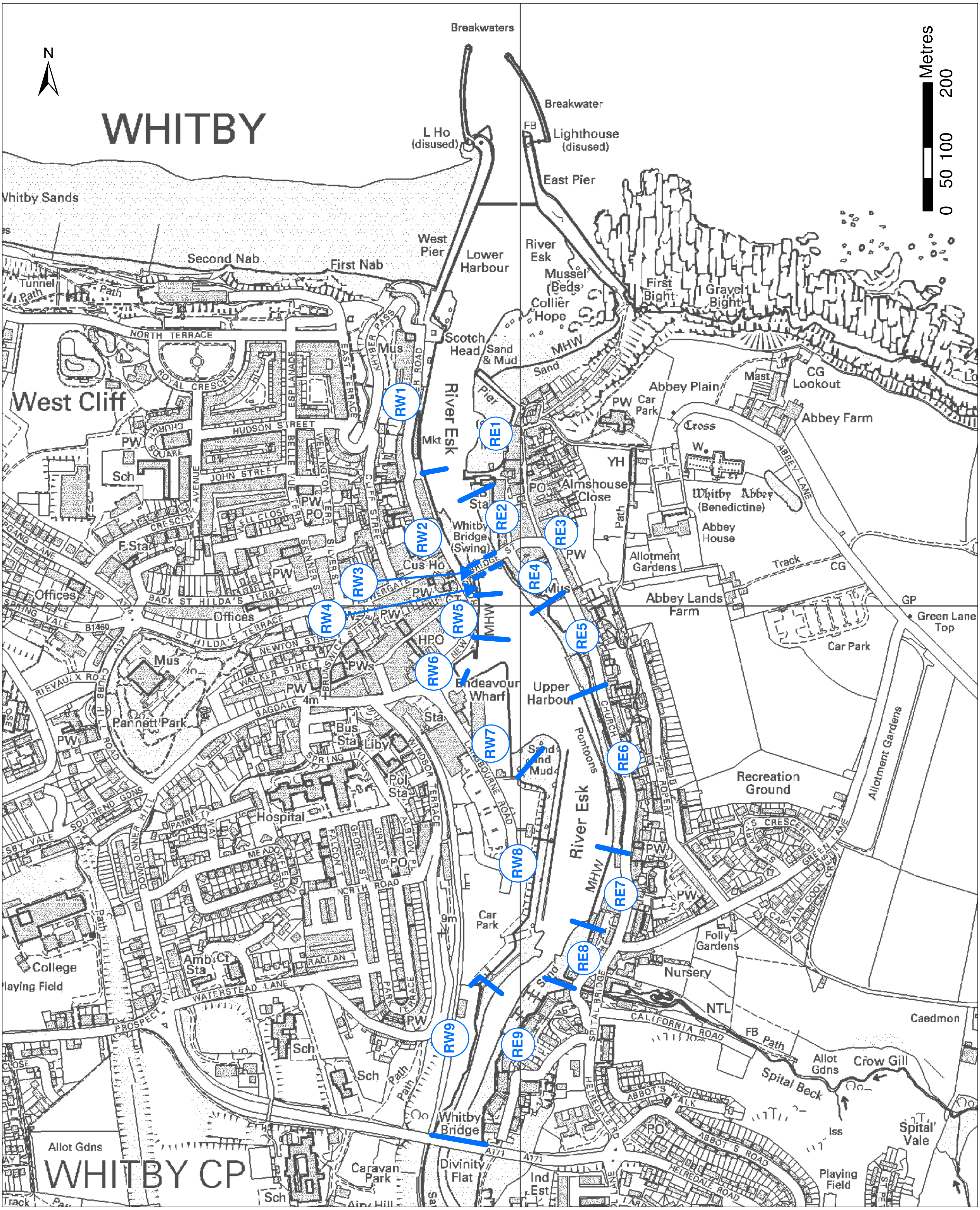

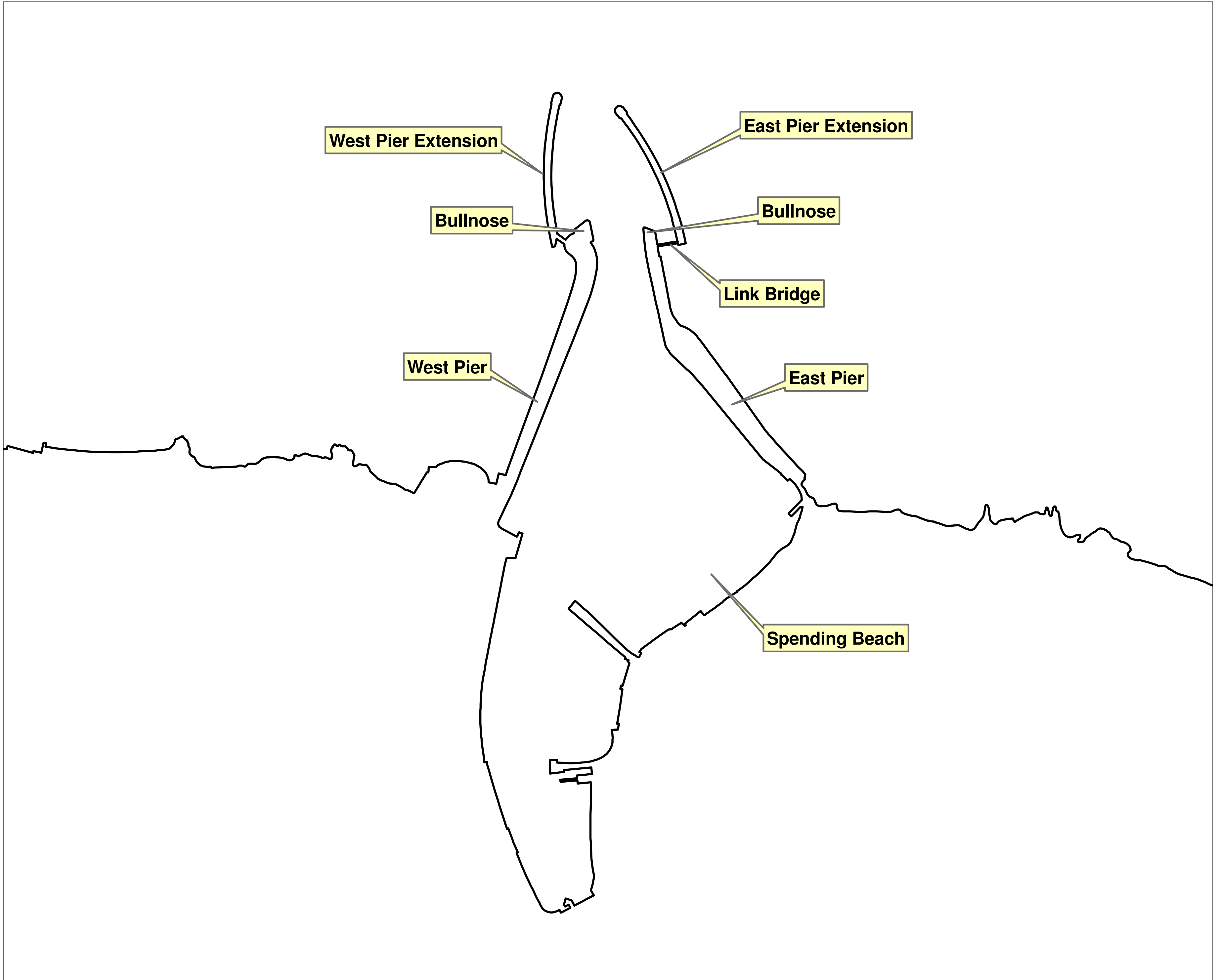

Note: The Link Bridge was demolishd following storm damage and there is presently no pedestrian access between the East Pier and its extension.

Title:
Whitby Harbour Structures

Project:
Whitby Coastal Strategy Further Investigations at Whitby Harbour

Client:
Scarborough Borough Council

Date:	Scale:
January 2009	1 : 6,000

Figure:	Drawn:	Checked:
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The scheme costs were estimated to be in the range £6,200,000 to £9,6000,000 for the main piers and £4,400,000 to £6,850,000 for the pier extensions. This range reflected the uncertainty in the extent of work that would be required to strengthening of the core of the structures. For assessment purposes 'most likely' costs of £8,950,000 for the main piers and £6,850,000 for the extensions were assumed. The capital schemes were proposed to incorporate:

- major refurbishment of the West Pier, including upgrading and partial reconstruction of the bullnose;
- rock armour revetment on the outer face of the West Pier Extension coupled with repairs to the structure;
- rock armour revetment on the outer face of the East Pier coupled with repairs to fill voids and replace damage or missing blocks and replace/repair sheet piling; and
- rock armour revetment on the outer face of the East Pier Extension coupled with repairs to the structure.

Under the national funding prioritisation mechanisms that were current at that time, the capital schemes did not generate a sufficient priority score to enable implementation within the desired timescales. However, funding was made available in 2008/09 for undertaking the further investigations that were recommended in the Strategy to better characterise the extent and nature of the structural problems at Whitby Harbour and help better define the capital works required and associated costs and timescales for their implementation.

This report presents the findings from the further investigations that have now been undertaken on the Whitby Harbour structures. This information has also been used to re-evaluate the concept schemes that were proposed for Management Units 17 and 18 in the original Whitby Coastal Strategy. The re-evaluation has also been undertaken in accordance with changes since the original Strategy was published in 2002, including new scheme prioritisation and assessment procedures, changes in guidance relating to sea level rise, and emerging information from the update to the River Tyne to Flamborough Head Shoreline Management Plan 2 (Royal Haskoning, 2007).

1.2 The Role of the Whitby Harbour Piers

As previously discussed, the Whitby Harbour piers (main piers and extensions) are deemed critical structures within the Strategy area. This section briefly describes the role and importance of the structures within this wider context.

The Whitby Harbour structures are:

- Essential in providing a coastal defence to the town of Whitby against erosion.
- Essential in reducing tidal flood risk along the lower reaches of the River Esk estuary.
- Critical structures within the overall system of flood and coastal defence within the Strategy area.
- Essential for providing navigational shelter to vessels during storms.
- Essential in retaining beach sediment along Whitby Sands and Upgang Beach that provides natural protection to backing defences and sea cliffs.

Figure 3 shows the harbour and surrounding nearshore area under a storm event in 1999. This figure shows that offshore of the pier extensions (location A) wave conditions are quite severe. With progression towards the coastline (location B) there is a natural reduction in wave height outside of the harbour arms due to changes in sea bed bathymetry, but even directly at the shore (location C) wave heights remain relatively high, potentially leading to erosion of the sea cliffs along the shore.

In marked contrast, wave conditions within the harbour are vastly reduced by the influence of the main piers and the pier extensions. Immediately within the harbour mouth (location D) waves are less than at a corresponding sea bed position outside of the harbour and conditions reduce further still with progression up-harbour (location E) until waves are relatively benign at the spending beach (location F) and by some of the town's key infrastructure at the natural mouth of the river (location G). From this figure it can very easily be envisaged that in the absence of the harbour structures, considerably greater wave conditions would propagate up-estuary, leading to massively increased erosion and tidal flooding.

Importantly, the West Pier and its extension also play a vital role in retaining beach and nearshore sediment to the west of the harbour; this plays three important functions. First, it helps retain healthier beaches along the Whitby Sands and Upgang Beach frontages that contributes to improved natural attenuation of wave and tidal energy and helps in the overall defence 'system' of the backing sea cliffs. Second, it reduces significantly the volume of sand that would otherwise drift along the shore or be transported in suspension along the nearshore zone and become deposited in Whitby Harbour, requiring dredging of the navigation channel and disposal of the spoil. Third, by retaining material to the west of the harbour it keeps the geological interest of the foreshore between the East Pier and Saltwick fresh and prevents it from becoming buried by sand.

The West Pier and extension also provide direct protection to the Whitby Sands cliffs from any waves approaching from east of north. Similarly, direct protection is provided to the cliffs to the east of the harbour from waves coming from west of north by the East Pier and its extension. Furthermore, the relict landslip complex within the harbour mouth is protected by the structures against waves from all directions. The more sheltered wave climate within this zone also enables sand to accumulate in a spending beach which further contributes to the natural protection against cliff erosion of this populated area.

The pier extensions are important parts of this overall flood and coastal defence system and are not simply navigational structures. The extensions not only trap a considerable volume of sand that is transported in the nearshore zone, thereby helping retain healthier beaches along Whitby Sands, but they also directly shelter the main piers under the most severe incoming wave directions.

Overall, then, it is clear to see why the Whitby Harbour structures are deemed so important in providing flood and coastal defence to not only the harbour itself, but also to considerable lengths of frontage up-estuary and to adjacent sections of open coastline to both the west and east. Through gaining this understanding of how the overall system functions, the findings from the further investigations on the structures themselves can now be fully appreciated within an appropriate wider context.

Title:
Wave Conditions in and around the Harbour

Project:
Whitby Coastal Strategy Further Investigations at Whitby Harbour

Client:
Scarborough Borough Council

Date:	Scale:
January 2009	NTS

Figure:	Drawn:	Checked:
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1.3 Scope of Works

The further investigations at Whitby Harbour comprised the following tasks:

- **Establishment of Strategic Aims and Objectives** - no further work was required on this aspect because the strategic aims and objectives were identified in the Strategy and remain unchanged from that time. Key information from the Strategy is reproduced in Section 2 of this report for ease of reference.
- **Identification of Problems and Key Issues** – no further work was required on this aspect because the problems and key issues were identified in the Strategy and remain unchanged from that time. Key information from the Strategy is reproduced in Section 3 of this report for ease of reference.
- **Design, Procurement and Project Management of Further Investigations** – based on the previously identified structural problems and performance issues with the Whitby Harbour piers and extensions a comprehensive suite of further investigations was specified and undertaken to obtain additional information to inform coastal management decisions. These are reported in Section 4 (surveys, inspections and investigations) and Section 5 (modelling).
- **Provision of CDM-Coordinator Services** – this was undertaken throughout all stages of the study, covering both the surveys/investigations and the re-evaluation of coastal management options and concept schemes. This was undertaken to ensure that Health and Safety issues have been considered throughout all stages of the project. In addition to the production and maintenance of a Health and Safety File, key related health and safety issues have been embedded within the concept design philosophy adopted on the study.
- **Re-evaluation of Management Options and Concept Designs** – Based on the findings from the further investigations, an up to date assessment of the present structural condition and performance issues associated with the Whitby Harbour piers has been undertaken. This is reported in Section 6. From this improved understanding, a 'long-list' of potential strategic level management options has been identified and screened against technical, economic and environmental criteria (Section 7) to produce a 'short-list' of the most sustainable and effective options. These options have then been subject to development as concept schemes and more detailed evaluation against technical, economic, environmental and risk criteria in accordance with Defra's Flood and Coastal Defence Project Appraisal Guidance procedures (Section 8).
- **Consultation** – This has been undertaken at various stages throughout the investigations and re-evaluation of options. The approach to, and key findings from the consultation process, are described in Section 9.
- **Selection of the Preferred Option** – Following the detailed assessments and the important consultation exercises, a decision has been made on the preferred option and concept scheme at Whitby Harbour. This is reported in Section 10. Accompanying this is a recommended Action Plan in Section 11 for taking the preferred option from the present option re-evaluation and concept design stage (Stage 1) through a detailed design, assessment and approvals stage (Stage 2) to a delivery stage (Stage 3).

This main report is accompanied by a large number of other deliverables from the further investigations at Whitby Harbour. This includes a Project Appraisal Report (PAR) used by Scarborough Borough Council in support of its application to the Environment Agency for Grant-in-Aid of further development and implementation of the preferred option. Other outputs from the present study are referred to in Sections 4 and 5.

2 ESTABLISHMENT OF STRATEGIC AIM AND OBJECTIVES

The Whitby Coastal Strategy established the strategic aim and specific objectives for the whole Strategy frontage. These are reproduced here to provide the wider context within which the further investigations at Whitby Harbour are being undertaken.

Strategic Aim:

- The stated overall aim of the Strategy was to provide an environmentally and technically acceptable coastal and river defence plan that is sustainable over the next 50-60 years

Specific Objectives:

- To identify coastal and river Management Units (within the existing SMP framework);
- To assess the condition of the coastal and river defences, including Whitby Harbour;
- To review the history of damages and repairs to the coastal and river defences;
- To assess the nearshore wave climate and overtopping performance of the coastal defences;
- To assess the historic rates of coastal erosion and identify instability problems associated with the cliffs and coastal slopes;
- To review the coastal processes and historic beach behaviour in order to assess how these may affect the coastline in the future;
- To develop a preliminary sediment budget;
- To undertake a flood risk assessment along the lower reaches of the River Esk;
- To identify coastal and river defence strategies, preliminary options and opportunities for environmental improvement for each Management Unit;
- To identify planning and environmental constraints for each Management Unit;
- To identify and evaluate the costs, benefits and uncertainties of each option;
- To prepare preliminary budget estimates for the preferred options;
- To prioritise the works required for specific Management Units on the basis of condition, performance and consequences of failure of existing slopes and defences;
- To develop a programme of works for the monitoring, maintenance and improvement options and associated timescale for expenditure;

- To provide recommendations for further studies required to support the implementation and design of preferred options.

3 IDENTIFICATION OF THE PROBLEMS AND KEY ISSUES

The Whitby Coastal Strategy identified the problems and key issues for the whole Strategy frontage. These are reproduced here to provide the wider context within which the further investigations at Whitby Harbour are being undertaken.

General Issues:

- Coastal and river processes present a number of risks to people, property and the environment.
- Many of the coastal defences are showing sight of distress and in most places, will not provide an adequate level of protection against erosion, cliff instability or flooding over the next 60 years.
- Many of the most critical defence structures are approaching the end of their serviceable life and are in urgent need of major improvement.

Specific Problems and Risks:

- Breaching of the East and West Piers – the poor condition of the harbour piers, combined with overtopping, was regarded as the most significant problem identified as part of the Strategy.
- There is potential for renewed recession of protected cliffs (particularly the Metropole area and along the A174 Sandsend Road).
- There is considerable potential flood risk to property along the lower reaches at the River Esk and Whitby Harbour quays.
- Wave overtopping of the sea defences on the open coast is likely to increase with sea level rise.
- Recession of unprotected cliffs will continue.
- The condition of the coastal and river defences is, in places, in need of improvement.
- There is a history of variability and long-term trends in beach level.
- The projected effects of sea level rise and, in places, continued foreshore lowering were considered to further compound these key problems and risks, leading to greater wave loading on defences and enhanced overtopping problems.

Breach of East and West Piers

- The piers provide coast protection and flood defence to properties along the lower reaches of the River Esk and provide shelter to vessels using the harbour.
- West Pier is important in controlling the build up of the beaches in front of West Cliff, which contribute to the coast protection schemes along this frontage.

- Serious defects were found to affect both piers. For example, the main arm of West Pier is affected by voids, missing and dislocated blocks, together with undermining of the toe, particularly around and along the inside face of the bullnose. On East Pier there are two areas of bulging in the alignment of the wall and localised settlement and dislocation of the blockwork.

- There is the potential for West Pier and/or East Pier of Whitby Harbour to breach under storm conditions as a result of their poor condition, possibly within the next 10 years or so[1]. This would lead to increased flooding along the River Esk, disruption or closure of the harbour, loss of access for vessels to shelter and to service the numerous commercial operations along the river.

- A pier breach could have major secondary effects on the levels of risk experienced elsewhere within the study area, especially along West Cliff.

[1] This timescale operates from the date of publication of the Strategy (i.e. 2002) and not from the present date.

4 FURTHER INVESTIGATIONS OF STRUCTURAL CONDITION

4.1 Background

In order to further investigate some of the defects associated with the main piers and pier extensions that were identified in the original Strategy, and to provide new, comprehensive and up-to-date information on the condition of these structures, a series of physical investigations was designed and undertaken between February and October 2008.

Firstly, existing surveys and associated reports were reviewed to highlight known problem areas and to identify gaps in data. An appropriate programme of investigations, using a range of both non-intrusive and intrusive techniques, was then designed to provide additional data. Specifications and contract documents were then written and used to procure suitable contractors, who were then managed in their execution of the investigations. The following investigations were undertaken:

- Topographic, digital measured and photographic surveys
- Dive survey and visual inspections
- Ground probing radar and microgravity surveys
- Ground investigation; and
- Hydrographic, geophysical and seismic surveys.

The further investigations focused on the main piers, their bullnoses and the pier extensions, but did not cover the timber supra-structure walkways above both the pier extensions, the pilot light gantries at the north end of each pier extension, the derelict gantry support pillar between the East Pier and its extensions, the lighthouses on the northern ends of both main piers or the gantry between the West Pier and its extension.

For some investigations the provision of CDM Coordinator (CDM-C) services was required and a series of licences, consents and permissions were necessarily obtained.

Results from the investigations were analysed and interpreted to provide an updated assessment of the condition of the pier and pier extension structures at Whitby harbour.

The following documents have been produced as outputs from the further investigations of structural condition and provided to Scarborough Borough Council as deliverables from the present condition:

- Whitby Coastal Strategy Harbour Pier Survey – Topographical and Digital Measured Survey by Durham University, dated March – April 2008 (UoD ref: RH_08_001) and attached survey drawings referenced in the report.

- Whitby Coastal Strategy Harbour Pier Survey – Topographical and Digital Measured Survey Cross Sections by Durham University, dated March – April 2008 (no reference).

- Whitby Coastal Strategy Harbour Pier Survey – Additional Cross Sections by Durham University, Dated March – April 2008 (UoD ref: RH_08_001a).

- Whitby Coastal Strategy Harbour Piers Survey – Diving and Visual Survey by Royal Haskoning, dated July 2008 (RH ref: 9T0429/05/R080215/303315/Hayw).
- West & East Piers Whitby Harbour – Investigation of Voiding Within Pier Construction By GB Geotechnics Ltd, dated July 2008 (GBG ref: 3034) and appendices folder with Drawing nos. 3034-1 & 3034-2.
- Whitby Pier Ground Investigation – Factual Ground Investigation Report by Soil Mechanics, dated September 2008 (SM report No: A8067).
- Whitby Coastal Strategy Harbour Piers Survey – Interpretative Report on Ground Investigation. Royal Haskoning, August 2008 (RH ref: 9T0429/R003/MS/Newc).
- Whitby Piers Geophysical Survey Report by EGS International Ltd, dated November 2008 (EGS ref: 4531).
- Whitby Coastal Strategy Harbour Piers Survey – Structural Inspection of East Pier Extension. Royal Haskoning, dated November 2008 (RH ref: 9T0429/R004/303392/Newc).

In addition to the above, the following Health and Safety documents were produced by the CDM-Coordinator, with the Health and Safety File also being a formal deliverable.

- East and West Piers Survey – Whitby Geometric Survey – Preconstruction Information by Royal Haskoning, dated February 2008 (RH ref:9T0429/HS/R080124/Newc).
- East and West Piers Survey – Whitby Diving – Preconstruction Information by Royal Haskoning (RH ref:9T0429/R080124/MW).
- East and West Piers Survey – Whitby Geophysical Survey – Preconstruction Information by Royal Haskoning, dated February 2008 (RH ref:9T0429/PCI - GS/Newc).
- East and West Piers Survey – Whitby Land Based GI – Preconstruction Information by Royal Haskoning (RH ref:9T0429/R002/Newc).
- East and West Piers Survey – Whitby Hydrographic Survey – Preconstruction Information by Royal Haskoning, dated April 2008 (RH ref:9T0429/HS/R010/Newc).
- Whitby Coastal Strategy Surveys of East & West Piers – Health & Safety File. Royal Haskoning.

Key findings from each of the investigations is summarised in following sections.

4.2 Review of Existing Information

The principal source of available information comes from the Whitby Coastal Strategy, which incorporated a summary of background information relating to Whitby Harbour and findings from a visual inspection and dive survey of the main piers. This revealed that the main piers are constructed of masonry sandstone blocks covering a core of materials, with the pier extensions comprising mass concrete bases supporting a timber superstructure. The toe of each extension has been subsequently strengthened by the installation of sheet piling and concrete.

A summary of the history and form of construction is reproduced in Box A directly from the Strategy.

Box A: History and Form of Construction

(reproduced directly from Whitby Coastal Strategy, High-Point Rendel 2002)

West Pier

Some form of harbour protection at the mouth of the River Esk was present in the early 1300's. Protection was achieved by a combination of Tate Hill Pier, Scotch Head and West Pier and construction was likely to have comprised timber, boulders and stone collected form cliff falls. In 1632 West Pier was rebuilt using sandstone blocks. Repairs, rebuilding and lengthening continued throughout the 1600's, 1700's and 1800's. An extension was added to the pier between 1908 and 1914 and an interceptor wall was added to the bullnose of the main arm to reduce the swell entering the harbour.

The present form of construction of the main arm of West Pier is large sandstone blocks, the structure is approximately 300m in length and has an elevation between 6 and 8m OD. It varies in width between about 10m at the root increasing up to about 17m at the roundhead. Construction details of the main arm are not available at present time. The extension comprises concrete trapeziform base with a sheet piled wall at the toe and a timber superstructure. The extension is approximately 150m in length and slightly arcuate in shape.

East Pier

The main arm of the East Pier was originally constructed in 1702, although some form of protection has been present at the mouth of the River Esk since the early 1300's (see above). The pier was progressively lengthened, raised in height and extended during the 1700's and 1800's. At the same time as the West Pier, an extension was constructed to the main arm of East Pier between 1908 and 1914.

The present form of construction of the main arm of East Pier is large sandstone blocks, similar to West Pier, although precise construction details are not available at the present time. East Pier is approximately 300m in length and has an elevation of between 6 and 8m OD. It varies in width between about 12m at the root increasing up to about 27m at the widest point (marking the end of the original structure prior to it extension in the mid 1800's) and reducing to about 9m at the roundhead. The extension comprises a concrete trapeziform base with a sheet piled wall at the toe and a timber superstructure, similar in form and dimension to that described for West Pier.

West Pier was completed in its present form in 1831 and East Pier in 1854, thus the latest parts of the structures are between about 150 and 170 years old, with the original parts of the structures being much older. The extensions are approximately 85 years old and have undergone at least two major phases of refurbishment and repairs, since their construction.

The extensions were completely underpinned with concrete and steel piles and were subject to major repairs in 1959-1960. A subsequent set of major repairs were undertaken to the extensions in 1975-1976 including piling of the bullnose of the main arm of West Pier. The main function of the extensions was to improve navigation into the main harbour mouth, because extremely strong currents cross the harbour mouth, although the extensions also have a coast protection role.

From the investigations that were carried out as part of the Strategy serious defects were found to affect both piers and both extensions, including:

West Pier (main arm)
- Voids
- Missing and dislocated blocks
- Undermining of the toe (particularly around and along the inside of the bullnose)
- Cracking
- Settlement of the top surface

West Pier (extension)
- Erosion of concrete at some construction joints
- Holes in sheet piling near bed level
- Localised voids behind sheet piles

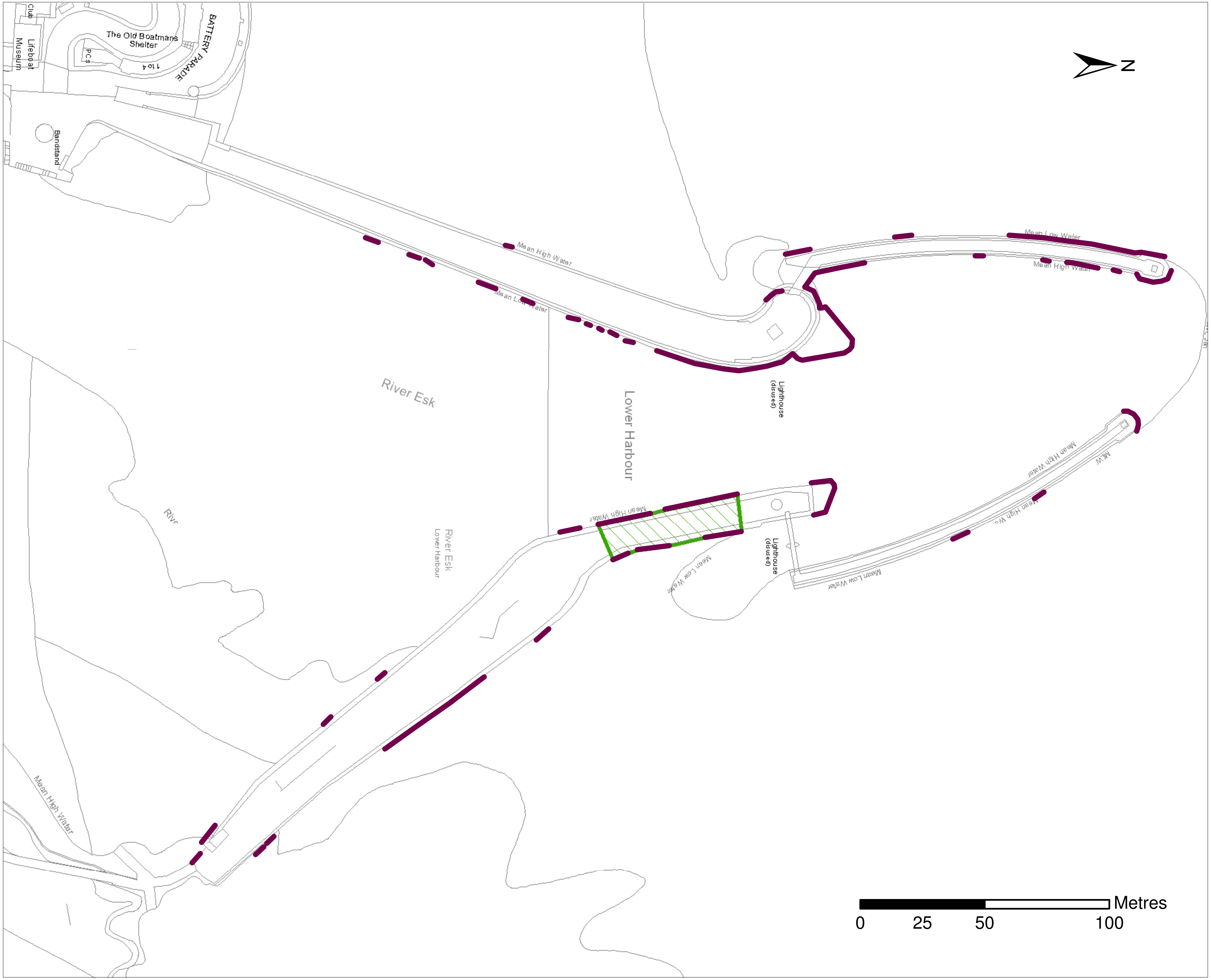
East Pier (main arm)
- Bulging in alignment
- Localised settlement
- Dislocation of blockwork
- Cracked concrete

Problems were identified to be particularly prevalent along the outer 100m or so of the main arm.

East Pier (extension)
- Localised significant erosion of the concrete toe
- Holes in sheet piling at seaward end

The principal areas of defects were located on a plan of the Whitby Harbour structures. This has been reproduced in the present report as Figure 4.

The conclusion of the Strategy, given the nature and extent of identified defects, was that the residual life of both the main piers was less than 10 years and that a breach could occur to either pier. It was considered more likely that a breach would first occur to the East Pier because this structure is exposed to greater wave forces than the West Pier due to lower foreshore levels, direction of wave approach and lack of beach deposits adjacent to the structure. This was most likely to be formed in the seaward section of the main pier where undermining was identified to be greatest. The postulated breach formation process comprised three stages, described in Box B.



Areas of defects previously identified in the Strategy

Area of most probable breaching previously identified in the Strategy

Title:
Areas of defects previously identified in the strategy

Project:
Whitby Coastal Strategy Further Investigations at Whitby Harbour

Client:
Scarborough Borough Council

Date:	Scale:
January 2009	1 : 2,000

Figure:	Drawn:	Checked:
4	TC	NC

ROYAL HASKONING

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Box B: Postulated Breach Formation Process (reproduced directly from Whitby Coastal Strategy, High-Point Rendel 2002)
Stage 1 *– displacement of the lower blocks of sandstone and removal of fill material between the inner and outer face, cavities may already be present in this area. As the worst conditions are from north and north east the blocks would be dislodged into the narrowest section of the harbour presenting an immediate hazard to vessels using the harbour, but possible still passable with care.* ***Stage 2*** *– collapse in the upper section of the structure over the length of the breach, of both the sandstone blocks and the core material, as a result of displacement and partial removal of the lower blocks which supported the upper section of the structure. Individual blocks, which weigh typically 1 and 2 tonnes, will be rolled in to the harbour and settle in the deepest part of the channel. The reduced height of the structure over the collapsed section would allow larger waves to enter the harbour and cause further displacement of blocks into the harbour, and may prevent safe access for vessels.* ***Stage 3*** *– the breach will continue to extend laterally during storm and high tide conditions as increasingly larger waves will be able to propagate over and through the breach. The interlocking and wedge effects of the sandstone blocks will be progressively lost causing further collapse of the structure of the structure on each side of the initial breach. Use of the harbour would be completely prevented and eventually the whole of the northern section of the main arm will collapse into a mound with a crest level in the order of half or a third of its original height, to ~3-4m OD.*

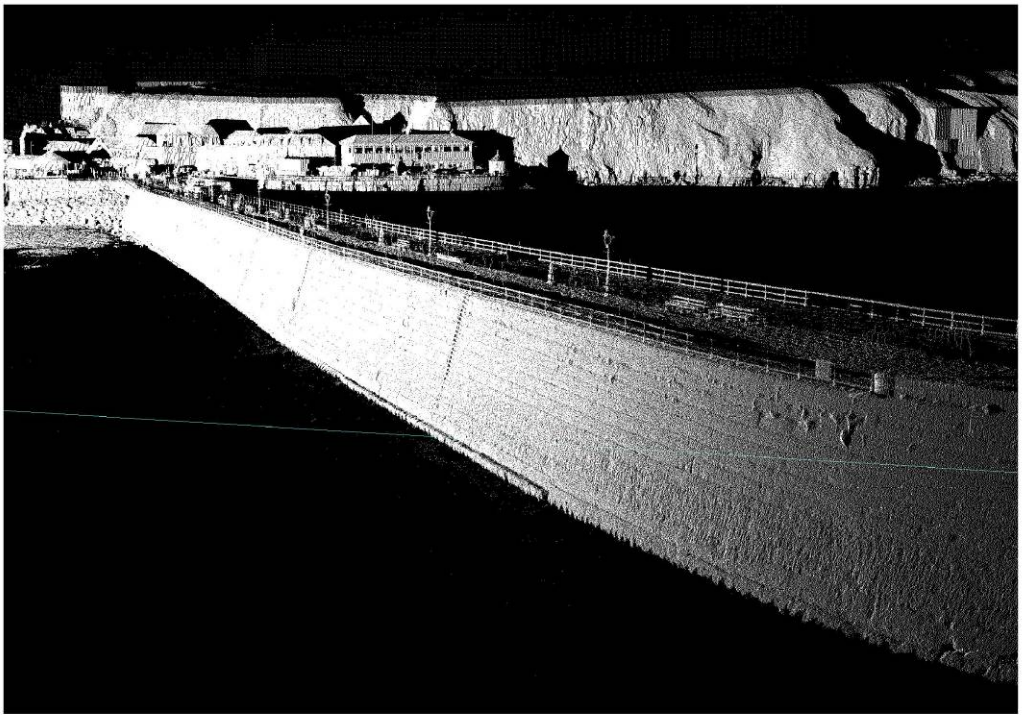
It was concluded in the Strategy that once a breach had occurred, gaining access to temporarily or permanently construct remedial measures would be extremely difficult, especially as the breach is likely to form during winter storm conditions. Consequently prevention of a breach was deemed essential. A timescale for implementing the recommended capital upgrade works on the East Pier of 5 years and on the West Pier of 10 years was identified.

Although the Strategy also identified the need for capital works on both pier extensions, it assessed the residual life of these structures at 40-50 years. It should be noted, however, that this was based on visual inspections only as the dive survey was focused on the main piers and did not cover the extensions.

4.3 Topographic, Digital Measured and Photographic Surveys

These surveys (right) were undertaken by Durham University in March and April 2008. The surveys were undertaken using a 3D terrestrial laser scanning technique in combination with high-precision geospatial control using differential GPS. This enabled the digital capture of information relating to the topography of the structures and adjacent inter-tidal foreshores. The survey also simultaneously captured scaled digital photographic images.

In excess of 16.5 million data points were captured and used to create a 3D Digital Elevation Model (DEM) from which digital measurements can be retrieved.



11/03/08 ScanStation_01 data coverage, West Pier, East Face, oblique view

Figure 5 Oblique View of West Pier, East Face

4.4 Dive Survey and Visual Inspections

The dive survey was undertaken by Royal Haskoning's in-house dive team with support from Anglian Marine Services. The work was undertaken over three visits to the site in February, April and June 2008.

The survey involved diving inspections of the structures below the water level by a commercial diving engineer and visual surveys of the piers from the beaches and a boat. This produced a detailed log and video/audio evidence of the defects to all four parts of the harbour piers.

The survey covered all structures above water and the majority of the structures below water. Inspections were not possible over a 20m length on the West Pier Bullnose, the base of the collapsed gantry support pillar and a 4m section in the southeast corner of the West Pier extension, adjacent to the concrete flume between the structures.

Access for diving operations was undertaken using two methods:

(1) For the inspections of both main piers, including their bullnoses, access was gained from deck level of the piers via a man-riding cage attached to a hi-ab crane system (right). Generally these operations were undertaken around the slack of the low tide.

(2) For the pier extensions access was gained utilising a dive vessel. In this case operations were undertaken around high tide in order for the vessel to be safely and securely moored alongside the structures.

The underwater inspections were undertaken in accordance with the Institute of Civil Engineers' *Guide to Inspection of Underwater Structures*.

The visual inspection of the structures focused on general condition, evidence of corrosion and damage to steelwork, scour at bed level, and the occurrence of structural defects to blockwork and concrete areas. Underwater video equipment was used on all dives as a record, although the quality of the visual information it provides can be limited due to poor underwater visibility. The videos also include the communications between the inspection diver and the team. Further to this, dimensions and locations of all defects were recorded.

For the visual inspections to the outer faces of the main piers, access was achieved by foot at low water. Where defects were noted in unreachable areas a photographic record was made along with estimates of dimensions.

Visual inspections of all other areas above the waterline were undertaken via the dive vessel. Again, this included photographic records and estimations of dimension if a defect was noted in unreachable areas.

For simplicity the Whitby Harbour structures were divided into six zones (the main piers, the bullnoses and the extensions on both the west and east sides) and each was graded on a scale 1 to 5 in accordance with its condition:

1	Very Good
2	Good
3	Reasonable
4	Poor
5	Very Poor

The grading takes into account all defects noted on that particular structure.

Further to the summary grading, all defects above and below water have been recorded, showing:

- The location along the structure using established chainages;
- The level of the defect (either in relation to Ordnance Datum, Newlyn, when above water, or in relation to the bed level for below);
- The type of defect as shown in Table 1 below;
- The height, width and depth of the defect;
- A reference to either a photographic or video record;
- The date the defect was located; and
- Any further comments.

Table 1 - Defect Types

Reference	Description
A	Open joint/void in blockwork
B	Crack within block
C	Chipped or broken block
D	Settled or Displaced block
E	Missing block
F	Replaced block
G	Notable erosion of block
H	Scour / Undercutting
M	Misc. object
J	Hole in steel pile
K	Notable corrosion to steel pile
L	Damaged ladder
Y	Erosion to concrete joints
Z	Additional concrete / grout patching

In summary, there are significant defects noted in the main pier structures relating to the sandstone blocks that form the outer faces of the piers. Evidence was noted of the blocks being extremely eroded with extensive erosion noted around the mortar joints in the face. The loss of mortar over the years has lead to voids forming around the blocks with scour and erosion occurring leading to damage of the blocks. The damage observed included cracking, chips, settlement and displacement and was evident along large areas of the structures, but particularly prevalent to the northern ends of the structures.

