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Subject: **South Denes Seawall High Level Assessment**

Report to: **Executive Leadership Team – 6th July 2022**

Environment Committee – 19th July 2022

Report by: **Senior Coastal Advisor and Coastal Manager, Coastal Partnership East**

SUBJECT MATTER

The purpose of this report is to provide an overview of the high-level technical and economic assessment which has been completed for the deteriorating sea wall frontage at South Denes, Great Yarmouth. The objective of the report is to investigate options for maintaining the 'hold-the-line' policy. High-level coastal management options have been compared against agreed criteria to identify a preferred option. A Partnership Funding Calculator has been used to determine the high-level maximum eligible grant in aid funding for the preferred option. The next steps have been identified to move the preferred option forward to the detailed economic justification and design stages.

RECOMMENDATION

That Committee

1. Notes progress on this work to date.
2. Approves that the Head of Property and Asset Management procures under delegated powers using funds from the existing Coast Protection Reserves Budget, the production of an outline business case and other necessary preconstruction assessments such as those outlined below to support an anticipated submission for capital funding from the Environment Agency for construction of a rock revetment.
    a. detailed condition survey of the existing sea wall at South Denes,
    b. detailed economic assessment of the potential impact of coastal flood inundation and coastal erosion related to the deteriorating sea wall frontage at South Denes
    c. economic review of future construction, operation and maintenance costs of the proposed rock revetment, within the context of inflationary pressures facing the wider economy under present economic conditions.
    d. scoping and screening of environmental designations for the proposed rock revetment scheme, to inform the requirement for environmental impact assessment and consents as deemed necessary.
3. Approves that Great Yarmouth Borough Council utilises the local government SCAPE framework to procure the production of the outline business case and necessary supporting pre construction activities.

1. Introduction

1.1 Great Yarmouth Borough Council, through the Coastal Partnership East team, commissioned Atkins to undertake a high-level technical and economic assessment for maintaining the 'hold-the-line' policy adopted in the Shoreline Management Plan by Great Yarmouth Borough Council for the South Denes location at Great Yarmouth, Norfolk. The South Denes Sea Wall is an asset owned and managed by the Council.

1.2 The aims of the assessment were to:

- assess the coastal process drivers for recent rapid changes in beach levels at South Denes, Great Yarmouth;
- undertake a high-level options appraisal to reduce flood and erosion risk in the area behind the wall; and
- undertake a high-level assessment of possible FCERMGiA (Flood and Coastal Erosion Risk Management Grant in Aid) and Partnership Funding contributions.

1.3 The purpose of this high-level technical and economic assessment completed by Atkins, was to provide information to enable the Great Yarmouth Borough Council to consider coastal management options and inform discussions with stakeholders as to management and funding options going forwards at this location. Photographs and diagrams used in this committee report are extracted from the Atkins 2022 South Denes Seawall High Level Assessment report.

1.4 At the southern extent of the frontage at South Denes, Great Yarmouth, a seawall is the primary defence structure, as the beach is not expected to provide ample protection to the area and is likely to narrow and steepen as sea levels rise. The seawall is a mass concrete wall with local reinforcement at the connection to the coping and connections to ancillary items e.g., access steps and ramp. Figure 1-3 below shows the extent of the of the South Denes seawall under investigation.

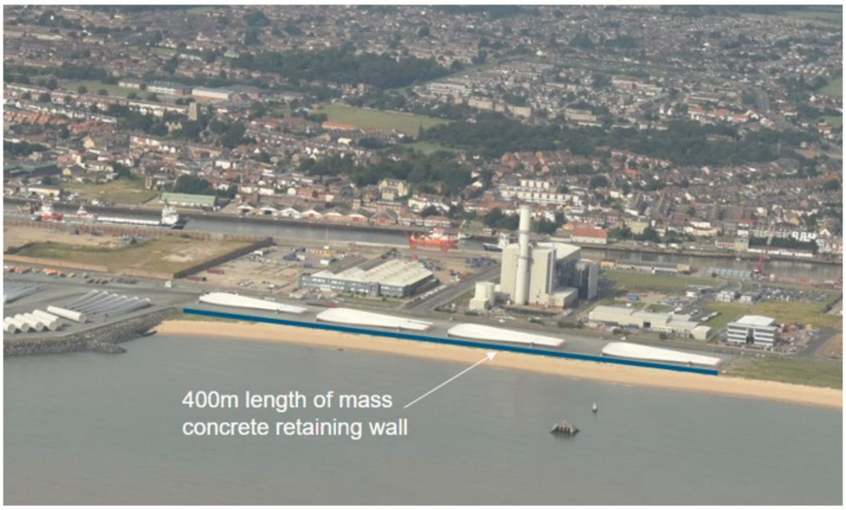

Figure 1-3 - Extent of the South Denes seawall under investigation

1.5 Following several storm events in early 2020, beach levels significantly reduced such that a section of the sea wall at South Denes, Great Yarmouth, was undermined, rotated forwards and a number of cracks formed. These are shown in Figures 1-5 and 1-6.

Figure 1-5 - Rotation of the wall (06/04/2020)

Figure 1-6 – Cracks formed on the wall (16/02/2021)

1.6 Emergency works were completed in this location to reduce the forces acting behind the wall through temporary removal of materials, as shown in Figure 1-7.

Figure 1-7 - Remedial works to relieve pressure on the landward side of the wall (23/09/2020)

1.7 The land behind the failed South Denes sea wall is leased by Peel Ports Great Yarmouth from Great Yarmouth Borough Council, and is being used as a storage compound for the Great Yarmouth Outer Harbour. Immediately landwards of the compound is South Denes Road, businesses and Great Yarmouth Power Station.

1.8 New long-term coast protection works are required at this location, to reduce flood and erosion risk and deliver the adopted 'hold the line' policy at this location.

2 Work to Date

2.1 Coastal Processes - The Shoreline Management Plan policy covering the Great Yarmouth frontage notes that the beach is expected to provide the primary defence without intervention, although this should be assessed in the medium to long term. At the southern extent of this frontage at

South Denes, a seawall is the primary defence structure, as the beach is not expected to provide ample protection to the area and is likely to narrow and steepen as sea levels rise. Changes in the alignment and extent of the nearshore bank system also influences sediment feed to the Great Yarmouth frontage.

2.2 Early in 2020 several high energy storms occurred that contributed to the depletion of the beach and undermining of the existing vertical wall at South Denes.

2.3 It is important to note that calmer, summer wave action deposits sand from offshore/beach bars on to the beach, ultimately widening it and increasing its elevation through accretion. Conversely, stronger, winter waves with more energy displaces beach material and form the offshore/beach bars, thus narrowing the beach through erosion.

2.4 Within this context, beach levels at South Denes, Great Yarmouth, have displayed a significant amount of variability over relatively short periods of time. During a site inspection in November 2021, beach levels appeared to be at more 'normal' levels, with only the top of the seawall visible. A storm event on the evening of 31st March and 1st April 2022 resulted in significant lowering of beach levels at the South Denes frontage. Other beaches along the Great Yarmouth Borough Council's frontage also suffered significant lowering of beach levels during these events. The wind direction for this event was reported to be from the north-east direction and tides were close to, but not at the peak of, spring tide.

2.5 However, in the case of the South Denes sea wall the natural profile of the beach has been altered through the introduction of a vertical wall, which increases wave reflection and in turn exacerbates beach narrowing through erosion. Detail in relation to beach levels is included within the Atkins report which is available should further detail be required.

2.6 Given evidence within the Atkins report, it is reasonable to assume that the retreat of the coast at South Denes enhanced through the reflection of waves off the vertical sea wall and the erosion caused by the close timing of high energy storms, led to the undermining and deteriorating stability of the sea wall. There is a good likelihood that recession at South Denes will continue. This could be increased in the future through the process of coastal catch up, whereby erosion can increase significantly immediately after the failure of a coastal defence. This has not been included in this high level assessment.

3 Next Steps

3.1 'Do Nothing' High-Level Economic Appraisal - A high-level economic appraisal compares an overview of the benefits of constructing a coastal defence scheme, in terms of the damages avoided from coastal flooding and coastal erosion, to the cost of construction of the coastal defence scheme. A 'Do Nothing' scenario forms the basis of this high-level economic appraisal, assuming in this case that no further works are undertaken at the deteriorating South Denes sea wall and the existing seawall is left to fail and collapse. This is a baseline scenario and is only used as the basis for comparing proposed options for future coastal defence. The economic impact of coastal flood damage and coastal erosion were used for the South Denes 'Do Nothing' high-level economic assessment.

3.2 The 'Do Nothing' scenario assumes flood damages due to wave overtopping of the existing South Denes sea wall during a storm event and inundation due to wave overtopping which would flood properties. These flood damages have been assessed based upon a 1 in 200 year return period flood event, which statistically is a major flood event which is likely to occur once in every 200 years. An allowance has also been made for potential sea level rise due to climate change over 100 years into the future. It must be emphasised that it is possible to have more than one 1 in 200 year return period flood event in any given 200 year time period, given the natural variability within the coastal system.

3.3 Below identifies the properties included in the flood damage scenario for the South Denes high-level economic assessment. Local topography has been assessed with professional judgement to derive a plausible flood route. The overtopping flood water moves from higher to lower ground, first in a westerly direction across the South Denes peninsula and north to lower ground. The scenario assumes that overtopping flood water is prevented from entering the river due to the presence of the flood defence. Property damages were assessed using the Multi Colour Manual (MCM) methodology. The MCM methodology provides a nationally recognised approach for assessment techniques of flood risk management benefits, including damage to property, indirect damages accounting for loss of the infrastructure due to a flood event and costs associated with emergency services responding to flood events.

3.4 An extract from the report shows the properties included in the coastal erosion scenario for the South Denes high-level economic assessment. An erosion rate of 2.8 metres per year has been used to identify properties and assets which may be at risk to loss due to coastal erosion as part of the 'Do Nothing' scenario. These are businesses potentially being lost after 30-35 years, following approximately 100m of erosion assuming immediate failure of the wall at the present point in time.

3.5 The table below provides a summary of the high-level economic appraisal over a 100-year appraisal period using the Environment Agency's Partnership Funding Calculator, for coastal flooding and erosion risk in a 'Do Nothing' scenario for the deteriorating South Denes sea wall.

	Do nothing Appraisal Baseline
PV Commercial property damages (£k)	£43,964 (Flooding: £37,909; Coastal erosion: £6,055)
PV emergency services (£k)	£3,894
PV Indirect Benefits (£k)	£8,793
PV whole life benefits (£k)	£56,651

3.6 Present Values (PV) are used in economic appraisals for coastal defence schemes, whereby future costs are adjusted/discounted back to the present-day values. The Partnership Funding Calculator, indicates that for this high-level, overview economic assessment there are £56,651,000 of damage costs, also termed as benefits. These are costs that potentially would be avoided through new, long-term coast protection works at the location of the deteriorating South Denes sea wall, in order to reduce flood and erosion risk and deliver the adopted 'hold the line' Shoreline Management Plan policy at this location.