Various remedial repairs have been undertaken through the years to both piers. These include grout fill, concrete repairs to the deck and facing, some sheet piling and construction of toe beams. Many of the concrete repairs undertaken, particularly to the decks, are in a poor state and deteriorating.

The bullnoses to the main piers are generally of concrete construction. Significant erosion is noted to the construction joints between the pours on both sides, above and below the waterline. Scour was also noted over two areas with 2-3m lengths, undercutting the structure by about 400mm. The northwest part of this structure was not inspected due to severe wave action but is assumed highly likely to be affected by scour probably to a greater degree due to the location of the concrete flume next to this area and the other evidence around its vicinity.

The pier extensions are generally formed of a concrete construction with sheet piles around the toe of the structures on all sides. The surveys noted significant erosion to the construction joints in the concrete similar to the bullnoses. This had also lead to spalling on the edge of the decks.

The most significant and extensive defects noted on these structures were in the sheet piles. On the West Pier extension, corrosion was noted extensively around the structure but specifically in two main areas; the seaward bullnose and the southeast corner. Scour has occurred under the structure through the corroded sections, which is on average 700 mm deep but was up to 2 m in some places.

On the East Pier extension, corrosion was noted slightly more extensively around the structure but specifically in two main areas; around the seaward bullnose and on the landward end, from midway along the east face around the landward end and partially along the west face. The corrosion of sheet piles at the landward end was noted to be so extensive that scour had worn a hole up to 2m high and approximately 5m deep under virtually the entire landward end of this structure. This effectively means that this end of the structure is suspended above the bed via cantilever action. Due to this finding a further visual survey of the East Pier extension was undertaken in October 2008 with access provided by vessel.

The inspection identified that repair works had been undertaken to both ends of the structure since it was originally constructed. From outline knowledge of the structure, it is estimated that the repairs were undertaken in 1970s. Thus, the concrete finish is generally good or fair finish with well formed corners. It is not certain if the repairs applied reinforcement to the concrete. It is thought that the original piers were cast with mass concrete. Both the original pier construction and the repaired sections were constructed in panels with construction joints across the width of the pier. These joints appeared to be set at approximately 2.9m centres.

At the extreme seaward end of the East Pier extension, there were two construction joints that had been formed across the pier in the repaired section. Both the joints appear to have opened by up to 3.5mm since construction. This was evident from inspection of the top concrete surface of the mid-deck level and could be seen down the sides of the structure. However, it is not known when the movement occurred if it is still occurring. This could coincide with the deterioration of the sheet pile toe and voids forming beneath the bullnose. Similar evidence was noted on the bullnose to the West Pier extension as well on the same visit.

At the landward end of the structure, there are clear signs that two construction joints nearest the pier end have opened by up to 5.5mm. Theses joints were widest at the top concrete surface and narrowed as they descended down the sides of the pier, although marine life may have covered any cracks at the base. The second joint showed the greatest evidence of movement. The third joint also showed some evidence of movement at the surface. There was also evidence at the base second joint on the east side that a stepped crack has formed away from the main line of the construction joint. The joint was also noted to have spalled edges and a series of rust spots.

It is considered that evidence from the first two joints shows that the rear portion of the structure is cantilevering from the main body of the pier. This is shown by the opening of joints in the top of the structure where it would be under tension and narrowing of joints in the base where it would act in tension. The stepped crack at the base of the east side potentially shows that the concrete may be unable to cope with the compression exerted on it by the cantilevering section. It is thought that the overhanging section is probably relying on any reinforcement that may have been used in the repair works in combination with skeletal support from the piles below and tensile strength from the timber gantry above.

Overall, the defects were occurring probably due to the failure/loss of the sheet pile toe. It is considered that the worst affected area is the landward end of the East Pier extension where the structure is notably hanging from the main body. This area is deteriorating and will collapse in the future if left.

Overall, the survey identified that from visual and diving inspections, all the structures were in poor or very poor condition. Some areas are at risk of failure or possible collapse unless remedial works are undertaken, although it was noted to be difficult to make any definitive assumption on when failure may occur.

4.5 Ground Probing Radar and Microgravity Surveys

These geophysical surveys (right) were undertaken by George Ballard Geotechnics (GBG) in late April/early May 2008.

The survey work applied ground penetrating radar system to the side walls and deck surface of the main piers (providing results down to approx. 2.5m depth in the structure from the surface) and used a microgravity system from the main pier decks.

The purpose of the work was to determine changes in density of the pier material which provides a good indication of voids present within the structure below the surfaces.

The survey was focused to the main piers only as the body of the pier extensions were formed from solid concrete, so very unlikely to contain voids unless formed during construction. Limited data was retrieved from the outer walls of both piers due to the irregularity of the outer stone wall proving it harder to calibrate (e.g. the stone face had a stepped construction with irregular faced stone). The survey extent was focused to the 75 – 80 % of the main piers at the seaward end where the conditions were expected to be the worse case.

The survey was able to identify the overall construction of the piers in terms of the surfacing, pier wall construction and fill material. This included information on the previous repairs and improvements structural integrity.

The survey identified that there were voids present within the structures, which were mainly located below the pier deck and behind the stone block facing. On the main West Pier, the greatest likelihood of voiding was noted to be towards the seaward end and along the east face of the pier structure. The report notes that there is little differential movement between the concrete surfacing slabs or major defects noted, although the presence of reinforced concrete sections and various repairs indicates that extensive problems may have been encountered in the past.

On the main East Pier, the significant likelihood of voiding is identified to the seaward end of the structure, particularly where the pier width reduces from 30 m to 9 m. this appears to be in a worse condition over this area than for the West Pier. Again, past damage in the form of bulging and substantial repairs are noted along the outer face and deck. The repairs include a concrete toe beam to the east face and a full height concrete revetment on the outer face adjacent to the pier width reduction.

Overall, the survey identified that the core of the both the main piers has limited voiding and is essentially a solid structure. However, the likely presence of voiding below the deck surface and behind the facing blocks is high and verified by observations and the borehole data from the ground investigation. The worst of the damage appears to be at the seaward ends of both structures. The report suggested that the voiding was likely caused by suction through hydraulic action to the pointing between the blocks and flushing of the fill material behind the facing and surfacing stones.

4.6 Ground Investigation

The ground investigation (right) was undertaken by Soil Mechanics with site supervision by Royal Haskoning during June 2008. The ground investigation was used to verify the materials within the core of the piers, and identify the founding conditions to the structures.

This was carried out by sinking 8 no. boreholes through both the main piers (4 each pier), using both cable percussion and rotary coring techniques.

The locations of the boreholes were formalised from the interim results of the ground probing radar survey above, so allowing specific areas to be targeted for verification of the GPR survey as well as providing bench mark holes.

The investigation was identified the generally construction of both the piers was formed mostly from the following layers:

- Made ground surfacing – generally sandstone blocks forming the original surface, although the West Pier and a small part of the East Pier has a concrete paving construction.

- Made ground granular fill – most boreholes detected sands, gravels and cobbles in a layer beneath the surfacing stone blocks.

- Made ground sandstone rockfill – generally the main fill material to the piers was noted to be sandstone boulders, probably won from the local coastal cliffs.

The founding conditions to the piers were noted mainly to be directly onto the Whitby mudstone formation. This bed rock was encountered on six out of the eight boreholes. The last two boreholes were located on the landward end of the main West Pier, and identified a deep alluvial deposit layer beneath the structure. This change in strata is likely to reflect the location of the Whitby fault under the seaward end of the main West Pier, thought to be aligned north south under the pier centre.

4.7 Hydrographic, Geophysical and Seismic Surveys

These marine surveys (right) were undertaken in June 2008 by EGS International Ltd.

The survey work entailed a hydrographic (or 'bathymetric') survey, a side scan sonar survey, seismic boomer survey and bed samples of the foreshore, river channel and sea bed around the piers.

The bathymetric survey determined the levels of the seabed and river channel in comparison to the ordnance datum and the structural features. The side scan sonar identified obstacles, cavities, boulders, structural elements and features in the sea and channel bed including the change in bed materials. Seismic survey was able to indicative the depth of sediments and rough geological profile of the bed around the piers.

The survey recorded data covering the full extent requested, although some data remains outstanding relating to the seismic data. The bathymetric data provided has been checked and calibrated against other survey data collected, although a minor discrepancy was identified in base station level it is acceptable for use in the modelling and design work. The side scan sonar data provided could potentially be out of position by up to a metre, due to the relative position of the boat to boomer when traversing arc's or curves around the structure.

The survey was able to identify the exposed bedrock sea bed extending from the geological features of the SSSI site to the east of the piers, under the pier structures to centre of the West Pier extension with the exception of the river channel, East Pier beach and the west beach. The river channel shows that the bed rock is covered with a sediment deposit of sand and silt material. The East Pier beach and west beach are identified as gravel and sand deposits respectively.

The survey identified several features of interest around the piers. These included the concrete ledge and sheet piling toes to the east and West Pier extensions and main East Pier, rock ramps and formations to the landward ends of the west and east main piers, and isolated boulder piles around the West Pier extension. The most important engineering feature noted was two localised hollows in the bedrock adjacent to inner face of the main East Pier at the narrow section. These are shown tightly adjacent to the pier wall, so indicating potential reduced support from the bedrock to the structure above. It is noted that the location of these hollows coincides with damage visible on the wall above the waterline.

Overall, these surveys have identified useful data for the modelling, confirmed observations and assumptions from the ground investigation, and identified key features of significance around the piers.

4.8 Structural Inspection of the East Pier Extension

Subsequent to the other physical surveys on site, it was decided to undertake a visual structural inspection of the East Pier extension. This decision arose particularly from the specific findings of the dive survey, which identified no support to the landward section of this pier. This inspection was undertaken on 10th October 2008 and involved a visual inspection of the landward and seaward ends from the structure and by boat.

The inspection identified that repair works had been undertaken to both ends of the structure since it was originally constructed. From outline knowledge of the structure, it is estimated that the repairs were undertaken in 1970s. Thus, the concrete finish is generally good or fair finish with well formed corners. It is not certain if the repairs applied reinforcement to the concrete. Both the original pier construction and the repaired sections were constructed in panels with construction joints across the width of the pier. These joints appeared to be set at approximately 2.9 m centres.

At the extreme seaward end of the East Pier extension, there were two construction joints that had been formed across the pier in the repaired section. Both the joints appear to have opened by up to 3.5 mm since construction. This was evident from inspection of the top concrete surface of the mid-deck level and could be seen down the sides of the structure. However, it is not known when the movement occurred if it is still occurring. This could coincide with the deterioration of the sheet pile toe and voids forming beneath the bullnose. Similar evidence was noted on the bullnose to the West Pier extension as well on the same visit.

At the landward end of the structure, there are clear signs that two construction joints nearest the pier end have opened by up to 5.5 mm. this joints were widest at the top concrete surface and narrowed as they descended down the sides of the pier, although marine life may have covered any cracks at the base. The second joint showed the greatest evidence of movement. The third joint also showed some evidence of movement at the surface. There was also evidence at the base second joint on the east side that a stepped crack has formed away from the main line of the construction joint. The joint was also noted to have spalled edges and a series of rust spots.

It is considered that evidence from the first two joints shows that the rear portion of the structure is cantilevering from the main body of the pier. This is shown by the opening of joints in the top of the structure where it would be under tension and narrowing of joints in the base where it would act in tension. The stepped crack at the base of the east side potentially shows that the concrete may be unable to cope with the compression exerted on it by the cantilevering section. It is thought that the overhanging section is probably relying on any reinforcement that may have been used in the repair works in combination with skeletal support from the piles below and tensile strength from the timber gantry above.

Overall, the structural inspection identified that defects were occurring probably due to the failure/loss of the sheet pile toe. It is considered that the worst affected area is the landward end of the East Pier extension where the structure is notably hanging from the main body. This area is deteriorating and will collapse in the future if left. No certainty can be provided as to a timescale on when this may occur, as it is dependent upon storm frequency and severity.

5 FURTHER INVESTIGATIONS OF DEFENCE PERFORMANCE

5.1 Background

In order to further investigate some of the defence performance and physical process issues associated with the piers and pier extensions, a series of physical process investigations was designed and undertaken. These have informed an understanding of the present-day processes in the vicinity of Whitby Harbour, tested the vulnerability from structural failure of the harbour piers, and assessed the implications of different management options on overtopping discharges.

These investigations build from the knowledge base that was gained as part of the original Whitby Coastal Strategy in 2002. Associated with that study, HR Wallingford undertook an assessment of wave climate, coastal processes and flood risk (HR Wallingford, 2002). This comprised the following components:

- Wave climate modelling and water level assessments;
- Beach behaviour and sediment budget analysis;
- Overtopping assessments; and
- Flood levels along the River Esk estuary.

These topics have been further investigated during the present study, together with an assessment of the effects of the piers on wave conditions in and around the harbour. Summary findings are presented in following sections, with full detail contained within the following accompanying document:

Whitby Coastal Strategy Further Studies: Physical Processes. Royal Haskoning, November 2008.

5.2 Review of Existing Information

Historical photographs kindly provided from the Whitby Literary and Philosophical Society demonstrate the ferocity of the sea during storm conditions (Figures 6, 7 and 8). Here, in photographs from circa 1907, considerable overtopping is demonstrated. Note that these photographs pre-date construction of the pier extensions.

Figure 6 – Overtopping of the West Pier (circa 1907)

Figure 7 – Overtopping and Localised FLooding (circa 1907)

Figure 8 – Overtopping (circa 1907)

For purposes of the present study, a digital copy of the relevant Admiralty Chart was purchased (Figure 9). This clearly shows the presence of important rock outcrops such as Upgang Rocks and Whitby Rock which can influence nearshore coastal processes, such as wave propagation and sediment transport.

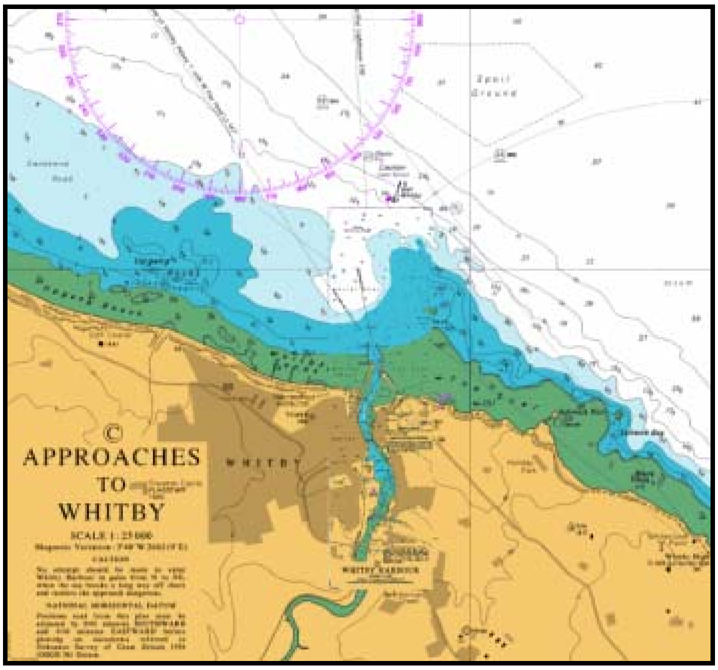


Figure 9 – Admiralty Chart: Approaches to Whitby

Previous technical work on wave climate assessment, coastal processes and flood risk associated with the Whitby Coastal Strategy in 2002 involved:

- Calculation of offshore wave conditions using HINDWAVE based on twelve years of wind predictions derived from the UK Met Office Forecasting Model at a single prediction point located some 30km offshore;

- Transformation using TELURAY of these offshore conditions inshore to six points (labelled ‘A’ to ‘F’) along the -13m CD (-16mODN) contour and a further six points along the -5m CD (-8mODN) and calculation of extreme nearshore wave conditions;

- Use of the ‘POL Method’ (POL, 1997) to calculate extreme water levels, both now and 50 years into the future to take account of sea level rise;

- Analysis to determine the joint probability of waves and water levels acting in different combinations;

- Developing a conceptual understanding of beach processes, based upon results from littoral drift modelling, historic evolution assessment and sediment budget analysis;

- Overtopping assessments at one (only) location along the East Pier;

- ISIS river modelling of the lower reaches of the River Esk to assess the relative effects of high tides and high river flows on extreme water levels in the estuary;

- Use of a Digital Ground Model (DGM) to map extreme tidal levels to demonstrate the extent of tidal flooding that would occur should water levels rise above the quay walls.

The above work was fully reported in Appendix I of the Whitby Coastal Strategy (HR Wallingford, 2002). The physical process work undertaken in the present study re-evaluates the findings and further develops the understanding of these aspects through a variety of assessment approaches.

5.3 Wave Climate and Water Levels

In the present study, the following activities have been undertaken:

- Analysis of extreme water levels has been brought up to date using the full historic record of tide gauge data from Whitby (this includes data up to the end of 2007) using two methods, namely the GEV (Gumble) Method and the POL Method.

- Extreme water levels have been projected 50 years ahead using the latest available Defra guidance on sea level rise (Defra, 2006).

- Comparisons have been made with the HR Wallingford analyses and a decision made that there is not a need to update the JPA due to comparability of results from both studies.

5.3.1 Extreme Water Levels

The extreme water levels used in the study are presented in Table 2 for 2007, 2057 and 2107 under a range of different return period events. This takes into account the latest available guidance on sea level rise from Defra (2006) which recommends the following allowances for the north east coastline located north of Flamborough Head:

- 1990 – 2025 2.5 mm/year
- 2025 – 2055 7.0 mm/year
- 2055 – 2085 10.0 mm/year
- 2085 – 21005 13.0 mm/year

Table 2 – Present and Future Extreme Water Levels

Date	Extreme Water Level at Stated Return Period						
	1 in 1 yr	1 in 3 yr	1 in 10 yr	1 in 50 yr	1 in 100 yr	1 in 200 yr	1 in 1000 yr
2007	3.30	3.45	3.61	3.85	3.99	4.10	4.31
2057	3.58	3.73	3.89	4.13	4.27	4.38	4.59
2107	4.14	4.29	4.45	4.69	4.83	4.94	5.15

These values have been used as input to the overtopping assessments and the mapping of flood extents.

5.3.2 Offshore Waves

Offshore wave conditions approach the shoreline from all sectors between the north-west and the north-east. The most severe conditions are from due north and the predominant wave direction is from just east of north. However, in order to determine the effects of wave climate on beach sediment transport processes, structural overtopping performance and loading conditions, information is also required on the wave climate nearer to the shore.

5.3.3 Nearshore Waves

In the original Whitby Coastal Strategy, the nearshore wave climate along the whole strategy frontage (i.e. between Sandsend and Abbey Cliff) was characterised at six points along the -13mCD (-16mODN) contour and a further six points along the -5mCD (-8mODN) contour using TELURAY wave transformation modelling from deep offshore water.

One of the nearshore locations, ‘Point E’, was located directly offshore of Whitby Harbour. Results from the transformation at this point show that at the -16mODN contour the most severe waves approach Whitby Harbour from due north and these can reach significant wave heights in excess of 7m. Figure 10 presents a rose of wave heights and directions at the -16mODN contour at Point E, created for purposes of the present study.

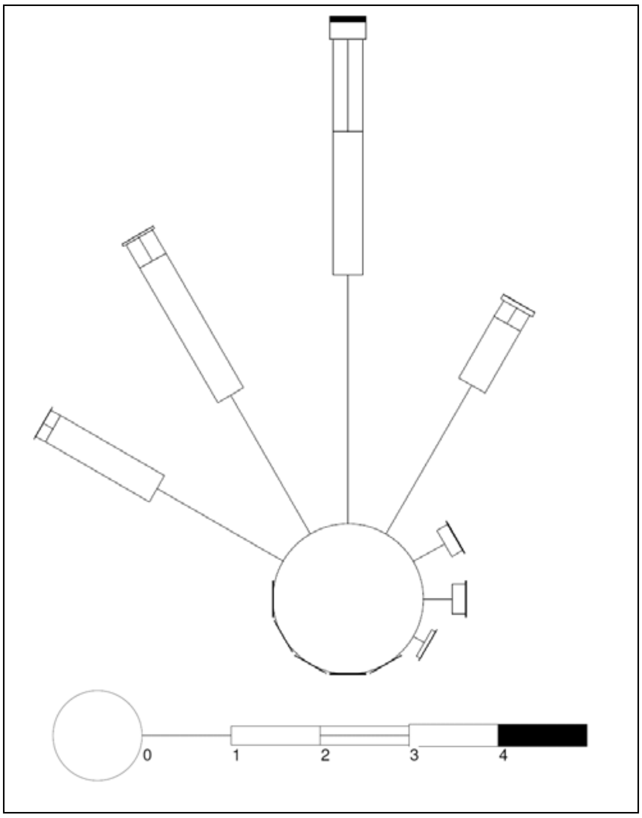


Figure 10 - Nearshore Wave Rose (at -16mODN contour)

Extreme wave climate characteristics for this position were also calculated and these are presented in Table 3 for different return period events.

Table 3 – Extreme Nearshore Wave Conditions offshore from Whitby Harbour

Return Period (years)	-16mODN Contour		-8mODN Contour	
	Wave height (m)	Wave period (s)	Wave height (m)	Wave period (s)
0.25	4.12	7.4	3.87	7.1
0.5	4.59	7.7	4.15	7.4
1	4.93	8.0	4.42	7.6
5	5.71	8.6	5.29	8.3
20	6.36	9.0	-	-
100	7.10	9.4	6.10	8.9
200	7.41	9.6	6.19	9.1
500	7.81	9.7	6.48	9.3

5.3.4 Joint Probability of Waves and Water Levels

As the new extreme water levels analysis has resulted in the recommendation to use the values previously derived for Whitby, there has been no need in the present study to update the assessments of the joint probability of waves and water levels. Due to this, the data previously provided by HR Wallingford at Point E (at the -8mODN contour) has been used in the present study. These data are replicated in Table 4.

Table 4 – Joint Probability of Waves and Water Levels at Point E (on the -8mODN contour)

Joint Return Period (yrs)	Water Levels		Wave Conditions		
				Point E	
	Return Period (yrs)	Water Level (mODN)	Return Period (yrs)	Significant Wave Height H_s (m)	Mean Wave Period T_m (s)
1	0.025	2.75	1	4.93	8.00
	0.05	2.85	0.5	4.59	7.70
	0.10	2.95	0.25	4.27	7.56
	0.25	3.10	0.1	3.83	7.28
	0.50	3.20	0.05	3.51	7.07
	1	3.30	0.025	3.18	6.86
50	0.12	3.00	50	6.76	9.16
	0.25	3.10	25	6.44	8.95
	0.6	3.25	10	6.00	8.68
	1	3.30	6	5.76	8.52
	6	3.55	1	4.93	8.00
	10	3.61	0.6	4.68	7.82
	25	3.77	0.25	4.27	7.56
	50	3.85	0.12	3.92	7.34
100	0.15	3.05	100	7.10	9.40
	0.3	3.20	50	6.76	9.16
	0.6	3.25	25	6.44	8.95
	1.5	3.30	10	6.00	8.68
	10	3.61	1.5	5.11	8.10
	25	3.77	0.6	4.68	7.82
	50	3.85	0.3	4.35	7.61
	100	3.99	0.15	4.02	7.40
200	0.2	3.08	200	7.41	9.60
	0.5	3.22	80	6.98	9.30
	1	3.30	40	6.66	9.09
	4	3.50	10	6.00	8.68
	10	3.61	4	5.57	8.40
	40	3.83	1	4.92	7.98
	80	3.95	0.5	4.59	7.77
	200	4.10	0.2	4.16	7.49

5.4 Effects of the Harbour Piers on Wave Conditions

Upon reviewing the previous physical process assessments, it was apparent that no work has been undertaken to date to explicitly demonstrate the effect that the piers have in limiting wave conditions within the harbour and along the immediate adjacent coastlines and hence in reducing the potential for sea flooding of low-lying areas and erosion of adjacent coastal frontages. This is the fundamental benefit of retaining the piers as coastal defence structures.

In the present study, the effectiveness of the piers in this regard has been demonstrated through use of SWAN wave modelling to investigate the propagation of waves from offshore to nearshore and into the harbour under three different management scenarios. This approach was not intended as a detailed study of wave propagation into the harbour (which would be needed for detailed design) but instead was a simple exercise to demonstrate that the piers do have a positive effect on wave conditions in the harbour. Outputs from the SWAN model were also used to inform characterisation of the wave climate in and around the harbour and as input to the overtopping modelling.

The extent of the SWAN model grid is shown in Figure 11, together with the location (on the -16mODN contour) of Point E that was referred to in Section 5.3.3.

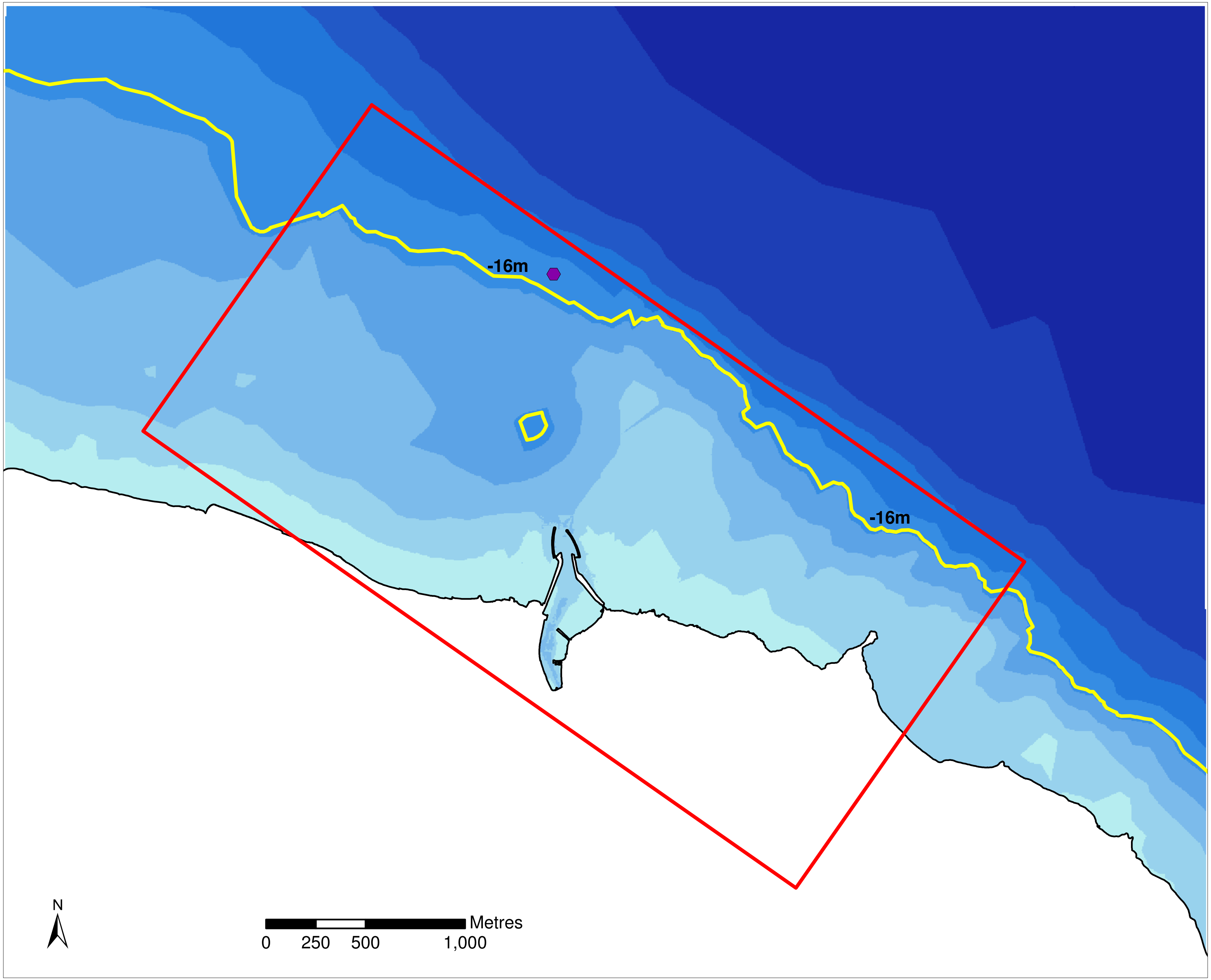
The three management scenarios that were modelled are shown in Figure 12.

- The Base Case was used to determine wave conditions under the present management scenario in and around the harbour. The resulting data have been used to inform understanding of contemporary processes as well as being used as direct input to the overtopping assessments.

- Option 1 was modelled to determine what the wave conditions would be in and around the harbour in the absence of the piers to enable comparison with the present 'base case' and hence determine the effectiveness of the piers.

- Option 2 was modelled to determine what the wave conditions would be in and around the harbour in the event of a breach through the most vulnerable section of the East Pier (as identified from the previous Strategy and the present investigations).

Results from this exercise demonstrate that the harbour piers significantly reduce wave heights within the harbour and upstream within the River Esk estuary. Full results are presented in the accompanying Physical Processes report (Royal Haskoning, 2008) but Figure 13 summarises some key differences in wave height depending on location during a 1 in 1 year event approaching from due north. As can be seen from this figure (plot A), wave conditions within the harbour mouth are typically some 0.5m to 0.6m lower than values at corresponding positions outside of the harbour. Plot B shows that in the absence of the piers, wave conditions would increase by around 40-60% within the estuary mouth (well within the harbour) and by 70-80% further upstream in the estuary.



SWAN Model Boundary
Transformation Point E
-16mOD Contour

Bathymetry (mOD)

- -1.99 - 0
- -4.99 - -2
- -9.9 - -5
- -14.9 - -10
- -19.9 - -15
- -24.9 - -20
- -29.9 - -25
- -39.9 - -30
- -47.8 - -40
- -47.9

Title:
SWAN Model Boundary

Project:
Whitby Coastal Strategy Further Investigations at Whitby Harbour

Client:
Scarborough Borough Council

Date:	Scale:
January 2009	1 : 25,000

Figure:	Drawn:	Checked:
11	TC	NC

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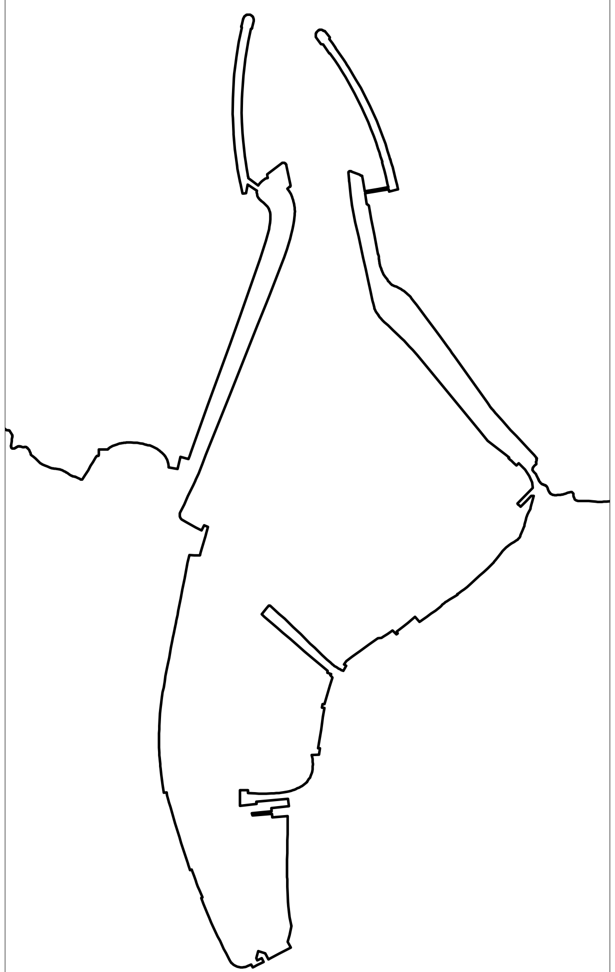
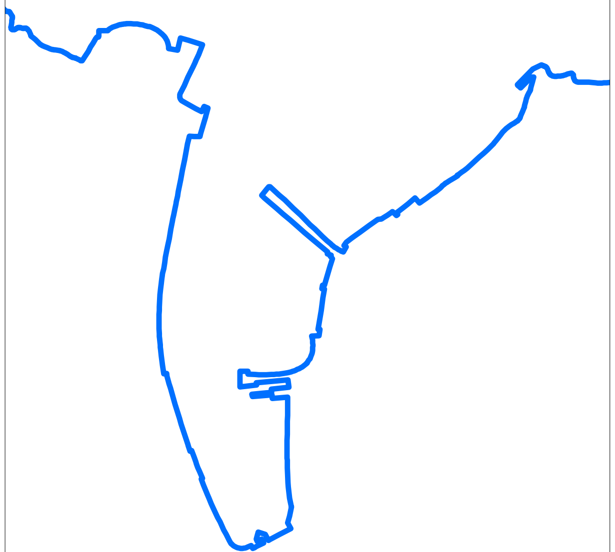
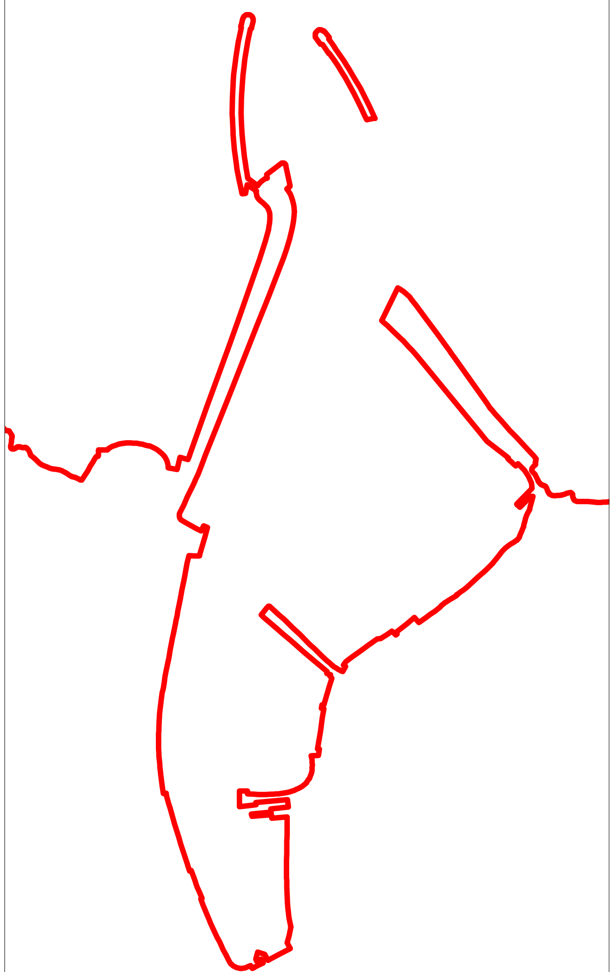
BASE



OPTION 1



OPTION 2



Base Case:
Present Day Configuration

Option 1:
No Piers

Option 2:
Breach East Pier

Title:
3 Management Options

Project:
Whitby Coastal Strategy Further Investigations at Whitby Harbour

Client:
Scarborough Borough Council

Date:	Scale:
January 2009	1 : 6,500

Figure:	Drawn:	Checked:
12	TC	NC

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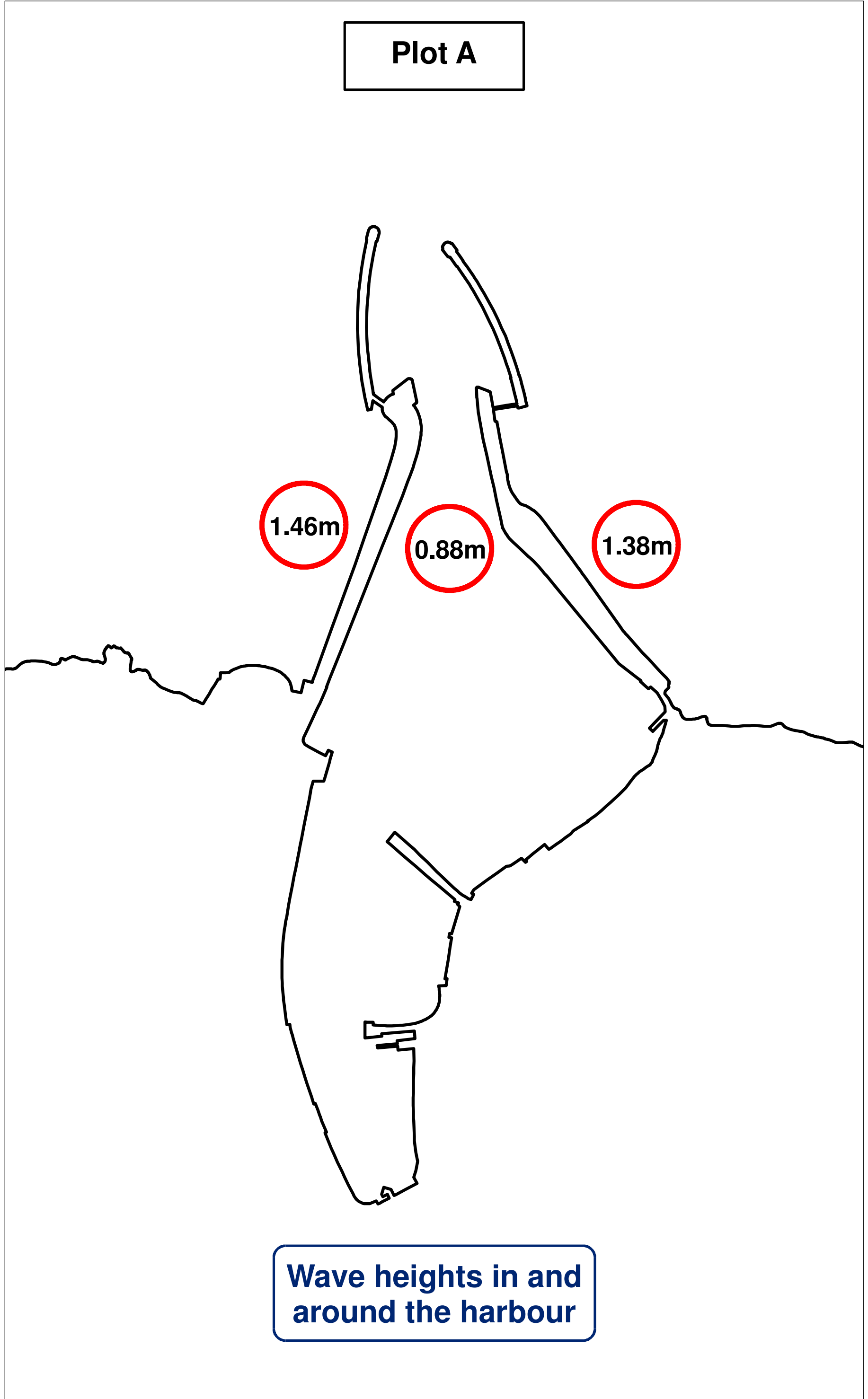

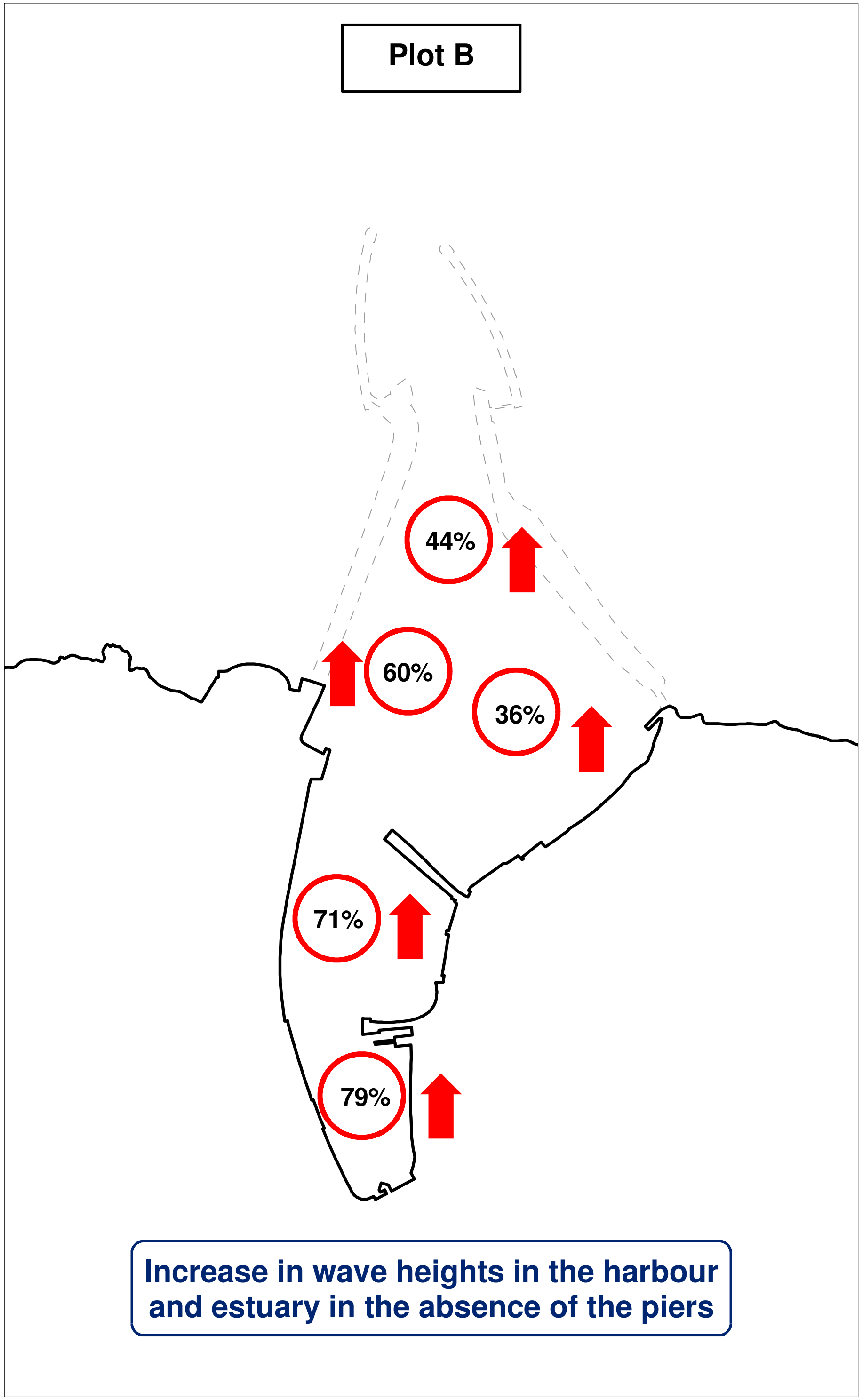

Title:
Wave Conditions during a 1 in 1 Year Event from Due North

Project:
Whitby Coastal Strategy Further Investigations at Whitby Harbour

Client:
Scarborough Borough Council

Date:	Scale:
January 2009	1 : 6,000

Figure:	Drawn:	Checked:
13	TC	NC

ROYAL HASKONING

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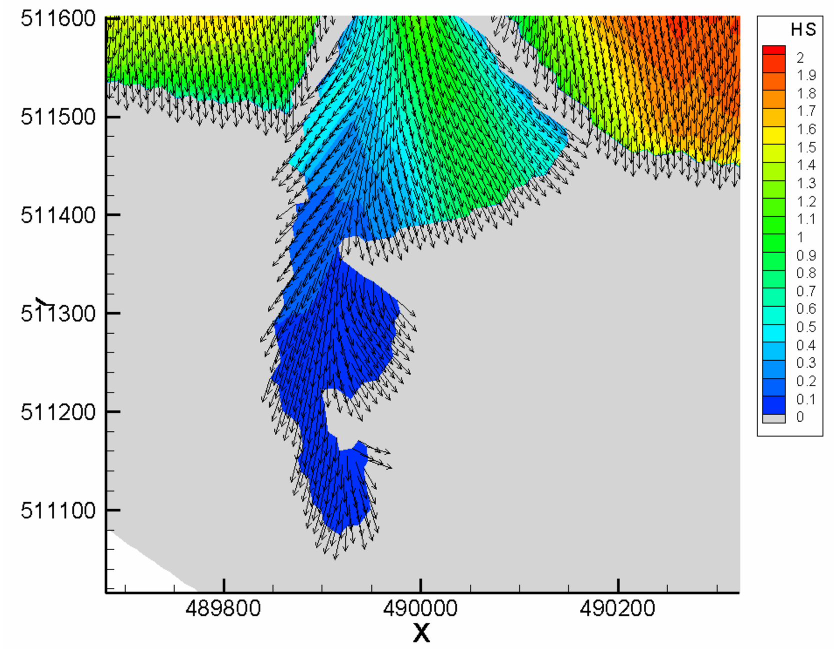
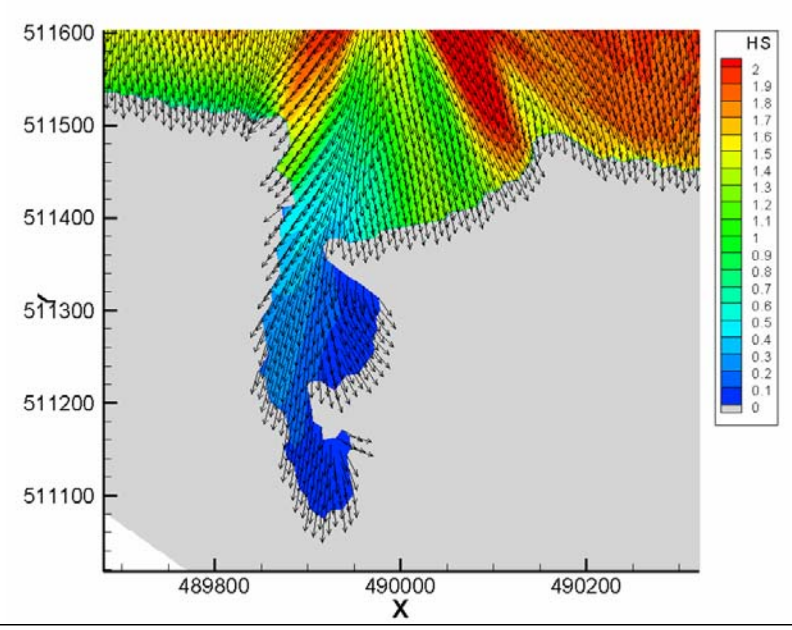
Figure 14 shows similar effectiveness of the piers in reducing wave heights. Plot A shows the wave height contours in the harbour and estuary under a 1 in 100 year event with the piers present, while plot B shows the wave height contours under an identical event with the piers absent. The scale showing the different wave heights is identical on each plot, and it can be seen that values are much more severe without the piers, not only in the estuary and harbour, but also along the adjacent coast and nearshore areas.



(A) 1 in 100 year return period (With Harbour Piers)



(B) 1 in 100 year return period (Without Harbour Piers)

Figure 14 Wave Heights under a 1 in 100 year Return Period Event

The modelling has also shown that in the event of a breach through the East Pier (as modelled under Option 2) wave heights would increase by around 8% in the vicinity of the breach but the residual structure would (initially) remain exerting a reasonable degree of protection to most of the harbour and estuary. However, exposure to the inner face of the West Pier would increase and over time the breach would unravel and widen, allowing greater wave penetration and causing progressively more damage to remaining structures. Ultimately, these processes would move the wave conditions towards the 'no piers' scenario.

5.5 Beach Behaviour and Sediment Budget Analysis

In the present study, the previously-defined conceptual understanding of beach behaviour and sediment budget analysis has been reviewed and used to inform assessments of the potential impacts of various management options on adjacent stretches of coast. Key findings of relevance to the processes in and around Whitby Harbour, and their interactions with the adjacent coastal system, are listed below:

- Sand is transported generally west to east along the coastal frontage between Sandsend and Abbey Cliff, although offshore transport and temporary drift reversals can occur depending on governing wave conditions. Nearly half of the alongshore transport occurs along the nearshore sea bed, outside of the inter-tidal zone.

- Some sand is transported eastwards past the West Pier before settling out on the bar near the harbour mouth.

- A significant proportion of sand and some shingle is transported into the harbour and settles out in the lower reaches of the estuary (downstream of the Swing Bridge). Between 1992 and 1999 the average annual dredging of sand from this area was of the order of 23,000m^3.

- Finer material that enters the harbour is transported further upstream, generally beyond the Swing Bridge, before settling. Between 1992 and 1999 the average annual dredging of silt from this area was of the order of 48,000m^3.

- The coast downdrift (i.e. to the east) of the harbour has little in the way of mobile beach deposits.

- Any material that does not settle in the harbour continues along an offshore-directed transport pathway, having been forced offshore by the harbour arms. A proportion of this sediment may ultimately return to the coastline, but not in the vicinity of the harbour.

- The existing harbour arms trap approximately 80% of the potential shingle material and 60% of the potential sand material being transported along the beach.

- Prior to the construction of the pier extensions, only around 20% of the total transport load was retained by the piers, thus more material was transported eastwards into the harbour and beyond.

- If the harbour arms were extended to the -6mODN contour, almost no sediment would by-pass the harbour mouth.

- The piers at Whitby Harbour are critical in controlling the loss of beach material from the frontage to the west of the harbour. The West Pier has two important functions: (i) it shelters the harbour from north-westerly waves; and (ii) it acts as a groyne that retains the beach along the coastal frontage to the west. The East Pier shelters the harbour from waves east of north.

5.6 Overtopping Assessments

In the Whitby Coastal Strategy, overtopping assessments were performed at only one location, towards the landward end of the East Pier. Overtopping discharges were investigated under present arrangements and under various potential management options, including raising foreshore levels, providing armour revetment and constructing a wave return wall. The work concluded that the preferred approach to improve overtopping performance was to construct a rock revetment along the seaward face of the East Pier to a slope angle of 1 in 1.5.

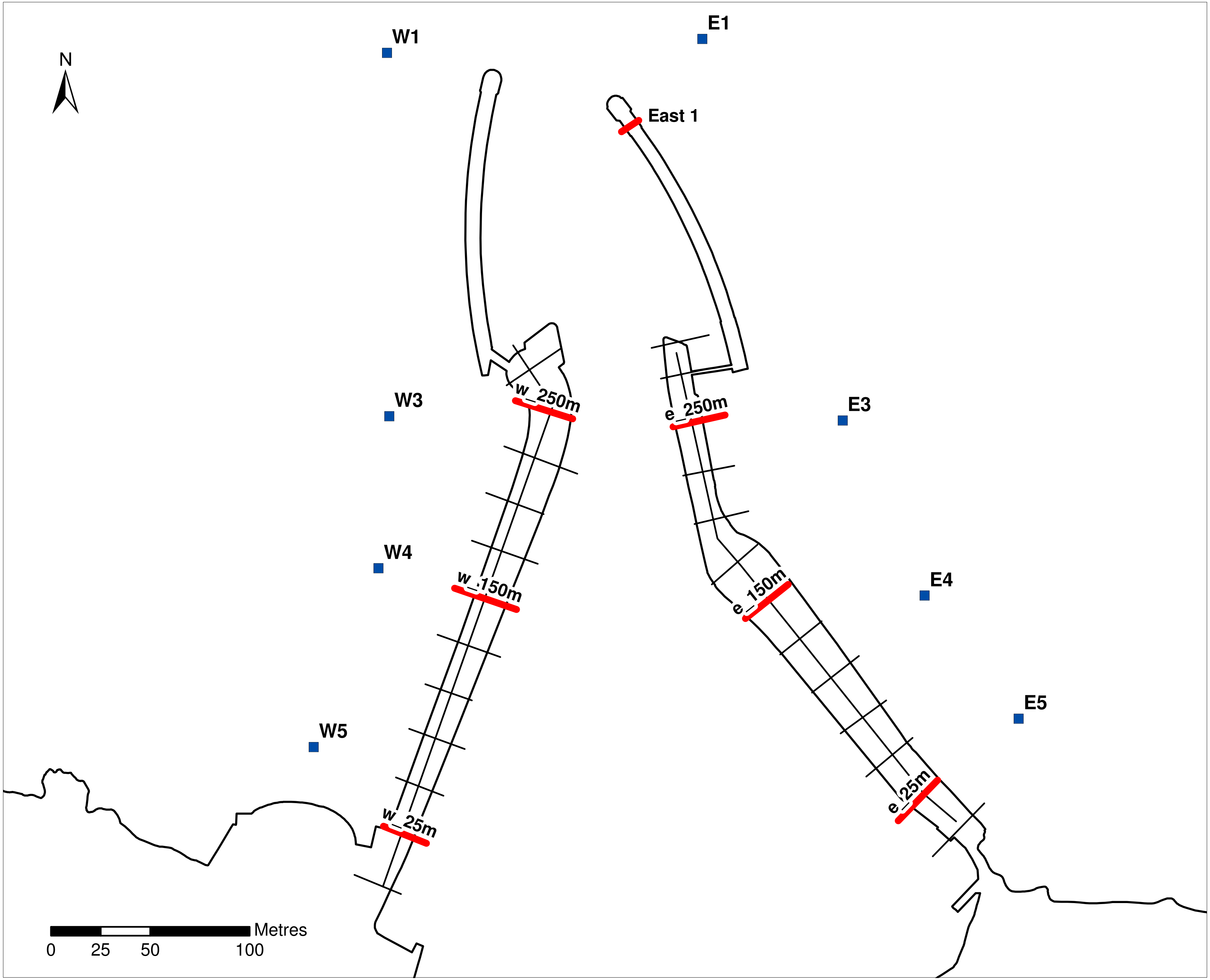
In the present study, wave overtopping assessments were made at various cross-sections along both the West and East Piers. Methods described in the Environment Agency's Overtopping Manual (Besley, 1999) were applied. The Overtopping Manual presents a means of calculating overtopping discharges of walls of different typologies when exposed to different hydraulic loading parameters. This approach was used to determine overtopping discharges at three cross-sections along the West Pier, three along the East Pier and one at the northern end of the East Pier extension. The locations of these cross-sections is shown in Figure 15 and they have been located to capture the landward (25m chainage), mid (150m chainage) and seaward (250m chainage) sections of each of the main piers.

For each cross-section the 'worst-case' overtopping assessment was undertaken for a water level and wave event with a combined ('joint probability') return period of 1 in 1 year, 1 in 50 years, 1 in 100 years and 1 in 200 years. The cross-section topography of the structures was derived from the detailed terrestrial laser survey of the piers, with the levels at the toe of the structures taken from this same survey and/or the hydrographic survey. In all overtopping assessments, it was assumed that the wave conditions were normal to the structure. In addition to these 'present-day' scenarios, the water level value was elevated by 0.278m to provide an indication of the effect of sea level rise on overtopping discharges by 2057.

Results from this exercise reveal the following conclusions:

- Of the modelled sections, overtopping was greatest at the East Pier extension. Here discharges are in excess of thresholds that could lead to structural damage.

- By inference from the above, it can be assumed that overtopping will be similar along the West Pier extension since wave exposure and bed level conditions are broadly similar.



Model Result Points

Cross-sections used for overtopping calculations

Title:
Location of overtopping cross-sections

Project:
Whitby Coastal Strategy Further Investigations at Whitby Harbour

Client:
Scarborough Borough Council

Date:	Scale:
January 2009	1 : 1,250

Figure:	Drawn:	Checked:
15	TC	NC

ROYAL HASKONING

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- Overtopping along the East Pier is greater than that along the West Pier. In both cases, discharges are lower than the structural damage threshold but always in excess of serviceability thresholds under the defined input conditions.

- The landward section is the location where overtopping is greatest on each main pier.

- The seaward section has the next greatest overtopping on each main pier.

- The mid-section is the location where overtopping is least on each main pier.

- The landward section of the East Pier is the worst section of the main piers. Here public access to the main pier has been reinstated as part of the Haggerlythe Coastal Defence Scheme. In October 2007 the Whitby Gazette reported on its front page how two fishermen were nearly swept off the pier at this location by an overtopping wave (Figure 16), demonstrating the particular vulnerability of this section and the public safety issues associated with overtopping of the piers.

- The overtopping situation along all structures (main piers and extensions) worsens over 50, 100 and 200 years due to rising sea levels.


Whitby Gazette

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TUESDAY 2 OCTOBER 2007

Clinging on for dear life

Two fishermen desperately cling to Whitby's East Pier after they were almost swept off by a wave. Their frantic friends can be seen to the left rushing towards them. This dramatic image was captured by Gazette reader Stuart Trumper on Saturday evening. Read the full story on page 3.

Figure 16 – Whitby Gazette News Coverage

Having identified the present and future-day risks from overtopping of the structures, efforts were made to reduce overtopping discharges in the models to tolerable target levels through the introduction of two management approaches, namely (i) raising of the wall crest; and (ii) introduction of a rock revetment on the seaward face.

Results show that in order to achieve tolerable target overtopping discharges for serviceability along the main piers, it would be necessary to raise crest levels by quite extreme values (i.e. by several metres in height). Improved performance in terms of achieving these threshold target levels could more preferentially be achieved through the construction of a permeable berm (i.e. a rock revetment) along the seaward face of each pier.

5.7 Flood Levels along the River Esk Estuary

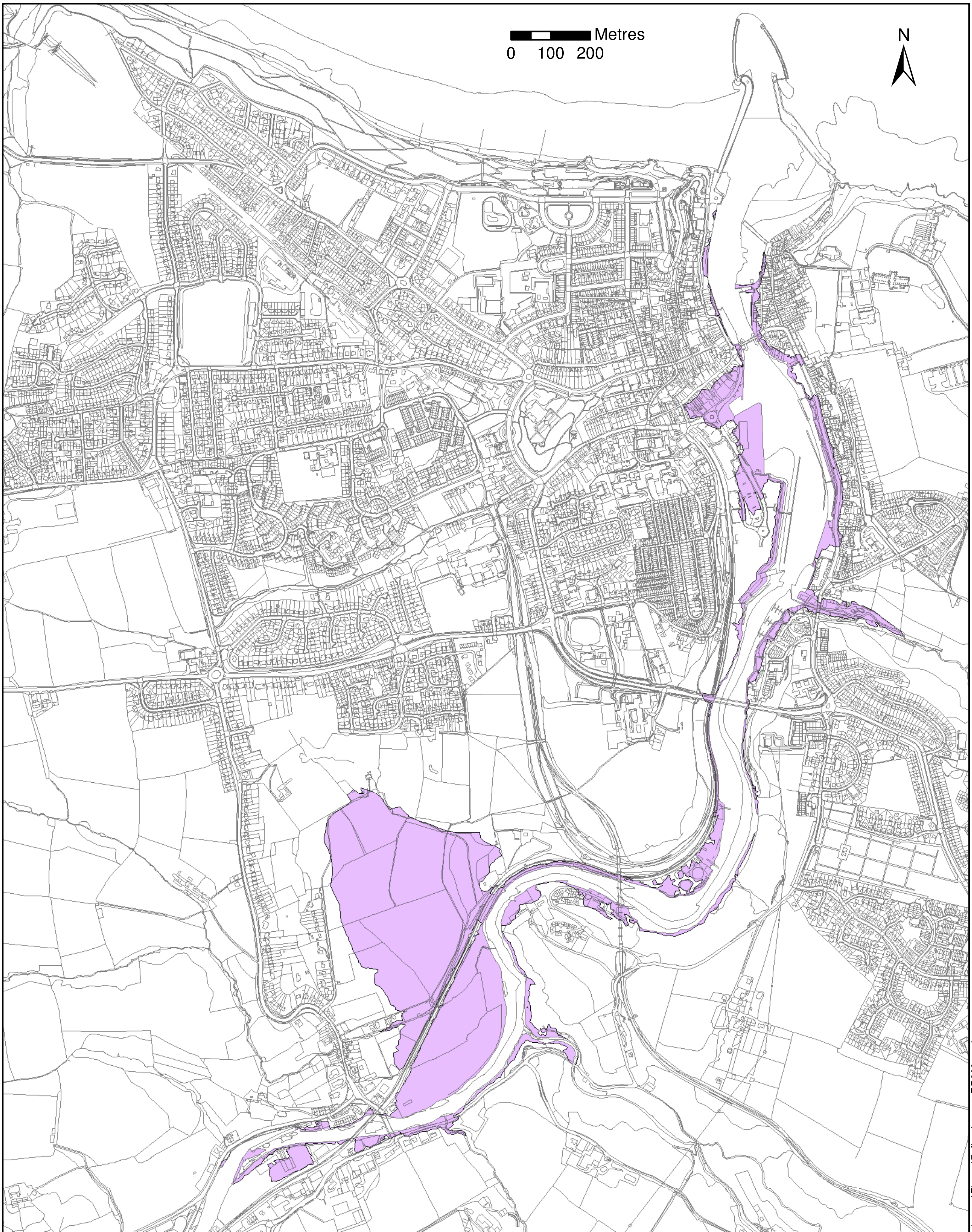
In the Whitby Coastal Strategy assessments were made of flood levels along the River Esk estuary, based on a Digital Ground Model (DGM) and extreme water level values. This approach has been duplicated in the present study, with the latest guidance allowances for future sea level rise over the next 50 years utilised.

These assessments show that sea level rise will have a notable effect in terms of increased flood extents for an equivalent return period event compared with the present day, meaning that more properties will become affected by flooding when it does occur.

Under present day extreme water levels, 321 properties identified on the National Property Dataset are at potential risk of flooding from a 1 in 200 year return period event (Figure 17). Of these, 204 are residential properties. In comparison by 2057 some 365 properties (of which 227 are residential) will potentially be at risk when sea level rise allowances are factored in to the assessments (Figure 18).

5.8 Wave Run-up

In addition to tidal flooding from the estuary and the risks from overtopping waves, part of the town to the west of the harbour is at risk of flooding due to run-up of breaking waves. Under storm events, waves can run-up the RNLI slipway immediately at the root of the West Pier (Figure 19) causing local flooding to the road and properties. This process is not new, however, and has been recorded in historic photographs (Figure 20). Also, referring back to earlier Figure 3, location H clearly demonstrates this process occurring during a storm in 1999.



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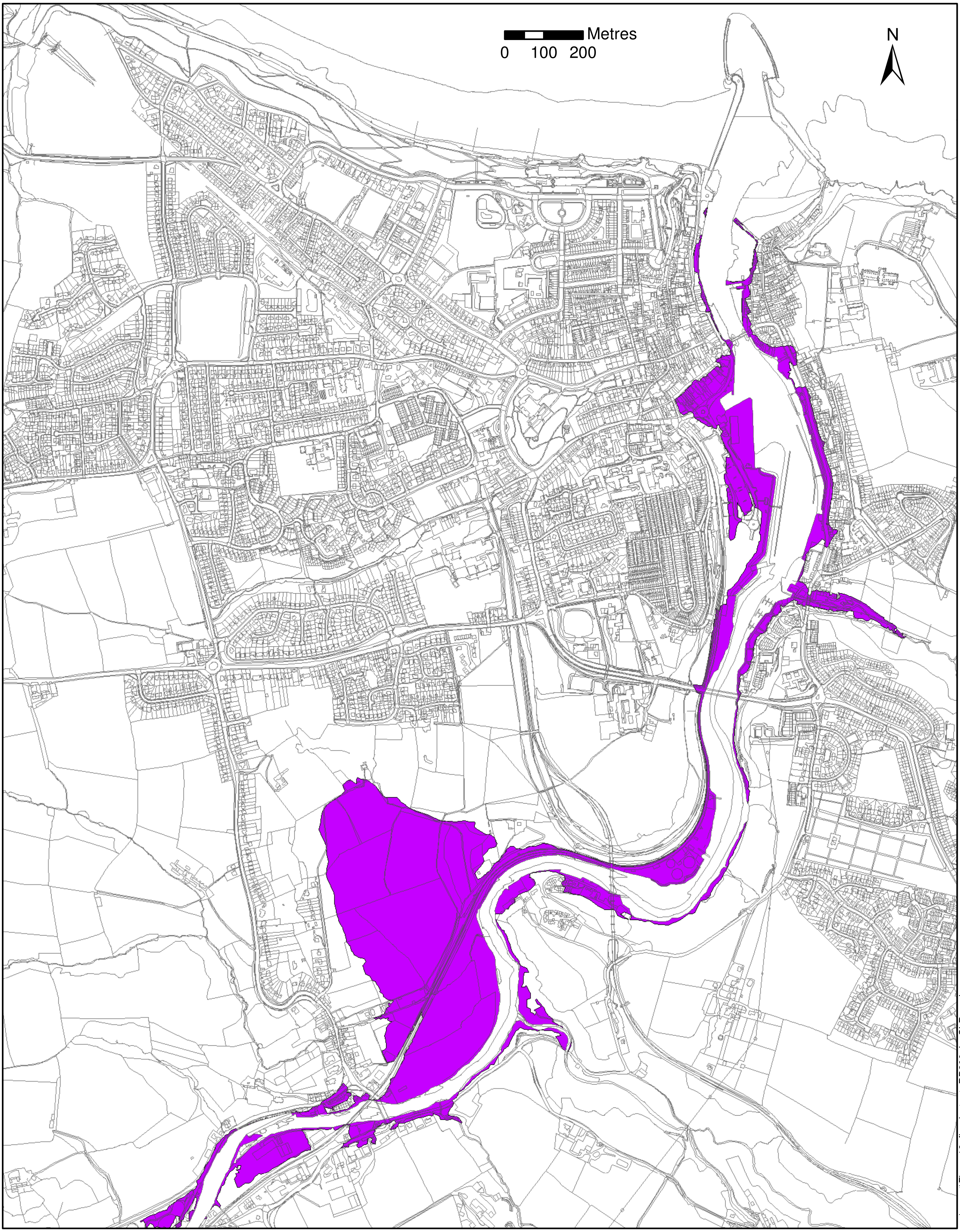
Key:

200RP: 4.1m

Title: 1 in 200 year Extreme Water Level Event	Date: January 2009	Scale: 1 : 12,000	
Project: Whitby Coastal Strategy Further Investigations at Whitby Harbour	Figure: 17	Drawn: TC	Checked: NC
Client: Scarborough Borough Council			

ROYAL HASKONING



Key:

200RP + SLR: 4.38m

Title:
1 in 200 year Extreme Water Level Event plus 50 years SLR

Project:
Whitby Coastal Strategy Further Investigations at Whitby Harbour

Client:
Scarborough Borough Council

Date:	Scale:
January 2009	1 : 12,000

Figure:	Drawn:	Checked:
18	TC	NC

ROYAL HASKONING

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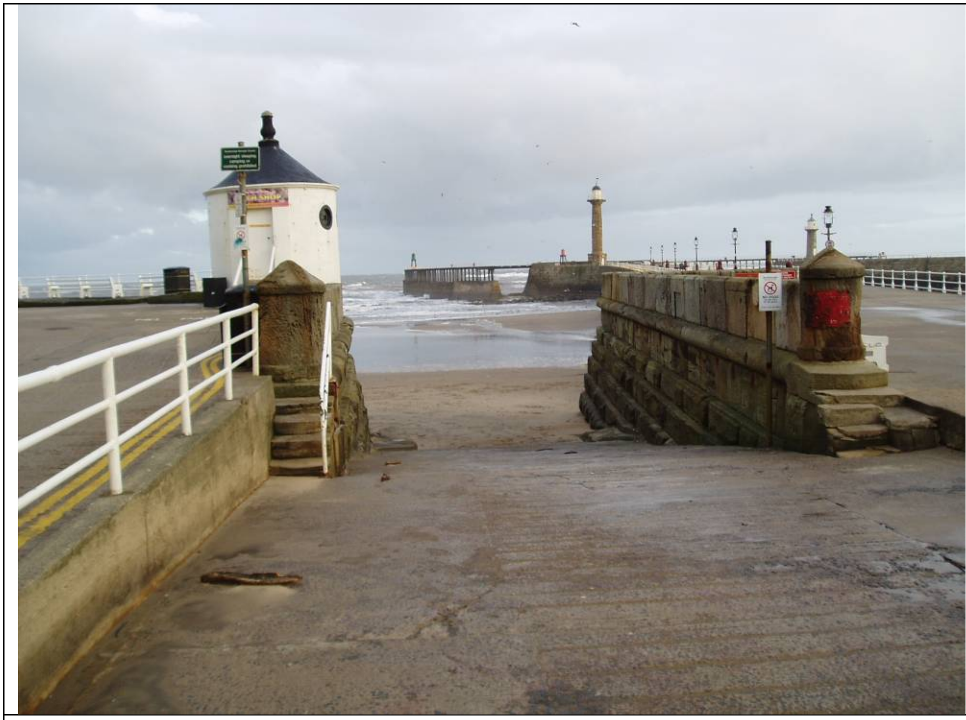


Figure 19 – Slipway Adjacent to the West Pier

Figure 20 – Historic Photograph of Wave Run-up at the Slipway
(photo courtesy of Whitby Literary and Philosophical Society

6 OVERALL ASSESSMENT OF EXISTING STRUCTURES

6.1 Background

In order to understand the overall condition of the existing structures, it is worth understanding the history and construction of the pier structures in their current form. This information has been determined from previous studies and verified through the recent investigations.

Some form of harbour protection has been present at the mouth of the River Esk at Whitby since the early 1300s. The original pier construction is thought to have been of timber and stone boulder construction. The first stone sandstone block piers are thought to have been constructed as the West Pier in 1632 and later for the East Pier in 1702. Both piers were progressively raised and lengthened throughout the 1600s 1700s and 1800s, indicating the increasing need for a substantial defence to the estuary. The main West Pier was completed in its current form in 1831 with the Main East Pier being completed in 1854, so these structures are in the region of 150 to 180 years old, with some elements dating back further. Minor repair works have evidently been undertaken since then but at unknown dates.

The pier extensions were constructed between 1908 to 1914, along with the interceptor walls to the bullnoses on each of the main piers. The extensions were allegedly underpinned with concrete and sheet piles in 1959-60. Subsequent major repairs were carried out to the extensions in 1975-76 as well as the main pier bullnoses.

The main piers are generally constructed from large sandstone blocks that form the faces of the piers. These blocks are known to be mostly single blocks between 900 – 1100 mm wide, which would have been originally bedded on lime mortar. These outer faces provide the main structural stability the harbour structures, retaining the fill material behind and taking the initial impact from the sea conditions. At the seaward end of the West Pier, metal ties have been used to tie the smaller stone blocks on the outer radius back into the fill material.

The fill material between the faces is known to be locally won natural sandstone rock fill for the majority of the depth. The top 1.0 - 1.2m of fill material changes from the rock fill to a sand and gravel fill, most likely to be locally won beach material, with some man made rubble. The pier deck is constructed from sandstone blocks 200 – 400mm thick which have shown to be strapped together with metal staples across the deck. The main piers are generally founded the Whitby mudstone formation bedrock, although the landward end of the main West Pier is founded on a sand and gravel band.

The main West Pier differs from the east in that it has a concrete surfacing approximately 100 mm deep, which is reinforced around the seaward end. Patch repairs have been undertaken to the main piers probably over the last 150 years. These have included grouting, sheet pile toe protection, concrete toe beam, concrete deck repairs and infill wall.

The main pier bullnoses are constructed from mass concrete facing walls, between 1.0 – 1.2m thick with a uniformly compact fill material behind. The fill material in this area is unknown. The surface of the bullnose is mass concrete construction, about 700mm thick, directly overlying the fill material.

The pier extensions are considered to have been constructed by firstly installing a sheet pile cofferdam around the perimeter of the structure. Then it is assumed that locally won sands and gravels or rockfill were used to fill the base of the cofferdam, which was overlain with a mass concrete foundation to the top of the piles. The mass concrete trapezoidal body would have been cast on top, finishing with the timber gantry structure to provide the complete structure. The pier extensions are founded on the Whitby mudstone formation bedrock.

From the further investigations that have been undertaken as part of the present study, the previous Strategy's conclusion is confirmed that the piers and pier extensions are in a poor condition. Some areas, notably the southern end of the East Pier extension, are at risk of failure and possible collapse, unless remedial works are undertaken.

The following sections synthesise the overall condition and performance of the structures and gives details of the major defects. The grading is provided in accordance with Institution of Civil Engineers "Guide to Inspection of Underwater Structures" (October 2001).

6.2 Main West Pier

The overall condition of this structure is poor **(Grade 4)**.

Above the waterline many types of defects were observed, mainly pertaining to the large sandstone blocks. The blocks have become extremely eroded over their life span which has caused them to crack, chip, settle or become displaced. Through this action openings have occurred between the blocks joints. The open joints have again become worn through wind and wave action which has exacerbated the problem, removing the mortar.

There is evidence throughout the structure's faces that some remedial work, such as providing a grout infill to the open joints, has been undertaken. This is especially apparent on the east face, between chainage 536 and 547, although other areas do exist. Any remedial works noted are now in a very poor condition and almost serve no protection to the remaining structure.

The movement of the blocks, as mentioned above, has caused damage to almost all the coping level. Again, some remedial work has been undertaken, primarily using concrete. The remediation is also in a poor state.

The defects to the structure surveyed during the diving operations are similar to those above water. The structure has suffered from movement of the sandstone blocks, allowing openings to form between the joints. The movement has potentially come due to scour caused by hydraulic action at bed level and across the face. A variety of voids were noted beneath the bottom course of blocks, some up to 1500 mm in depth. The washing out of any fill material at this level will have destabilised the courses above causing the settlement shown in certain locations. However, in general the openings between blocks seem of less significance than those observed above water. This may be due to the presence of hard marine growth that has found the voids a suitable habitat. There is also less damaged to blocks to the chips and cracks observed in dry areas.

The defects noted below the waterline show no patterns or concentration, except that they are consistent along the structure's east face.

The geophysical survey identified that there was a significant degree of voiding present behind facing blocks and below the deck on the east face of this main pier. The survey also noted that the voiding increased towards the more exposed seaward end of the pier. This correlated with the extensive damage to the facing blocks noted in the dive and visual survey. The evidence of damage and voiding on the west face are less due to the significant protection provided by the deposited beach material against the face.

The combination damage, scour and voiding in the structure is considered to be sufficiently significant to that the structure could become unstable and potentially lead to collapse as described in Section 6.8. The damage to the blocks caused by hydraulic action across the face and at bed level leading loss of mortar. In turn, this would cause the blocks to settle and move opening the joints between them. The hydraulic action of water flushing in and out of these joints would lead to the voids forming behind the facing.

Taking into account to the size, age and exposure of the Main West Pier its condition could be worse, yet the defects noted are of great significance and as they continue to worsen the structure may become further unstable and partial collapses may occur. From an engineering perspective it is difficult to make any assumption as to when failure may occur, although from what has been witnessed it is believed that any large storm could potential displace the sandstone blocks causing some collapse.

From a safety point, it was noted that two access ladders were noted to be damaged during the surveys, one on either side of the pier. Similarly, it was observed that a section of the metal guardrail was deformed but this may not have affected its performance.

Overtopping discharges were calculated to be lower than along any other harbour structure but despite this remain in excess of target thresholds for serviceability. The overtopping discharges were calculated to increase further with sea level rise added.

6.3 West Pier Bullnose

The overall condition of this section of the structure is reasonable **(Grade 3)**.

The visible concrete above water shows signs of wind erosion and wave damage, especially to the concrete joints formed during its construction. These joints have opened by an average of 100 mm and to a depth of 50 mm. There is evidence that some remedial works have been undertaken in the form of grout/concrete infill to these joints. The remedial works appear to have failed and have disappeared in the most part. The opening of the concrete construction joints has not significantly decreased the integrity of the structure.

Below the waterline the condition is similar, with the exception that no remedial works were obvious during the investigation. Again, there is opening of the concrete construction joints, although the rate of degradation is not a severe as above water.

The underwater condition survey noted threes significant voids on the West Pier Bullnose. At chainages 22 and 34 there are two areas of scour 2 m and 3 m in length respectively. The scour undercuts the structure by up to 400 mm. The third void is much smaller, and could have possibly been caused through impact damage.

The diving operations were unable to reach chainage 0 to 20. At this point a concrete ramp divides this structure and the WPE and severe hydraulic action caused diving in this location to be unsafe. Further investigations on the West Pier Extension near this area show significant damage (see Section 6.4). From all information gathered an assumption can be made that between chainages 0 and 20 there is a high possibility that scour has occurred.

The geophysical survey identified there were voids below the mass concrete deck to the pier bullnose. This would correlate with the scour action observed at the base of the bullnose. The scour would undercut the structure base forming a void under the wall to the fill material behind and potentially open the joints in the walls. Hydraulic action would potentially flush the fine fill material from inside the structure.

6.4 West Pier Extension

The overall condition of this structure is poor **(Grade 4)**.

Above water the structure’s middle section of concrete, from chainage 27 to 137 on its west face and from chainage 181 to 288 on it east face, is in a reasonable condition with only degradation of the material occurring at the construction joints, which were formed during the concrete pouring. These joints have opened by an average width of approximately 100 mm and a depth of up to 50 mm through wind erosion and wave action. The openings of the joints have not decreased the integrity of the structure.

At various places along the interface between the east face and the deck level the opening of the construction joints have caused some weathering and fractures to the edge. In some cases this damage has been repaired with an addition grout/concrete infill. Further fracturing of this edge may occur without any treatment or remedial works.

At both the two ends of the West Pier Extension the above water defects are of less significance. This is due to an additional concrete pour encasing the existing structure. It is unknown when this remediation was undertaken. The newer concrete also shows signs weathering at the construction joints to a lesser degree.

The defects observed during diving operations are more severe than those in dry areas. The main concrete core is showing signs of opening at its construction joints, although the size and frequency of this occurrence is to a lesser extent, potentially because hard marine growth has helped to protect against hydraulic action. The major defects concern is the sheet piles around the perimeter of the structure. 35 no. voids were visible in the steel sheet piles mainly concentrated in two areas; the south-eastern corner from chainage 226 to 306 and on the seaward bullnose to the structure from chainage 147 to 166. The west face of the structure is almost entirely free from defects.

The voids in the sheet piles have been caused through corrosion of the steel. The corrosion has mostly occurred to the out-pans of the piles, although there is some evidence of patches of corrosion to in-pans that haven’t as yet created voids. Most voids are located within the bottom metre of the pile, up from the sea bed, and are on average 300 mm wide. Behind the position of the sheet pile the concrete is also missing. This has created openings that can be over 2 metres deep, but on average are approximately 700 mm. Inspection of these openings found that the overhanging concrete (the soffit of the opening) generally consisted of a flat face. This has led to the assumption that the construction methodology consisted of; driving the steel piles, backfilling with a loose material as a blinding layer, and then continuing with the concrete pour. Since the formation of the voids through the loss of the sheet pile the loose backfill material has been washed away causing larger voids.

The corrosion to the steel sheet piles, along with further loss of any loose material and the degradation of internal areas of concrete will continue without any remedial works undertaken.

From a safety point, it was noted that some of the metal access ladders up the side of the lower tier were noted to be extensively corroded during the surveys. Whilst these are not used regularly by the public or maintenance staff, they could be required for emergency access or occasionally for maintenance activities. Similarly, it was observed that a wire rope guardrail was significantly corroded which would limit its performance capability. Whilst the areas observed are not open to the public, they may be used in emergency and by operation and maintenance staff.

Overtopping discharges were not directly calculated along the West Pier extension, but analogy with the East Pier extension suggests that value would be well in excess of target thresholds for serviceability and are likely to be in excess of target levels for avoidance of damage. The overtopping discharges are expected to increase further when sea level rise is considered.

6.5 Main East Pier

The overall condition of this structure is poor **(Grade 4)**.

During the inspection of the dry areas many types of defects were observed, mainly pertaining to the large sandstone blocks. The blocks have become extremely eroded over their life span which has caused them to crack, chip, settle or become displaced. Through this action openings have occurred between the blocks joints. The open joints have again become worn through wind and wave action which has exacerbated the problem.