4 Option Assessment and Selection

4.1 Options for new coastal defence works were assessed against agreed criteria, in order to manage further erosion and limit overtopping at the southern extremity of the South Denes frontage where the seawall is the primary defence. The criteria used to complete this high-level assessment of options were:

- Technical - Does the option stabilise the wall or the beach levels in front of the wall?
- Environmental - Impact on local environment, designated sites, and public amenity.
- Economic - Potential benefits against relative cost.
- Operation and maintenance obligation - Monitoring, minor repairs, significant interventions.
- Stakeholder acceptance - Council, environmental stakeholders, local businesses and public.
- Resilience to future episodic beach lowering events - Episodes of beach lowering have now been observed and may happen again in the future. Does the option provide resilience to this happening?

4.2 The options were assigned a score ranging from high to low i.e., High (3), Medium (2), Low (1) as shown in Table 5-1. Further details of each of the coastal defence options assessed through this process are available in the Atkins 2022 South Denes Seawall High Level Assessment report.

	Technical	Environmental	Economic	Operation & Maintenance	Stakeholder acceptance	Resilience to future beach lowering	Final Score
Rock Revetment	**3**	**2**	**3**	**3**	**2**	**2**	**15**
Shore Connected Breakwater	3	1	2	2	2	3	13
Stepped Concrete Revetment	2	2	1	2	2	2	11
Sheet Pile Wall	1	1	3	3	2	1	11
Submerged Breakwater	2	1	1	1	2	3	10
Beach replenishment	1	2	1	1	2	1	8

4.3 Preferred Coastal Defence Option **-** A rock revetment, involving placing rock armour seawards of the existing wall to prevent erosion and scour of the wall was identified as the preferred option. The advantages of this option include readily available material, ease of construction, reduced wave reflection, future flexibility and reduced wave forces and overtopping. Disadvantages include visual impact, amenity loss due to there being less beach space

5 Financial Implications - Cost of Preferred Coastal Defence Option

5.1 The typical rock revetment was used as the basis for deriving a high level, outline cost estimate, for the preferred coastal defence option for the deteriorating South Denes sea wall. This was applied to an assumed length of 400 metres, required to protect the South Denes frontage. Unit rates used to develop the cost estimates were extracted from Spon's Civil Engineering and Highway Works Price Book 2021 and from recent Coastal Partnership East projects. It should be noted that the rates used in this outline cost estimate reflect rates from February 2022 and do not consider inflationary pressures facing the wider economy under present economic conditions. The cost estimate is shown in the table below. The estimate of the cost of construction of a 400 metre rock revetment at South Denes was calculated to be £4,172,000.

	Amour stone	Underlayer	Geotextile
Cross section area (m^2)	31.5	16.7	5,680
Assumed length of structure (m)	400	400	-
Volume (m^3)	12,600	6,680	-
Cost rate per unit volume (£/m^3)	162	158	20
Estimated cost (£k)	2,041	1,054	114
Sub-total cost (£k)	**3,209**		
Overheads and profit (30%)	**963**		
Total cost (£k)	**4,172**		

5.2 The results of the 'Do Nothing' high-level economic analysis and the cost estimate for construction of a new rock revetement at South Denes have been compared, through the application of a Partnership Funding Calculator used nationally by the Environment Agency when assessing the economic viability of coastal defence schemes. In this case a Partnership Funding Calculator has been used to give an indication of whether a coastal defence scheme at the South Denes may be eligible for Flood and Coastal Erosion Risk Management Grant in Aid (FCERMGiA) and if so the amount of Grant in Aid which may be available in comparison with partnership funding which may be required from other sources.

5.3 The Partnership Funding Calculator was used in the first instance to determine the maximum eligible Grant-in-Aid funding for the preferred option of a 400m rock revetment, covering the whole of the length of the Great Yarmouth Outer Harbour compound. This is a greater length than that of the presently deteriorated South Denes sea wall and hence provides greater resilience in the integrity of coastal defence structures along this frontage into the future. The Table summarises the results of this high-level assessment for proposed a 400m rock revetment at the South denes frontage.

	Option 1 – Rock revetment
PV appraisal costs (£k)	£100
PV construction costs (£k)	£4,172
PV risk contingency (£k)	£1,836
PV future costs (£k)	£49
PV whole life costs (over duration of benefits) (£k)	£6,157
PV whole life benefits (£k)	£56,651
Benefit Cost Ratio	9.2
PV estimated contributions towards PV appraisal costs (£k)	£100
PV maximum eligible FCERM GiA (£k)	£3,399

5.4 Present Values (PV) are used in economic appraisals for coastal defence schemes, whereby future costs are adjusted/discounted back to the present-day values.

5.5 PV Appraisal Costs of £100,000 include the cost of production of an outline business case, statutory consents and environmental impact assessment if deemed necessary, in order to support a submission for capital funding for construction of the rock revetment from the Environment Agency. These costs are not grant-aided by the Environment Agency and would need to be funded by Great Yarmouth Borough Council. A current source identified is the Great Yarmouth Borough Council Coast Protection Reserve Budget. These costs may be able to be claimed back retrospectively from the Environment Agency, upon successfully achieving Grant in Aid funding for the proposed South Denes coastal defence scheme.

5.6 The high-level Partnership Funding calculation identified potential Grant in Aid £3,399,000 for a proposed 400 metre rock revetment at South Denes, with PV Whole Life Costs of £6,157,000. This leaves a deficit of £2,758,000, requiring funding from sources not yet identified.

5.7 Sensitivity Test - 200 Metre Rock Revetment Option - A revised Partnership Funding Calculator was used as a sensitivity test, based upon a 50% reduction in the length of the proposed rock revetment at South Denes. The more targeted use of a rock revetment structure, focussed specifically upon the length of deteriorated sea wall at South Denes. This reflects the requirement for a detailed condition survey of the existing sea wall at South Denes, as part of the economic assessment of the outline business case for future grant aid funding from the Environment Agency, which may in turn refine the length required for the proposed rock revetment. The following table summarises the results of this sensitivity test high-level assessment for proposed a 200m rock revetment at the South Denes frontage.

	Option 1 – Rock revetment (200m length)
PV appraisal costs (£k)	£100
PV construction costs (£k)	£2,086
PV risk contingency (£k)	£917
PV future costs (£k)	£49
PV whole life costs (over duration of benefits) (£k)	£3,152
PV whole life benefits (£k)	£56,651
Benefit Cost Ratio	18
PV estimated contributions towards PV appraisal costs (£k)	£100
PV maximum eligible FCERM GiA (£k)	£3,399

5.8 The high-level Partnership Funding calculation identified potential Grant in Aid £3,399,000 for a proposed 200 metre rock revetment at South Denes, with PV Whole Life Costs of £3,152,000.

5.9 Further assessment during the development of the outline business case would enable a refined scheme proposal with regards to length, costs, damages and grant in aid.

6 Indicative Timeline

6.1 An indicative timeline for the proposed construction of a rock revetment along the deteriorating South Denes sea wall frontage has been submitted to the Environment Agency, in order to meet the May 2022 cut-off date for national forward planning for potential flood and coastal erosion risk management project funding. This is shown below. This timeline can only be indicative, given the many external variables associated with a project of this nature including production of an outline business case, environmental scoping and consents as appropriate, marine licences, contract procurement, lead-in time and construction.

Outline business case start date	October 2022
Contract awarded	October 2023
Start construction	April 2024
Ready for service	April 2025

7 Risk Implications

Risks	. Mitigating Actions
. Non-completion of detailed flood inundation and damage modelling, resulting in a 'Do Nothing' scenario which is not robust and representative.	. Technical refinement of flood inundation modelling based upon environmental and infrastructure parameters, through completion of outline business case.
. Non-completion of detailed coastal erosion and damage modelling, resulting in a 'Do Nothing' scenario which is not robust and representative.	. Technical refinement of coastal erosion modelling based upon environmental parameters, through completion of outline business case. Including reference to 'coastal catch-up' and potential future long-term increases in future erosion rates, within the context short-term beach level variability.
. Non-completion of scoping and screening of environmental designations, resulting in proposed scheme being delayed through not gaining required environmental consents.	. Scoping and screening of environmental designations completed during outline business case development, with environmental impact assessment and consents gained as deemed necessary.
. Calculation of damages used to derive the economic benefits for the proposed	• Technical refinement of flood inundation and coastal erosion damage modelling through

project are lower than anticipated, based upon the 'Do Nothing' scenario used to assess economic damages due to flood and coastal erosion risk. Lower than anticipated value of damages in 'Do Noting' scenario, leading to a resultant drop in potential availability of Grant in Aid.	completion of outline business case, producing a robust and representative 'Do Nothing' scenario.
Construction and future costs are higher than anticipated, due to inflationary pressures facing the wider economy under present economic conditions. Higher than anticipated construction and future costs, leading to a resultant drop in potential availability of Grant in Aid.	Present Value Risk Contingency for the proposed rock revetment scheme incudes an optimism bias/increase in costs of 44% and 10% added to all PV construction costs and PV future costs respectively. Present value construction costs and present value future costs to be reviewed and updated with the context of present inflationary pressures, through completion of outline business case.
The outline business case results in a scenario whereby Grant-in-Aid is lower than anticipated due to lower damages and/or higher costs from completion of a detailed economic appraisal. The proposed rock revetment scheme along the deteriorating sea wall frontage at South Denes, Great Yarmouth is not seen as being financially viable and cannot be progressed. Costs for production of the outline business case cannot be recovered. Present Value Appraisal Costs of £100,000 have been included in this South Denes Sea Wall High Level Assessment report, including the cost of production of an outline business case, statutory consents and environmental impact assessment if deemed necessary.	A revised Partnership Funding Calculator was used as a sensitivity test, based upon a 50% reduction in the length of the proposed rock revetment at South Denes. This reduced the projected costs of the proposed rock revetment, through reducing the length of the proposed rock revetment from 400 metres to 200 metres. This sensitivity test reflects the potential for a rise in Present Value construction costs and Present Value future costs, due to inflationary pressures facing the wider economy under present economic conditions. Higher than anticipated construction and future costs, could lead to a resultant drop in potential availability of Grant in Aid. The reduction in construction costs acts to mitigate the financial impact of a drop in potential availability of Grant in Aid.
Collapse of the deteriorating sea wall frontage at South Denes, Great Yarmouth, prior to commencement of a	Existing removal of sand from behind sea wall, to reduce force placed on the rear of the

coast protection scheme for maintaining the 'hold-the-line' policy at this location.	deteriorating structure, which is exacerbated during prolonged periods of low beach levels. Ongoing review of warning measures and regular, standardised photographic monitoring of beach level/existing sea wall changes at this site, to maintain a proactive presence on site and react as appropriate Beach levels at South Denes, Great Yarmouth, have displayed a significant amount of variability over relatively short periods of time and could possibly continue to do so in the immediate future. This makes funding and construction of further short-term mitigation measures inappropriate, along the deteriorating South Denes sea wall frontage.
Failure of the sea wall could lead to reputational risk and potential economic impacts relating to the port etc.	Procession of the investigation of a scheme to maintain the Hold the Line policy. Need to engage with beneficiaries and stakeholders of the scheme in order for them to understand the level of current and future risk and discuss potential third party contributions.