This problem is especially apparent on the eastern face, where the structure is exposed to more severe weather conditions. At three locations along this face there is major evidence of the settlement of the courses. Further to this some remedial works have been undertaken in this area. The works generally consist of concrete patching or the grouting of the open joints and voids caused during displacement. Where minor patching has occurred any remedial works have failed caused exposure of the face.

On the Main East Pier’s east side there is a large section of concrete covering the blockwork face, from chainage 390 to 400. This is assumed to be a reasonably modern addition to the structure as its condition is still good considering the areas exposure. It is unknown as to why the concrete works have taken place, or what defects it may be covering.

To the west face there are two notable patches of concrete added to the face, located at chainage 117 and 130. These two patches have been added in a non-uniform manner.

The defects recorded during the diving operations were less frequent than above water. There are, however, two major of voids of noted at chainage 310 and 320. Here the voids are 2 metres and 1.5 metres in length and are both over 2 metres in depth, meaning that the sandstone blocks above are being suspended through a cantilever action. Both of the voids are at seabed level.

The geophysical survey identified a significant degree of voiding behind the facing blocks and below the deck over the last 90 m at the seaward end of this pier, where the structure narrows in width from 30 m to 10 m. similarly to the Main West Pier, the is a clear correlation between the block damage and the voids identified behind. Again this confirms the failure mechanism identified in section 6.2 above, identifies the structure could become unstable and could lead to the potential collapse as described in section 6.8 below.

Along the eastern face of the Main East Pier a low-level section, up to 2 metres in height, of steel sheet piling exists for most of the length. It is assumed that this piling was an addition to the original structure in order to correct any scouring that may have occurred at this point. All of this sheet piling is a good condition, as is the concrete infill behind it. There is some minor evidence that accelerated low-water corrosion (ALWC) is starting to affect the piles along there top edge. This area is in the tidal zone, which dries during the low tide. The ALWC occurs on most piles, but the patches of corrosion are at an average of 20-500 mm in diameter. Further monitoring of this defect is recommended.

The hydrographic and side scan survey identified an area of concern on the east face between 50 – 60 m from the seaward end. A series of three hollows or scoops were recorded in the seabed adjacent to the pier wall. These could be formed by weathering of the bed rock over a localised area or by mechanical means such as dredging. The hollows could potentially destabilise or undermine the facing blocks, causing a collapse. However, the survey also noted that a concrete and pile toe beam appears to have been formed along the 100 m length of the west face from the seaward end.

From a safety point, it was noted that two access ladders were noted to be damaged during the surveys, both on the northwest quadrant of the pier. This pier has no guard rail around the pier edge despite drops of up to 8m, with the exception of the last 80m at the seaward end. Whilst this pier is less popular with the public, the risk of falls by the public, operational and maintenance staff remains due to the exposed nature of the pier, worn surfacing with trip hazards.

Overtopping discharges were calculated to be greater than along the West Pier, and are greatest at the landward end of the East Pier. Here discharges in excess of target thresholds for serviceability. The overtopping discharges were calculated to increase further with sea level rise added.

6.6 East Pier Bullnose

The overall condition of this section of the structure is reasonable **(Grade 3)**.

The visible concrete above water shows signs of wind erosion and wave damage, especially to the concrete joints formed during its construction. These joints have opened by an average of 100 mm and to a depth of 50 mm. There is evidence that some remedial works have been undertaken in the form of grout/concrete infill to these joints. The remedial works appear to have failed and have disappeared in the most part. The opening of the concrete construction joints has not significantly decreased the integrity of the structure.

Below the waterline the condition is similar, with the exception that no remedial works were obvious during the investigation. Again, there is opening of the concrete construction joints, although the rate of degradation is not a severe as above water.

Only minor evidence of scour was noted during the investigation.

The geophysical survey noted minor areas of reduced compaction under the mass concrete deck to the bullnose. This is not sufficient to cause concern at present, although deterioration should be monitored in the future.

6.7 East Pier Extension

The overall condition of this structure is very poor **(Grade 5)**.

Above water the structure's middle section of concrete, from chainage 25 to 135 on its west face and from chainage 179 to 287 on it east face, is in a reasonable condition with only degradation of the material occurring at the construction joints, which were formed during the concrete pouring. These joints have opened by an average width of approximately 100 mm and a depth of up to 50 mm through wind erosion and wave action. The openings of the joints have not decreased the integrity of the structure.

At both the two ends of the East Pier Extension the above water defects are generally of less significance. This is due to an additional concrete pour encasing the existing structure. It is unknown when this remediation was undertaken. The newer concrete also shows signs weathering at the construction joints to a lesser degree, although significant damage was noted at the landward end on closer inspection as described below.

The defects observed during diving operations are more severe than those in dry areas. The main concrete core is showing signs of opening at its construction joints, although the size and frequency of this occurrence is to a lesser extent, potentially because hard marine growth has helped to protect against hydraulic action. The major defects concern the sheet piles around the perimeter of the structure. Over 60 no. voids were visible in the steel sheet piles mainly concentrated in two main areas; from approximately halfway along the eastern face and around the landward end, chainage 222, through chainage 0/320 on to chainage 6, and around the seaward bullnose of the structure, chainage 130 to 164.

The voids in the sheet piles have been caused through corrosion of the steel. The corrosion has mostly occurred to the out-pans of the piles, although there is evidence of patches of corrosion to in-pans that have not as yet created voids. Most voids are located within the bottom metre of the pile, up from the sea bed, and are on average 300 mm wide. Behind the position of the sheet pile the concrete is also missing. This has created openings that can be as deep as 800 mm, but on average are approximately 300 mm.

Inspection of these openings found that the overhanging concrete (the soffit of the opening) generally consisted of a flat face. This has led to the assumption that the construction methodology consisted of; driving the steel piles, backfilling with a loose material as a blinding layer, and then continuing with the concrete pour. Since the formation of the voids through the loss of the sheet pile the loose backfill material has been washed away causing larger voids.

The corrosion to the steel sheet piles, along with further loss of any loose material and the degradation of internal areas of concrete will continue without any remedial works undertaken.

The most severe damage to the sheet piles and has occurred to the south-eastern corner. Here almost all the steel sheet piles are missing, with the exception of the vertical clutches, due to their increased thickness. The void caused in this corner runs the entire length of the southern face, and for approximately 8 metres up the eastern side. The opening beneath was estimated to have a height of 2 metres and a depth of approximately 5 metres. This means that almost the entire final section of the concrete visible above water, including the timber walkway positioned above, is suspended via a cantilevering action from the rest of the structure.

The structural inspection of the landward end of the East Pier extension identified that the cantilevering concrete structure was in deed showing signs of movement and distress from the loss of supporting material under the structure. This was evident from the construction joints opening at the top and closing at the base. It was accompanied by signs of spalling, cracking and a stepped crack joint probably from the compressive force.

It was considered that the structure only remained in tact from the potential reinforcement in the repaired section. It is unknown for how long this area has survived in this condition but it is at a high risk of failure should no remedial works be undertaken in the immediate future. No certainty can be provided as to a timescale for failure, as it is dependent upon storm frequency and severity.

The East Pier extension used to be connected to the east main pier via a link bridge supported by a central pier mid span. It is understood that the central pier subsided due to scour action in 2002, causing the bridge deck to tilt to the landward side. As a precautionary measure the bridge was removed, so removing pedestrian access from the main pier. The remains of the pier base are visible and clearly show signs of settlement on the landward side, in the order of approximately 600 to 1000 mm. Access to the East Pier extension is currently gained by boat to ladders up the lower tier side.

From a safety point, it was noted that all the metal access ladders up the side of the lower tier were noted to be extensively corroded with missing rungs during the surveys. It was also noted that the sole ladder from the lower deck to the timber gantry was severely corroded with loss of section and deformed. This ladder should not be used until it is replaced. Whilst these ladders are not used by the public, they could be required for emergency egress from the water and are occasionally used for maintenance activities and access to the harbour lights. Similarly, it was observed that a wire rope guardrail was significantly corroded which would limit its performance capability. Whilst the areas observed are not open to the public, they may be used in emergency and are used by operation and maintenance staff.

Overtopping discharges were calculated to be greater along the East Pier extension than any other harbour structure. Calculated values are well in excess of target thresholds for both serviceability and avoidance of damage. The overtopping discharges will increase further due to sea level rise.

6.8 Overall Summary

The further investigations at Whitby Harbour have highlighted that all main piers and pier extensions are presently in a poor or very poor condition due to a wide range of defects. Despite these, they presently continue to provide a vital role in providing coastal and flood risk protection to Whitby Harbour, the lower reaches of the River Esk estuary and the adjacent coastlines as intended. A summary of the key defects and performance issues is provided in Table 5 and in Figure 21.

The *Whitby Coastal Strategy*, produced in 2002, highlighted that the harbour piers were considered to have a residual life of less than 10 years and that they were likely to collapse through what was identified as a breach scenario to the main piers. In reviewing the findings from the recent surveys, it can be confirmed that this scenario would be the failure mechanism for the structure leading to the loss of the harbour piers and coastal protection to Whitby and the surrounding area, if no further action was undertaken. However, the recent surveys also identified the breach scenario should be extended to include the pier extensions.

The most critical areas requiring works occurs on the landward end of the East Pier extension where there is a high risk of collapse due to loss of the supporting material (steel and granular fill) at the bed level. The removal of this material has caused the concrete pier above to cantilever or hang off the existing structure, which is not how the structure is intended to perform.

The present investigations have highlighted that the existing piers are in poor condition and that the East Pier Extension particularly is at risk of failure and could possibly collapse in the short term. The probable failure and breach scenario is identified below.

1) The landward end of the East Pier extension is likely to collapse, due to the scouring of the supporting material under the landward end of the structure. This collapse would lead to increased exposure to the bullnose and seaward end of the main East Pier from tidal surges and wave attack.

2) The collapse would expose the core of the East Pier extension. The sea would continue to attack the remains of the outer sheet piles, scour the foundation to the next section of the structure and outwash the newly exposed core of the structure. This is likely to have been formed of the original weaker mass concrete construction and will erode faster than the reinforced concrete repair on the outer face. With time, further sections of the East Pier extension are likely to collapse in the same manner, propagating the breach.

3) The outer face of the main East Pier at the seaward end currently has damage to the stone block facing where scour has eroded the mortar from the joints and blocks are settled and cracked. The displaced blocks mean that seawater flushes the fill material out from the pier core from behind the blocks leaving cavities. This narrow section of pier is shown to have significant voiding behind the stone block faces on

both sides and below the deck at present. These voids would increase in size at a greater pace than previously due to the increased exposure to sea conditions caused by the absence of protection from the East Pier extension.

4) As the worst conditions are from the north and northeast, the blocks would be dislodged into the voids by wave energy, causing the outer face to collapse taking away part of the pier deck. This would exposure the core of the main pier structure.

5) With the core exposed, the waves would further attack the core of the structure, dislodging the fill material and removing the support to the deck. This would reduce the pier height and eventually lead to a breach of the East Pier. With the breach, debris could disperse into the navigational channel presenting a hazard to vessels using the harbour.

6) The breach would continue to extend laterally during storm and high tide conditions as waves will propagate over and through the breach, causing it to enlarge. Eventually the whole of the northern section of the main East Pier would collapse into a mound with an ever decreasing defence height and effectiveness. This would allow larger waves to enter the harbour and attack the inner face of the main West Pier and its extension. Waves may also begin to impact assets further upstream in the River Esk estuary.

7) With the increased exposure to the main West Pier on its inner faces this structure too would eventually collapse and breach in a similar manner described for main East Pier. This is demonstrated by the defects recorded along the inner face of the main West Pier which leave it vulnerable to such processes. The analogue can be further extended to the West Pier extension, due to the scour action on the inner landward end, which could extend to collapse part of this structure.

8) If the structures receive no capital investment, they will continue to erode, collapse and disintegrate until only the ruins remain. This will expose the town and estuary to increase wave and tide conditions.

9) With the loss of the main West Pier and its extension, the beach deposits shift and deplete from the current profiles on the Whitby Sands beach. The sediment would block the navigation channel and drift further along the coast to cover the bedrock foreshore to the east of the harbour.

In reality, it is possible that the scenario described above may not occur in the order shown, as the surveys highlighted significant weaknesses to all structures. It is possible that either of the main piers could be subject to failures before the East Pier extension, although it would appear unlikely given the very poor condition of the landward section of the extension. The above scenario is provided as the most likely situation, and importantly the overall failure mechanisms and ultimate impacts identified would occur irrespective of the sequencing of failure.

With the benefit of the evidence from the recent detailed investigations, the statement in the Strategy that the residual life of both main piers is less than 10 years is considered to be conservative. However, the recent investigations have also identified that some sections of the main piers are in a worse condition and certainly that the East Pier extension is in a far worse condition than previously identified.

One difficulty in considering rates of deterioration, which helps to provide a more reliable estimate of residual life, lies with the limited information previously recorded on the pier condition during the previous assessment for use as a benchmark. Some indications on deterioration can be gained from comparing the dive surveys, although some damage appears to have been overlooked in, or occurred since, the previous survey (e.g. the scour hole under the south east corner). The level of information recorded for defects differs vastly between the two surveys. The initial survey recorded very little detail on the location, size, extent or degree of corrosion observed in the piles. The present survey is able to provide quantifiable evidence so that future surveys can provide detailed comparisons.

It is possible to provide an indication of residual life of the sheet piles through consideration of remaining sheet pile thickness. In this instance, the sheet piles around the pier extensions have virtually no life remaining in several areas and presently provide little protection, as scour holes have developed under the structure. However, these sheet piles do not appear to provide significant strength to the overall structure as whole.

The sheet piles on the main piers appear to be in fair condition except at the bullnoses, although their structural significance is less certain. It is clear that they provide scour protection to pier wall toes / foundations and may retain the supporting material in some areas. Recordings on pile thicknesses were noted to be unreliable due to inconsistencies and anomalies in the recorded data. It should be noted that the development of corrosion holes in the piles alone would not lead to the collapse or breach of the structure.

The likely failure mechanism to the pier extensions would be that the scour continues to erode the sheet piles and supporting material until it becomes unstable and collapses. General indications on when this could occur can not be determine from the present survey information recorded to date, but could be in the future. However, it is considered that immediate action is required to the southeast corner of the East Pier extension, as significant signs of structural damage are noted in the cantilever section.

The situation at the main pier bullnoses is similar to the pier extensions in that the sheet piles have little structural significance as a structural element but provide scour protection to the founding material of the concrete structure. With time, continual scour would undermine the bullnoses potentially causing them to separate from the main pier.

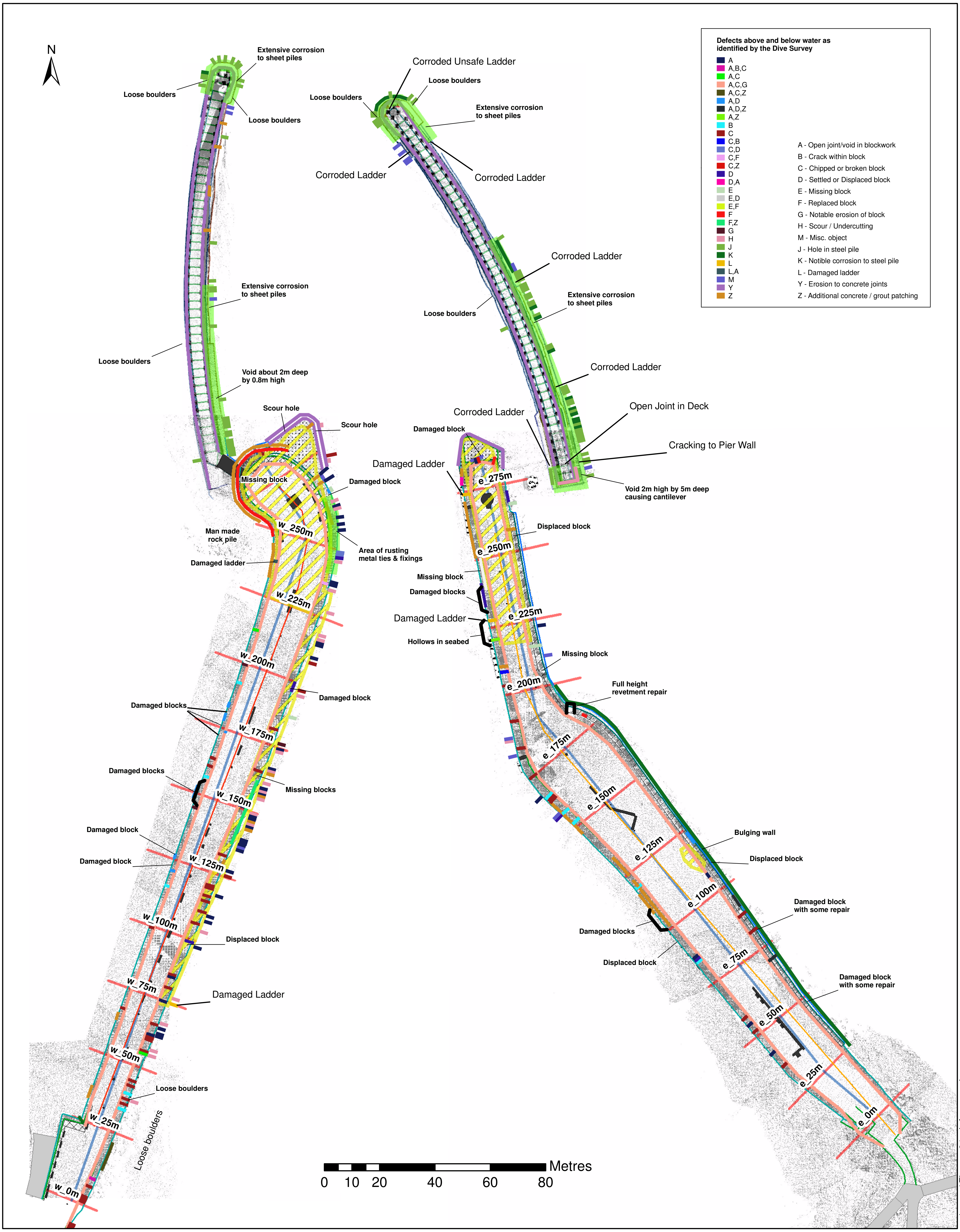
The main indicator for structural stability of the main piers would probably be the condition of the stone facing blocks and the degree of voiding behind. It is currently noted that there is extensive erosion of mortar joints and damage to the stone blocks far too numerous to accurately record, although key areas of damage were identified. However, the period over which it has occurred and the degree of deterioration over time can not be determined as there are no records of a similar nature from previous surveys.

The surveys have identified that there is significant voiding behind the cladding and below the pier decks. Again, it is difficult to quantify residual life as there are no previous surveys to compare in order to make an assessment. Equally, it was not possible to obtain much meaningful data for the outer walls of the piers due to difficulties with the surface profile.

It is understood that last major reconstruction of the piers was undertaken in around 1910. This would mean that the harbour pier structures in their current form have been in service for in the order of 100 years. This is quite a considerable length of service for a structure and is understandably in a deteriorating condition. The life expectancy of most structures designed today is nominally between 50 to 120 years with continual maintenance. The quality of the original construction has enabled the structure to last for this considerable period, although the materials have naturally deteriorated with wear and tear, operation and significant battering from the sea. This is shown in its current condition.

The residual life of the structure remains uncertain but given its age and need of capital investment, it is considered that substantial works are required in order to maintain its current function over the next 50 years, let alone improve its condition. The priority key used in Table 5 is provided as an indicator as to when works should be undertaken to avoid partial structural collapse and is based on the engineering judgement from the current data available.

It is particularly recommended that work is undertaken to the landward end of East Pier extension as a matter of urgency, so as to avoid the collapse of this element. The cost of replacing this part of the structure should it collapse is likely to exceed the cost of remedial works and may also lead to the need for further repairs to other structures due to consequential damage.



Key:

- Corrosion to sheet piles
- Damage to external face of block walls
- Areas of potential voids
- Section Baseline
- Cross-Sections

Title:
Whitby Piers - Overview Condition

Project:
Whitby Coastal Strategy Further Investigations at Whitby Harbour

Client:
Scarborough Council

Date: Jan 2009

Scale: 1 : 1,200

Figure: 21

Drawn: TC

Checked: CG

ROYAL HASKONING

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Table 5 – Summary of Key Defects and Performance Issues

Item	Defects / Performance Issue	Extent	Consequence of Issue	Priority
Strategic Issues				
S1	Large scour hole under landward end of structure forming overhanging section. Hole is 2m high by 5m deep. Opening of construction joints and cracking of adjacent concrete above scour hole by 5.5mm	East Pier extension	Cracking through structure notable at deck level. If reinforced, exposed steel will corrode. The joint will continue to open and crack propagation will lead to collapse of structure.	Urgent
S2	Significant scour to toes / foundations of structures, especially at holed sheet piles. Scour depth varies from 0.3m to 2m.	All structures particularly pier extensions & bullnoses	Scour causes undermining of supporting material to structures, which leads to instability of the structure and collapse	High
S3	Significant voiding noted behind stone faces and below pier crest. Voiding noted throughout but worse towards seaward ends.	East & West Piers, worse at seaward ends	Instability of pier faces & crest in combination settlement leading to collapse of pier edges and potential breach of structure.	High
S4	Extensive corrosion to sheet piles forming holes through pans in numerous places. Main damage to main pier bullnoses and pier extensions	All structures, particularly pier extensions	Corrosion of metal piles leads to holes in piles as observed and then scour to the structure toe and foundation	High
S5	Extensive erosion to mortar joints between stone blocks	East & West Piers	instability of the pier face with voids between blocks leading to flushing of fill material to form voids	High
S6	Extensive damage to stone blocks inc. cracking, chips, settlement & displacement	East & West Piers	instability of the pier face with voids between blocks leading to flushing of fill material to form voids	High
S7	Missing stone blocks at toe of pier face noted in four locations on the inner faces of piers. Voids 800 mm high by 900 mm deep	East & West Piers	Instability of pier faces & crest in combination settlement leading to collapse of pier edges and potential breach of structure	High
S8	Wave surge / flooding from wave run up at the slipway onto Pier Road	West Beach Slipway	Flooding to pier road and the properties on and adjacent to this road	High

Item	Defects / Performance Issue	Extent	Consequence of Issue	Priority
Strategic Issues				
S9	Two localised hollows identified in seabed adjacent to inner face of main pier. Some remedial work evident but not extensive enough. Causes could be weathered soft spot or dredging	Inner face of East Pier	Weathering and scour could extend under adjacent pier wall causing it to collapse	Medium
S10	Deterioration of past repair works. Particularly noted to deck surfacing on main piers & landward and seaward ends of pier extensions	East & West Piers & extensions	On the main pier decks, the defects will lead trip hazards for public and staff in short term. They are also long term indications of voiding and collapse below the surface. On pier extensions, medium term indications of collapse	Medium
S11	Overtopping performance beyond serviceability thresholds	Main piers and pier extensions	Hazardous for people on the piers during overtopping events. Lack of regular maintenance and deterioration in condition could lead to damage before theoretical threshold is reached	Medium
S12	Overtopping performance beyond damage avoidance thresholds	Pier extensions	Extensions become damaged by overtopping and ultimately lead to failure	Medium
S13	Significant erosion to concrete construction joints by between 50 – 100mm.	Pier extensions & bullnoses	Continued erosion to joint will remove monolithic connection between concrete sections leading to the structure becoming unstable.	Low

Item	Defects / Performance Issue	Extent	Consequence of Issue	Priority
Local Maintenance Issues				
L1	Extensive corrosion to metal access ladders with missing and severely corroded rungs. East Pier extension ladder between deck & gantry corroded to unsafe level	All structures particularly East Pier extension	Public, operational and maintenance staff will fall from ladders leading to severe injury, potentially fatality	Urgent
L2	Damage to timber ladders with rotten timbers and loose fixings	West and East Piers	Public, operational and maintenance staff will fall from ladders leading to severe injury, potentially fatality	Urgent
L3	Significant corrosion to wire rope rails around lower decks	West & East Pier extensions	Public, operational and maintenance staff will fall from ladders leading to severe injury, potentially fatality	High

<u>Priority Key:</u>

Urgent = works to occur immediately
High = works to occur in less than 5 years
Medium = works to occur between 5 – 25 years
Low = works to occur between 25 – 50
years

7 IDENTIFICATION AND SCREENING OF MANAGEMENT OPTIONS

7.1 Background

To address the present condition and performance problems of the piers and pier extensions at Whitby Harbour, there are three principal categories of options, namely:

- Do Nothing;
- Do Minimum; and
- Do Something.

Do Nothing is considered here primarily for the purposes of assessing a base case against which other options will be compared. It would involve no further management or maintenance of the piers or pier extensions.

Do Minimum is considered to be the 'continue present practice' option, whereby relatively modest maintenance is undertaken annually. This mainly focuses on visual inspection and local reactive repairs for operational and health and safety purposes.

Do Something covers a wide range of potential options aimed at improving the present condition and/or performance situation through some formal intervention. There are various means of implementing this option, with different types and standards of improvement that can be attained through implementation of each.

The strategic management options for Whitby harbour are described in the following section. Table 6 summarises the options considered within the following section.

Table 6 - Identified Strategic Management Options

<table>
<tr><th colspan="2">Option</th><th>Description</th></tr>
<tr><td colspan="2">1</td><td>Do Nothing – the 'walk-away' base case against which other options are compared.</td></tr>
<tr><td colspan="2">2</td><td>Do Minimum – continue with present practice involving modest reactive maintenance, primarily for reasons of harbour operations and health and safety.</td></tr>
<tr><td rowspan="8">Do Something</td><td>3</td><td>Advance the Line - protect the existing harbour structures through construction of a new structure(s) to seaward.</td></tr>
<tr><td>4</td><td>Managed Realignment – changes in harbour plan form alignment to reduce exposure.</td></tr>
<tr><td>5</td><td>Modify existing structures to improve present structural condition.</td></tr>
<tr><td>6</td><td>Modify existing structures to improve present defence performance (especially with respect to overtopping discharges).</td></tr>
<tr><td>7</td><td>Modify existing structures to improve present structural condition and present defence performance.</td></tr>
<tr><td>8</td><td>Managed Removal - removal of harbour structures and management of flood and erosion risk through other means.</td></tr>
<tr><td>9</td><td>Managed Relocation of vulnerable assets – relocation of properties, businesses, infrastructure and other assets at risk of erosion and flooding.</td></tr>
<tr><td>10</td><td>Demolish and Rebuild – the existing piers and extensions would be demolished and rebuilt on their existing alignment.</td></tr>
</table>

When considering improvements to the existing structural condition (Options 5 and 7), it is possible to sub-divide the option between the following envelopes of improvement:

- Improve sufficiently to ensure that no structure fails or breaches over the next 50 years;

- Improve to an optimal structural condition.

When considering defence performance (Options 6 and 7), it is possible to sub-divide the option between the following envelopes:

- Maintaining the standard of service provided against sea water overtopping at present day-values and accept increasing overtopping discharges into the future as sea levels rise;

- Improve the standard of service to reduce overtopping discharges to zero levels, both at the present-day and continuing into the future over the next 50 years.

In between these extremes of the envelope of possible strategic responses there are two commonly considered intervals:

- Improve the standard of service sufficiently to sustain the present-day standard against overtopping into the future in line with projected sea level rise (i.e. no worsening of present-day conditions with sea level rise); and

- Improve the standard of service sufficiently to achieve target thresholds levels of overtopping for avoidance of structural damage and/or serviceability.

Furthermore, the flood and coastal defence system at Whitby harbour comprises a number of artificial and natural (or semi-natural) defence elements that function in an inter-related manner. Therefore it is possible that one strategic option could apply to the whole defence system or that a suite of options is preferred depending on the optimum arrangements for each element of the system.

Since the focus of the present study is on the harbour piers and their extensions, the options have been directed primarily to these structures. However, the inter-related consequences on other defence components (such as the West Cliff defences, the Haggerlythe rock revetment, the inner harbour spending beach and jetties, and the estuary quayside walls) have been discussed.

Finally, a further variable is the time dependency of the implementation of the preferred option(s). Since the identified structural defects and performance issues have different levels of urgency in different elements of the system it may be that a phased approach to the implementation of a long-term strategic solution is identified as the optimum way forward. This issue is addressed through the development of an Action Plan for the preferred option(s) in Section 11.

7.2 Description of Options

7.2.1 Option 1: Do Nothing

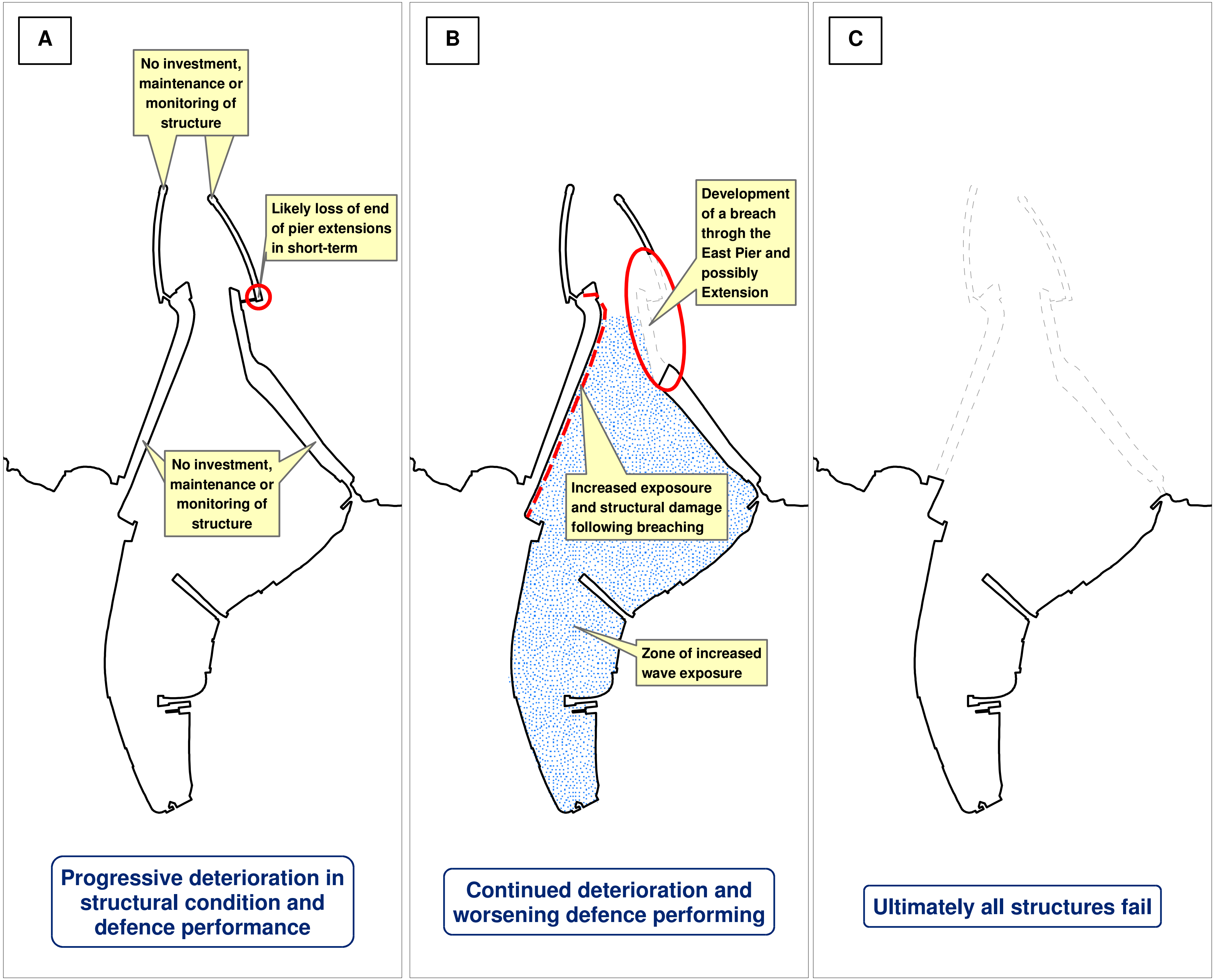
Description:
This option would involve walking-away from management of the existing harbour structures (piers and extensions) and undertaking no further capital investment, maintenance, monitoring or any other forms of intervention for flood and coastal defence purposes.

Technical:
Under this option, the present structural condition of the piers would continue to worsen (Figure 22A). This deterioration would lead to further settlement, undermining, voiding, damage such as cracking, abrasion and spalling, and ultimately collapse and breach of the most vulnerable sections. Whilst the residual structures would initially remain *in situ*, they would experience greater loading forces due to the waves penetrating through the breach and hence would also deteriorate further over time (Figure 22B). Also, the breached area would progressively widen and over time the standard of protection offered by the derelict structures would significantly reduce.

The initial breach mechanism is most likely to occur towards the landward end of the East Pier extension followed by the seaward end of the main East Pier. It would involve the continued scour action to the underside of the East Pier extension, undermining the foundation and causing a partial collapse of the end section. This would increase exposure to the main East Pier. The increased exposure would displace the stone facing blocks in areas where there are presently cavities forming behind the outer facing on the sides and deck. The facing blocks would collapse due to wave impact. With continual impact from the sea, the core of the structure would collapse, forming the breach. Further storm damage would unravel the structure and then propagate the breach along the structure, so widening it and reducing its effectiveness to provide coastal protection. This would continue to develop until the whole structure had collapsed or some self-regulating stability had been (temporarily) achieved. During this process, the exposure to wave activity of the West Pier and lower estuary would increase, resulting in degradation of the inner face of the West Pier, mobilisation of sediment from the spending beach and destabilisation of the inner estuary jetties.

The pier extensions would most likely fail at the toe due to sheet pile corrosion leading to extensive scour undermining the concrete structure. This is presently occurring significantly on the East Pier extension. The concrete structures would then crack and collapse on to the sea bed and continue to break up and deteriorate.

This scenario would ultimately lead to total failure of the structures (Figure 22C) and re-activation of recessional processes along the cliffs at the harbour mouth along both the western and eastern frontages and within the inner harbour area. Higher waves would also propagate further upstream and hence increase flood risk in the estuary. Beach sediment presently retained by the West Pier and its extension would become mobilised and much of this would be transported into the harbour causing siltation of the channel and hence a reduction in channel capacity. This would reduce the channel's ability to convey fluvial and tidal flows and hence provide another mechanism of increasing flood risk to the town.



Title:
Option 1 - Do Nothing

Project:
Whitby Coastal Strategy Further Investigations at Whitby Harbour

Client:
Scarborough Borough Council

Date: January 2009	Scale: 1 : 6,500

Figure: 22	Drawn: TC	Checked: NC

ROYAL HASKONING

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Economic:
Whilst this option would not incur any capital expenditure on works or any revenue expenditure on maintenance or monitoring, the associated economic damages would be high. These damages would be realised from:

- flood damage to properties, businesses, infrastructure, services and other assets;
- disruption damages to traffic, businesses and loss of livelihood;
- social impacts, such as increased demand on health and welfare services;
- loss of tourism revenue;
- disruption to the harbour operations and potential closure of the harbour due to loss of safe navigation; and
- environmental damage in terms of direct losses (erosion, smothering), pollution clear-up (release of debris from deteriorating structures) and long-term changes in natural physical process regimes which could affect sites of designated nature conservation and earth science heritage importance.

Environmental:
This option would allow natural evolution of the coast, which has both positive and negative environmental impacts since some features of interest are present only because of the piers. Debris from the deteriorating piers would remain for a substantial period of time and may provide marine habitat, but would clearly have adverse aesthetic and landscape effects. The breach and collapse of the structure will release fill material and sediment into the coastal environment on a gradual and continual basis until the structures reach a stable condition. This is likely to affect local sea life including the mussel beds inside the harbour. The loss of the structure would mean loss of amenity to tourists, anglers and the local population. It would also mean the loss of a national treasure as dictated by the Grade II listed status and a popular tourist icon. The increased exposure of the harbour quay could lead to vehicles and objects on the quay being swept into the harbour, potentially leading to pollution and contamination. Equally, vessels could be damaged leading to pollution of the harbour.

Health and Safety:
The breach and collapse of the piers would increase the current safety risk as it would expose users and residents of the harbour frontage to higher exposure to storms and waves. Impact damage to properties from waves and sediment would lead to potential injury and health risks from flooding. The debris from the collapsed structure would form a hazard to vessel navigation and vessels would be exposed to the storm and wave conditions on the quayside. Access to the navigation structures would become hazardous due to the loss of pedestrian and vehicular access. This is presently the situation with respect to East Pier extension since the walkway was washed-away during a storm event. The current safety issues identified on the piers would not be corrected.

Summary:
- No action would be taken to maintain the existing structure
- The piers would gradually deteriorate and collapse leaving the harbour and town centre exposed to storms and high tide conditions.
- Damages would be incurred from flooding and erosion to properties, businesses, infrastructure, services and other assets; disruption and delay; loss of recreation and amenity facilities; social impacts; damage to the natural and historic environments; and impacts on the local economy (tourism and fishing in particular).

- Significant increase in health and safety risk to the population of, and visitors to, the town for the long term due to the loss of the coastal protection, although there would be no short term risks associated with construction, operation and maintenance.

7.2.2 Option 2: Do Minimum

Description:
This option would involve the continued use of the existing maintenance budget of circa £35k per annum in order to undertake reactive repairs to minor damaged areas of the structure. This would be undertaken in a manner commensurate with that which historically has been carried out as necessary to ensure continued use of the harbour for operational purposes (Figure 23A). Under this option, the maintenance budget would not increase over time and therefore its ability to address the structural defects and performance issues would reduce over time due to sea level rise leading to worsening structures (i.e. the fixed budget would be spread more thinly). Any significant damage to the structure would require substantial capital expenditure and under this option such damage would not be repaired.

The existing pier structures are subjected to regular storms and wave overtopping damage. This option would keep the piers in their current form and exposure with no major works to improve the current condition.