8 Conclusions

8.1 A high-level technical and economic assessment has been undertaken for the deteriorating sea wall frontage at South Denes, Great Yarmouth.

8.2 Coastal management options have been compared against agreed criteria to identify a preferred option for this frontage. Considering all criteria, a rock revetment was selected as the preferred option to reduce flood and erosion risk behind the sea wall based on the selected criteria. A typical section has been developed for the rock revetment to inform cost estimates. Effective lengths of 400m and 200m have been examined as indicative protection by a rock revetment for the South Denes frontage.

8.3 A Partnership Funding Calculator was used to determine the potential maximum eligible grand in aid funding for the preferred option of a 400 metre rock revetment. Based on this high-level economic appraisal, Present Value Whole Life Costs of £6,157,000 were calculated for a 400 metre rock revetment. £3,399,000 was shown to potentially be available for construction of a 400 metre rock revetment, through Flood and Coastal Erosion Risk Management Grant in Aid funding. This indicates that there is likely to be a deficit of £2,758,000 requiring funding from sources not yet identified, if a 400 metre revetment was taken forward as the preferred future coastal defence at South Denes. A shorter 200 metre length of revetment was assessed as a sensitivity test, The high-level Partnership Funding Calculator identified potential grant in aid £3,399,000 for a 200 metre rock revetment, with Present Value Whole Life Costs of £3,152,000. This suggests that there is potential for a financially viable scheme to continue to Hold the Line in this location.

8.4 The completion of an outline business case is now required in order to progress with the submission of a full application for FCERM GiA funding, for the construction of a rock revetment at the site of the deteriorating sea wall frontage at South Denes, Great Yarmouth. This would comprise a detailed economic assessment of the potential impact of coastal flood inundation and coastal erosion related to the deteriorating sea wall frontage at South Denes, Great Yarmouth. In addition, a detailed condition survey of the existing sea wall at South Denes, Great Yarmouth would be completed. This is to confirm the extent of the proposed rock revetment required along the frontage, refine the profile and optimise the rock revetment cross-section through detailed design. An economic review of future construction, operation and maintenance costs of the proposed rock revetment would be completed, within the context of inflationary pressures facing the wider economy under present economic conditions. The outline business case phase should also include environmental screening and scoping for the rock revetment scheme, to inform the requirements of an environmental impact assessment and consents as deemed necessary.

9 Background Papers

Atkins 2022 South Denes Seawall High Level Assessment report – available for review.

Area for consideration	**Comment**
Monitoring Officer Consultation:	
Section 151 Officer Consultation:	
Existing Council Policies:	
Financial Implications (including VAT and tax):	Included
Legal Implications (including human rights):	
Risk Implications:	
Equality Issues/EQIA assessment:	
Crime & Disorder:	
Every Child Matters:	

ATKINS

Member of the SNC-Lavalin Group

South Denes Seawall High Level Assessment

Report

Great Yarmouth Borough Council

May 2022

5210393-REP-001

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This document has 36 pages including the cover.

Document history

Document title: Report

Document reference: 5210393-REP-001

Revision	Purpose description	Originated	Checked	Reviewed	Authorised	Date
1	Draft for Council review	DN/RSF	AM	RP	AM	24/03/2022
2	Updated following client comments	DN	AM	RP	AM	26/05/2022

Client signoff

Client	Great Yarmouth Borough Council
Project	South Denes Seawall High Level Assessment
Job number	5210393
Client signature/date	

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Executive Summary

Overview

Great Yarmouth Borough Council, through the Coastal Partnership East team, commissioned Atkins to undertake a high level technical and economic assessment for maintaining the ‘hold-the-line’ policy of the South Denes location at Great Yarmouth, Norfolk.

The aims of the assignment were to:

- assess the coastal process drivers for recent rapid changes in beach levels at South Denes, Great Yarmouth;
- undertake a high-level options appraisal to reduce flood and erosion risk in the area behind the wall; and
- undertake a high level assessment of possible FCERM Grant-in-aid/Partnership contributions.

The purpose of this report is to provide information to enable the Council to consider coastal management options and to inform discussions with stakeholders as to management and funding options. A high level technical and economic assessment has been undertaken with the objective of maintaining the ‘hold-the-line’ policy for the South Denes frontage at Great Yarmouth.

Coastal processes

The Shoreline Management Plan policy for South Denes notes that the beach is expected to provide the primary defence to most of the Great Yarmouth frontage without intervention, although this should be assessed in the medium to long term. At the southern extent of the frontage at South Denes, a seawall is the primary defence structure, as the beach is not expected to provide ample protection to the area and is likely to narrow and steepen as sea levels rise. The seawall is a mass concrete wall with local reinforcement at the connection to the coping and connections to ancillary items.

Changes in the alignment and extent of the nearshore bank system also influence sediment feed to the Great Yarmouth frontage.

Most of the main Great Yarmouth beaches are showing accretion except for the southern section at South Denes. To the south and at the location of the Great Yarmouth Outer Harbour (GYOH), shorelines are stable or eroding. The erosion rates immediately to the north the GYOH were approximately -2.8m per year between 1991 to 2010.

Following several storm events in early 2020, beach levels significantly reduced such that the wall was undermined, rotated forwards and a number of cracks formed. Early in 2020 several high energy storms occurred in the area that contributed to the depletion of the beach and undermining of the existing vertical wall. These storms are captured in the Annual Wave Report 2020.

The undermining and deteriorating stability of the wall since early 2020 are a result of a combination of factors: depleted winter beach profile; wave reflection due to the vertical wall; and the severity and close timing of the storms which occurred at the start of 2020.

During a site walkover for this project in November 2021, beach levels appeared to be at ‘normal’ levels, with only the top of wall visible.

A storm event on the evening of 31st March and 1st April 2022 resulted in significant lowering of beach levels at the South Denes frontage. Other beaches along the Council’s frontage also suffered significant lowering of beach levels. The wind direction for this event was reported to be from the north-east direction and tides were close to, but not at the peak of, spring tide.

High level economic analysis

The Do Nothing scenario, used to assess economic damages due to flood and coastal erosion risk is presented, followed by an overview of the calculation of damages to derive the economic benefits for the project.

The Do Nothing scenario assumes flood damages due to wave overtopping of the existing wall during a storm event and inundation of wave overtopping volumes landwards to flood properties.

Erosion rates have been used to identify non-residential properties which may be lost to coastal erosion during the appraisal period. These are non-residential properties being lost after 30-35 years, following approximately 100m of erosion, assuming immediate failure of the wall and erosion of approximately 3m per year.

Indirect damages are taken as 20% of the Do Nothing damages due to flooding and coastal erosion and account for loss of the infrastructure.

Property damages were assessed using the Multi Colour Manual (MCM) methodology and depth damage curves.

	Do nothing Appraisal Baseline
PV Commercial property damages (£k)	£43,964 (Flooding: £37,909; Coastal erosion: £6,055)
PV emergency services (£k)	£3,894
PV Indirect Benefits (£k)	£8,793
PV whole life benefits (£k)	£56,651

Option assessment and selection

Options were assessed against criteria agreed with the Council.

	Technical	Environmental	Economic	Operation & Maintenance	Stakeholder acceptance	Resilience to future beach lowering	Final Score
Rock Revetment	**3**	**2**	**3**	**3**	**2**	**2**	**15**
Shore Connected Breakwater	3	1	2	2	2	3	13
Stepped Concrete Revetment	2	2	1	2	2	2	11
Sheet Pile Wall	1	1	3	3	2	1	11
Submerged Breakwater	2	1	1	1	2	3	10
Beach replenishment	1	2	1	1	2	1	8

Considering all criteria, rock revetment was selected as the most appropriate option to reduce flood risk behind the sea wall based on the selected criteria.

A cost estimate was produced for the preferred option based on a typical cross-section.

FCERM GiA and Partnership Funding

The Partnership Funding Calculator was used to determine the maximum eligible grand-in-aid funding for the preferred option. The maximum eligible FCERM GiA available for the project is £3,399k.

Present value whole life benefits for the scheme have been estimated to be £56,651k.

Present value costs have been estimated for a 400m length of rock revetment and 200m length of rock revetment. Present value costs and benefit cost ratios for the 400m and 200m lengths of rock revetment are:

- 400m length rock revetment: PV whole life costs: £6,157k; BCR: 9.2; Funding deficit: £2,758k
- 200m length rock revetment: PV whole life costs: £3,152k; BCR: 18.0

1. Introduction

1.1. The commission

Great Yarmouth Borough Council, through the Coastal Partnership East team, commissioned Atkins to undertake a high level technical and economic assessment for maintaining the hold-the-line policy of the South Denes location at Great Yarmouth, Norfolk. The project was procured through the Coastal Partnership East Coastal Management Dynamic Purchasing System Lot 3 and the reference for this project was PROC-2099-RFQ-DPS.

1.2. Aims of the study

The aims of the assignment were to:

- assess the coastal process drivers for recent rapid changes in beach levels at South Denes, Great Yarmouth;
- undertake a high-level options appraisal to reduce flood and erosion risk in the area behind the wall; and
- undertake a high level assessment of possible FCERM Grant-in-aid/Partnership contributions.

1.3. Location plan

The extent of the study is the South Denes frontage in Great Yarmouth, Norfolk (see Figure 1-1). Coastal change over an extended area to the north and south and the effects of offshore sand banks and channels on the coastline are considered as part of the assessment.

Figure 1-1 - Site location plan

1.4. Project background

Great Yarmouth is a major area of industry and commerce and has also recently seen the construction of the Great Yarmouth Outer Harbour (GYOH) in 2007/2008. Except for the northern and southern extents of the town, defence is primarily provided by the wide beach, which has been fed by sediment derived from cliff erosion in north-east Norfolk. Figure 1-2 below shows the South Denes beach with relatively healthy beach levels.