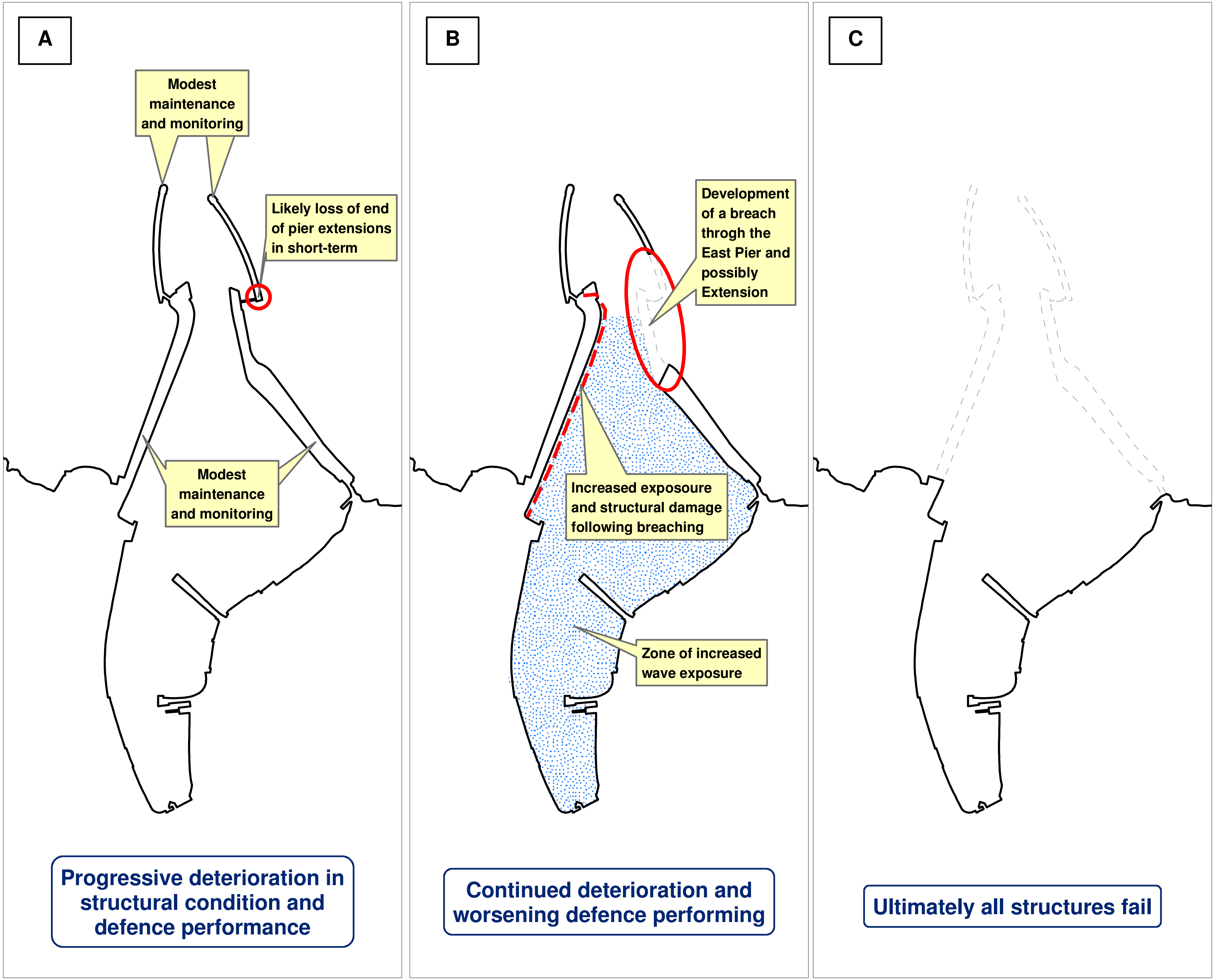
Technical:
As the structures would not receive any major expenditure for improvement of existing defects and performance issues notable likely deterioration in both would occur over the 50 year life of the strategy. Under this option the condition of the piers and pier extensions is likely to continue to deteriorate in a similar time frame and manner to the Do Nothing option.

The condition of the main piers would deteriorate with the collapse of the outer shell leading to a breach of the East Pier structure, from which the structure would gradually collapse over a significant time period (Figure 23B and 23C). The pier extensions would deteriorate through corrosion of the sheet piles and scour to the base causing the structure to become unstable and gradually collapse over a significant time period.

The annual maintenance works are unlikely to reduce the rate of deterioration as there would be no major intervention to stabilise the existing structures and maintenance would be mostly reactive, rather than pro-active, in nature. However, minor works would improve some aspects such as safety and operational issues.

Economic:
Recent historical annual expenditure for the maintenance and operation of the harbour piers and extensions is in the order of £35k. Over 50 years this amounts to £1.75M (not accounting for inflation or discounting). However, this has not and would not be spent on substantial works or major upgrades of the type required to address defects in the current condition and performance of the structures. The expenditure is currently used for minor repairs such as ladders, railings, timber repairs and day to day issues.

The structures are understood to be around 100 years old and their construction materials are substantially deteriorating due to the natural ageing processes as well as storm damage. Thus, the structure would continue to deteriorate despite the current expenditure on a broadly similar time frame to the Do Nothing option, until the piers collapse leaving no protection. Consequently, the direct and indirect economic damages associated with this option would be similar to the Do Nothing option.



Title:
Option 2 - Do Minimum

Project:
Whitby Coastal Strategy Further Investigations at Whitby Harbour

Client:
Scarborough Borough Council

Date:	Scale:
January 2009	1 : 6,500

Figure:	Drawn:	Checked:
23	TC	NC

ROYAL HASKONING

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Environmental:
Similar to the above argument, the environmental impacts and benefits of this option would the similar to the Do Nothing option.

Health and Safety:
The health and safety risks associated with this option would be similar to the Do Nothing option. However, the operational and maintenance related risks would be addressed through use of the annual maintenance budget, so improving this aspect compared to the Do Nothing option.

Summary:
- Present-day action to maintain the existing structures would be continued into the future through use of the existing maintenance budget expenditure on an annual basis over the next 50 years
- The effectiveness of this expenditure will diminish over time as the finite budget will be spread more thinly across an increasing number and increasing severity of defects and as sea level rise affects performance issues
- The piers would gradually deteriorate and collapse leaving the harbour and town centre exposed to storms and high tide conditions.
- Damages would be incurred from flooding and erosion to properties, businesses, infrastructure, services and other assets; disruption and delay; loss of recreation and amenity facilities; social impacts; damage to the natural and historic environments; and impacts on the local economy (tourism and fishing in particular).
- Significant increase in health and safety risk to the population of the town for the long term due to the loss of the coastal protection, although there would be no short term risks associated with construction, operation and maintenance. Operational and maintenance risks would be partially reduced due to limited measures to improve basic safety aspects (e.g. ladders and handrails).

7.2.3 Option 3: Advance the Line

Description:
This option would involve the construction of a new structure, or structures, seaward of the existing harbour to provide shelter to the existing piers and pier extensions.

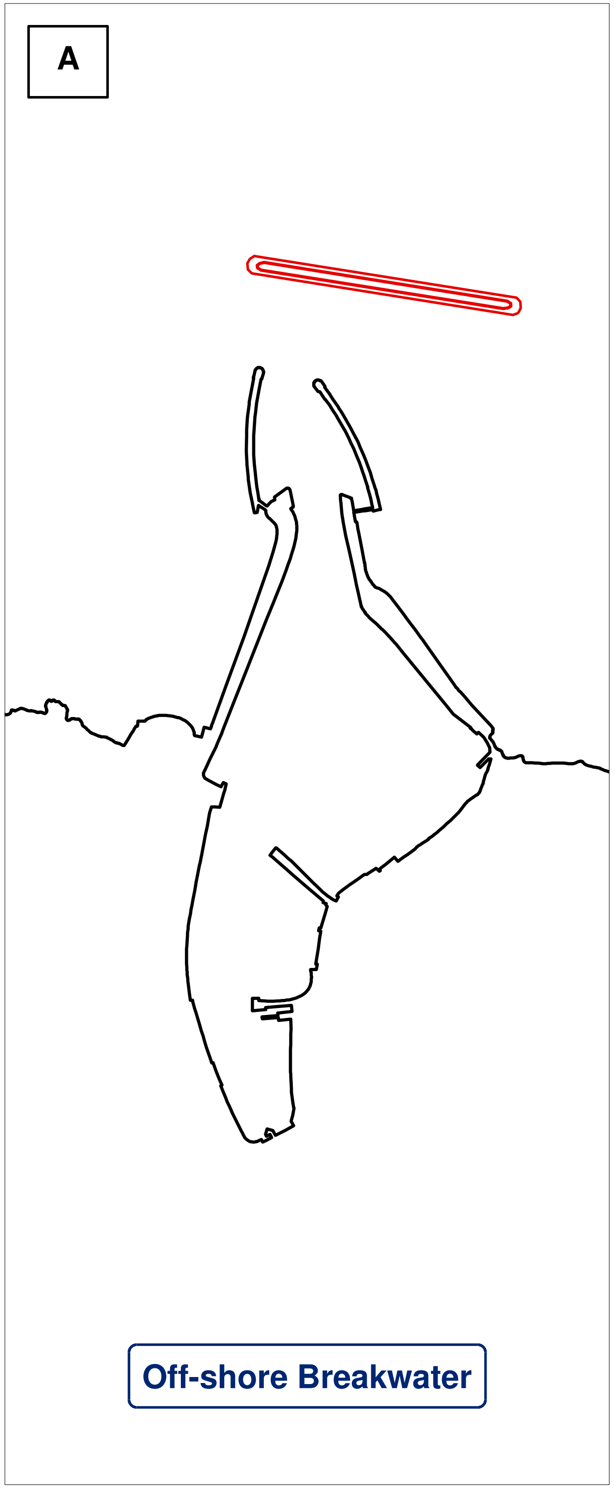
Technical:
This option could be achieved through the following methods:

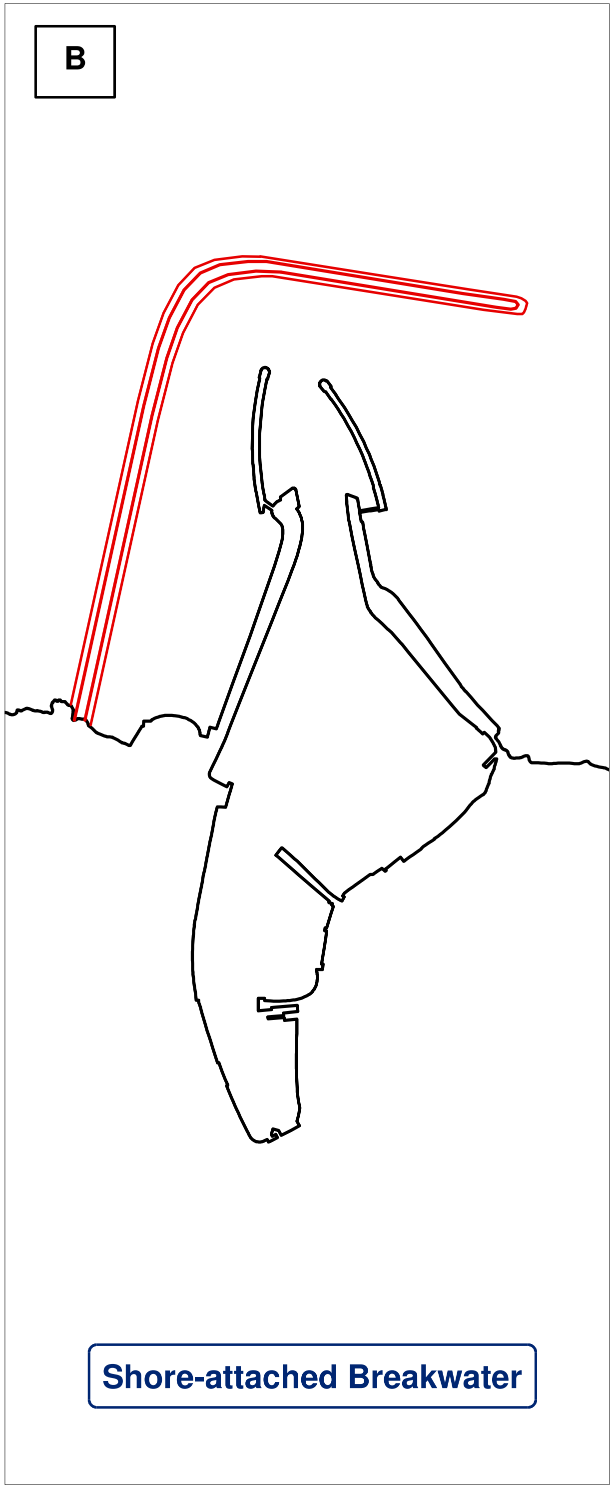
- Construction of a detached offshore breakwater located north of the harbour mouth to reduce the energy of waves from the north before they propagate into the harbour (Figure 24A).
- Construction of a shore-attached breakwater from the western side of the harbour, extending nor'-north-east and then east around the existing mouth, both to protect the West Pier and reduce the energy of waves from the north before they propagate into the harbour (Figure 24B).
- Construction of a shore-attached breakwater from the easttern side of the harbour, extending nor'-north-west and then west around the existing mouth, both to protect the East Pier and to reduce the energy of waves from the north before they propagate into the harbour (Figure 24C).
- Construction of a new wall structure around the seaward side of the existing pier and extensions to protect the existing structures from direct wave energy (Figure 24D).

With each sub-option, the new structure(s) would be designed to enable the existing harbour structures to remain intact as effectively an 'inner harbour' protected by an 'outer harbour'. This would reduce the exposure of existing structures to wave loading and wave overtopping and therefore prolong their lives.

Under Option 3A the detached offshore breakwater would preferentially be aligned normal to the predominant or most extreme wave approach directions. It could be constructed of large armourstone or interlocking concrete components. The breakwater could be submerged or, to provide greatest wave energy reduction, surface-piercing. This structure would reduce wave energy entering into the harbour and therefore help prolong the life of the existing structures but would have no effect in terms in the present poor structural condition of the piers and extensions, which would continue to deteriorate due to aging and continued storm damage. Consequently the option could be accompanied by an option of improving the present structural condition to provide optimum overall technical benefit.

Option 3B would both limit wave energy entering the harbour mouth and protect the West Pier and both extensions against direct wave attack. Similar to above, the breakwater could be submerged or surface-piercing and comprised of either rock or concrete components. The option may require capital dredging of a new navigation channel from the existing harbour mouth to the new exit in the east. The East Pier would still be subject to storm wave loading and wave overtopping as at present. Similar to above, the breakwater would prolong the life of the existing structures but this option alone would not correct the numerous structural defects that presently exist. Due to this the option could be accompanied by an option of improving the present structural condition to provide optimum overall technical benefit.





Title:
Option 3 - Advance the Line

Project:
Whitby Coastal Strategy Further Investigations at Whitby Harbour

Client:
Scarborough Borough Council

Date: January 2009	Scale: 1 : 8,000

Figure: 24a	Drawn: TC	Checked: NC

ROYAL HASKONING

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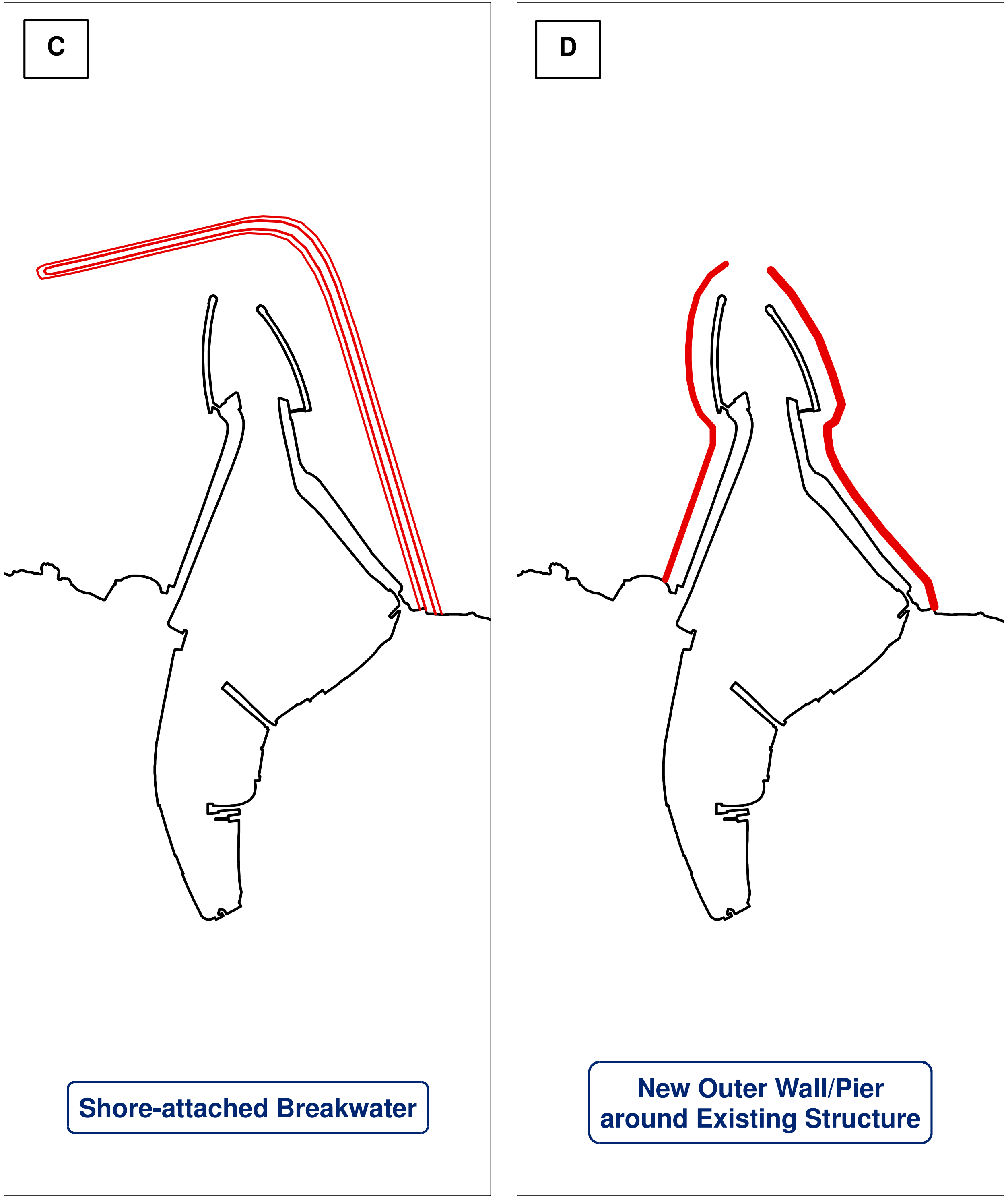

Title:
Option 3 - Advance the Line

Project:
Whitby Coastal Strategy Further Investigations at Whitby Harbour

Client:
Scarborough Borough Council

Date:	Scale:
January 2009	1 : 8,000

Figure:	Drawn:	Checked:
24b	TC	NC

ROYAL HASKONING

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Option 3C is similar to the above but designed to protect the East Pier and both extensions. The West Pier would still be subject to storm wave loading and wave overtopping as at present. The option may require capital dredging of a new navigation channel from the existing harbour mouth to the new exit in the west and would almost certainly have high maintenance dredging costs as the nearshore sediment moving from west to east as both bed load and suspended load becomes transported into the new mouth.

Option D would involve the construction of a new rubble mound or concrete structure to effectively create a shell around the existing structures, but detached from them and located a short distance to seaward. Again, this could be in the form or submerged or surface-piercing structures. Similar to other sub-options described above, this would prolong the life of the existing structures but not correct their present defects.

Under all sub-options described above, the new structures will be located seaward of the existing structures in even more hostile marine conditions than those to which the present structures are subjected. This means that the structures will need to be substantial to remain effective over the 50 years horizon considered here.

Economic:
Due to the more exposed marine location, and the considerable lengths of defence that would be newly required, the cost of constructing the structures associated with each of the sub-options would be prohibitively high. Furthermore, these structures alone would not resolve the structural defects that presently exist on the piers and extensions and therefore further investment would be required if these aspects were required to be addressed.

Environmental:
The new structures would have environmental impacts during construction, but also would have considerable operational impacts, particularly in terms of their footprints across the sub-tidal sea bed and inter-tidal zone (including the designated foreshore in the east under sub-options 3C and 3D) and in their impacts on the existing coastal process regime.

Under options B and C there may also be the requirement for capital dredging and disposal of the dredged arisings, whilst under sub-option C there would be a likely requirement for extensive maintenance dredging and disposal of dredged arisings.

The advantage of this option is that the present heritage value of the piers remains unaffected, but the new structures would have adverse aesthetic and landscape issues.

Health and Safety:
There would be considerable health and safety challenges to overcome during construction of these schemes in the hostile marine environment. Navigation into and out from the harbour mouth would also become somewhat riskier.

Summary:
- New structures located seaward provide enhanced protection to the existing structures against direct wave attack.
- The present defects in the existing structures would not be addressed and further deterioration of these would occur.

- There are various ways of implementing this strategic option, but each will involve considerable capital cost, result in high environmental impact and have associated health and safety implications, including to navigation.
- Under some options capital and maintenance dredging and disposal of arising spoil material may be required.
- The heritage value of the piers is unaffected.

7.2.4 Option 4: Managed Realignment

Description:
This involves changes in the plan form alignment of the piers to reduce their exposure vulnerability.

Technical:
This option could best be achieved by maximising use of the existing harbour arms to ensure that sufficiently deep water is reached for navigational purposes and then using newly constructed surface-piercing pier walls or surface-piercing breakwaters to form a new harbour mouth alignment to face either north-west (Figure 25A and B) or north-east (Figure 25C and D). Associated with each of these options would be necessary capital upgrades to repair present defects.

The advantage of the new mouth alignment is that the harbour would be less exposed to the most severe waves (from the north) and the predominant waves (just east of north) and therefore wave conditions within the harbour and the River Esk estuary would be reduced compared with the present day alignment.

The technical problems with these alignments, however, are: (i) the north-east facing structure would be subject to some quite severe waves propagating straight through the entrance; and (ii) the north-west facing structures would act as a trap for nearshore sediment transport and the new mouth would rapidly silt-up.

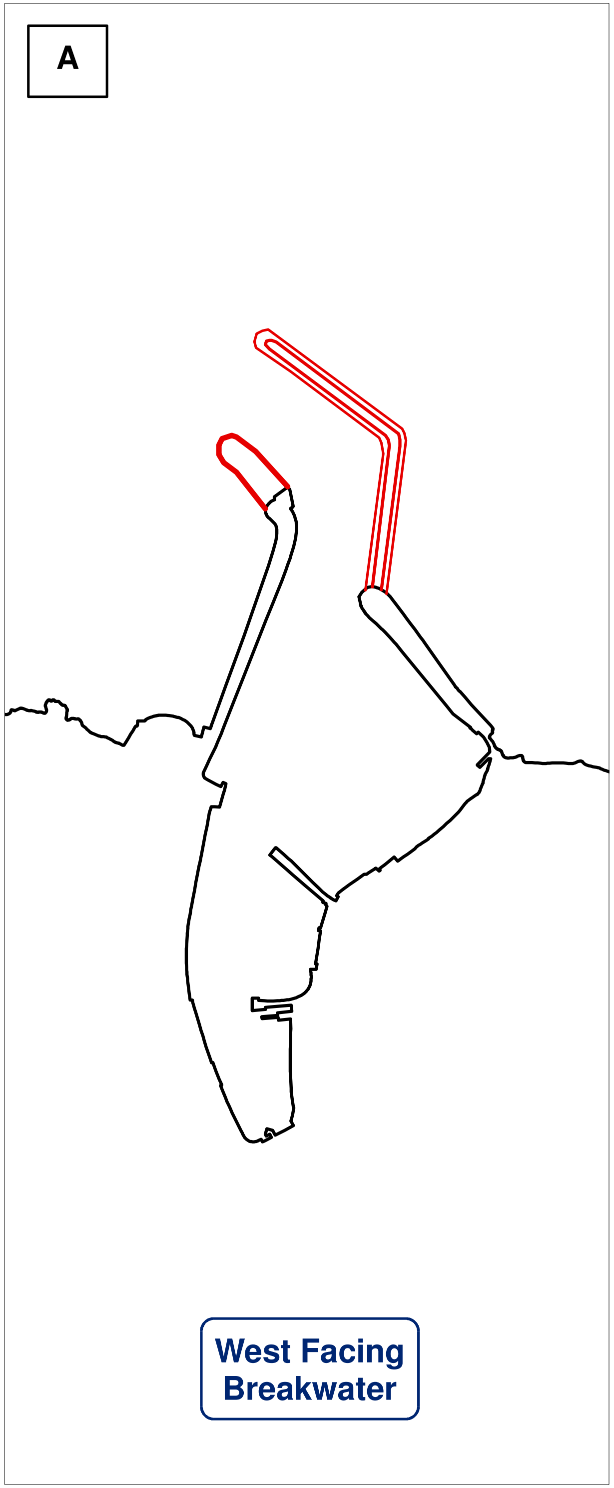
Economic:
The option would require upgrade to the sections of the existing main piers that would remain intact and the construction of new structures at the realigned seaward ends. Consequently the associated costs will be very high.

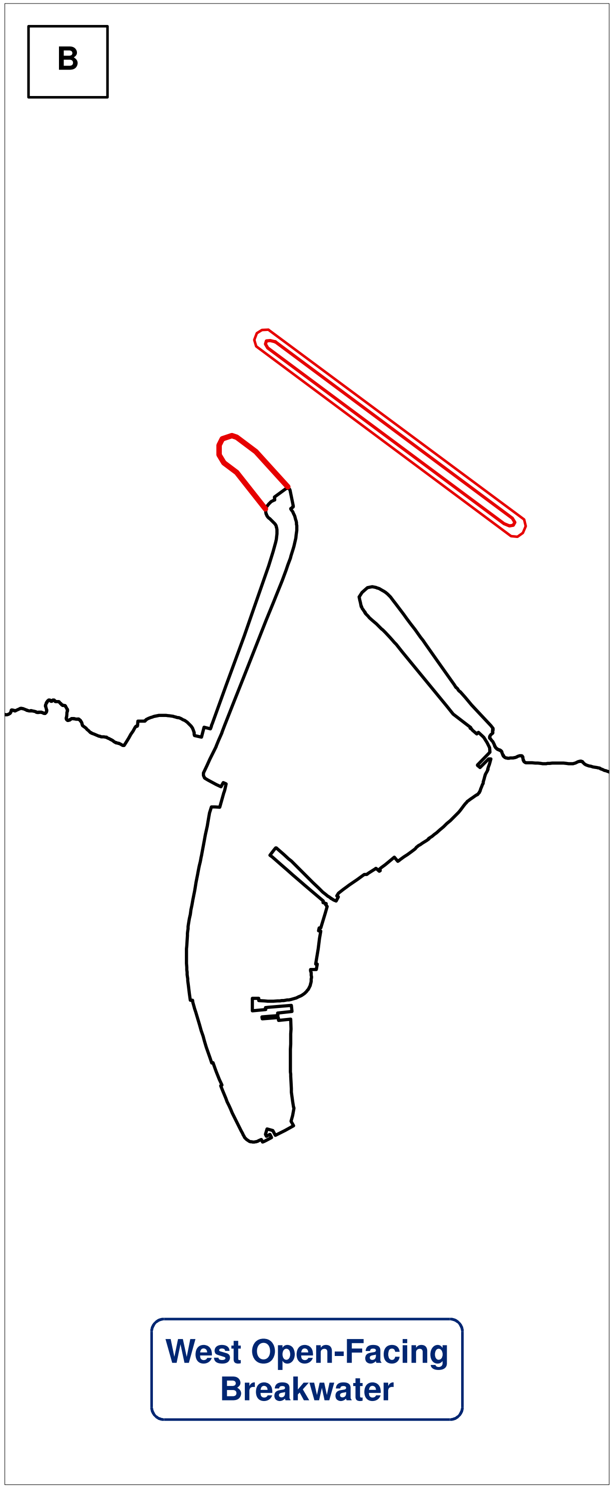
Environmental:
The new structures would have environmental impacts during construction, but also would have considerable operational impacts, particularly in terms of their footprints across new areas of the sub-tidal sea bed and inter-tidal zone (including the designated foreshore in the east under sub-options 3C and 3D) and in their impacts on the existing coastal process regime.

Large sections of the main piers would retain their heritage value. Consideration would have to be given to construction materials and the effect that this has on landscape/seascape aesthetics of the frontage.

Under sub-options C and D the structures would encroach close to, or on to, the designated sites of earth heritage importance and vessel traffic across this sea bed area would increase.

Health and Safety:
There would be considerable health and safety challenges to overcome during construction of these schemes in the hostile marine environment.





Title:
Option 4 - Managed Re-alignment

Project:
Whitby Coastal Strategy Further Investigations at Whitby Harbour

Client:
Scarborough Borough Council

Date:	Scale:
January 2009	1 : 8,000

Figure:	Drawn:	Checked:
25a	TC	NC

ROYAL HASKONING

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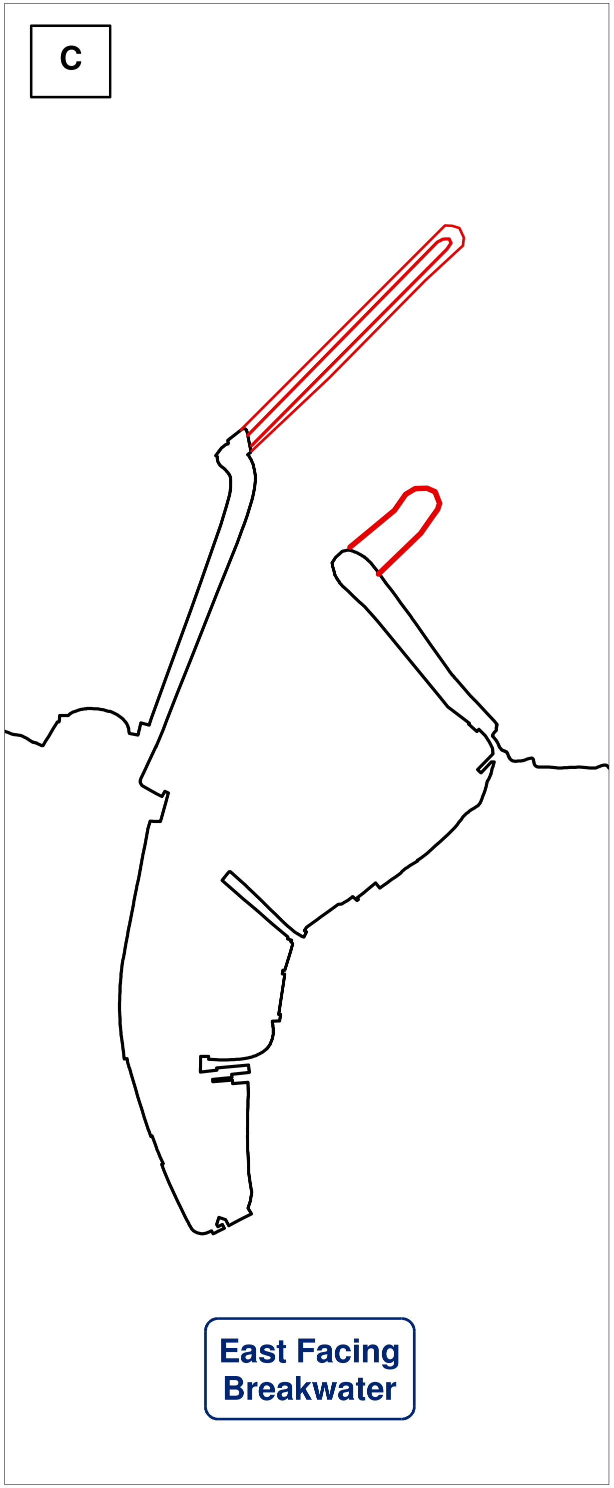

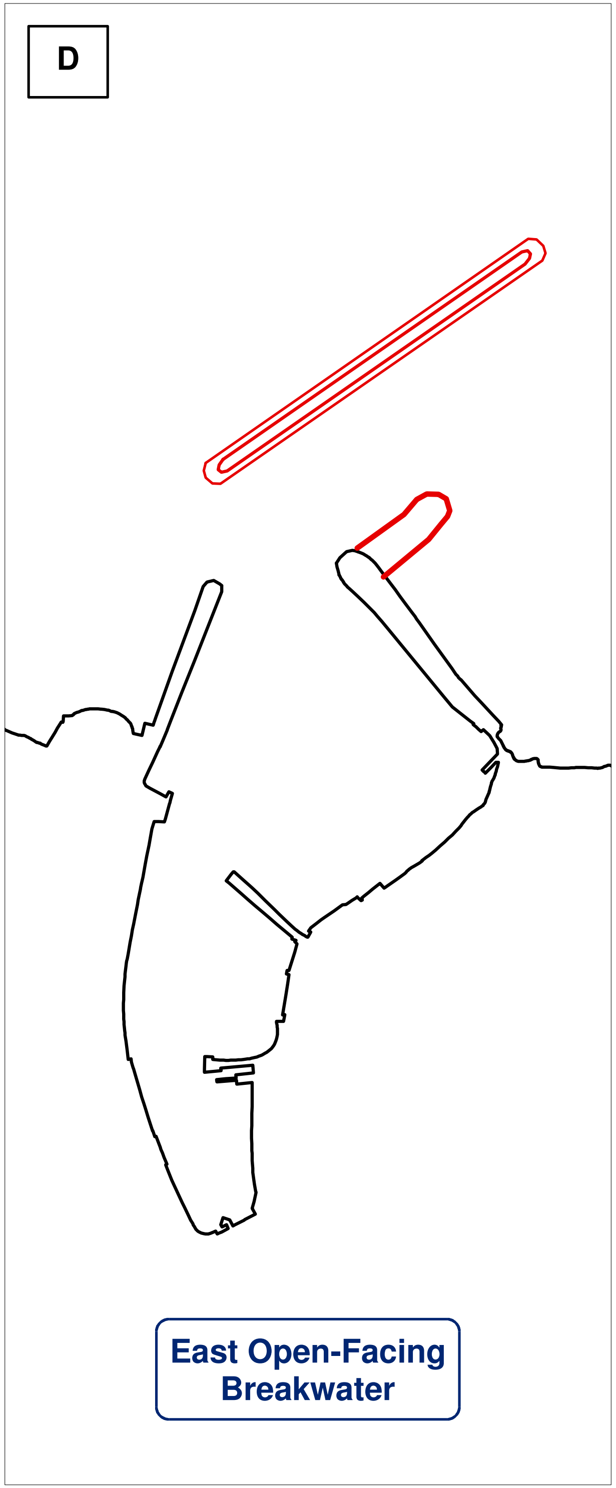

Title:
Option 4 - Managed Re-alignment

Project:
Whitby Coastal Strategy Further Investigations at Whitby Harbour

Client:
Scarborough Borough Council

Date:	Scale:
January 2009	1 : 8,000

Figure:	Drawn:	Checked:
25b	TC	NC

ROYAL HASKONING

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Summary:

- Realignment of harbour mouth so that it is not directly facing the most extreme wave approach direction.
- Maximum use of existing main piers to retain heritage value.
- Structural upgrade required to remaining main pier structures to address present defects with new structures built in new alignment at seaward ends.
- High cost and high environmental impacts.

7.2.5 Option 5: Modify Existing Structures to Improve Present Structural Condition

Description:
This option involves retaining use of the existing structures in their present alignment by addressing present structural defects through a capital upgrade that would be sufficient for ensuring a further 50 years life from the structures.

Technical:
A number of means exist for delivering this strategic option, depending on the level of investment that is provided. This ranges from the minimum required works to address identified present-day defects, with the expectation that further problems could re-appear or newly appear during the 50 year timeframe, through to the optimum works required to proactively create a robust structure that will not suffer from future structural problems over the 50 years.

Given the range of structural defects, typical works would include (in various locations and in various combinations):

- Pointing, grouting and void filling (Figure 26)
- Sheet piling (Figure 27 and 28)
- Outer cladding replacement (Figure 29)
- Removal and resetting of displaced blocks
- Replacement of missing blocks

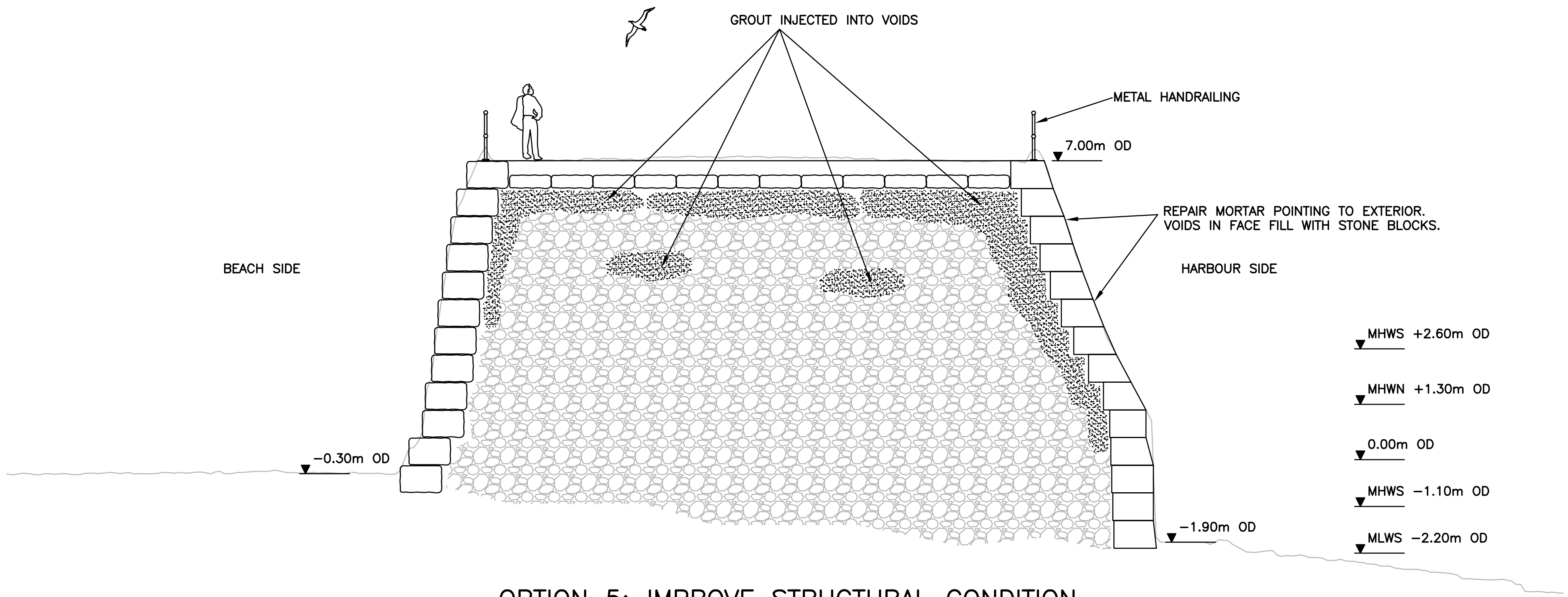
Since the pier extensions are an important component in the overall flood and coastal defence system, both providing protection to the main pier structures and influencing sediment transport along the nearshore zone, capital upgrades should be undertaken to the main piers and the pier extensions, rather than to the main piers alone.

Economic:
The economic cost of the works will vary depending on the desired end standard from the investment. At a minimum level, the costs are likely to be in excess of £1M given the nature and extent of present defects. At the upper level a comprehensive and pro-active upgrade scheme would be multi-millions of pounds.

Environmental:
The capital upgrade works would have impacts during construction and care will have to be taken that materials potentially hazardous to the marine environment, (e.g. concrete, grout, etc.) is not spilt. There will be associated noise and vibration disturbance and traffic disruption due to the confined access to the piers.

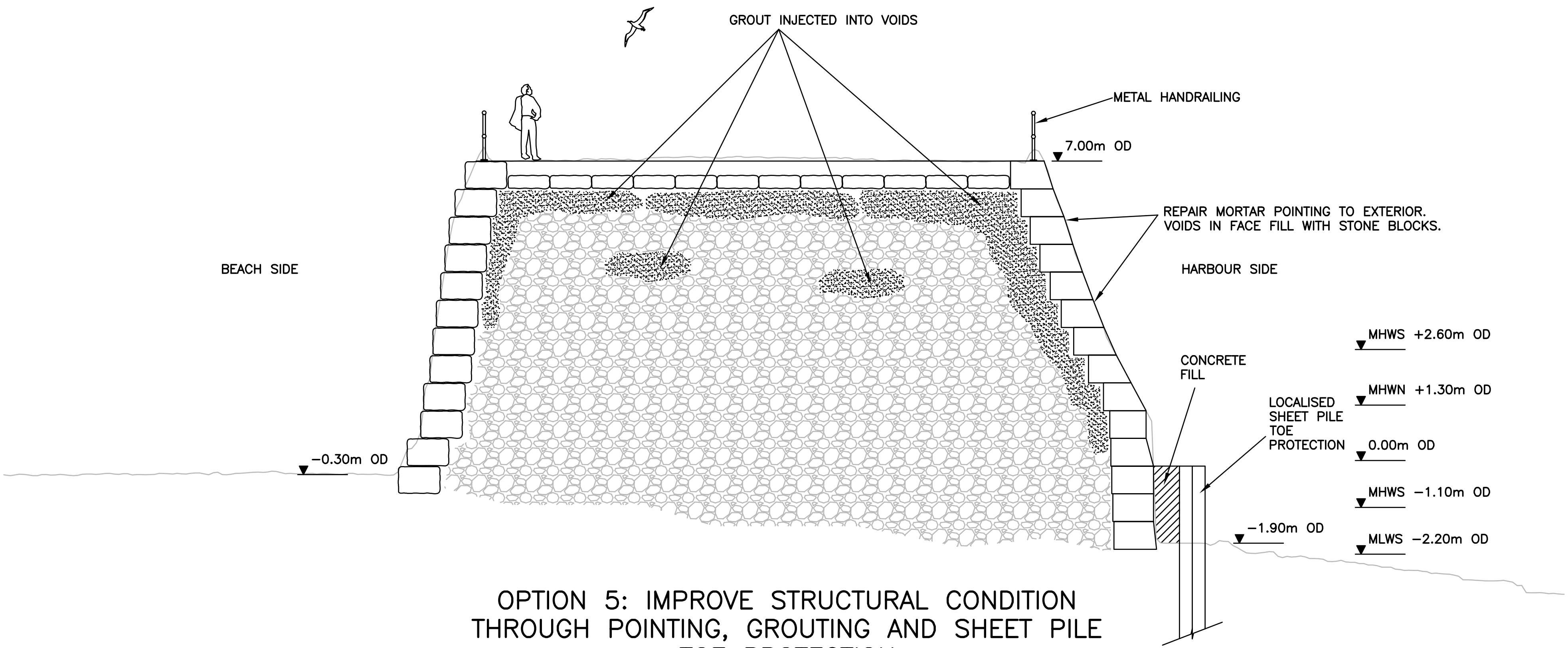
However, this option does minimise the activities likely to cause environmental impact since the focus is on optimising the condition of what is already present on site, rather than demolishing old and/or constructing new structures.

Furthermore, implementation of the scheme would improve present condition and therefore reduce the likelihood of damage, deterioration and ultimately failure or breaching of the existing structures and therefore avoids the potential contamination of the marine environment with debris.



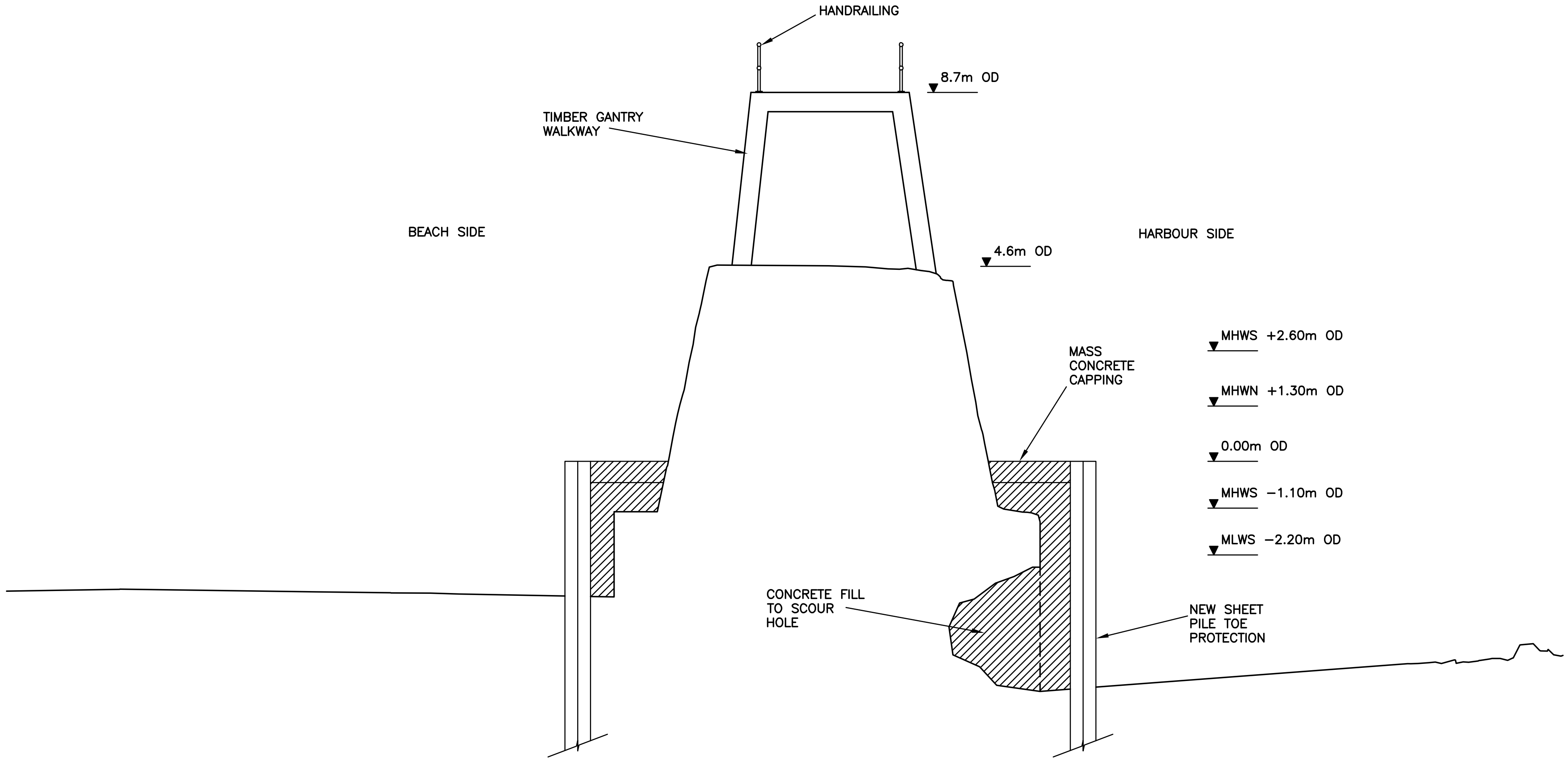
OPTION 5: IMPROVE STRUCTURAL CONDITION
THROUGH POINTING AND GROUTING

TITLE	PROJECT				
FIGURE 26 WEST MAIN PIER SECTION SHOWING OPTION 5	WHITBY COASTAL STRATEGY OPTIONS APPRAISAL	ROYAL HASKONING HASKONING UK LTD NEWCASTLE Marlborough House Marlborough Crescent Newcastle upon Tyne NE1 4EE +44 (0)191 211 1300 Telephone +44 (0)191 211 1313 Fax info@newcastle.royalhaskoning.com E-mail www.royalhaskoning.com Internet	DRAWN IT SCALE AT A3 1:100 DRAWING No. FIGURE 26	DATE NOV' 08 AUTOCAD REF. 9T0429-1002	JOB No. 9T0429 REV 0



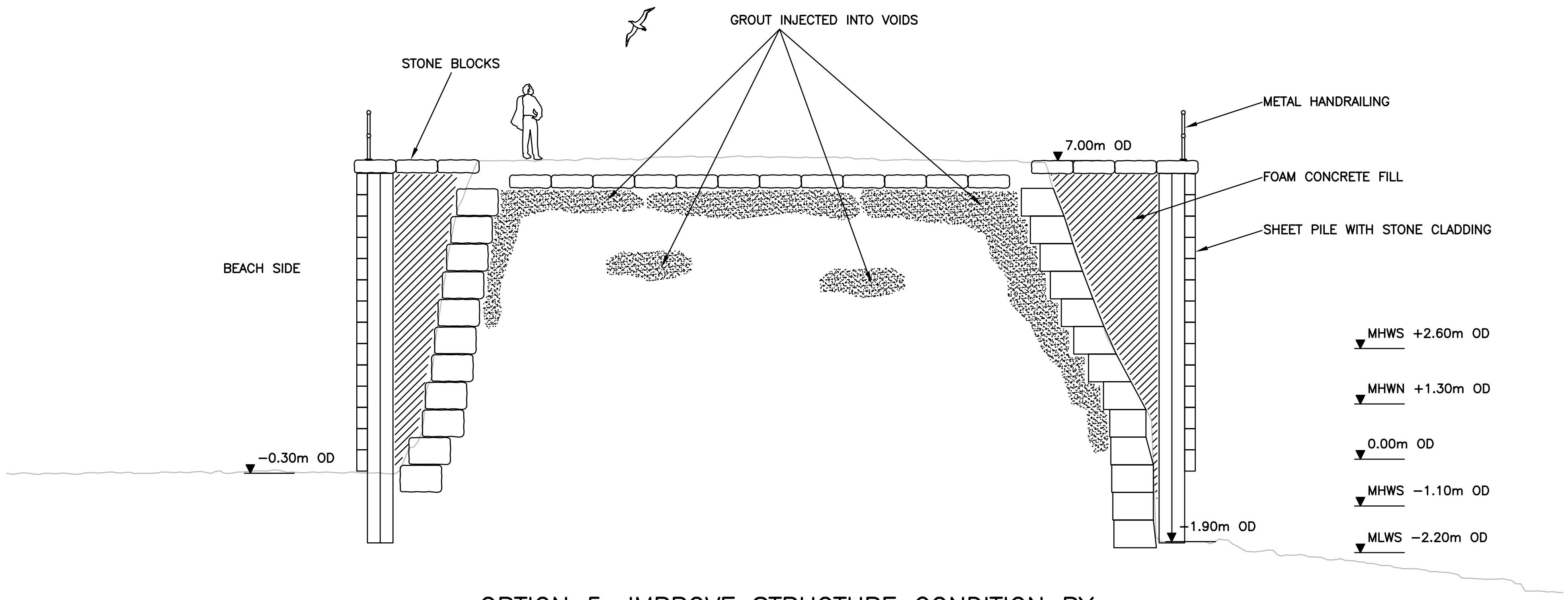
OPTION 5: IMPROVE STRUCTURAL CONDITION THROUGH POINTING, GROUTING AND SHEET PILE TOE PROTECTION

TITLE	PROJECT				
FIGURE 27 WEST MAIN PIER SECTION SHOWING OPTION 5	WHITBY COASTAL STRATEGY OPTIONS APPRAISAL	ROYAL HASKONING HASKONING UK LTD NEWCASTLE Marlborough House Marlborough Crescent Newcastle upon Tyne NE1 4EE +44 (0)191 211 1300 Telephone +44 (0)191 211 1313 Fax info@newcastle.royalhaskoning.com E-mail www.royalhaskoning.com Internet	DRAWN IT	DATE NOV' 08	JOB No. 9T0429
			SCALE AT A3 1:100	AUTOCAD REF. 9T0429−1007	
			DRAWING No. FIGURE 27		REV 0



TYPICAL PIER EXTENSION SECTION

TITLE	PROJECT				
FIGURE 28 OPTION 5: MODIFY STRUCTURE TO IMPROVE CONDITION BY SHEET PILING AND GROUT FILL	WHITBY COASTAL STRATEGY OPTIONS APPRAISAL	ROYAL HASKONING HASKONING UK LTD NEWCASTLE Marlborough House Marlborough Crescent Newcastle upon Tyne NE1 4EE +44 (0)191 211 1300 Telephone +44 (0)191 211 1313 Fax Info@newcastle.royalhaskoning.com E-mail www.royalhaskoning.com Internet	DRAWN IT SCALE AT A3 1:100 DRAWING No. FIGURE 28	DATE NOV' 08 AUTOCAD REF. 9T0429−1006	JOB No. 9T0429 REV 0



OPTION 5: IMPROVE STRUCTURE CONDITION BY PROVIDING OUTER PROTECTION SHELL

TITLE FIGURE 29 WEST MAIN PIER TYPICAL SECTION SHOWING OPTION 5	PROJECT WHITBY COASTAL STRATEGY OPTIONS APPRAISAL	ROYAL HASKONING HASKONING UK LTD NEWCASTLE Marlborough House Marlborough Crescent Newcastle upon Tyne NE1 4EE +44 (0)191 211 1300 Telephone +44 (0)191 211 1313 Fax info@newcastle.royalhaskoning.com E-mail www.royalhaskoning.com Internet	DRAWN IT SCALE AT A3 1:100 DRAWING No. FIGURE 29	DATE NOV' 08 AUTOCAD REF. 9T0429−1005 JOB No. 9T0429 REV 0

Since the piers will remain in their present alignments, the requirements for capital and maintenance dredging will be no worse than present and the coastal process regime will be unaffected, meaning that present inter-tidal habitats to both the west and east of the harbour mouth will remain broadly in their present conditions.

The option also enables maximum heritage and amenity value to be retained from the pier structures.

Health and Safety:
During construction activities, there would be health and safety issues associated with construction activities in a hostile marine environment.

The option is designed to minimise the risk or failure and breaching of existing structures and therefore is a pro-active approach to management of the health and safety risks.

During operation, the present overtopping performance will worsen over time due to sea level rise.

Summary:

- Existing pier and pier extensions will be upgraded in condition through a capital investment scheme to correct identified defects.
- There is a range of levels to which the upgrade could be undertaken, depending on the desired condition and future maintenance following the initial capital investment.
- The option retains the alignment (and hence both function and influence) of the piers as the present day, thereby retaining their heritage and amenity value and their importance to nearshore coastal processes.
- The capital upgrade works would have positive effects in terms of reducing both flood risk in the River Esk estuary and coastal erosion risk in the harbour mouth and along adjacent coastlines to both the west and east.
- The option would not address overtopping performance issues and hence discharges during storms would worsen compared with present-day rates as sea levels rise.
- There will be positive flood and erosion risk management, environmental and health and safety impacts through the pro-active nature of this option (i.e. improving present-day condition to reduce the risk of structural damage, deterioration, failure and breaching).
- The option would likely involve multi-million pound capital investment due to the large number and nature of present-day defects.

7.2.6 Option 6: Modify Existing Structures to Improve Present Defence Performance

Description:
If no further investment was made in upgrading the standard of protection (sometimes referred to as the standard of service) offered by the defences then rates overtopping discharges would worsen over time, compared to present-day discharges, due to rising sea levels. Option 6 assumes that this is not considered to be acceptable for the longer-term performance and that the standard of service of the defences will be improved.

Technical:
There are various means of implementing this option, depending on the desired outcome performance of the defences. The three main improvement target outcomes are to:

- Maintain rates of overtopping discharge at present-day values through raising crest levels of the piers and/or extensions by a level commensurate with the anticipated sea level rise over the next 50 years (i.e. sustaining the standard of service);

- Improve rates of overtopping discharge to some pre-defined target thresholds values under given design events (i.e. improving the defence performance compared to the present day); or

- Eliminate overtopping discharges for given design events.

Overtopping performance is affected by a number of factors. As well as the incident wave conditions at the toe of the defence (which is a ‘forcing’ condition), other important aspects (considered as ‘responsive’ conditions); (i) foreshore level at the toe of the defence; (ii) crest level of the defence; and (iii) defence typology (e.g. sloping or vertical seaward face, surface permeability of structure, etc.).

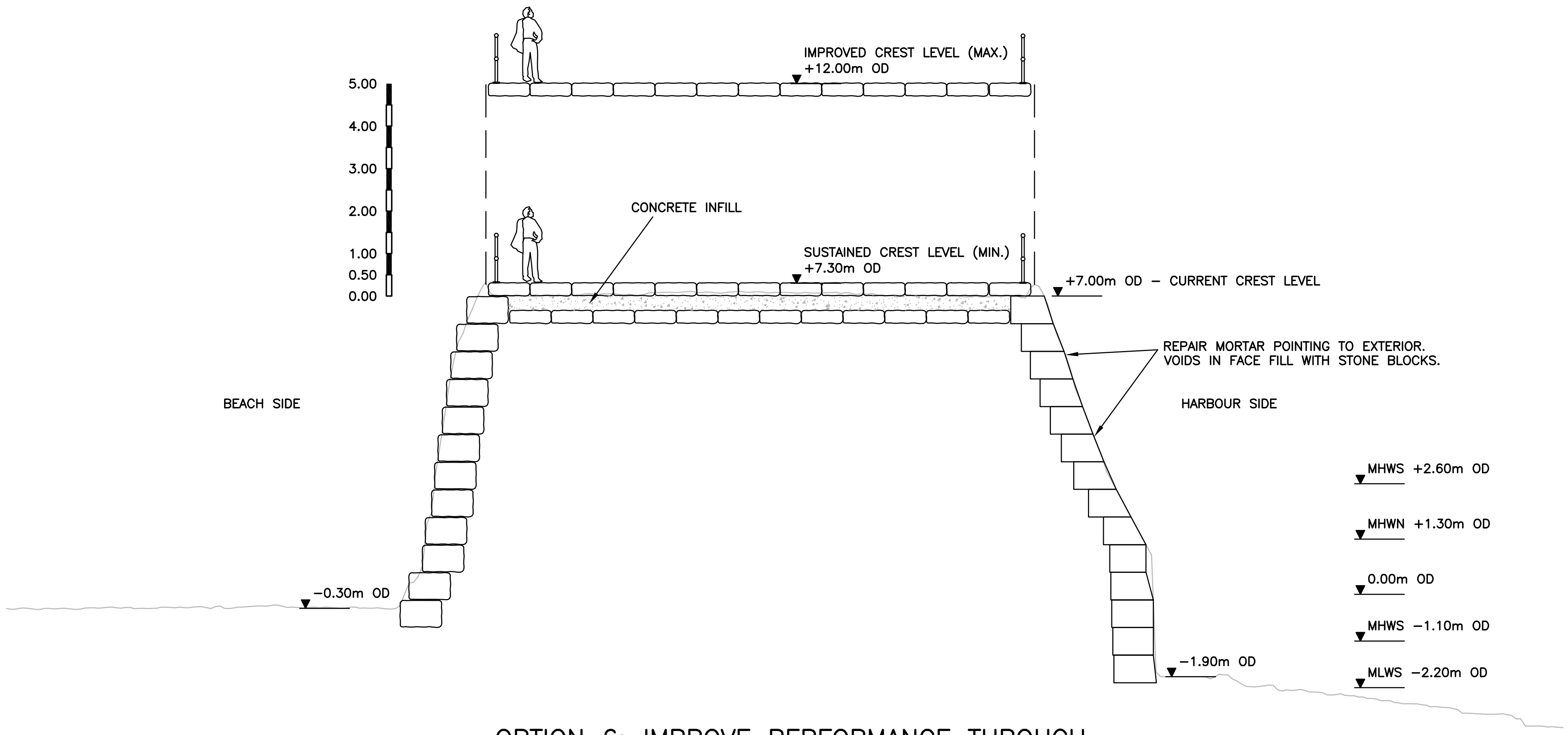
There are three principal means of addressing the more ‘responsive’ conditions are:

- Raising the foreshore level at the toe of the structures through beach recharge (possibly with groynes or breakwaters also used to help retain the imported sediment);

- Raising the crest level of the defence, through either wholesale crest raising (Figure 30) or the addition of a crest wall (Figure 31); and

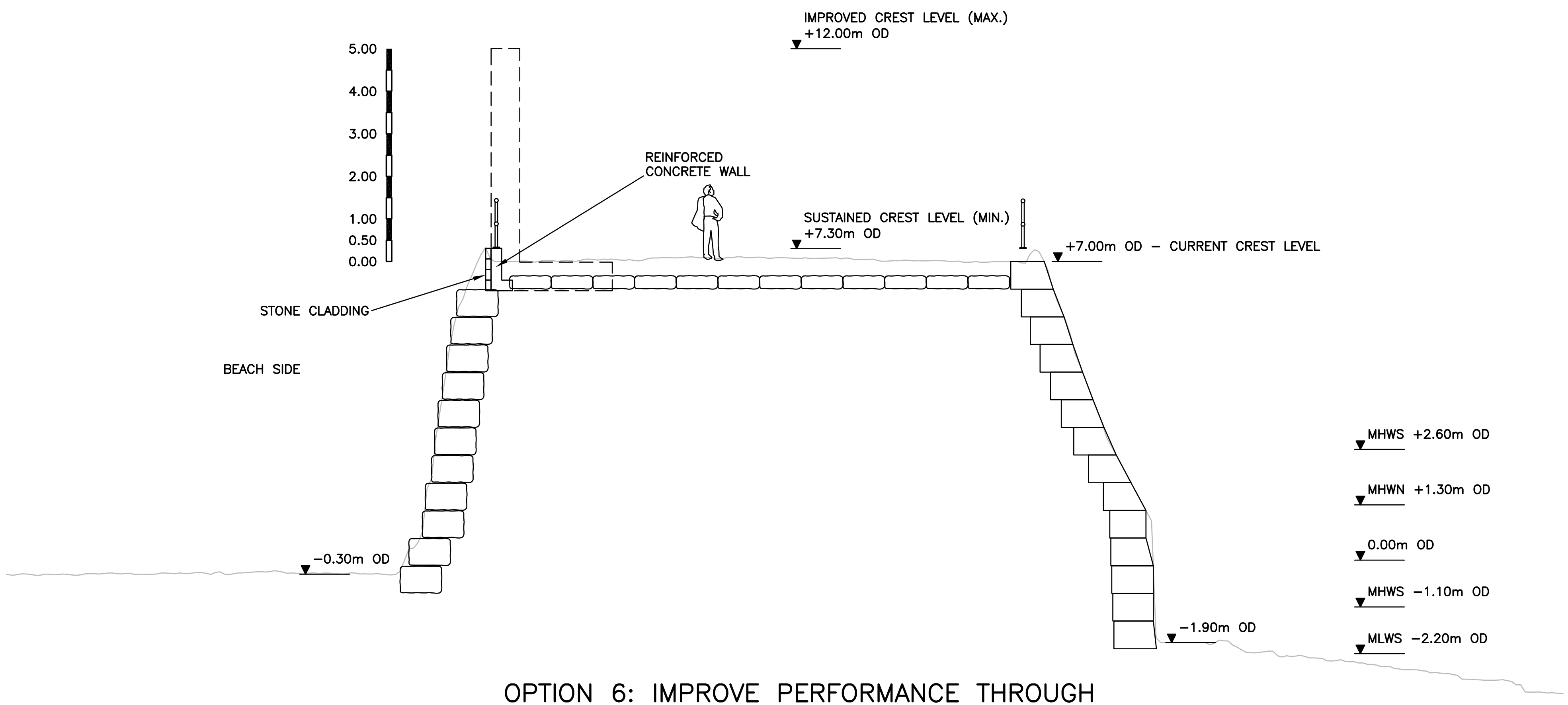
- Placing a permeable berm along the seaward extent of the structure (Figure 32) to both: (i) reduce incident wave conditions (by energy dissipation through the voids between individual rock armourstones / interlocking concrete blocks); and (ii) raising the foreshore level at the toe (and hence reducing the effective water depth).

Of these options, placement of beach recharge material would have limited effectiveness because the high energy environment would readily mobilise place sediment. The use of groynes or breakwaters to help retain the imported stock would only be effective when used in an alongshore sense and not in the cross-shore sense demanded from the present alignment of the piers and extensions.



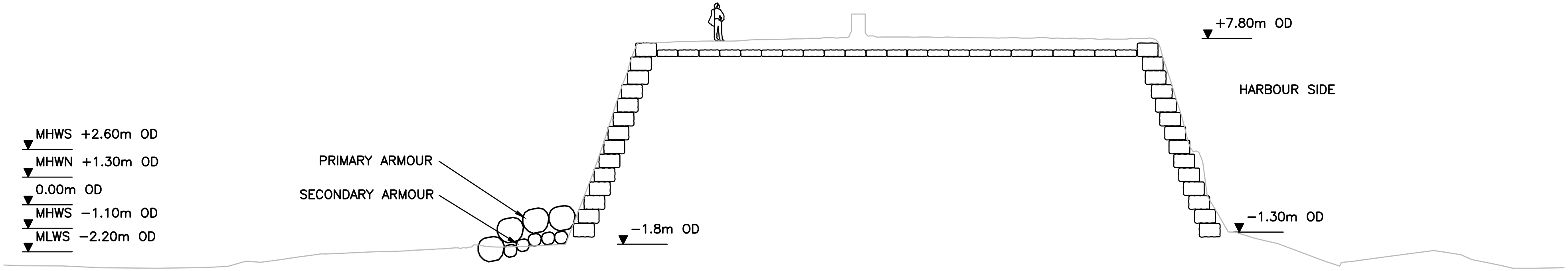
OPTION 6: IMPROVE PERFORMANCE THROUGH
RAISING DEFENCE LEVEL BY RAISING ENTIRE CREST

TITLE	PROJECT				
FIGURE 30 WEST MAIN PIER TYPICAL SECTION SHOWING OPTION 6	WHITBY COASTAL STRATEGY OPTIONS APPRAISAL	ROYAL HASKONING HASKONING UK LTD NEWCASTLE Marlborough House Marlborough Crescent Newcastle upon Tyne NE1 4EE +44 (0)191 211 1300 Telephone +44 (0)191 211 1313 Fax info@newcastle.royalhaskoning.com E-mail www.royalhaskoning.com Internet	DRAWN IT	DATE NOV' 08	JOB No. 9T0429
			SCALE AT A3 1:100	AUTOCAD REF. 9T0429–1003	
			DRAWING No. FIGURE 30		REV 0

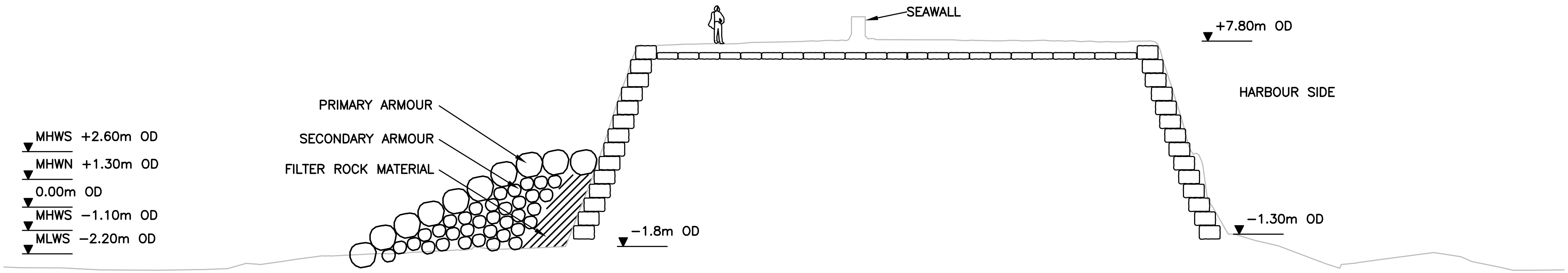


OPTION 6: IMPROVE PERFORMANCE THROUGH RAISING DEFENCE LEVEL BY CREST WALL

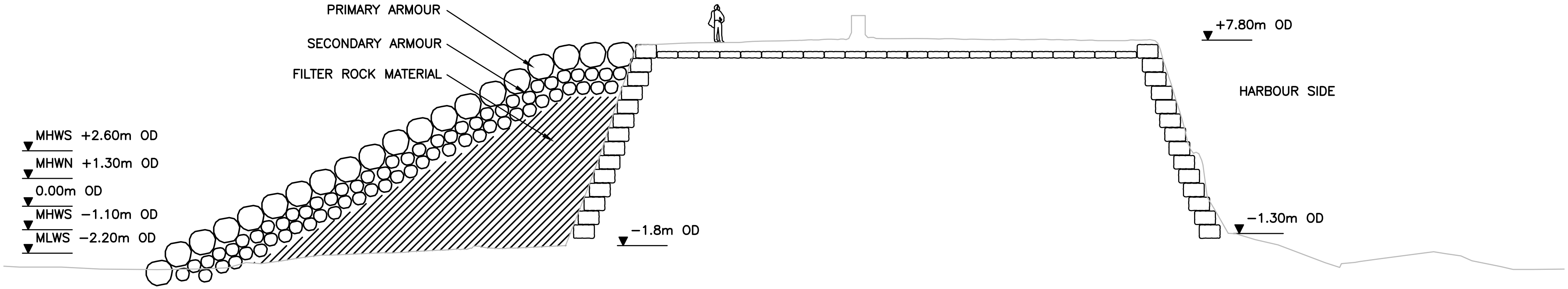
TITLE	PROJECT				
FIGURE 31 WEST MAIN PIER TYPICAL SECTION SHOWING OPTION 6	WHITBY COASTAL STRATEGY OPTIONS APPRAISAL	ROYAL HASKONING HASKONING UK LTD NEWCASTLE Marlborough House Marlborough Crescent Newcastle upon Tyne NE1 4EE +44 (0)191 211 1300 Telephone +44 (0)191 211 1313 Fax info@newcastle.royalhaskoning.com E-mail www.royalhaskoning.com Internet	DRAWN IT	DATE NOV' 08	JOB No. 9T0429
			SCALE AT A3 1:100	AUTOCAD REF. 9T0429–1004	
			DRAWING No. FIGURE 31		REV 0



OPTION 6 – IMPROVE PERFORMANCE THROUGH PROVIDING ROCK REVETEMENT (QUARTER HEIGHT)



OPTION 6 – IMPROVE PERFORMANCE THROUGH PROVIDING ROCK REVETEMENT (HALF HEIGHT)



OPTION 6 – IMPROVE PERFORMANCE THROUGH PROVIDING ROCK REVETEMENT (FULL HEIGHT)

TITLE FIGURE 32 TYPICAL SECTION THROUGH EAST MAIN PIER	PROJECT WHITBY COASTAL STRATEGY OPTIONS APPRAISAL	ROYAL HASKONING — HASKONING UK LTD NEWCASTLE, Marlborough House, Marlborough Crescent, Newcastle upon Tyne NE1 4EE, Telephone +44 (0)191 211 1300, Fax +44 (0)191 211 1313, E-mail info@newcastle.royalhaskoning.com, Internet www.royalhaskoning.com	DRAWN IT	DATE NOV' 08	JOB No. 9T0429
			SCALE AT A3 1:200	AUTOCAD REF. 9T0429−1001	
			DRAWING No. FIGURE 32		REV 0

This option, implemented alone, would not directly address the structural condition issues identified from the further investigations that have been undertaken during this study and therefore the condition of the piers and extensions would continue to worsen over time, ultimately leading to failure and breaching. However, the permeable berm placed along the seaward length of the existing structures would have a beneficial impact on some aspects of structural condition through providing stability at the toe and helping to overcome undermining issues.

Economic:
Due to the longitudinal extent of the structures, this option would have considerable (multi-million pound) associated costs. The ‘minimum’ improvement option of keeping overtopping discharges in line with present-day values would involve raising the crest level by an amount commensurate with the projected rate of sea level rise or constructing a relatively low-level rock/concrete armour berm at the toe and therefore would be the least cost way of implementing this option. Improving performance to achieve threshold target overtopping discharges for serviceability along the main piers would require more investment, with achievement of thresholds for avoidance of structural damage along the extensions requiring a considerably more robust approach and hence considerable greater cost. Most costly of all would be improving performance to achieve zero overtopping discharges. The associated costs of this are likely to be prohibitive and therefore a management decision would need to be made about what level of overtopping is considered acceptable along the piers and extensions if this option is investigated further.

It would be possible to optimise economic investment through more detailed investigation of overtopping discharges at different sections of the piers and extensions during a detailed design stage, thereby tailoring a bespoke solution to achieve a common standard of service along the length, taking into account differing wave exposure, foreshore levels and crest heights along each structure’s length.

Environmental:
This option would have environmental impacts during construction and care would have to be taken concerning the use of certain materials, such as concrete, in the marine environment.

Raising crest levels or constructing a crest wall along the piers and/or extensions would have associated landscape/seascape and amenity impacts as well as impacts on the heritage value of the structure.

Placement of a rock or interlocking concrete berm at the toe of the main piers and/or pier extensions would have an impact in terms of its direct footprint across the inter-tidal and nearshore sea bed zones, including a designated inter-tidal foreshore to the east of the harbour. Also, there would be impacts associated with importing large quantities of rock or interlocking concrete blocks and it may be necessary to confine such activities to vessel-based delivery systems due to logistics associated with access and disruption associated with large quantities of deliveries through the town. A berm structure would, however, provide additional habitat for marine life, such as lobsters.

Health and Safety:
There would be health and safety issues associated with construction activities, with the delivery of materials by sea being a key issue that would need to be addressed if a berm were preferred. Also, under the berm sub-option, there would be health and safety issues during operation and the public would need to be advise not to climb across the structure.

The overall intent of this option, however, is positive with respect to health and safety since it is aimed at sustaining or improving overtopping discharges and reducing risks to the public and to the existing structures.

Summary:
- Existing structures will be upgraded in condition through a capital investment scheme to enable present-day performance with respect to overtopping discharges to be sustained into the future or improved to achieve specific threshold targets.
- There is a range of standards of service to which the upgrade could be undertaken, depending on the desired performance targets following the capital investment.
- The option retains the alignment (and hence both function and influence) of the piers as the present day, thereby retaining their heritage and amenity value and their importance to nearshore coastal processes.
- The capital upgrade works would have positive effects in terms of reducing risks from overtopping to both people and to the existing structures.
- The option would not directly address structural condition issues, although the permeable berm options would contribute beneficially to avoidance of condition deterioration and provide toe stability. Hence overall condition of the piers and extensions would be likely to degrade over time.
- There will be positive flood and erosion risk management, environmental and health and safety impacts through the pro-active nature of this option.
- The major adverse environmental impacts would be associated with the delivery of construction materials and with the creation of a new footprint across the inter-tidal and nearshore sub-tidal zones, including across an area of designated earth science heritage importance.
- The option would likely involve multi-million pound capital investment but this investment could be optimised through creation of bespoke designs for different lengths of the structures.

7.2.7 Option 7: Modify Existing Structures to Improve Present Structural Condition and Defence Performance

Description:
This option involves capital improvement works both to upgrade the present structural condition and to improve the present structural performance.

Technical:
This option would be implemented through a combination of the technical approaches described for Options 5 and 6. The permeable berm approach to address overtopping performance would have also associated structural benefits in terms of improved stability at the toe and prevention of undermining at the toe of the existing structures.

Economic:
The economic costs of this option would be extremely high (multi-million pounds) but the work could be phased to address different priorities and risks. For example, overtopping discharges could be accepted initially and the focus of the first phase of investment could be on addressing structural condition. Alternatively, focus could first be placed on the East Pier and extension to address the areas at greatest risk of potential failure and breaching with most immediacy.

Environmental:
The environmental impacts (both negative and positive) will be a combination of the impacts previously identified for Options 5 and 6.

Health and Safety:
The health and safety impacts (both negative and positive) will be a combination of the impacts previously identified for Options 5 and 6.

Summary:
- This would involve a combination of Options 5 and 6 to address both structural condition and structural performance issues through capital investment.
- The option is both pro-active and strategic in its approach and therefore has positive benefits in terms of flood and erosion risk management, environmental issues and health and safety aspects.
- There would be some undoubted adverse environmental and health and safety impacts associated with implementation of this option, but this should be minimised through carefully and considered detailed design.
- The greatest environmental impacts would be associated with the introduction of a new structural footprint across the inter-tidal and nearshore sub-tidal zones, including across an area of designated earth science heritage importance, and with the options for delivery of construction materials.
- The cost of the option will be multi-millions of pounds (perhaps >£10M) but investment can be phased according to priorities and risks.

7.2.8 Option 8: Managed Removal and Alternative Defence Provision

Description:
This would involve the managed removal (preferred to abandonment) of the existing piers and pier extensions and the provision of alternative solutions to manage the residual erosion and tidal flood risk (Figure 33).

Technical:
With the piers and pier extensions removed, there would be the need for enhanced protection in the form of:

- Coastal defences along the shorelines adjacent to the mouth on the western frontage;
- Coastal defences along the shorelines adjacent to the mouth on the eastern frontage;
- Coastal defences within the harbour mouth;
- Flood defence improvements along the tidal reaches of the estuary.

In addition, removal of the piers would lead to increased maintenance dredging requirements in the harbour to maintain a channel to convey fluvial and tidal flows and prevent the increase in flood risk that would otherwise be associated with siltation and reduced channel capacity.

The engineering works required to provide the new coastal defence would involve the construction of new coastal defences (most likely in the form of rock or interlocking concrete revetments or concrete sea walls, and sea cliff stability works as relict landslides become reactivated.

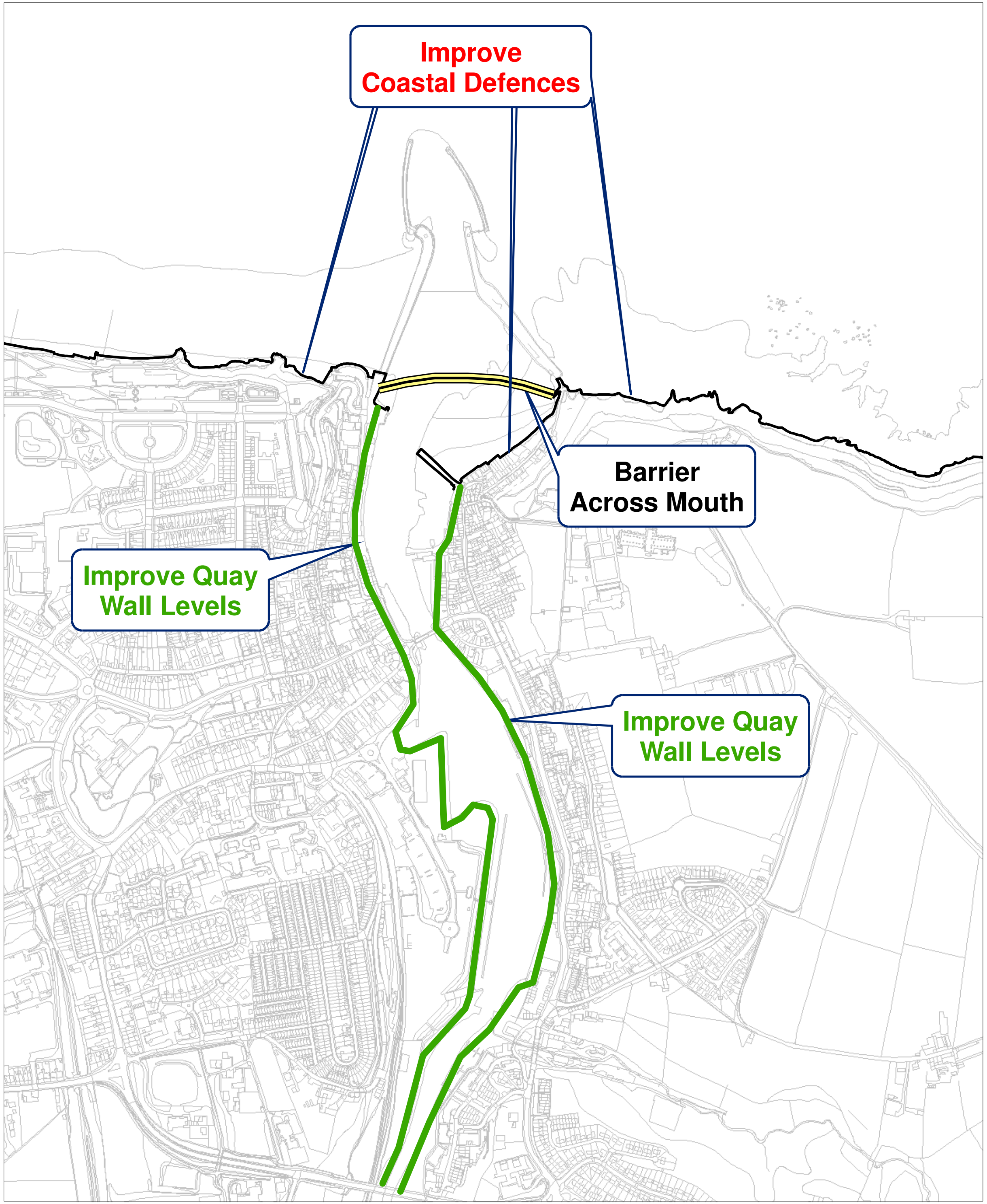
The engineering works required to provide the new tidal flood defence would be either quay wall raising, new flood walls on the crests of existing quay walls, or a tidal barrage at the estuary mouth which could be closed during North Sea storm surges or the highest astronomical tidal events.