Figure 1-2 - South Denes beach (15/01/2014)

The Shoreline Management Plan policy for South Denes notes that the beach is expected to continue to provide ample protection without the need for any intervention, other than at the extremities, provided that a sediment supply is maintained. This should be assessed in the medium to long term. At the southern extent of the frontage at South Denes, a seawall is the primary defence structure, as the beach is not expected to provide ample protection to the area and is likely to narrow and steepen as sea levels rise. The seawall is a mass concrete wall with local reinforcement at the connection to the coping and connections to ancillary items e.g., access steps and ramp. Figure 1-3 below shows the extent of the of the South Denes seawall under investigation.

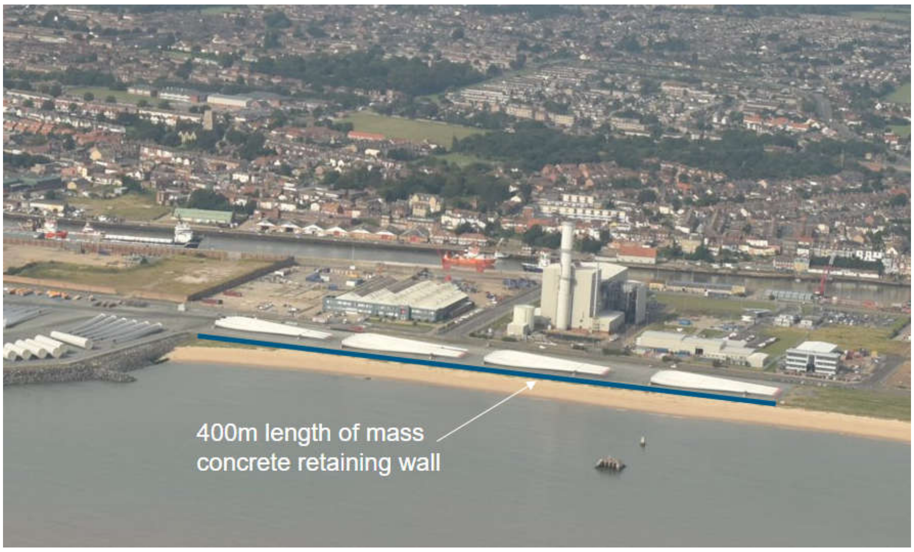


Figure 1-3 - Extent of the South Denes seawall under investigation

Following several storm events in early 2020, beach levels significantly reduced such that the wall was undermined, rotated forwards and a number of cracks formed (see Figure 1-4, Figure 1-5 and Figure 1-6 below).

Figure 1-4 - South Denes beach with sea wall exposed (06/04/2020)

Figure 1-5 - Rotation of the wall (06/04/2020)

Figure 1-6 - Cracks formed on the wall (16/02/2021)

Emergency works were completed in this location to reduce the forces acting behind the wall through temporary removal of materials (see Figure 1-7). However, further works are still required to repair or upgrade the seawall to reduce the risk of erosion and limit overtopping.

Figure 1-7 - Remedial works to relieve pressure on the landward side of the wall (23/09/2020)

1.5. Purpose of this report

The purpose of this report is to provide information to enable the Council to consider coastal management options and to inform discussions with stakeholders as to management and funding options. A high level technical and economic assessment has been undertaken with the objective of maintaining the 'hold-the-line' policy for the South Denes frontage at Great Yarmouth.

1.6. Structure of this report

- Section 2, Data: Summary of relevant data collected for this project.
- Section 3, Coastal processes: Review of coastal process drivers for the recent rapid changes in beach level.
- Section 4, Economic Appraisal: Assess flood and erosion damages for Do Nothing baseline.
- Section 5, Option Assessment: Identify/assess viable options to select a preferred option.
- Section 6, Summary of preferred option: High level assessment of possible FCERM Grant-in-aid/Partnership Funding contributions for the preferred option.
- Section 7, References

2. Data collection

2.1. Introduction

Relevant data was provided by the Council, obtained under licence from the Environment Agency and from freely available sources. Data collected for the project is provided in Table 2-1. Water level and wave conditions used for this study is presented later in this section.

Table 2-1 - Summary of data collated for the Economic Appraisal

Dataset	Source	Purpose
Tide levels	Admiralty Tide Tables, NP201 Volume 1, 2014	Used in economic analysis to inform property flood damages
Extreme sea levels	Environment Agency	Used in economic analysis to inform property flood damages
Wave data	Coastal Channel Observatory report at Lowestoft	To assess wave forces on the seawall
Beach profiles	Environment Agency	To assess coastal trends along the frontage
LiDAR	Environment Agency	Used in economic analysis to inform property flood damages
National Receptors Data	Environment Agency	To create property dataset for economic analysis
Ordnance Survey MasterMap	Environment Agency	To create property dataset for economic analysis

2.2. Tide Levels

Tide levels for the site were obtained at the closest standard port i.e., Great Yarmouth (Gorleston-on-sea) from the Admiralty Tide Tables NP201 Volume 1, 2014 and are provided in Table 2-2.

Table 2-2 - Tide levels at Great Yarmouth (Gorleston-on-sea)

	Water levels (m OD)
LAT (Lowest Astronomical Tide)	-1.60
MLWS (Mean Low Water Springs)	-1.00
MLWN (Mean Low Water Neaps)	-0.50
MSL (Mean Sea Level)	0.10
MHWN (Mean High Water Neaps)	0.60
MHWS (Mean High Water Springs)	0.90
HAT (Highest Astronomical Tide)	1.40

Admiralty Tide Tables NP201 Volume 1, 2014

2.3. Extreme Sea Levels

Extreme sea levels for the site were extracted from the Coastal Flood Boundary Dataset, 2018 at chainage point 4148 (see Table 2-3 below).

Table 2-3 - Extreme Sea levels for Lowestoft (CFB Chainage 4148)

Return period (years)	Water level (m OD)
1	2.1
2	2.25

Return period (years)	Water level (m OD)
5	2.46
10	2.62
20	2.79
25	2.84
50	3.01
75	3.11
100	3.19
150	3.29
200	3.37
250	3.42
300	3.47
500	3.62
1000	3.82

2.4. Sea Level Rise

The extreme sea levels provided in Table 2-3 are to base year 2017. For future extreme sea levels, it is important to consider allowances for increases due to sea level rise. Site specific time-mean sea level rise allowances were used to account for climate impacts in line with the climate change guidance for coastal flooding [1]. The guidance states that the higher central (70th percentile from UKCP18 RCP 8.5) allowance should be used as the design allowance to manage coastal flooding.

Sea level rise allowances were extracted from UKCP18 data using RCP 8.5 with the 70th percentile of confidence, for the 100-year appraisal period (i.e., 2021 to 2121) at Latitude 52.61 and Longitude 1.75.

Table 2-4 - Sea level rise values from UKCP18 data (Accessed on 22/11/2021)

Date	Sea Level Rise (m)
2021	0.13
2046	0.30
2071	0.53
2096	0.81
2121	1.12

2.5. Wave data

Significant wave heights for each return period were extracted from the Coastal Channel Observatory report at Lowestoft (see Table 2-5 below).

Table 2-5 - Significant wave heights for Lowestoft

Return period (years)[1]	Significant wave height (m)
0.25	3.11
1	3.76
2	3.95
5	4.11
10	4.19

[1] 100 and 200-year return period significant wave heights extrapolated using available return period data.

Return period (years)[1]	Significant wave height (m)
20	4.24
50	4.29
100	4.37
200	4.54

Annual Wave Report 2020 – Lowestoft. Available from: https://coastalmonitoring.org/reports/#anglia

3. Coastal processes

3.1. Background and management policy

The Shoreline Management Plan policy for South Denes is Policy Unit 6.17 [2] which is to continue to hold-the-line over all three epochs (2025, 2055 and 2105) and protect all built assets within the town.

The beach is expected to provide the primary defence to most of the frontage without intervention. Defence works may be required to maintain existing seawalls and groynes and the port entrance in the present day. Monitoring of sediment downdrift and further studies on holding the line policy will be necessary to assess the SMP policy (hold-the-line).

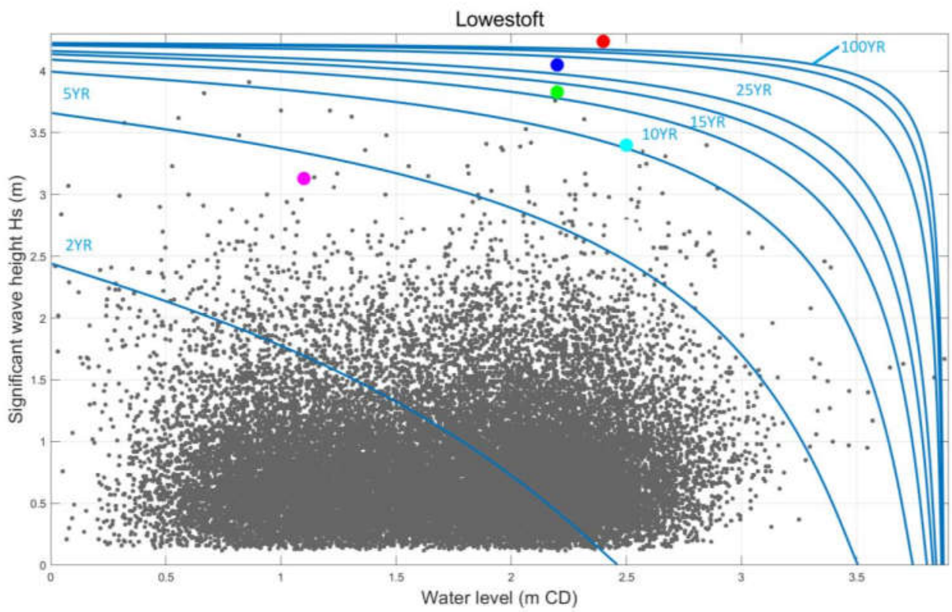
However, parts of the seawall particularly towards the northern and southern extent of the frontage may need to be upgraded or replaced in the medium and long term as a result of the beach beginning to narrow and steepen due to sea level rise and limited sediment feed as a result of policy options further north. Changes in the alignment and extent of the nearshore bank system may also influence sediment feed to the Great Yarmouth frontage.

See extracted policies from [2] below:

- *The* ***present-day policy*** *option for this area is to continue to hold-the-line and protect all built assets within the town. Achievement of this requires no intervention along much of this frontage due to the wide beach, although some defence works may be required at the southern end to maintain existing seawalls and groynes and the port entrance. This policy option will protect the maximum number of assets and satisfy nature conservation requirements at North Denes as the area in front of the seawall is expected to remain fairly stable during this period.*
- *The* ***medium-term policy*** *option is to continue defending the frontage beyond the short term, through a policy of hold-the-line. This would most likely be provided through maintaining, replacing and upgrading existing structures where necessary, with the beach continuing to provide the primary defence to much of the area.*
- *Due to the high value and extent of socio-economic assets here, the* ***long-term policy*** *option is to continue to hold-the-line and defend the frontage. This would most likely be provided through maintaining, replacing and upgrading existing structures, although the beach is expected to provide the primary defence to much of the area. With adoption of long-term policy options along other updrift frontages, the beach should be supplied with fresh sediment to remain healthy over the next century.*

3.2. Recent activity

Early in 2020 several high energy storms occurred in the area that contributed to the depletion of the beach and undermining of the existing vertical wall. These storms are captured in the Annual Wave Report 2020 for Lowestoft [3], see Figure 3-1. It is noted that the Council removed material landwards of the wall to reduce pressure behind the wall and prevent overturning of the wall.