Economic:
The option is driven by reducing the costs of capital and ongoing maintenance investment in the existing structures due to their exposed marine locations and securing alternative means of providing the same standard of defence to the estuary and adjacent coastlines against tidal flooding and coastal erosion. Consequently, no further investment in the piers would be required. However, the costs of removing the piers in a managed manner would be multi-millions of pounds

In addition, the economic cost of providing the extensive (both geographically and in terms of robustness) new defences would be multi-millions of pounds.

The economic damages associated with loss of the harbour and impacts on associated business such as fishing and tourism would be massive.

The economic costs associated with this option (both in terms of direct costs for demolition, construction and ongoing maintenance and in terms of damage to the local and regional economy) would prohibit selection of this option.



Title:
Option 8 - Managed Removal and Alternative Defences

Project:
Whitby Coastal Strategy Further Investigations at Whitby Harbour

Client:
Scarborough Borough Council

Date:	Scale:
January 2009	1 : 10,000

Figure:	Drawn:	Checked:
33	TC	NC

ROYAL HASKONING

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Environmental:
The environmental impacts of constructing new coastal and tidal flood defences would be considerable as although the types of construction impact would be similar to those previously described for Options 5, 6 and 7, the geographical extent of intervention works would be greater. Furthermore, loss of the harbour arms would result in loss of material from the inter-tidal and nearshore zone of the frontage to the west of the harbour and movement of much of this material into the harbour and across the mouth to become deposited on the foreshore to the east. This would result in smothering of the exposed designated rocky foreshore to the east of the harbour and increase the requirement for dredging of the harbour and estuary to maintain channel conveyance capacity.

The option of a tidal barrage at the mouth of the estuary would have major environmental implications on the estuary, affecting fisheries, biodiversity, amenity, heritage, landscape/seascape, and sediment transport and associated water and sediment quality interests in particular.

Health and Safety:
The managed removal of the piers and extensions and construction of new coastal and tidal flood defences would have major health and safety impacts due to the type (construction and demolition) and geographic scale and locations of operations that would be required.

Summary:
- The existing main piers and extensions would be removed so that future investment in these structures, located in the hostile marine environment, would not be required.
- The coastal erosion and tidal flooding risks would need to be managed through new structures along the adjacent open coasts, within the harbour and within the tidal reaches of the estuary. One option for managing the tidal flood risk is a barrage at the mouth.
- The economic cost of implementing this option would be prohibitive and the economic damages associated with the loss of the harbour would be massive.
- The environmental impacts associated with this option would be great as the geographical extent of new works would be large and much of the sediment presently retained by the harbour arms would newly be transported both into the harbour and eastwards to smother the designated rocky foreshore.
- The option of a tidal barrage at the mouth of the estuary to address tidal flood risk would have considerable costs and considerable environmental impacts.

7.2.9 Option 9: Managed Relocation of Assets

Description:
This option involves relocating assets presently (or in the future 50 years projected to be) at risk of erosion and/or tidal flooding and thereby avoiding the need for capital or revenue investment in flood and coastal defences (Figure 34).

Technical:
At present there are a number of different types of assets at risk from either coastal erosion or tidal flooding (or both). These include:

- residential properties
- business properties
- services and utilities
- infrastructure
- harbour facilities
- harbour vessels
- tourist and amenity facilities
- habitats

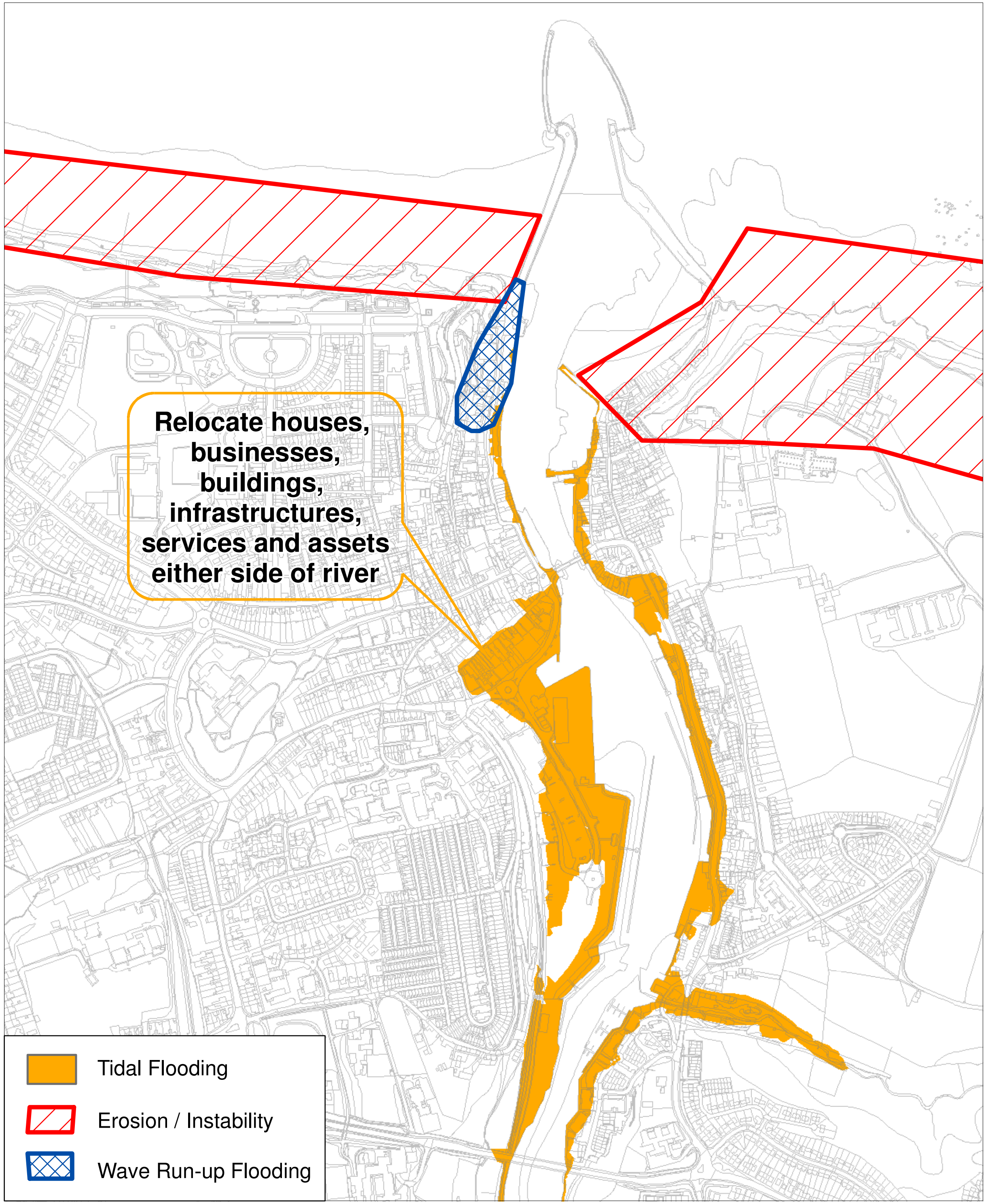
Many of these assets have associated social, economic, environmental and heritage values that are being protected by the existing harbour piers and extensions.

These assets could be relocated to new areas of land that are not exposed to flood and erosion risks, thereby avoiding the need for defences. This would require unprecedented intervention to relocate large parts of Whitby town, the harbour and associated facilities. Effectively the operations would entail the creation of a new part of town and a new harbour upstream of the present harbour, beyond the limit of wave activity.

Economic:
The direct economic costs of such a large-scale relocation activity would be prohibitive. The economy of the town, driven by its harbour, would take a drastic down-turn. Soci-economics would also be adversely affected as existing communities are broken-up by the relocation and many local businesses would be forced to cease trading due to their dependencies on the values provided by the present harbour and town.

Environmental:
The relocation activities would have massive environmental impacts, not least in terms of the new areas of land that would become urbanised or industrialised. Many of the present assets have their intrinsic value because of their marine location and aesthetic setting and this is irreplaceable.

Health and Safety:
The health and safety implications of such a major relocation would be large but not prohibitive as mostly conventional construction practices would be employed.



Title:
Option 9 - Relocation of Assets

Project:
Whitby Coastal Strategy Further Investigations at Whitby Harbour

Client:
Scarborough Borough Council

Date:	Scale:
January 2009	1 : 9,300

Figure:	Drawn:	Checked:
34	TC	NC

ROYAL HASKONING

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Summary:

- Assets presently, or in the future 50 years projected to be, at risk of flooding and/or erosion would be relocated to new locations not at risk.
- This would involve creation of new sections of the town and a new upstream harbour.
- The economic, social and environmental cost of this option is prohibitive.

7.2.10 Option 10: Demolish and Rebuild

Description:
This option involves the total demolition of the harbour piers and extensions and complete reconstruction on their existing alignments (Figure 35).

Technical:
Due to the identified structural defects, the harbour piers and extensions would be demolished entirely using conventional maritime engineering techniques. Following this, new structures would be built from similar materials and in a similar typological form along the existing alignment of the harbour.

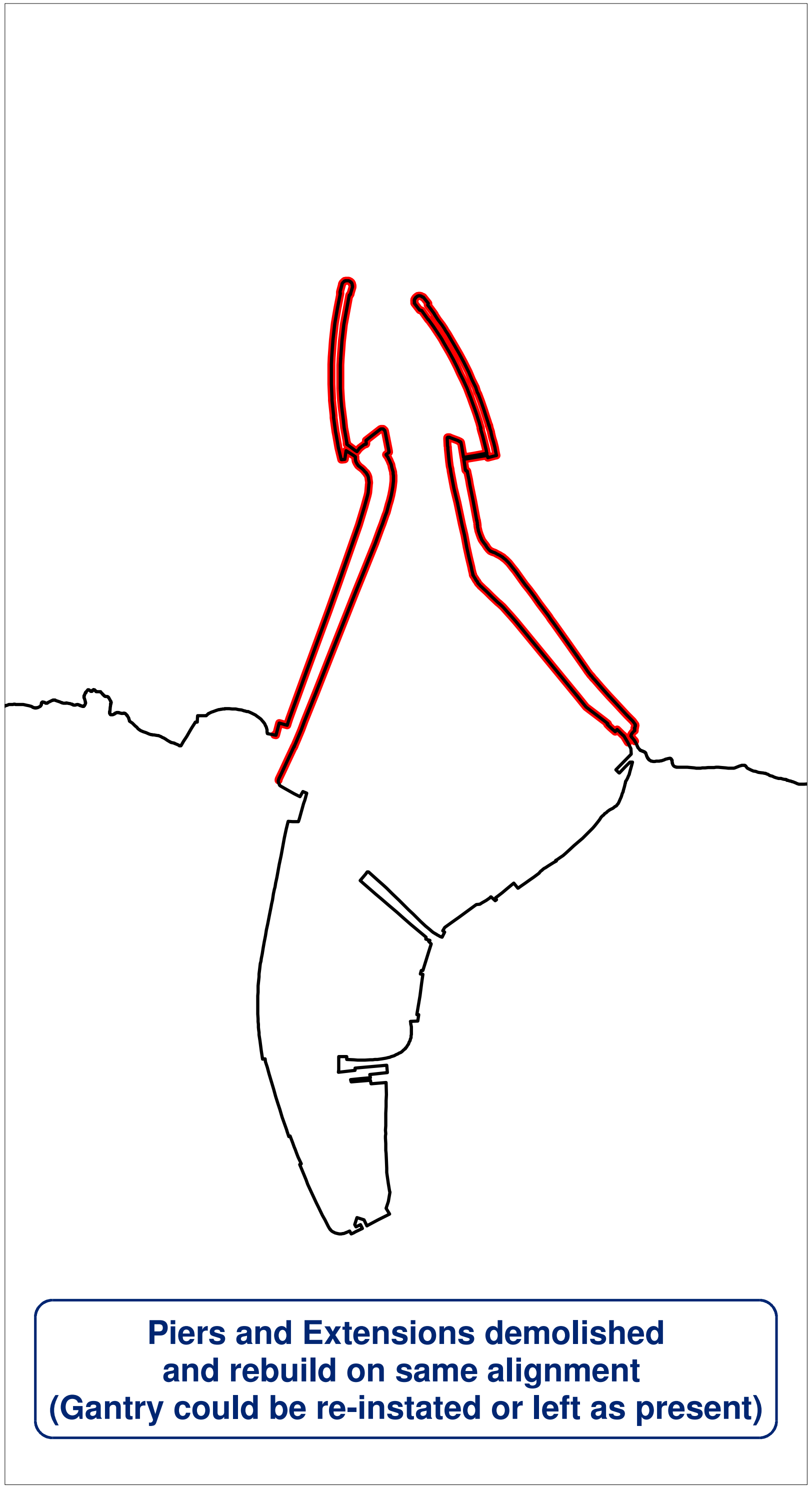
In rebuilding the structures, consideration could be given to the standard of protection offered against wave overtopping and standards could either existing be replicated to present-day values or improved to new target values.

Economic:
The economic cost of this option would be multiple tens of millions of pounds and would not represent cost-effectiveness as the residual use of the existing structures is not optimised.

Environmental:
Environmental impacts associated with this option would be great due to both demolition and construction activities being extensive. Considerable waste will be generated from the demolition.

Health and Safety:
Health and safety impacts associated with this option would also be great due to both demolition and construction activities being extensive, although conventional maritime engineering techniques would apply.

Summary:
- Existing piers and extensions would be demolished and rebuilt.
- In rebuilding, the standard of performance could be improved to deliver desired targets.
- The economic costs, environmental impacts and health and safety issues associated with this option are unnecessarily great and considerable waste will be generated.
- The option does not optimise the residual life of existing structures.



Title:
Option 10 - Demolish & Re-build

Project:
Whitby Coastal Strategy Further Investigations at Whitby Harbour

Client:
Scarborough Borough Council

Date:	Scale:
January 2009	1 : 6,500

Figure:	Drawn:	Checked:
35	TC	NC

ROYAL HASKONING

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7.3 Screening of Options

In Section 7.2, a 'long-list' of available options was identified, and each option described and assessed in outline.

Following this, an 'Optioneering and Risk Workshop' was held on 20th November 2008. The purpose of this workshop was to identify any potential showstoppers, issues or additional opportunities that had not previously been considered and to help identify which of the 'long-list' of ten options should progress through to more detailed assessments.

Key findings from the Workshop are presented in Appendix A.

In addition to this, the 'long-list' of options has been screened against technical, environmental, and economic criteria to identify a 'short-list' of options for further more detailed consideration.

This screening appraisal is presented in Table 7, with a summary of the outcomes from presented in Table 8.

Table 7 Screening Appraisal of Options

Option		Technical	Environmental	Economic	Sustainability
1	Do Nothing	• Achievable but will lead to breach and loss of piers • Significantly increased erosion and flood risk to Whitby	• Reactivation of cliff recession along updrift frontages. • Debris will pollute sea water and foreshore. • Geological SSSI will be smothered by sand released from Whitby Sands. • Loss of Grade II listed structures to the nation.	• No capital cost. • Considerable damages (direct and indirect) • Major negative impacts on economy of Whitby, leading to its demise	• Not a sustainable flood and coastal defence solution
2	Do Minimum	• Achievable but will lead to breach and loss of piers • Significantly increased erosion and flood risk to Whitby	• Reactivation of cliff recession along updrift frontages. • Debris will pollute sea water and foreshore. • Geological SSSI will be smothered by sand released from Whitby Sands. • Loss of Grade II listed structures to the nation.	• No capital cost but ongoing maintenance and future monitoring costs. • Considerable damages (direct and indirect) • Major negative impacts on economy of Whitby, leading to its demise	• Not a sustainable flood and coastal defence solution

Option		Technical	Environmental	Economic	Sustainability
3	Advance the Line	• Achievable but will involve construction of major maritime structures in a hostile marine environment. • Will still need to address structural defects on existing piers. • West-facing structure will fill with sediment. • East-facing structure will require major capital dredge across Whitby Rock.	• Footprint across large areas of sea bed. • Construction impacts. • Changes to coastal processes may affect geological foreshore. • Disposal of (capital or maintenance) dredged sediment will be required. • Maintains heritage value of piers.	• Extremely high costs due to hostile environment in which schemes constructed and likely associated maintenance or capital dredging costs with west- and east-facing entrances, respectively. • Still need investment in existing harbour structures to improve condition. • High maintenance requirements.	• Not a sustainable flood and coastal defence solution since more technically feasible, environmental acceptable and economically beneficial alternatives exist.
4	Managed Realignment	• Achievable but will involve construction of major maritime structures in a hostile marine environment. • Will need to address structural defects on existing piers. • West-facing structure will fill with sediment. • East-facing structure will require major capital dredge across Whitby Rock.	• Footprint across large areas of sea bed. • Construction impacts. • Changes to coastal processes may affect geological foreshore. • Disposal of (capital or maintenance) dredged sediment will be required. • Maintains heritage value of main piers.	• High costs due to hostile environment in which schemes constructed and likely associated maintenance or capital dredging costs with west- and east-facing entrances. • Still need investment in harbour structures to improve condition. • High maintenance requirements.	• Not a sustainable flood and coastal defence solution since more technically feasible, environmental acceptable and economically beneficial alternatives exist.

Option		Technical	Environmental	Economic	Sustainability
5	Modify Existing Structures (Condition only)	• Achievable through a variety of implementation methods depending on robustness of desired outcome. • Maximises use of existing structures. • Does not address performance against overtopping.	• Construction impacts, but minimised through optimisation of existing materials. • Maintains heritage value of main piers.	• Significant investment required, but based on optimising use of existing structures rather than requiring new structures.	• Potentially sustainable.
6	Modify Existing Structures (Performance only)	• Achievable through a variety of implementation methods depending on standard of service of desired outcome. • Maximises use of existing structures. • Does not address poor condition and therefore structures will breach and be lost.	• Construction impacts, but minimised through optimisation of existing materials. • Maintains heritage value of main piers. • Footprint across foreshore to west (amenity beach) and east (geological SSSI) if rock armour used, although east could tie-in with Haggerlyth Coastal Defence Scheme.	• Significant investment required, but based on optimising use of existing structures rather than requiring new structures.	• Not sustainable as poor structural condition will lead to ultimate failure.

Option		Technical	Environmental	Economic	Sustainability
7	Modify Existing Structures (Condition & Performance)	• Achievable through a variety of implementation methods depending on robustness and standard of service of desired outcome. • Maximises use of existing structures.	• Construction impacts, but minimised through optimisation of existing materials. • Maintains heritage value of main piers. • Footprint across foreshore to west (amenity beach) and east (geological SSSI) if rock armour used, although east could tie-in with Haggerlythe Coastal Defence Scheme.	• Significant investment required, but based on optimising use of existing structures rather than requiring new.	• Potentially sustainable.
8	Managed Removal and Alternative Defence Provision	• Achievable. • Would require additional defences along the coastline, the spending beach, and the quayside (or a tidal barrier/barrage). • Increased dredging.	• Environmental impacts of new defences (construction and performance). • Loss of geological SSSI due to smothering by sand.	• Significant investment required, disproportionate to the benefit. • High costs for new defences. • High maintenance dredging costs.	• Not a sustainable flood and coastal defence solution since more technically feasible, environmental acceptable and economically beneficial alternatives exist.

Option		Technical	Environmental	Economic	Sustainability
9	Managed Relocation	• Not technically realistic to move a town's entire vulnerable assets.	• Massive environmental impacts associated with new land take. • Loss of landscape, seascape and aesthetics.	• Significant investment required, disproportionate to the benefit. • Major impact on town's economy.	• Not a sustainable flood and coastal defence solution since more technically feasible, environmental acceptable and economically beneficial alternatives exist.
10	Demolish and Rebuild	• Logistically difficult but achievable. • Jack-up barge required. • Opportunity to design appropriate standard of service of new structures.	• Major disruption and damage. • Considerable waste generation. • High risk of pollution from debris/machinery.	• Significant investment required, disproportionate to the benefit.	• Not a sustainable flood and coastal defence solution since more technically feasible, environmental acceptable and economically beneficial alternatives exist.

Table 8 Summary Outcome of Screening Appraisal

Option[2]		Outcome
1	**Do Nothing**	**This option is not recommended as a viable approach, but it does represent a necessary base case scenario against which other options should be compared.**
2	**Do Minimum**	**This option is not recommended as a viable approach for the long-term strategic management of the harbour structures, but it does represent a necessary short-term investment scenario until a longer-term strategic solution is implemented.**
3	Advance the Line	This option is not recommended for further consideration due to anticipated high capital costs, ongoing maintenance needs, the need to still address present-day structural condition of existing structures and high environmental and health and safety impacts.
4	Managed Realignment	This option is recommended for further, more detailed, assessment.
5	**Modify Existing Structures (Condition only)**	**This option is recommended for further, more detailed, assessment.**
6	Modify Existing Structures (Performance only)	This option alone is not recommended for further, more detailed, assessment as it does not address the issues associated with the present structural condition.
7	**Modify Existing Structures (Condition & Performance)**	**This option is recommended for further, more detailed, assessment.**
8	Managed Removal	This option is not recommended for further consideration.
9	Managed Relocation	This option is not recommended for further consideration.
10	Demolish and Rebuild	This option is not recommended for further consideration.

[2] Options in **bold** are recommended passing through the screening exercise and on to more detailed assessment.

8 DEVELOPMENT OF MANAGEMENT OPTIONS

8.1 Background

This section presents more detailed technical, economic, and environmental assessments for each of the four 'short-listed' options.

8.2 Technical Assessment

8.2.1 Option 1 – Do Nothing

This option would involve walking-away from management of the existing harbour structures (piers and extensions) and undertaking no further capital investment, maintenance, monitoring or any other forms of intervention for flood and coastal defence purposes.

As discussed previously, this approach would lead to the breach of the existing coastal defence assets present at Whitby Harbour in accordance with the breach scenario discussed in Section 6.8 of this report.

The present structural condition of the piers would continue to worsen. This deterioration would lead to further settlement, undermining, voiding, damage such as cracking, abrasion and spalling, and ultimately collapse and breach of the most vulnerable sections. Whilst the residual structures would initially remain *in situ*, they would experience greater loading forces due to the waves penetrating through the breach and hence would also deteriorate further over time. The breached area would progressively widen and over time the standard of protection offered by the derelict structures would significantly reduce.

This scenario would ultimately lead to total failure of the structures and re-activation of recessional processes along the cliffs at the harbour mouth along both the western and eastern frontages and within the inner harbour area. Higher waves would also propagate further upstream and hence increase flood risk in the estuary. Beach sediment presently retained by the West Pier and its extension would become mobilised and much of this would be transported into the harbour causing siltation of the channel and hence a reduction in channel capacity. This would reduce the channel's ability to convey fluvial and tidal flows and hence provide another mechanism of increasing flood risk to the town.

8.2.2 Option 2 – Do Minimum

This option would involve the continued use of the existing maintenance budget of circa £35k per annum in order to undertake reactive repairs to minor damaged areas of the structure. Under this option, the maintenance budget would not increase over time and therefore its ability to address the structural defects and performance issues would reduce over time due to sea level rise leading to worsening structures (i.e. the fixed budget would be spread more thinly). Any significant damage to the structure would require substantial capital expenditure and under this option such damage would not be repaired.

The existing pier structures are subjected to regular storms and wave overtopping damage. This option would keep the piers in their current form and exposure with no major works to improve the current condition.

The condition of the main piers would deteriorate with the collapse of the outer shell leading to a breach of the East Pier structure, from which the structure would gradually collapse over a significant time period. The pier extensions would deteriorate through corrosion of the sheet piles and scour to the base causing the structure to become unstable and gradually collapse over a significant time period.

The annual maintenance works are unlikely to reduce the rate of deterioration as there would be no major intervention to stabilise the existing structures and maintenance would be mostly reactive, rather than pro-active, in nature. However, minor works would improve some aspects such as safety and operational issues. This would address the damaged access ladders, guardrails, wire rope rails, etc. highlighted in the visual surveys.

8.2.3 Option 5 - Modify Existing Structures to Improve Present Structural Condition

This option involves retaining use of the existing structures in their present alignment by addressing present structural defects through a capital upgrade that would be sufficient for ensuring a further 50 years life from the structures. This option would not address the performance issues identified in Section 6 of the report.

A number of means exist for delivering this strategic option, depending on the level of investment that is provided. This ranges from the minimum required works to address identified present-day defects, with the expectation that further problems could re-appear or newly appear during the 50 year timeframe, through to the optimum works required to proactively create a robust structure that will not suffer from future structural problems over the 50 years. The methods for achieving these ranges of investment are discussed below:-

Method A – Pointing to the Main Piers

This method would provide a hydraulically resistant designed mortar between all the joints in the stone block facing to the pier walls, as a means of replacing and strengthening the remaining mortar. Damaged sections of loose stonework would be replaced and missing blocks and voids filled with similar masonry sections. This would prevent water from flushing though the openings and damaged sections to remove the core fill material. The pointing would be placed by divers below the water surface and would require either scaffolding, underbridge working access platform or abseil access for the upper walls. The works undertaken would address the safety and operational issues for all the piers.

The disadvantage is that the voids would remain behind the facing leaving some instability to the walls, the mortar joints would deteriorate again leading to further cracking and settlement, and it would not resolve the scour issues to the toes of the walls. This method would also not address the stability issue and condition of the pier extensions. On this basis, this approach has been discounted.

Method B – Pointing and Grouting to the Main Piers

This method would provide a hydraulically resistant designed mortar between all the joints in the stone block facing to the pier walls, as described above. Damaged sections of loose stonework would be replaced and missing blocks and voids filled with similar masonry sections. In addition, the voids behind the stone block walls and beneath the deck would be grout filled with an appropriately design cementious mix which could control potential pollution issues. The works undertaken would address the safety and operational issues for all the piers.

The pointing would be placed by divers below the water surface and would require either scaffolding, underbridge working access platform or abseil access for the upper walls. The grouting of the voids could be undertaken either pumping the grout through small bores from the surface or through traditional methods of pumping the grout in gradual stages through the face of the stone block wall. This would like require divers below the surface and apply scaffolding, underbridge access platform or abseil access fro the upper walls, similar to the pointing.

This approach would address the structural integrity issues associated with the main piers with the exception of scour action at the wall toes. The scour action would continue to cause the blocks to settle and crack from the base so reducing the long term durability of the structure. Periodic maintenance would be required to repair minor areas of damage when they occurred to the outer wall face (e.g. pointing to the joints). This method would also not address condition of the pier extensions. On this basis, this approach has been discounted.

Method C – Pointing, Grouting and Sheet Pile Protection to Main Piers

This method would apply the pointing and grouting techniques mentioned in methods A and B above in order to stabilise the masonry pier walls and the bulk of the structure, including infilling voids around the periphery. In addition, sheet piles would be installed around the localised areas where erosion and missing blocks to the wall toe was recorded. These areas include localised areas at the seaward end of both the main pier structures on the inner faces, seaward end of the outer main East Pier face and around the West Pier bullnose. The works undertaken would address the safety and operational issues for all the piers.

The pile installation would require pre-excavation of the rock bed, as driving the piles directly into the bed would not be possible. This would mostly be undertaken by pre-augering the bed material to loosen the bed rock sufficiently to provide a toe for the sheet piles. The augered holes would need to be grouted up to ensure adequate purchase was gained. The piles would probably be anchored back to the existing structure and the voids behind filled with concrete to protect the toe.

Access to the site is difficult, due to the narrow streets and the town is a popular tourist destination including the piers. Thus, it is assumed that this operation would be undertaken by marine transportation only. In order to install the sheet piles, it is likely that a jack-up barge would be required to sit the auger rig and sheet pile driver on. Concrete, grout and mortar would be delivered by barge probably from Endeavour Wharf and craned on to the pier or the jack-up barge for placement.

An alternative approach would be to construct a concrete toe beam along the toe of the wall. However, this would be subjected to considerable battering from the sea conditions during construction, which could reduce the long term integrity of the works.

This approach would address the structural integrity issues associated with the main piers. Periodic maintenance would be required to repair minor areas of damage when they occurred to the outer wall face (e.g. pointing to the joints).This method would not address condition of the pier extensions. On this basis, this approach has been discounted although it could be applied in combination with other works.

Method D – Outer Protection Shell to the Main Piers

The basis of this method would be to provide an outer protective shell around the main piers in order to preserve the existing structure in its current form. This would consist of driving sheet piles into the adjacent seabed to the full height of the structure and filling the void between the piles and the structure with concrete to the surface. The sheet piles would be clad with locally won stone to a similar pattern and standard as the original pier structure, in order to match its listed status. The voids within the existing structure would be filled grout as described in method B above. The works undertaken would address the safety and operational issues for all the piers.

The pile installation would require pre-excavation of the rock bed, as driving the piles directly into the bed would not be possible. This would mostly be undertaken by pre-augering the bed material to loosen the bed rock sufficiently to provide a toe for the sheet piles. The augered holes would need to be grouted up to ensure adequate purchase was gained. The piles would probably be anchored back to the existing structure and the voids behind filled with concrete to protect the toe.

Access to the site is difficult, due to the narrow streets and the town is a popular tourist destination including the piers. Thus, it is assumed that this operation would be undertaken by marine transportation only. In order to install the sheet piles, it is likely that a jack-up barge would be required to sit the auger rig and sheet pile driver on. The rigs will not be able to negotiate the terrain to the piers over land, nor will the piers take the forces imposed by this equipment. Concrete, grout and mortar would be delivered by barge probably from Endeavour Wharf and craned on to the pier or the jack-up barge for placement.

This approach would address the structural integrity issues associated with the main piers. Periodic maintenance would be required to repair minor areas of damage when they occurred to the outer wall face (e.g. pointing to the joints). The maintenance could be greater than method C as the cladding may come loose from the piles due to sea conditions as the blocks would be smaller sections than the original stone blocks. This method would not address condition of the pier extensions. On this basis, this approach has been discounted although it could be applied in combination with other works.

Method E – Sheet Piling and Concrete Fill around Pier Extensions

This method has previously been applied to the pier extensions in 1970's but possibilities for constructing toe protection works are limited given the hostile nature of the sea environment. This approach would install a sheet pile cofferdam around the pier extensions, slightly higher than the current sheet pile apron and slightly further out. The sheet piles would be anchored back to the existing structure and then the void between and under the structure and the sheet piles filled with concrete fill. The works undertaken would address the safety and operational issues for all the piers.

The pile installation would require pre-excavation of the rock bed, as required in method C and D. The augered holes would need to be grouted up to ensure adequate purchase was gained. This process is likely to cause significant levels of vibration adjacent to the existing structure, part of which is currently unstable.

Access to the site is generally difficult, due to the narrow streets and the town is a popular tourist destination including the piers. In the case of the pier extensions, there is no land access and pedestrian access to the East Pier extension. Thus, it is assumed that this operation would be undertaken by marine transportation only. In order to install the sheet piles, it is likely that a jack-up barge would be required to sit the auger rig and sheet pile driver on. The rigs would not be able to gain access to the piers, nor will the piers take the forces imposed by this equipment. Concrete, grout and mortar would be delivered by barge probably from Endeavour Wharf and craned on to the pier or the jack-up barge for placement.

An alternative approach was identified to providing toe and scour protection to the pier extensions. This would consist of installing precast concrete walls units on to the bed of the sea adjacent to the existing structure so they were slightly higher than the current toe, and anchoring them to the seabed using ground anchors. The void between the units and the existing structure would be filled with mass concrete fill, as before. The advantages of this approach would be less damage to the seabed and geological feature, less vibration to the adjacent structures, limited use of concrete in open water, and reduced installation time at sea. This method has been used in a small controlled environment in the Scilly Isles but would require development to this larger scale before it could be considered feasible.

This approach would address the structural integrity issues associated with the pier extensions only. Periodic maintenance would be required to repair minor areas of damage when they occurred to the sheet piles (e.g. welding of holes). However, this method would not address the structural integrity issues associated with the main piers. On this basis, this approach has been discounted although it could be applied in combination with other works.

Method F – Combined Pointing, Grouting and Sheet Piles to Main Piers and Sheet Pile and Concrete Filling to Pier Extensions

This approach would effectively combine methods C and E above to provide an all-round solution to the structural integrity issues uncovered by the investigations. Thus, the works would consist of pointing and filling the mortar joints and infilling the missing blocks, grout injection of the voids behind the stone walls and below the deck, and sheet piling to localised areas on the main piers. For the pier extensions, a sheet pile cofferdam would be driven around the perimeter of the structures, anchored back to the main structure and the voids between the piles and the structure filled with concrete. The works undertaken would address the safety and operational issues for all the piers.

As before, the pointing and grout injection works would require divers below the surface and scaffolding or underbridge access platform to access the upper walls. The pile installation would require pre-excavation of the rock bed, most likely in the form of pre-augering and then the augered holes would be grouted up.

Access to the site is difficult, due to the narrow streets and the town is a popular tourist destination including the piers. Thus, it is assumed that this operation would be undertaken by marine transportation only. In order to install the sheet piles, it is likely that a jack-up barge would be required to sit the auger rig and sheet pile driver on. All materials would be delivered by barge probably from Endeavour Wharf and craned on to the piers or the jack-up barge for placement.

This approach would address the structural integrity issues associated with the main piers and pier extensions. Periodic maintenance would be required to repair minor areas of damage when they occurred to the structures. This method would resolve the structural condition and durability issues identified during the investigations.

Summary

In consideration of the methods of improving the structural condition of the piers, it can be seen a combined approach of works to both the main piers and pier extensions is required to improve the structural condition. One method, method F, would provide an improved structural condition to all the pier structures as it is combines the approach of works to main piers and pier extensions. Technically, the best solution for the main piers is pointing, grouting and localised sheet piles, as it provides a robust solution for the piers over the next 50 years.

With regards to the pier extensions, the sheet pile and concrete filling solution currently provides a traditional and feasible solution to these structures. However, the alternative solution to use precast concrete walls units fixed with ground anchors and concrete infilling could be developed into a workable solution with benefits over the sheet piled approach.

8.2.4 Option 7 - Modify Existing Structures to Improve Present Structural Condition and Defence Performance

This option involves capital improvement works both to upgrade the present structural condition and to improve the present structural performance. This option would be implemented through a combination of the technical approaches described for the structural condition in Options 5 above and possible techniques for improving performance as discussed below. There are three techniques that could be applied to these structures in order to reduce overtopping, which are:

- Raising the foreshore level at the toe of the structures through beach recharge – this technique was discounted in Section 7.2.6 of this report due to the high energy environment surrounding the piers;

- Raising the crest level of the defence through wholesale crest raising or the addition of a crest wall; and

- Placing a permeable berm along the seaward extent of the structure to both: (i) reduce incident wave conditions (by energy dissipation through the voids between individual rock armourstones / interlocking concrete blocks); and (ii) raising the foreshore level at the toe (and hence reducing the effective water depth).

In considering the technical feasibility of raising the defence crest level, it is important to quantify the amount by which the crest would require raising. The crest increase could range from the minimum, where the crest rises sufficiently to sustain the current performance standard in 50 years time (i.e. 300 mm rise in this case), to the maximum, where the crest rises to prevent overtopping creating a safety hazard on the piers over the next 50 years (i.e. 5 m rise in this case).

Clearly, the practicality of providing a 5 m rise in defence crest rise on these structures is an extreme solution, although it is feasibly possible. In order to achieve this level of improvement by wholesale crest rise or a crest wall would require substantial construction works, importation of materials and could change the character of this harbour against its listing. The effects of additional loading on the existing structures in terms of stability, bearing capacity and settlement would need to be addressed.

If a significant rise in crest level was required, then it would be likely that concrete piled foundations of some form would be required through the structure into the underlying bedrock to support the raised level. In addition, vertical steel dowels would be required through the stone masonry faces in order to stiffen the external wall to the additional horizontal pressure from the core material. Correspondingly, the greater the work, the larger the equipment required.

In this case, an auger piling rig mounted on a crane would be required to work from or be delivered by a jack-up barge to the main piers. The concrete for the piles and materials for the structure above would be transported by barge to the site. A crane on the jack-up barge would then transfer the materials to the pier.

If the crest increase is at the smaller end (e.g. say up to 1 m), then it would be possible for the existing structures to be able to carry the additional load with minimal improvements above those required for the structural condition. These could include use of geogrids underneath the raising structure to spread the load across the deck.

In identifying the crest rise required, it would be important to consider the practicality and the risks from implementing the works against risk from overtopping. A suitable approach may be to provide a smaller structure which could be raised in the future to suit changing performance conditions. To this end, a small crest wall could be a practical approach.

With regard to placing a permanent berm on the seaward face of the structures, the feasibility of providing a rock revetment has been considered in terms the effectiveness of differing size revetments placed directly against the pier structures. Those assessed included revetment height at quarter of the retained pier height, half of the retained pier height and full retained pier height. The engineering performance judgements provided by these assessments are that the quarter height revetment would have limited effect on reducing overtopping of the piers. The half and full height revetments would reduce the overtopping to an acceptable safe standard for pedestrian access (the lowest threshold). Thus, the half height revetment would be a feasible and practical solution to apply.

In providing a permanent berm rock revetment adjacent to the pier structures, the revetment would not only reduce overtopping for safety but reduce potential damage from overtopping. It would also protect the improved structural condition of piers from future damage by dissipating the wave energy before it directly impacts on to the structures, so increasing the life of the structures.

As previously noted, access to the site is difficult due to the narrow streets, heavy pedestrian traffic and lack of access to the pier extensions. Thus, it is assumed that this operation would be undertaken by marine transportation only. The supply of appropriate rock material could be sourced either from a few quarries near the northwest coast of the United Kingdom or from Scandinavia. Thus, transfer by sea would be cost effective. The construction of the revetment would require a key trench in the sea bedrock, which could be excavated by conventional excavators. Difficulties could arise with the placement of the armourstone below water particularly around the pier extensions. It is likely that the rock would be placed via a crane on a jack-up barge and the rock positioned using divers to ensure correct placement.

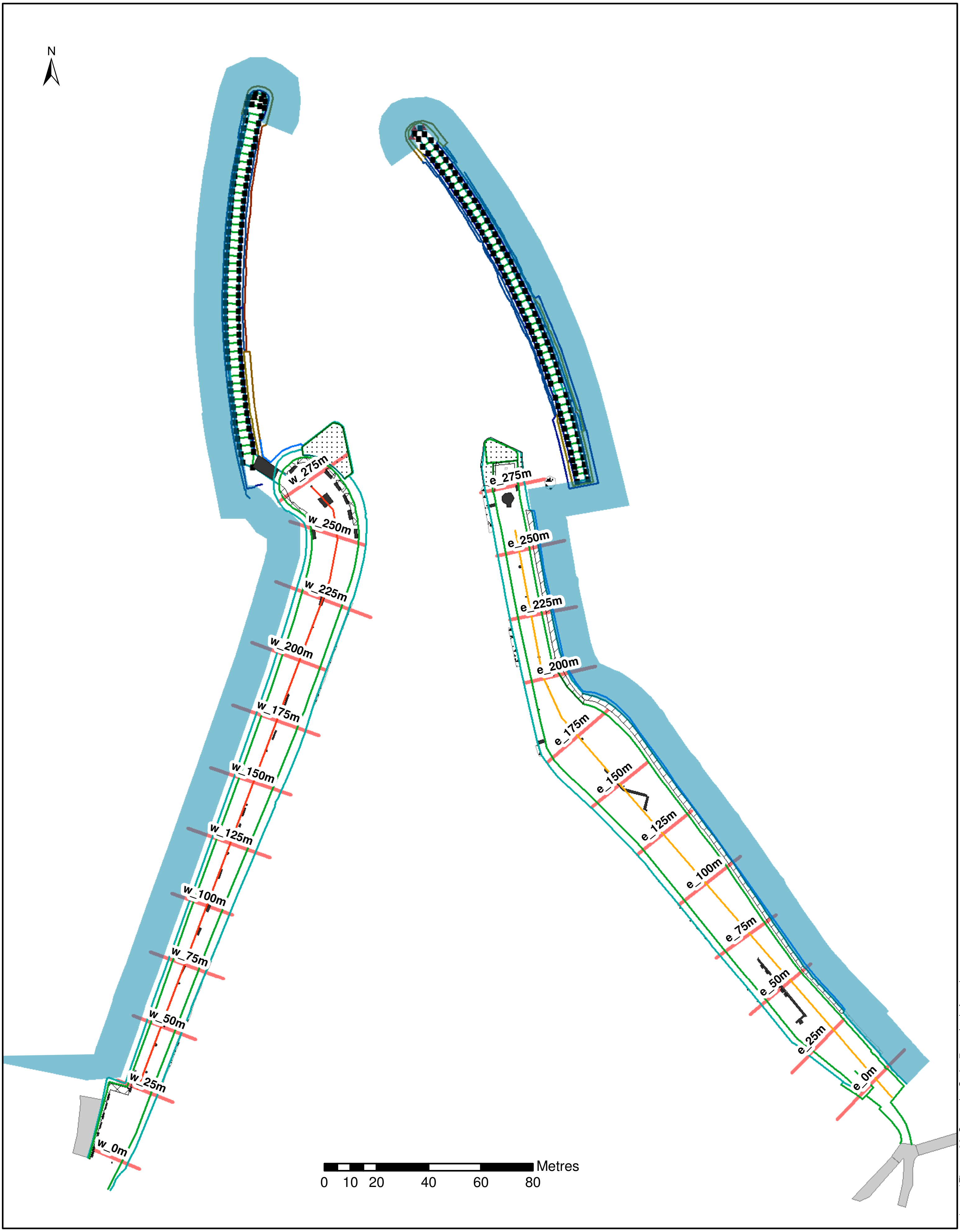
Providing a permanent berm on the seaward faces to reduce overtopping of the pier structures is consider to be the best technical approach to improving the performance of the harbour piers, as it achieves the acceptable safe standard for pedestrian access. However, it should be noted that combinations of raising the defence crest and providing permanent berm to the pier structures could also achieve the same standard of performance.