Date/Time	Symbol	H_s (m)	Water level elevation		Joint Return Period
			OD	CD	
09-Feb-2020 10:00:00	●	4.24	0.90	2.40	1 in 100 years
16-Feb-2020 04:00:00	●	4.05	0.70	2.20	1 in 25 years
27-Dec-2020 06:00:00	●	3.83	0.70	2.20	1 in 15 years
14-Jan-2020 23:00:00	●	3.40	1.00	2.50	1 in 10 years
29-Mar-2020 07:30:00	●	3.13	-0.40	1.10	1 in 2 years

Figure 3-1 - Measured joint wave heights and water levels at Lowestoft

It is important to note that ‘calmer’ summer wave action deposits sand from offshore/beach bars on to the beach, ultimately widening it and increasing its elevation (accretion). Conversely, ‘stronger’ winter waves with more energy displaces beach material, and form the offshore/beach bars, thus narrowing the beach (erosion).

These offshore/beach bars maintain the winter beach profile stability as they induce wave breaking further offshore, and therefore, limit the erosion caused by the energy dissipation of the breaking waves.

However, in this case, the natural profile of the beach has been altered with the introduction of a vertical wall, which increases wave reflection and, in turn, beach narrowing (erosion).

Therefore, taking into account that the coastline is retreating in this area (see Section 3.3.3) the depleted winter beach profile, the reflection of the vertical wall and the severity and close timing of the storms occurred in early 2020 (estimated to be 1 in 100 years, 1 in 25 years and 1 in 10 years return period storm events), it is reasonable to assume that the addition of all these factors led to the undermining and deteriorating stability of the wall during this period.

During a site walkover for this project in November 2021, beach levels appeared to be at ‘normal’ levels, with only the top of wall visible.

A storm event on the evening of 31st March and 1st April 2022 resulted in significant lowering of beach levels at the South Denes frontage. Other beaches along the Council’s frontage also suffered significant lowering of beach levels. The wind direction for this event was reported to be from the north-east direction and tides were close to, but not at the peak of, spring tide.

Due to the potential for beach level lowering in response to storm events, the ongoing monitoring of beach profiles, as part of the Environment Agency’s coastal monitoring programme, should be regularly reviewed with the wall in its current condition.

3.3. Erosion

3.3.1. Coastal Trends Report, North-East Norfolk and North Suffolk [4]

Most of the main Great Yarmouth beaches are showing accretion except for the southern section at South Denes. More specifically, sections identified as N4A6 and N4A7, Great Yarmouth South Denes, show eroding trends over the monitoring period [4].

3.3.2. Cefas Shoreline Variability Report [5]

The general pattern of shoreline behaviour in the study area over the past 18 – 20 years shows that North of the GYOH shorelines show a medium-term accretion trend (Wellington and Britannia Piers). To the south and at the location of the GYOH, shorelines are stable or eroding. The erosion rates immediately north of the GYOH were approximately -2.8m per year between 1991 to 2010.

3.3.3. Current trends

Using the data from the National Network of Regional Coastal Monitoring Programmes [7], an assessment has been undertaken on the coastal retreat from recent years (2009 to 2020), see Figure 3-2. Figure 1-1 shows a series of beach profiles surveyed between 2009 and 2020. The analysis has considered all available profiles relevant to the study area.

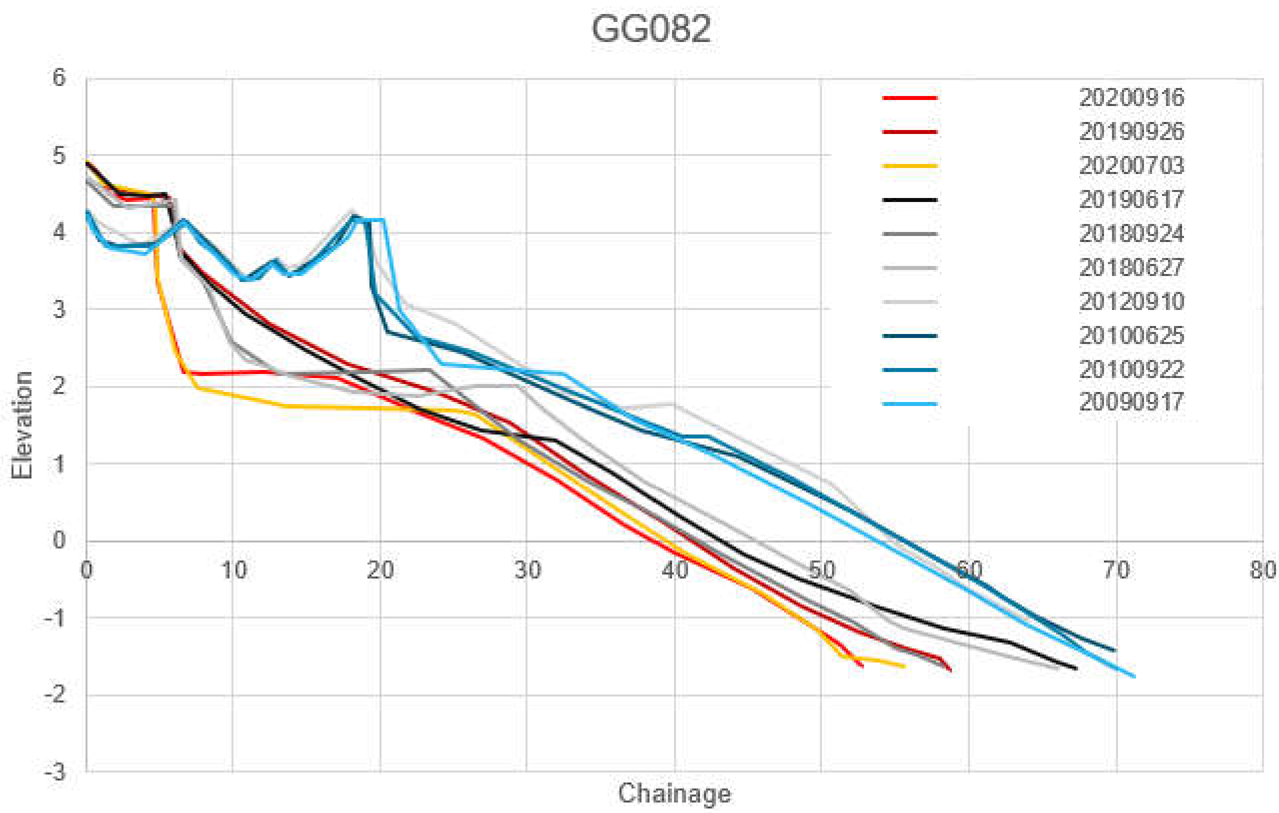


Figure 3-2 - Beach profiles from 2009 to 2020

Beach levels remained relatively stable until 2012 for both winter and summer profiles. Beach profiles vary but comparisons of data from 2020 and 2012 do show erosion rates of up to 3m per year over this period (e.g. 20120910 [Chainage 30m] and 20200916 [Chainage 6m] at +2.25mAOD), see Figure 3-3. This is consistent with Cefas's Shoreline Variability Report [5], which examines this same region between 1991 to 2010, and with the erosion trends mentioned in the reports assessed in the previous sections. Therefore, an erosion rate of 2.8m/year has been adopted for the purposes of the coastal erosion assessment.

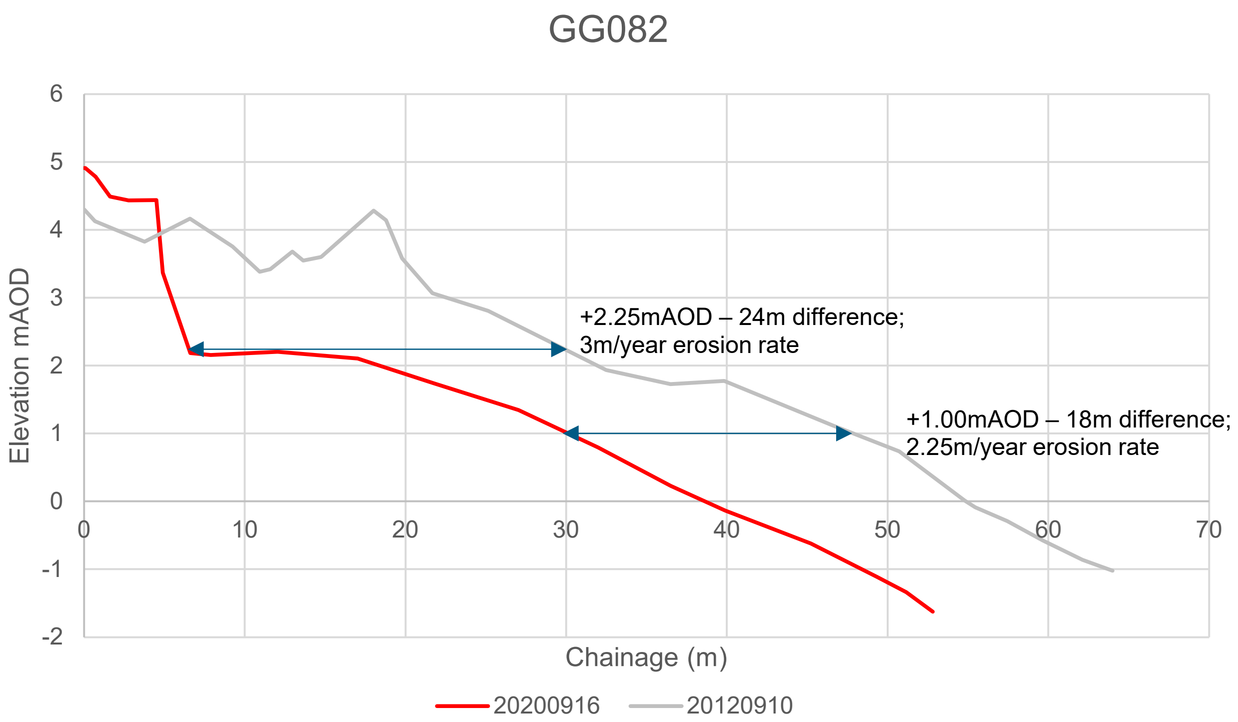


Figure 3-3 - Beach profile comparison between 2012 and 2020

3.4. Influence of nearshore sandbanks

As stated in 3.1, changes in the alignment and extent of the nearshore bank system also influences sediment feed to the Great Yarmouth frontage. The Gorleston to Lowestoft Coastal Strategy [8] includes Annex A.5, which provides a review and summary of study of the nearshore banks. The review also informs ongoing monitoring plans along the shoreline. A location plan from the study is included as Figure 3-4:

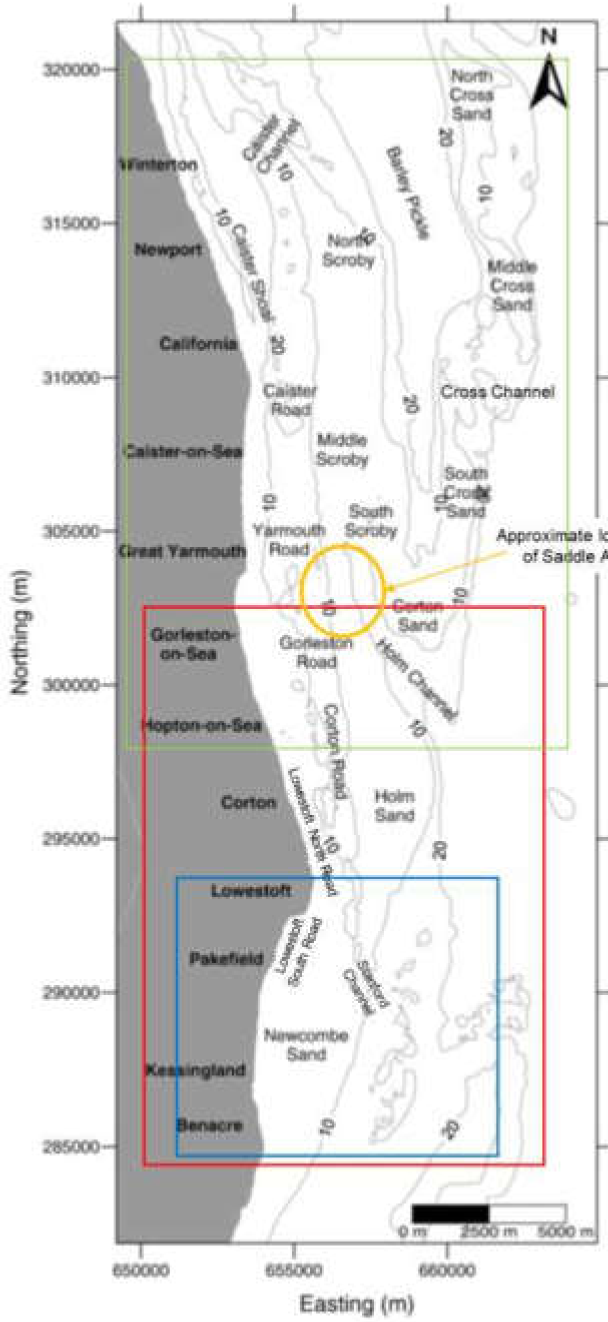


Figure 3-4 - Location plan of the nearshore sandbanks

A summary of the report is provided:

- The Great Yarmouth sandbanks have been extensively studies over the past 30 years due to their influence on navigation routes, coastal processes and influence on shoreline change and operational concerns for offshore windfarms.
- The observations showed considerable variations in height/depth and the shape of the seabed in the order of sub-decadal to decadal time-scale over the forty year period, demonstrating the dynamic nature of the Great Yarmouth Sandbank system.
- Modification in the configuration of the seabed located offshore of Gorleston, i.e. the Holm Sands and Holm Channel have an important influence on the whole sandbanks and channel system.
- No patterns or cyclic behaviour could be identified as a process ongoing over the past 40 years within the southern section of the Great Yarmouth.

The dynamic nature of the sandbank system and lack of evidence of cyclic behaviour demonstrates the ongoing need to collect monitoring data relating to the nearshore banks. Any recommendations for coastal management at Great Yarmouth need to consider the dynamic sandbank system, in terms of reliance on sediment supply or influence of any management intervention on the sandbank system.

3.5. Coastal catch-up

Current erosion rates can be increased by a factor of 20 over the following years after immediate failure of the sea defence (Uwe Dornbusch & Poppy Mylroie). Coastal catch-up has not been considered for this study but may be considered in more detailed studies as a sensitivity for flood damage assessment.

4. Economic Appraisal

4.1. Introduction

The economic appraisal calculation methodology is outlined in the sections below. The Do Nothing scenario, used to assess economic damages due to flood and coastal erosion risk is presented, followed by an overview of the calculation of damages to derive the economic benefits for the project.

4.2. Do Nothing scenario

4.2.1. Do Nothing flood damages

The Do Nothing scenario assumes flood damages (up to a 1:200 year return period event including sea level rise due to climate change over 100 years) due to wave overtopping of the existing wall during a storm event and inundation of wave overtopping volumes landwards to flood properties. Local topography has been assessed to derive a plausible flood route. The overtopping volume moves from higher to lower ground, first in a westerly direction across the South Denes peninsula and north to lower ground. The scenario assumes that overtopping volume is prevented from entering the river due to the presence of the flood defence. The flood extent assumed for the Do Nothing scenario is shown in Figure 4-1. The legend shows ground levels from LiDAR (mAOD); arrows show the assumed flood route landwards following wave overtopping of the wall; and properties included in the analysis are shown in grey. This level of assessment was appropriate for the high level study, however more detailed analysis may be required to validate this flood extent.

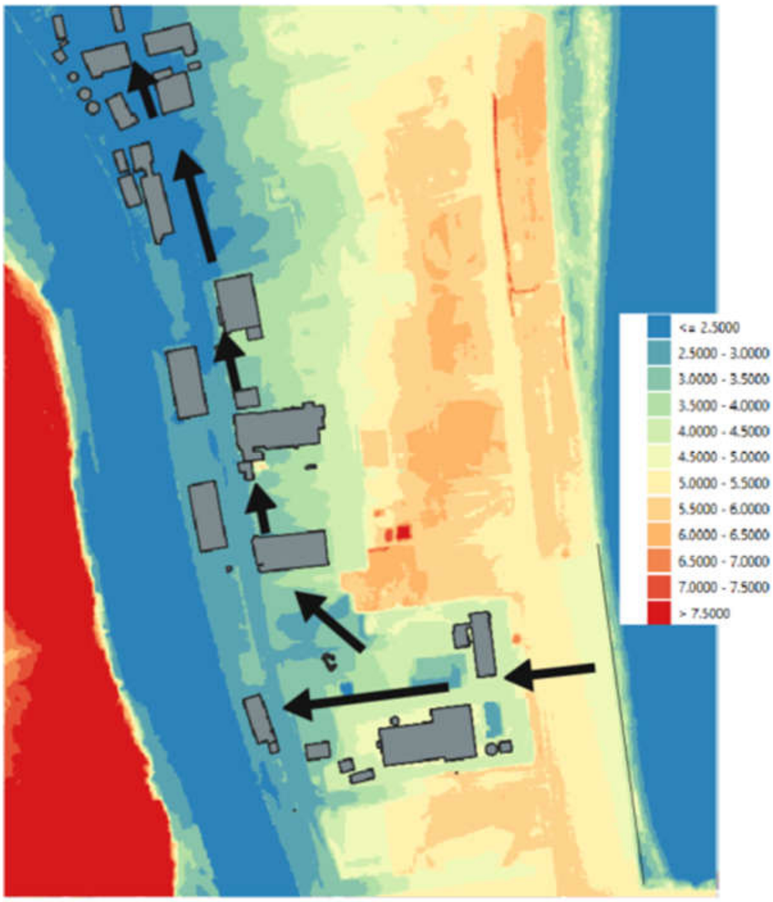


Figure 4-1 - Do Nothing flood extent (1:200 year return period including climate change)

Property damages were assessed using the Multi Colour Manual (MCM) methodology and depth damage curves (as updated in 2021). The property dataset for the assessment was derived from the National Receptor Database (NRD) 2014, combined with building outlines from the Ordnance Survey Master Map data (OSMM). A property list was defined based on properties expected to experience flood damages following failure of the wall under the Do Nothing scenario as shown in Figure 4-2. Developments built after 2012 were not considered to be at risk of flooding and are excluded from the economic appraisal in accordance with the National Planning Policy Framework (Ministry of Housing, Communities & Local Government, 2018).

The approach to calculating economic property damages is summarised below:

- Maximum flood depths at each property location were calculated using water levels (with climate change) for a range of design flood events for the Do Nothing scenario.
- Applied the MCM methodology and depth damage curves (as updated in 2021), specifically short-duration flooding with greater than 8 hours warning.
- Calculated internal depth of flooding by applying an assumed threshold uplift of 150 mm above ground level for residential properties and 50 mm above ground level for non-residential properties unless other information was available, for example from site visit or verification through observations using aerial photography. It is noted that the property list for this assessment comprised of only non-residential properties.
- Assumed no basements in any properties.
- Generated Annual Average Damages (AADs) for a range of design flood events were assessed for the Do-Nothing scenario and capped the property damages at their current market value.
- A variable discount rate (starting at 3.5%) was applied to the AADs to generate the Present Value Damages for each option over an appraisal period of 100 years.

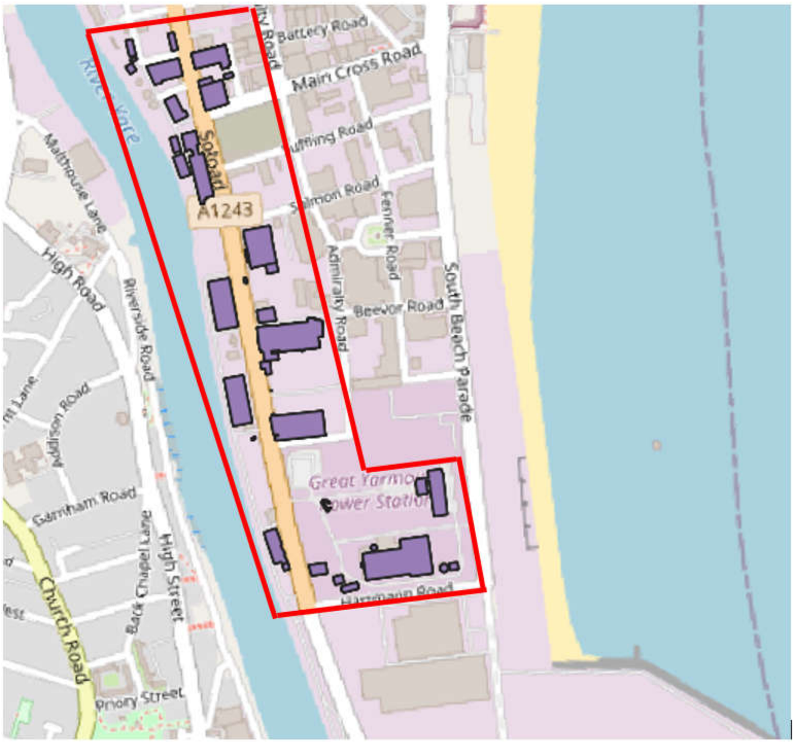


Figure 4-2 - Properties included within the Great Yarmouth seawall economic analysis

4.2.2. Do Nothing Coastal Erosion Damages

Erosion rates have been used to identify non-residential properties which may be lost to coastal erosion during the appraisal period. These are non-residential properties being lost after 30-35 years, following approximately 100m of erosion, assuming immediate failure of the wall and erosion of approximately 3m per year. The damages associated with the loss of these properties has been included in the Do Nothing damages. Damages have been estimated according to the property capping value, flood area and discount factor for the year of loss (Year 33 in this case), see Figure 4-3.