In considering the potential approaches to achieving this strategic option, a number of methods have been developed from the techniques described above that would improve the pier system performance based the level of capital investment available and the likely requirements fed back from the Optioneering and Risk Workshop (Appendix A). These methods are formed from various arrangements of the techniques discussed above to resolve the performance issues discussed in Section 6.8 above. The methods developed are:

Method A – Rock Revetment to All the Pier Structures

This method would provide a permanent berm to the outer faces of all the pier structures, both the main piers and the extensions (Figure 36). The rock revetment would best be provided to approximately the half retained height on all structures (subject to more detailed modelling and design) and all structural condition issues should first be resolved following recommended methods discussed for Option 5.

This would improve the performance standard to an acceptable safe level for pedestrian access on all the piers. However, it would mean that a rock revetment would be constructed on the Whitby Sands, which was a negative issue raised at the Optioneering and Risk Workshop.



Key:

Cross-Sections

Rock Revetment

Title:
Whitby Piers -
Strategic Option 7, Method A

Project:
Whitby Coastal Strategy Further Investigations at Whitby Harbour

Client:
Scarborough Borough Council

Date: Jan 2009	Scale: 1 : 1,800	
Figure: 36	Drawn: TC	Checked: CG

ROYAL HASKONING

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With regard to the slipway, a stub breakwater could be provided across the end of the slipway, perpendicularly to the main West Pier wall, or a flood gate installed. The breakwater would be positioned sufficiently to allow vehicular and pedestrian traffic to and from the beach and would tie-in with the rock armour along the West Pier. The rock structure would reduce the wave run up from the beach to the slipway through dissipating the wave energy, containing the water to the beach area. This approach has the advantage over a flood gate in that it does not rely on correct operation and regular maintenance in order to provide an effective solution, although it has the disadvantage of additional rock placed on a recreation and amenity beach.

Method B – Partial Rock Revetment to Landward End of Main West Pier

Similar to above, this method would provide a permanent berm but here to the outer faces of the main East Pier and both pier extensions and only along the landward section of the outer face of the main West Pier (Figure 37). As before, the rock revetment would best be provided to approximately the half retained height on the structures (subject to more detailed modelling and design) and all structural condition issues should first be resolved following recommended methods discussed for Option 5.

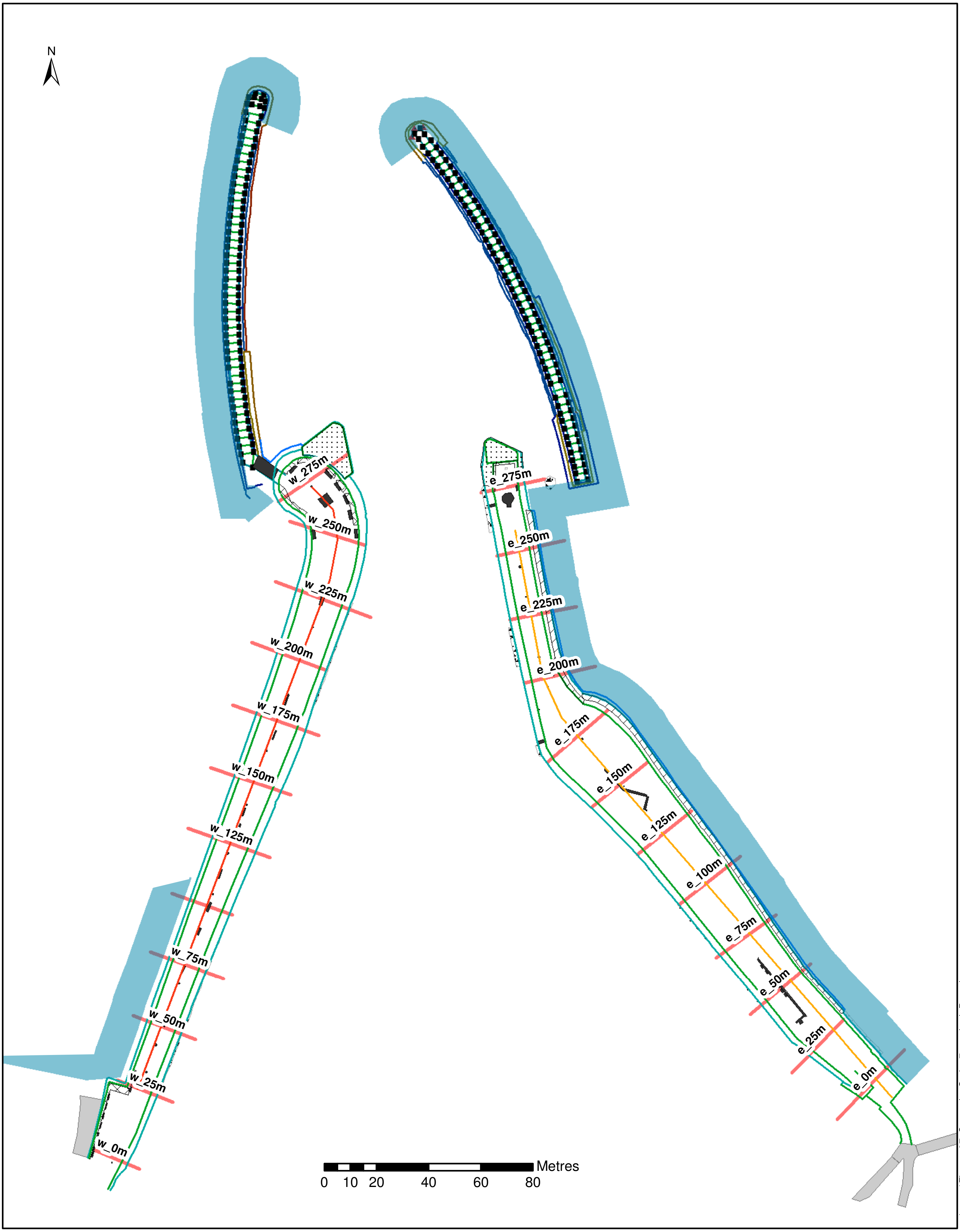
This method would improve the performance standard of the piers to an acceptable level for safe pedestrian access over most of the pier structures. With regard to main West Pier, overtopping would be reduced to the landward end to the acceptable standard, although this may not be achieved over the middle or seaward end of the structure. The overtopping waves in the area tend to run up along the pier wall, which would be likely to continue, although to a lesser degree than the current situation.

With regard to the slipway, a stub breakwater could be provided across the end of the slipway, perpendicularly to the main West Pier wall, or ma flood gate installed. The advantages and disadvantages of these approaches are as described for Method A.

Method C – Wave Wall to Main West Pier

Similar to above, this method would provide a permanent berm to the outer faces of the main East Pier and both pier extensions but would provide a wave return wall along the outer edge of the main West Pier, where the current railing is situated (Figure 38). It is suggested that the height of this wall be limited to 1.2m maximum based on the earlier discussion on raising the defence crest structures, but could more easily be accepted to be lower (subject to more detailed modelling and design). As before, the rock revetment would best be provided to approximately the half retained height on the structures (subject to more detailed modelling and design) and all structural condition issues should first be resolved following recommended methods discussed for Option 5.

In providing the wave wall, the performance standard would be improved above the current standard significantly reducing the current overtopping regime. However, overtopping would continue to occur above the safe pedestrian access limit and so access restrictions would be required at times. This would increase through the lifetime of the scheme.



Key:

Cross-Sections

Rock Revetment

Title:
Whitby Piers -
Strategic Option 7, Method D

Project:
Whitby Coastal Strategy Further Investigations at Whitby Harbour

Client:
Scarborough Borough Council

Date:	Scale:
Jan 2009	1 : 1,800

Figure:	Drawn:	Checked:
37	TC	CG

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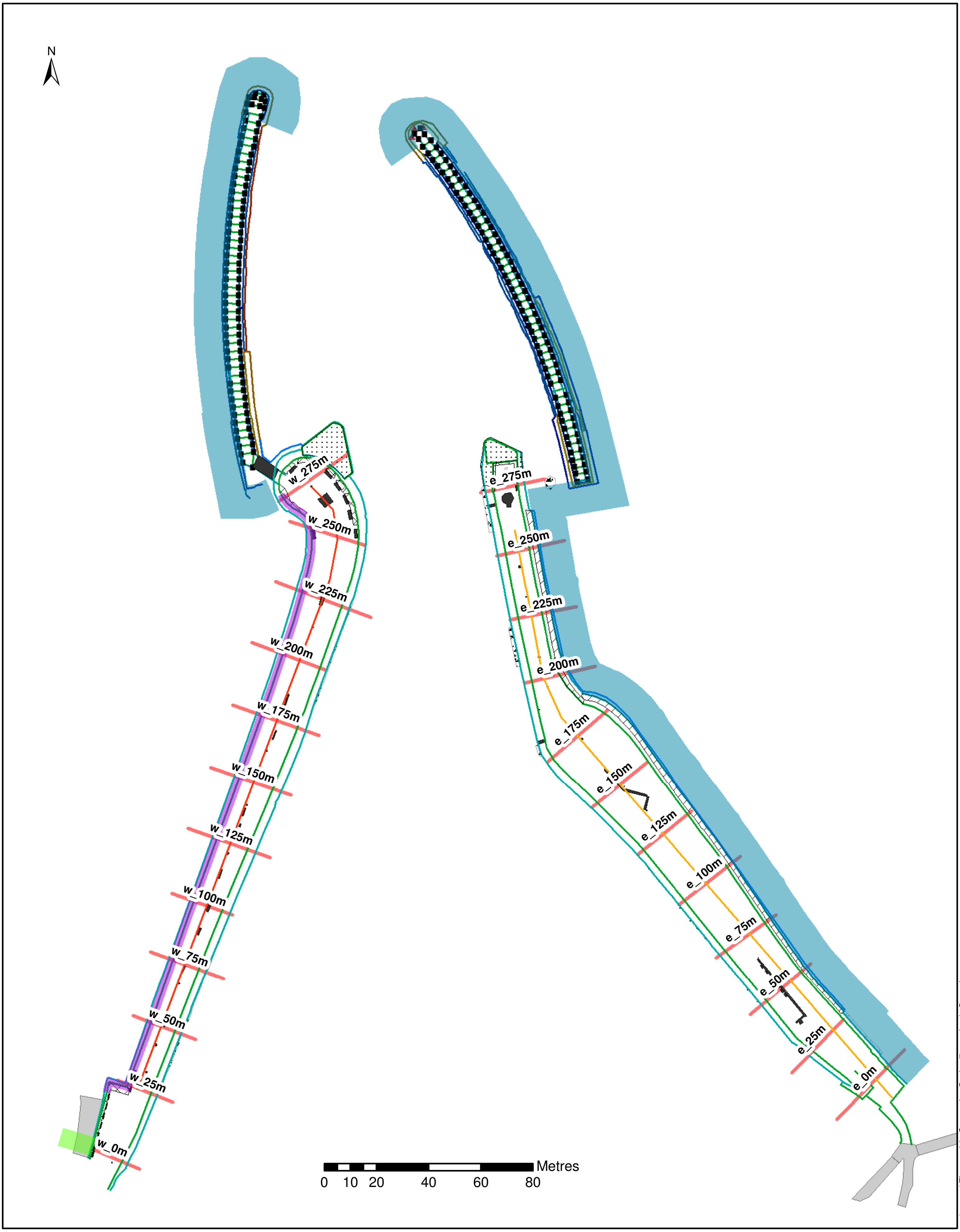

Key:

	Cross-Sections
	Rock Revetment
	Flood Gate
	Floodwall

Title:
Whitby Piers -
Strategic Option 7, Method C

Project:
Whitby Coastal Strategy Further Investigations at Whitby Harbour

Client:
Scarborough Borough Council

Date:	Scale:	
Jan 2009	1 : 1,800	

Figure:	Drawn:	Checked:
38	TC	CG

ROYAL HASKONING

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With regard to the wave run-up at the slipway, a floodgate could be installed at the top of the slipway to prevent waves from flooding the adjacent roads and property. These will require regular maintenance to ensure they operate correctly when required (e.g. seals need replacing, hinges greasing, tracks clearing).

Method D – Allow Overtopping and Restrict Access to Main West Pier

This approach would provide a permanent berm to the outer faces of the main East Pier and both pier extensions but would allow the overtopping to continue to the current levels now and worsening with sea level rise in the future (Figure 39). As before, the rock revetment would best be provided to approximately the half retained height on the structures (subject to more detailed modelling and design) and all structural condition issues should first be resolved following recommended methods discussed for Option 5.

No work would be undertaken to the main West Pier in terms of improving overtopping performance. This would mean that the frequency and discharges of overtopping would increase. This would increase the risk of pedestrian safety and structural damage. Thus, it is likely that maintenance works would increase over the scheme lifespan. With the increasing frequency of overtopping, it is likely that public access on to the West Pier would need to become more strictly regulated.

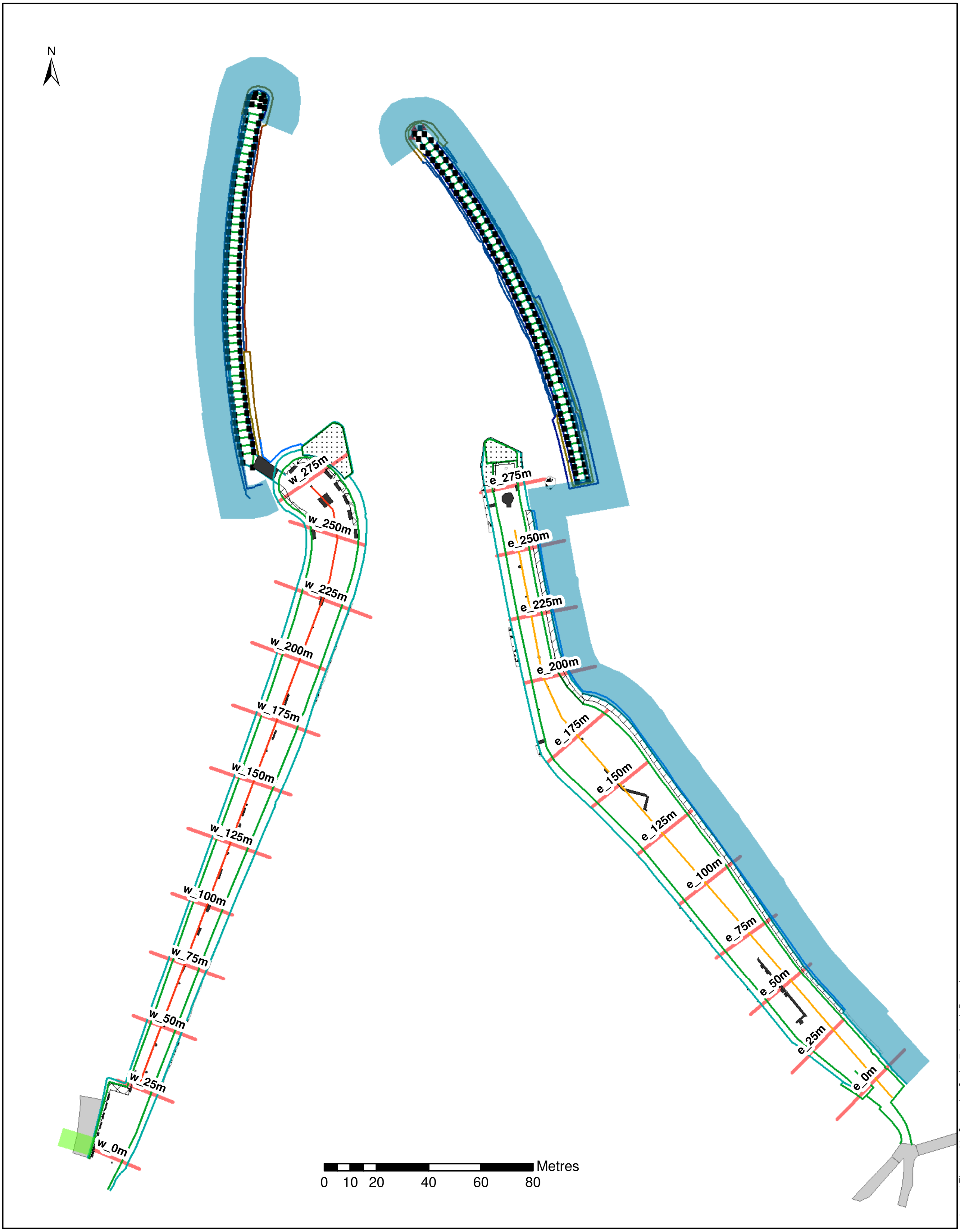
With regard to the wave run-up at the slipway, a floodgate could be installed at the top of the slipway to prevent waves from flooding the adjacent roads and property. These will require regular maintenance to ensure they operate correctly when required (e.g. seals need replacing, hinges greasing, tracks clearing).

Summary

In consideration of the methods and techniques for improving the performance of the harbour piers, it can be seen that a combination of defence techniques would provide a workable solution to reduce overtopping to an acceptable level for safe pedestrian access and avoidance of structural damage. From the methods developed, the arrangements are shown to provide varying standards of service. All methods reduce overtopping to the main East Pier and both pier extensions. Method D does not improve the standard of service provided by the main West Pier compared to the present day level, and this standard will reduce further over time due to sea level rise.

It is recommended that whatever implementation method is selected, that there be more detailed modelling, perhaps including comprehensive physical modelling, to test overtopping performance of the different implementation methods under a range of incoming wave directions, periods and heights. Outcomes from such investigations would then inform detailed design.

With regard to wave run-up at the slipway, both the approaches identified within the above methods would improve the standard of protection to this localised area.



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Key:

Cross-Sections

Rock Revetment

Flood Gate

Title: Whitby Piers - Strategic Option 7, Method D	Date: Jan 2009		Scale: 1 : 1,800
Project: Whitby Coastal Strategy Further Investigations at Whitby Harbour	Figure: 39	Drawn: TC	Checked: CG
Client: Scarborough Borough Council			

ROYAL HASKONING

8.3 Economic Appraisal

Assessing the economic benefits of the Whitby Harbour piers alone is not easily undertaken in a conventional PAG3 economic appraisal sense since the piers form an integral part of a wider coastal and flood defence system that also incorporates:

- Natural beaches and foreshore outcrops to both the west and east;
- Coastal defences protecting sea cliffs;
- Quay walls along the River Esk estuary;
- Jetties and other small structures within the harbour.

All of the above components, which have critical inter-dependencies, combine to provide an overall coastal and flood defence system to the coastline between Sandsend and Abbey Cliff and to the lower reaches of the River Esk estuary. The absence of any one of these components would severely increase the risk from flooding and/or coastal erosion.

It is for this reason that the Whitby Coastal Strategy assessed the economic damages that would occur to the whole strategy frontage and the costs of the measures that were collectively required across this wider area to address the risks presented from:

- Potential breach of the Whitby Harbour piers;
- Potential for renewed recession of protected sea cliffs;
- Flooding of property along the lower reaches of the River Esk estuary and Whitby Harbour quays;
- Wave overtopping of the sea defences on the open coast; and
- Recession of the unprotected sea cliffs.

The Strategy identified total present day benefits of £254,538,400 within the overall frontage over 60 years. This was composed of £17,478,000 relating to the flood risk damages along the lower reaches of the River Esk and £237,060,400 relating to the coastline. Of the coastal aspects, direct benefits of £25,218,700 were identified over 60 years and indirect benefits over the same timeframe were £211,841,700.

Following advice from the Environment Agency, the previous economics appraisal process has been re-evaluated for purposes of the further investigations at Whitby Harbour. The benefits appraisal that has been undertaken as part of the present study is presented in Appendix B and the scheme cost estimates in Appendix C. This section summarises the key findings relating to each of the four short-listed options.

8.3.1 Option 1 – Do Nothing

This option represents a necessary base case against which other options should be compared. In this assessment, the economic damages that would result from implementing this option are considered to include:

- Direct and indirect damages from tidal flooding in the lower reaches of the River Esk estuary caused by higher waves overtopping quayside defences;
- Direct and indirect damages from erosion of adjacent coastal frontages;
- Direct and indirect damages caused by wave run-up the slipway;
- Loss of life due to loss of refuge at Whitby Harbour;

- Increased dredging requirements in the estuary;
- Loss of Grade II Listed Structures;
- Loss of geological SSSI;
- Loss of fishing income;
- Loss of tourist income;
- Loss of amenity;
- Loss of jobs;
- Relocation of lifeboat station as part of the exit strategy.

The benefits appraisal is presented in Appendix B. This reveals that the net present value (PV) of the damages* over 50 years is £271,777,773 and over 100 years is £322,781,045.

* Note: This excludes the difficult to quantify categories covering loss of jobs and loss of amenity.

The costs associated with this option are zero.

8.3.2 Option 2 – Do Minimum

For purposes of this assessment, the same net present damage values have been assumed to apply for the Do Minimum option as the Do Nothing option. In reality, the existing maintenance regime would help slightly delay the onset of damages but it is recognised that the present Do Minimum expenditure is insufficient to adequately address the present condition and does not address the present performance issues at all.

The existing Do Minimum maintenance budget is £35k per year for the entire harbour area. Most of this is allocated to harbour operations rather than pier maintenance. If it is assumed that, on average, £7.5k per year is used for maintenance of the harbour structures, then the present value (PV) costs over 50 years is £428,810 and over 100 years is £515,729. These include a recommended £120,000 every ten years for further geophysical, dive, visual and digital laser-scan surveys so that deterioration can be monitored for healthy and safety reasons and so that the limited available maintenance budget can be directed to most needing areas.

However, this expenditure does not prevent the occurrence of damages and therefore this approach on its own is not cost-effective.

8.3.3 Option 5 - Modify Existing Structures to Improve Present Structural Condition

Appendix C explains the range of costs associated with this option, depending on which works implementation method is selected. The most technically robust solution is to undertake pointing, grouting and partial sheet pile toe protection to the main piers and sheet piling and concrete fill around the pier extensions. The cost of this option is estimated to be £17.8M.

For the economic appraisal it has been assumed that this cost will be spread across three years (year 2 to year 4) and that annual maintenance costs of 2% of the capital costs will be required because there will be structural fatigue and damage due to overtopping, which the scheme is not designed to address. In addition, an allowance of

£120,000 is made every ten years from scheme completion for further geophysical, dive, visual and digital laser-scan surveys so that deterioration can be monitored for health and safety reasons and so that the maintenance budget can be directed to most needing areas.

This gives present value (PV) 'whole life' costs over 50 years of £23,490,640 and over 100 years of £25,377,803.

When these PV costs are compared against the PV damages from Section 8.3.1, this gives a benefit to cost ratio of 11.5 over 50 years and 12.7 over 100 years.

In addition, this option has the qualitative benefits of avoiding loss of jobs. It does not however avoid loss (or at least disruption) to amenity because overtopping will worsen compared to the present day and to avoid loss of life access to the piers and extensions would need to be restricted.

8.3.4 Option 7 - Modify Existing Structures to Improve Present Structural Condition and Defence Performance

Appendix C also explains the range of costs associated with this option, depending on which works implementation method is selected. The most technically robust solution is to undertake pointing, grouting and partial sheet pile toe protection to the main piers and sheet piling and concrete fill around the pier extensions to improve the condition. Then, to improve the performance against rising sea levels, the most robust approach is to additionally use rock armour to form a revetment around the seaward side of all structures. The cost of this option is estimated to be £23.3M.

For the economic appraisal it has been assumed that this cost will be spread across four years (year 2 to year 5) and that annual maintenance costs of 0.5% of the capital costs will be required. These maintenance costs are lower than for Option 5 because overtopping of the structures will be considerably reduced. In addition, an allowance of £120,000 is made every ten years from scheme completion for further geophysical, dive, visual and digital laser-scan surveys so that deterioration can be monitored for healthy and safety reasons and so that the maintenance budget can be directed to most needing areas.

This gives present value (PV) 'whole life' costs over 50 years of £23,336,341 and over 100 years of £23,995,468.

When these PV costs are compared against the PV damages from Section 8.3.1, this gives a benefit to cost ratio of 11.7 over 50 years and 13.5 over 100 years.

In addition, this option has the qualitative benefits of avoiding loss of jobs and avoiding loss of amenity.

8.4 Environmental Appraisal

The Whitby Coastal Strategy was accompanied by an *Environmental Studies* appendix. This document has been reviewed as part of the present study and used to inform the environmental appraisal associated with the management options. It should be noted that as well as informing this section, the review has highlighted some aspects that will need to be considered further as part of an Environmental Impact Assessment (EIA) accompanying any planning application associated with a preferred scheme. This information is presented in Appendix D.

The key environmental aspects identified from this review are:

- Potential for loss of Grade II listed structures.

- Potential for disturbance to marine ecology (inc. fisheries and migratory species of conservation importance) via noise, water quality, and changes to sediment transport/geomorpohology.

- Potential for socio-economic effects on fisheries, tourism and maritime trade (including potential for effects to safety of navigation).

- Potential for disturbance to roosting and feeding bird species (especially summer and winter migrants). It is considered unlikely that breeding birds could be affected.

- Potential impacts from rock placement across the foreshore to both the immediate west (amenity) and immediate east (geological designations) of the harbour structures.

- Potential implications of the Water Framework Directive regarding inshore and river water quality.

8.4.1 Option 1 – Do Nothing

As discussed in Section 7.2.1, the principal environmental impacts associated with this option are:

- Debris from the deteriorating piers would remain for a substantial period of time and may provide marine habitat, but would clearly have adverse aesthetic and landscape effects.

- The breach and collapse of the structure will release fill material and sediment into the coastal environment on a gradual and continual basis until the structures reach a stable condition. This is likely to affect local sea life including the mussel beds inside the harbour.

- The loss of the structure would mean loss of amenity to tourists, anglers and the local population.

- It would also mean the loss of a national treasure as dictated by the Grade II listed status and a popular tourist icon.

- The increased exposure of the harbour quay could lead to vehicles and objects on the quay being swept into the harbour, potentially leading to pollution and contamination. Equally, vessels could be damaged leading to pollution of the harbour.

8.4.2 Option 2 – Do Minimum

Since the ultimate outcomes from a Do Minimum option are similar to the Do Nothing option, the above environmental impacts equally apply here.

8.4.3 Option 5 - Modify Existing Structures to Improve Present Structural Condition

As discussed in Section 7.2.5, the principal environmental impacts associated with this option are:

- The capital upgrade works would have impacts during construction and care will have to be taken that material potentially hazardous to the marine environment, (e.g. concrete, grout, etc.) is not spilt.
- There will be associated noise and vibration disturbance and traffic disruption due to the confined access to the piers.
- Work activities are likely to minimise environmental impact from construction since the focus is on optimising the condition of what is already present on site, rather than demolishing old and/or constructing new structures.
- Implementation of the scheme will improve present structural condition and therefore reduce the likelihood of damage, deterioration and ultimately failure or breaching of the existing structures and this therefore avoids the potential contamination of the marine environment with debris.

8.4.4 Option 7 - Modify Existing Structures to Improve Present Structural Condition and Defence Performance

As discussed in Section 7.2.7, the principal environmental impacts associated with this option are as above for the defence condition improvement works and, for the performance improvement works, the following:

- There would be environmental impacts during construction and care would have to be taken concerning the use of certain materials, such as concrete, in the marine environment.
- Raising crest levels or constructing a crest wall along the piers and/or extensions would have associated landscape/seascape and amenity impacts as well as impacts on the heritage value of the structure.
- Placement of a rock berm at the toe of the main piers and/or pier extensions would have an impact in terms of its direct footprint across the inter-tidal and nearshore sea bed zones, including a designated inter-tidal foreshore to the east of the harbour and heavily utilised amenity beach to the west.
- There would be impacts associated with importing large quantities of rock and it may be necessary to confine such activities to vessel-based delivery systems due to logistics associated with access and disruption associated with large quantities of deliveries through the town.

- A berm structure would provide additional habitat for marine life, such as lobsters.

9 CONSULTATION

Throughout the development of the study, regular meetings of the Project Board have been held. Membership of this Board was extended to Officers and Councillors of Scarborough Borough Council, the Whitby Harbour Master, and Officers from Environment Agency and Natural England.

Members of the public have been kept informed at key stages of the project (e.g. the Ground Investigations, diving surveys, option development) through updates on the Council website and targeted Press Releases. This has been successful in attracting media attention from the Whitby Gazette and Yorkshire Post as well as television news coverage from BBC Look North and TyneTees, ensuring that the project remains high profile.

In addition to this, further direct consultation was held with Whitby Harbour Master, Environment Agency, Natural England and English Heritage concerning specific aspects of direct relevance to them. In response to this form of consultation, both Natural England and English Heritage have provided formal letters of response which, in outline, support the principles and intent of the preferred approach (Appendix E).

As previously mentioned, an 'Optioneering and Risk Workshop' was held on 20th November 2008. This was convened once the scale and magnitude of the defects and performance issues associated with the Whitby Harbour structures was known following completion of the further surveys, investigations and studies. The purpose of this Workshop was to identify any potential showstoppers, issues or additional opportunities that had not previously been considered and to help identify which of the 'long-list' of ten options should progress to more detailed assessments. Key findings are presented in Appendix A.

Following detailed assessment of the four principal options agreed at the Optioneering and Risk Workshop, a main stage of consultation was undertaken. This has involved presentations to the following:

Committee / Cabinet	Date
Scarborough Borough Council Cabinet	16th December 2008
Scarborough Borough Council Northern Area Committee	20th January 2009
Whitby Town Council	27th January 2009
Scarborough Borough Council Overview and Scrutiny Committee	16th March 2009
Scarborough Borough Council Planning Committee	2nd April 2009

Also during the main stage of consultation, two public meetings were held at Whitby Pavillion, both on the 20th February with one in the afternoon and a repeat in the evening. A brochure was provided, with accompanying poster displays, and a feedback questionnaire (Appendix F). A total of thirty-six people attended across the two events.

At this time, a one-month period of on-line public consultation was held via the Council's website, where a full copy of the draft report was available for viewing/download and a feedback questionnaire was available.

Following closure of the public consultation period responses were collated and reviewed (Appendix G) before the draft report was finalised as the present document.

A further Workshop was then held so that the responses could be discussed and a balanced way forward agreed. There is no doubt that the principal, although not exclusive, issue raised during the consultation concerned the potential use of rock armouring along the main piers. Due to this, it was decided that Option 7 was the preferred approach, but with more detailed investigation required of the present and future overtopping performance of the structures through physical and/or numerical modelling.

10 SELECTION OF THE PREFERRED OPTION(S)

10.1 The Preferred Option

Following the options screening and appraisal process, and consultation with the public and statutory bodies, the preferred option is capital works to improve both condition and performance of the harbour structures (Option 7).

Given some of the responses from the consultation, however, more detailed investigation is required of the present and future overtopping performance of the structures, both with and without armouring and/or wave return walls so that the optimum solution could be designed for each segment of the structure, balancing technical performance and cost with environmental and public acceptability.

Of particular importance will be addressing the perceived negative impacts associated with the placement of any rock on an amenity beach (to the west of the Harbour), a designated geological SSSI (to the east of the Harbour) and a listed structure (both main piers).

10.2 Further Recommendations

The detailed design of the scheme to implement the preferred option will need to be informed by more detailed wave overtopping assessments of the structures. This is recommended to involve physical modelling so that the use of rock, increases in crest levels, or heights of wave return walls can be minimised whilst still offering technically robust solutions against present and future overtopping conditions.

The scheme is also likely to need to be accompanied by an Environmental Impact Assessment, although this will need to be confirmed through a Screening Opinion from the competent authority at the earliest opportunity.

Given the feedback to date from Natural England, specific environmental surveys will need to be undertaken of the geological SSSI. Also a specific landscape (or ‘seascape’) character assessment is likely to be required and particular focus will need to be placed on heritage and amenity value of the listed structures within the Environmental Impact Assessment.

It will also be important to continue consultation with the public and with statutory regulatory bodies throughout the next steps of the project to investigate opportunities for minimising concerns and impacts.

10.3 Management of Risk

Throughout all stages of the project, risk has been considered and managed. During the first stage, involving the investigations, a Risk Register was prepared and update on two successive occasions. This is presented in Appendix H.

During the second stage, involving the re-evaluation of strategic options and concept designs, a different focus was needed and a further Risk Register was prepared. This is presented in Appendix I.

10.4 Review and Revision of Whitby Coastal Strategy

The present further investigations have arisen from the Whitby Coastal Strategy and have been undertaken exclusively at Whitby Harbour. The Strategy frontage covers a wider geographical area than the harbour alone and typically Coastal Strategies will be reviewed and updated at nominally ten year periods. The findings of the present further investigations at Whitby Harbour should be used in helping to review and update the full Whitby Coastal Strategy in around 2012.

11 ACTION PLAN

The further investigations at Whitby Harbour have identified a number of key issues in relation to the current condition and performance of the harbour structures. This has shown that the piers are generally in a poor to very poor condition and require extensive capital investment works in order to provide a sustainable coastal protection system into the future. Some sections of the structures have been shown to be in critical condition and requiring fairly immediate repair works to retain the current structure. This is most urgently required at the landward end of the East Pier extension.

In identifying the key issues, an indicative priority has been provided for each element so as to ensure that the elements in the worst condition or at greatest exposure are addressed before those of a less urgent nature. This effective priority ranking system has been provided earlier in Table 5 (see Section 6.8).

In order to address the key issues, various strategic options have been considered from which a preferred option has been identified. This is considered to be Option 7; modifying the existing structures to improve present structural condition and defence performance. The quantity of construction works required to implement this preferred option are substantial and it is not possible to construct all the work at the same time without significantly affecting the current industries operating out of the town. Similarly, the structures will require regular maintenance and inspection into the future to ensure they are sustained in durable condition for their design life.

With the above in mind, it is considered that the works should be implemented in a staged approach with the more urgent works undertaken sooner and the less urgent works later. In essence, the most critical works required are in urgently addressing the defects at the landward end of the East Pier Extension and then in improving the structural condition of both main pier structures. These defence condition improvement works are required in advance of works to improve the performance of the structures.

On this basis, the following Action Plan is recommended for the implementation of the preferred option. This is accompanied by an outline Implementation Programme in Appendix J.

1) Urgent works to address the stability issue of the landward end of the East Pier Extension should be undertaken at the earliest opportunity. This work should be designed, procured and constructed separately from the main works construction programme, so that the cantilever can be supported before it collapses. The extent of the works that should be included can be varied to suit the available capital budget although the greater the length of works implemented now, the more cost effective these urgent works would be.

2) In support of the above, a separate funding application to the Environment Agency must be made for the urgent works. This will need to be requested through a separate Project Appraisal Report (PAR) submission from the main works application.

3) A funding application for design/detailed assessment and delivery of the main works should be applied for in the first year. Work on the detailed design and

relevant detailed investigations would probably not be able to commence until this application was approved.

4) The detailed design of the main construction works is shown over an 18 month period, which is quite a significant time period but would be required to develop the final design. The activities involved would consist of:

- physical process modelling into overtopping of the pier structures (as recommended in Section 10.3) to optimise design;

- detailed ground investigation focusing around the pier extensions (as recommended in the Interpretative GI report);

- statutory Environmental Impact Assessment process (assumed to be required);

- obtaining all legal consents licences and approvals (e.g. Planning, FEPA, etc);

- development of the detailed design (including investigation of the use of pre-cast units as described in Section 8.2.3);

- production of contract documentation for the works;

- compliance with the CDM Regulations as a notifiable project; and

- construction tender evaluation.

5) For the main construction works, it is recommended to undertake the works in a single phase contract in order to address the issues at the earliest opportunity and to provide the most cost effective approach. However, the works would be staged across the pier structures to minimise the impact on the community and amenities. The staged approach would be based on the priority ranking provided in Table 5 (see Section 6.8). Thus, structural condition works to the main East Pier would occur first (assuming the urgent works to the East Pier Extension have been undertaken under task 1 above), based on addressing the masonry damage and voiding at the seaward end of the structure. This would be followed by the main West Pier for similar reasons as the inner (harbour) face of the structure has significant damage, then the West Pier Extension. Finally, the remaining structural condition works would be implemented to the East Pier Extension, as the urgent works should prove sufficient to improve the stability to operate effectively in the intervening period.

6) The works to improve the structures performance would be constructed as the last task, once all the structural defects have been rectified, as a construction sequence.

7) Once the construction works are completed, a schedule of regular condition monitoring would be required in order to protect the capital investment spent on the works. It is proposed that annual monitoring inspections would be undertaken on a small scale basis (i.e. visual inspection from land and boat) to

note general defects from above the surface, and that full monitoring surveys to review the harbour pier structural condition would be undertaken on a 10-yearly basis. It is recommended that the full monitoring survey would entail digital measured surveys, visual and diving surveys, and geophysical surveys similar to those undertaken recently. Data from these surveys would be compared against the data collected using similar techniques from the present investigations in order to assess changes in condition.

8) The annual monitoring inspections and surveys will identify defects occurring in the structures during the design life. The durability of the structure to last its design life is dependent upon the noted defects being repaired before the structural condition worsens. This does not mean that every defect needs to be corrected instantly, just with sufficient time to avoid it propagating into a larger issue. Thus, maintenance works must be undertaken to the structure throughout its life to correct the defects in order for it to last the design duration.

The implementation of this Action Plan is designed to cover the full strategy period (e.g. 50 years), although the capital expenditure for all construction works would be completed within 6 years from the start. The key dates for delivering specific milestones are considered to be:

- Design, procurement and construction of urgent works completed by end of year zero.

- Design and procurement of all improvement works completed by beginning of year one.

- Structural condition works to all piers completed by late end of year five.

- All construction works complete by end of year six.

This programme does not include any risk allowances for bad weather, changes in funding priority, procurement issues, design changes, or unforeseen site conditions. It is recommended that some allowance is provided for these in implementation due to the hostile nature of the marine environment in which the piers are located.

Note: In support of the above recommendations a Project Appraisal Report (PAR) has already been prepared for the East Pier Extension Urgent Works (completed in February 2009) and a separate Project Appraisal Report (PAR) is now being prepared for the main works in April 2009.

12 REFERENCES

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