Figure 4-3 - Properties at risk due to erosion following immediate failure of the wall

4.2.3. Do Nothing indirect damages of infrastructure

Indirect damages are taken as 20% of the Do Nothing Damages [9] due to flooding and coastal erosion and account for loss of the following infrastructure:

- Roads (South Marine Parade and the A1243)
- Electricity transmission (Great Yarmouth combined-cycle gas and steam turbine power plant)
- Electricity distribution (to Great Yarmouth and Great Yarmouth Outer Harbour)

4.3. Emergency Services

Flood incidents need to be managed when they occur. As such, emergency services were incorporated in the assessment. These emergency costs come from active services from the police, fire and ambulance services, local authority emergency response team, and the Environment Agency's flood incident teams. The MCM guidance estimates that the emergency costs are 5.6% of the total property damages. This is the percentage applied in this appraisal and it is suitable for urban areas.

4.4. Outcome of Economic Assessment

Table 4-1 provides a summary of the economic appraisal over a 100-year appraisal period.

Table 4-1 - Summary of economic appraisal

	Do nothing Appraisal Baseline
PV Commercial property damages (£k)	£43,964 (Flooding: £37,909; Coastal erosion: £6,055)
PV emergency services (£k)	£3,894
PV Indirect Benefits (£k)	£8,793
PV whole life benefits (£k)	£56,651

A high level economic assessment has been undertaken for the purpose of this study. Prior to submitting formal applications for funding, a more detailed economic assessment may be required.

5. Option Assessment

5.1. Introduction

This section presents the list of options formed to manage further erosion and limit overtopping at the southern extremity of the South Denes frontage where the seawall is the primary defence, selection assessment criteria used to compare options and selection of a preferred option.

5.2. Options considered

5.2.1. Do Nothing

This option assumes no further works are undertaken and the existing seawall is left to deteriorate over time resulting in failure. This option would not manage erosion and overtopping risks across the frontage. It is assessed for baseline and comparative purposes only.

5.2.2. Option 1 – Rock Revetment

This option involves placing rock armour seawards of the existing wall to prevent erosion and scour of the wall as shown in Figure 5-1.

Advantages of this option include; readily available material, ease of construction, reduced wave reflection, and smaller wave forces and overtopping.

Disadvantages associated with the option include; visual impact, amenity loss (beach space).

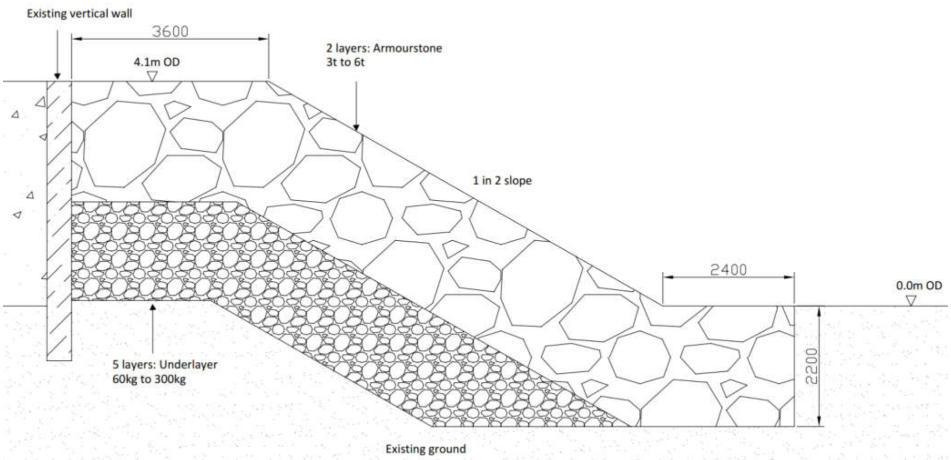


Figure 5-1 - Typical cross section of rock revetment

5.2.3. Option 2 – Stepped Concrete Revetment

This option involves installing a stepped concrete wall (see Figure 5-2) to replace the existing wall to increase the surface roughness of the coastal protection structure to reduce wave run-up and wave overtopping.

Advantages: Efficient, accurate and high quality construction with prefabricated components. It is noted that this option may require a sheet piled toe for stability.

Disadvantages; adverse visual impact, loss of amenity (beach space), relatively expensive when compared with a rock option, stability issues with energetic wave climates (e.g. where Hs>2m).

Figure 5-2 - Indicative stepped revetment structure [10]

5.2.4. Option 3 – Submerged Breakwater

This option involves the construction of breakwaters slightly offshore from the beach to provide shelter from wave action to the beach and existing wall as shown in Figure 5-3.

Advantages: material readily available (use of geotubes filled with locally won material or rock), higher wave energy dissipation (refraction), limits wave heights, minimal disturbance from waves at the beach, produces a hard point for material accumulation.

Disadvantages: environmental impact in the permanent situation, visual impact, construction within the marine environment.

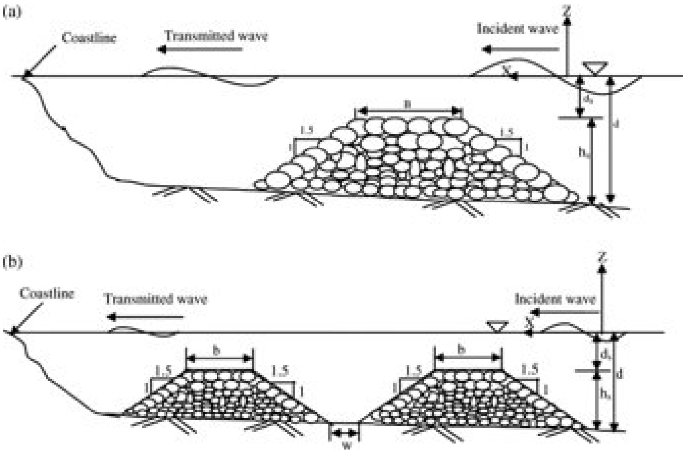


Figure 5-3 - Typical cross section of offshore (submerged) breakwater

5.2.5. Option 4 – Shore Connected Breakwater

This option involves the creation of a shore connected rock structure which acts to retain beach material within the smaller bay created by the rock structure as shown in Figure 5-4.

Advantages: material readily available (rock), produces a hard point for material accumulation, higher wave energy dissipation (refraction).

Disadvantages: environmental impact, visual impact, construction within the marine environment.

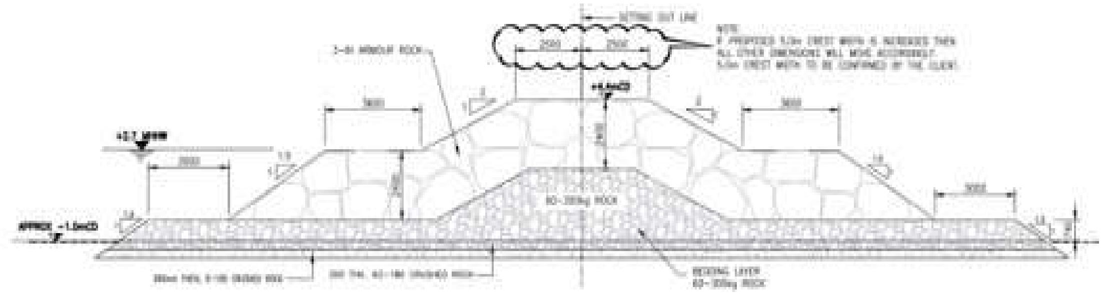


Figure 5-4 - Typical cross section of shore connected breakwater

5.2.6. Option 5 – Sheet Pile Wall

This option involves driving steel sheet piles in front of the existing wall with sufficient embedment to prevent undermining Figure 5-5.

Advantages: Installation using a piling rig placed behind the existing wall, limited footprint reducing the environmental impact.

Disadvantages: wave reflection on vertical structure.

Figure 5-5 - Indicative sheet pile wall layout [11]

5.2.7. Option 6 – Beach replenishment

This option involves significant beach recharge to minimise maintenance/replacement of the seawall as shown in Figure 5-6.

Advantages: ease of solution, import “X” m3 of material every “Y” years, Widens the beach, protects structures behind beach, environmentally friendly, helps stabilize tidal flats.

Disadvantages: material will wash off or move under the influence of storms, not a “one off solution”. It is noted that this option will have to be adopted along with one of the previous beach control structures.

Figure 5-6 - Beach nourishment at Hayling Island [12]

5.3. Selection of preferred option

5.3.1. Selection criteria

The above list of options was assessed at a high level against the following:

- Technical – Does the option stabilise the wall or the beach levels in front of the wall?
- Environmental – Impact on local environment, designated sites, and public amenity.
- Economic – Potential benefits against relative cost.
- Operation and maintenance obligation – Monitoring, minor repairs, significant interventions.
- Stakeholder acceptance – Council, environmental stakeholders, local businesses and public.
- Resilience to future episodic beach lowering events – Episodes of beach lowering have now been observed and may happen again in the future. Does the option provide resilience to this happening?

5.3.2. Option assessment

The options were assigned a score ranging from high to low i.e., High (3), Medium (2), Low (1) as shown in Table 5-1.

Table 5-1 - Option scoring from the South Denes External Options Workshop.

	Technical	Environmental	Economic	Operation & Maintenance	Stakeholder acceptance	Resilience to future beach lowering	Final Score
Rock Revetment	**3**	**2**	**3**	**3**	**2**	**2**	**15**
Shore Connected Breakwater	3	1	2	2	2	3	13
Stepped Concrete Revetment	2	2	1	2	2	2	11
Sheet Pile Wall	1	1	3	3	2	1	11
Submerged Breakwater	2	1	1	1	2	3	10
Beach replenishment	1	2	1	1	2	1	8

From Table 5-1 above, it is apparent that Option 1 - rock revetment is the most appropriate option to reduce flood risk behind the sea wall based on the selected criteria.

More detailed appraisal will be required prior to formal submissions of a business case.

6. Summary of preferred option

6.1. Introduction

This section describes the properties of the preferred option i.e., Option 1 – Rock Revetment. A typical section has been developed to inform a cost estimate. An assessment of the Flood Defence Grant-in-aid has been undertaken together with the required partnership funding.

6.2. Typical section

A typical section has been provided for the purpose of deriving a cost estimate with an assumed length of 400m required to protect the South Denes frontage. The rock revetment profile and extent should be refined when outline and detailed design is carried out. The sizing of the rock revetment, assuming a 1 in 2 slope, would be:

- 2.2m thick armour layer of 3t to 6t (Dn50 of 1.2m).
- 1.8m thick underlayer of 60kg to 300 kg (Dn50 of 0.4m). The underlayer comprises 5 layers and this has been selected as 1.5*Dn50 of the armour stone to use a higher permeability factor that enables us to use a smaller (and lighter) armour stone.

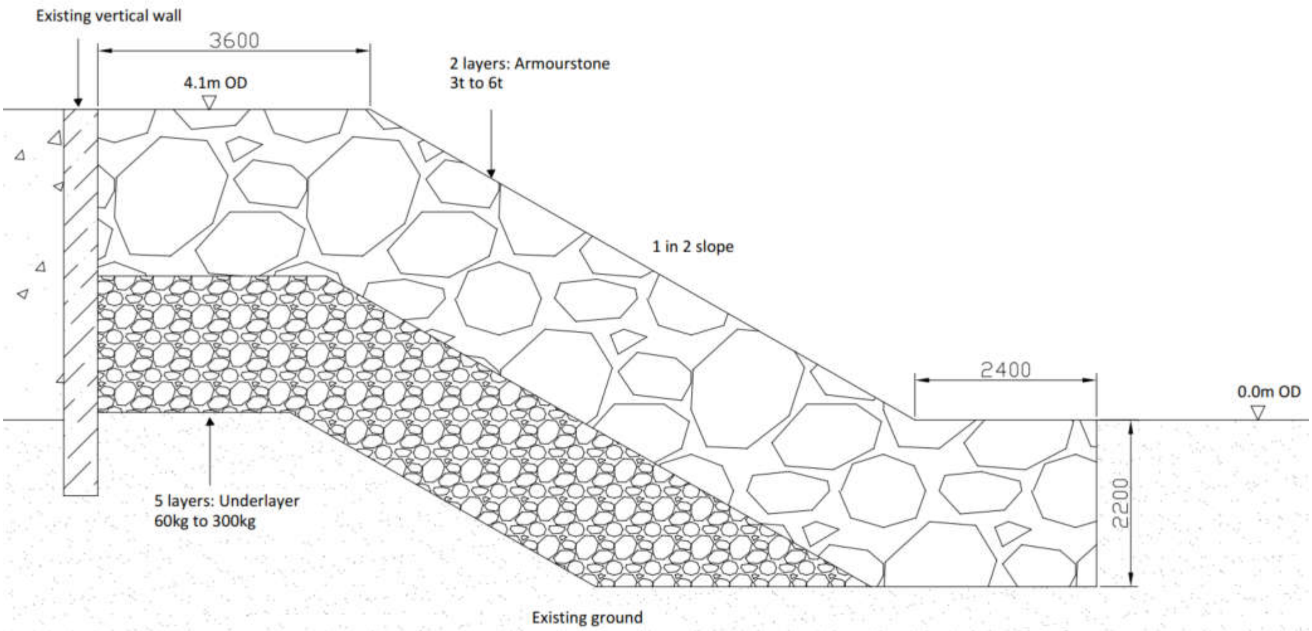


Figure 6-1 - Proposed indicative cross-section of rock revetment for the preferred option

6.3. Cost estimate

A cost estimate was produced for the preferred option based on the cross-section shown in Figure 6-1 above. Unit rates used to develop the cost estimates have been extracted from the Spon's Civil Engineering and Highway Works Price Book [13] and from recent Coastal Partnership East projects. It should be noted that the rates used reflect rates from February 2022, therefore are impacted by inflation rises since publication of [13] in 2021.

Table 6-1 - Cost estimate for preferred option

	Amour stone	Underlayer	Geotextile
Cross section area (m^2)	31.5	16.7	5,680
Assumed length of structure (m)	400	400	-
Volume (m^3)	12,600	6,680	-
Cost rate per unit volume (£/m^3)	162	158	20
Estimated cost (£k)	2,041	1,054	114
Sub-total cost (£k)	**3,209**		
Overheads and profit (30%)	**963**		
Total cost (£k)	**4,172**		

6.4. Partnership Funding Calculator

The Partnership Funding Calculator [14] was used to determine the maximum eligible Grant-in-aid funding for the preferred option assuming £100k contributions towards appraisal costs. Table 6-2 summarises the results of this assessment.

A £100k allowance was made for PV appraisal costs while a £4,172k allowance was made for PV construction costs including material procurement, site deliveries, backfilling material behind wall, excavation, and construction of the revetment.

For the future costs, an allowance of £1k per year was made for routine and post flood inspections. In addition, a £20k allowance was added every 25 years to replace damaged rocks. A variable discount rate (starting at 3.5%) was applied to the operation and maintenance costs to generate the Present Value Damages over an appraisal period of 100 years.

Optimism bias of 44% and 10% was added to all PV construction costs and PV future costs respectively. An assessment of risks associated with the delivery of the project and future operation and maintenance should be developed to provide a project specific detailed risk allowance.

Table 6-2 - Outcomes of Partnership Funding calculator

	Option 1 – Rock revetment
PV appraisal costs (£k)	£100
PV construction costs (£k)	£4,172
PV risk contingency (£k)	£1,836
PV future costs (£k)	£49
PV whole life costs (over duration of benefits) (£k)	£6,157
PV whole life benefits (£k)	£56,651
Benefit Cost Ratio	9.2
PV estimated contributions towards PV appraisal costs (£k)	£100
PV maximum eligible FCERM GiA (£k)	£3,399

The partnership funding calculation has identified a deficit of £2,758k between available Flood and Coastal Erosion Risk Management Grant-in-aid and the present value whole life costs.

6.5. Sensitivity testing

A revised partnership funding calculation has been undertaken assuming a 50% reduction in effective length of the rock revetment: 200m rather than 400m.

Table 6-3 - Outcomes of Partnership Funding calculator (sensitivity test)

	Option 1 – Rock revetment (200m length)
PV appraisal costs (£k)	£100
PV construction costs (£k)	£2,086
PV risk contingency (£k)	£917
PV future costs (£k)	£49
PV whole life costs (over duration of benefits) (£k)	£3,152
PV whole life benefits (£k)	£56,651
Benefit Cost Ratio	18
PV estimated contributions towards PV appraisal costs (£k)	£100
PV maximum eligible FCERM GiA (£k)	£3,399

Due to inflation uncertainty, the cost estimate should be regularly reviewed prior to submitting the outline business case or full business case application for Flood and Coastal Erosion Risk Management Grant-in-aid funding.

- Optimise cross-section (crest level, crest width, slope angle, toe detail, requirement for underlayer) during outline and detailed design.
- Undertake a detailed condition survey of the existing wall to confirm the extent of rock revetment required along the frontage.
- Review unit costs on a regular basis.

7. Conclusions and recommendations

7.1. Conclusions

Following a series of storms in 2020, beach levels were significantly reduced along the South Denes coastal frontage at Great Yarmouth. This led to deterioration in the condition of the mass concrete seawall, which provides coast protection to non-residential properties and infrastructure at the South Denes frontage. A high level assessment has been undertaken considering the following:

- Coastal processes which led to the low beach levels.
- Economic assessment considering do nothing damages due to flooding and coastal erosion.
- High level options appraisal and development of a cost estimate for the preferred option.
- The benefits and costs have been used to identify funding available through Flood and Coastal Erosion Risk Management Grant-in-aid and extent of partnership funding required.

The undermining and deteriorating stability of the wall since early 2020 are a result of a combination of factors: depleted winter beach profile; wave reflection due to the vertical wall; and the severity of the storms which occurred at the start of 2020. During a site walkover for this project in November 2021, beach levels appeared to be at 'normal' levels, with only the top of wall visible. A storm event on the evening of 31st March and 1st April 2022 resulted in significant lowering of beach levels at the South Denes frontage. Other beaches along the Council's frontage also suffered significant lowering of beach levels. The wind direction for this event was reported to be from the north-east direction and tides were close to, but not at the peak of, spring tide.

A high level economic assessment has been undertaken for the purpose of this study. The Do Nothing scenario assumes flood damages due to wave overtopping of the existing wall during a storm event and inundation of wave overtopping volumes landwards to flood properties.

Erosion rates have been used to identify properties which may be lost to coastal erosion within the next 30-35 years (100m of erosion), assuming immediate failure of the wall and erosion of approximately 3m per year.

Indirect damages are taken as 20% of the Do Nothing Damages due to flooding and coastal erosion and account for loss of the infrastructure.

Coastal management options have been compared against agreed criteria to identify a preferred option.

Considering all criteria, rock revetment was selected as the most appropriate option to reduce flood risk behind the sea wall based on the selected criteria. A typical section has been developed for the rock revetment to inform a cost estimate. Effective lengths of 400m (the preferred option) and 200m (sensitivity testing) have been used in the economic analysis for protecting the South Denes frontage.

A Partnership Funding Calculator was used to determine the maximum eligible grand in aid funding for the preferred option. Based on this calculation, £3,399k is available for implementation of the preferred option. There is a deficit in funding between the cost of the preferred option (400m length of rock revetment) and the Grant in Aid funding available of £2,758k.

7.2. Recommendations

The following recommendations are provided for further work to progress this project:

- The ongoing monitoring of beach profiles, as part of the Environment Agency's coastal monitoring programme, should be regularly reviewed with the wall in its current condition.
- Coastal catch-up has not been considered for this study but may be considered in more detailed studies as a sensitivity for flood damage assessment.
- Prior to submitting formal applications for funding, a more detailed economic assessment may be required.
- Detailed assessment of flood inundation landwards of the wall.
- More detailed appraisal will be required prior to formal submissions of a business case.
- An assessment of risks associated with the delivery of the project and future operation and maintenance should be developed to provide a project specific detailed risk allowance.
- The rock revetment profile and extent should be refined when outline and detailed design is carried out.
- Optimise rock revetment cross-section (crest level, crest width, slope angle, toe detail, requirement for underlayer) during outline and detailed design.

- Undertake a detailed condition survey of the existing wall to confirm the extent of rock revetment required along the frontage.
- Review unit costs on a regular basis.

8. References

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Appendices

Appendix A. Partnership Funding Calculator

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