

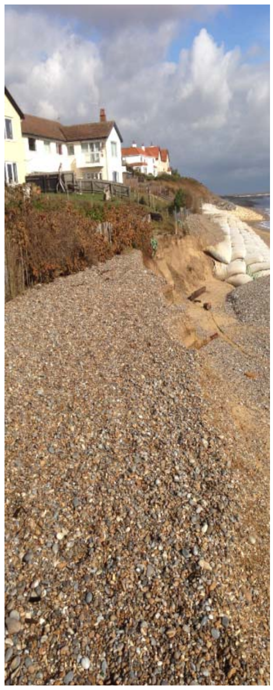

Thorpeness Coastal Protection

Options Appraisal Study

April 2016

Suffolk Coastal District Council

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Executive Summary

The coastal Defence Options Appraisal for Thorpeness reported here follows a study of coastal processes and morphodynamics (Mott MacDonald, 2014). It identifies and assesses options for management of the frontage within the context of the policies and the underlying intent for management as identified within the Suffolk SMP and the PAR (SCDC, 2010). These express a realistic expectation that defences will provide protection to the frontage during further periods of erosion. While also accepting that there may be some damage in the future, the defences have been designed to provide scope for local repairs to be undertaken without the risk of the whole structure deteriorating and failing. Local residents were involved in the option development process that resulted in the selection of the present scheme, and regular updates to inform of progress were provided. The study reported here has been carried out based on information available and on previous work undertaken by Mott MacDonald.

Taking the present Phase 1 and Phase 2 Geobag scheme in its present state as a starting point, the report presents an assessment of a range of coastal erosion defence options that address concerns expressed regarding the ability of the present scheme to defend properties along the frontage over the next 30 to 50 years. It considers the merits and drawbacks of potential schemes by considering efficacy and advantages, constraints and disadvantages, impacts and costs. Special attention is given to potential solutions that are acceptable economically and do not interfere with the continued supply of sediment through the area while at the same time addressing the recurrence of periods of severe local erosion. These are all requirements stated in SCDC (2010).

MM has examined 13 different conceptual defence options. At the conclusion of this process six options were selected for further investigation:

- Option 1 (Reactive Management);
- Option 2 (Proactive Management);
- Option 5a (rock buttresses + recharge);
- Option 9 (steel sheet pile wall);
- Option 10 (three rock revetment variants); and
- Option 12 (an artificial reef).

Designs have been developed to reflect the 2010 PAR objectives and to reflect the impacts of the damaging series of events in 2013 including a prolonged spell of easterly winds in the spring, autumn storms and the December 2013 storm estimated to have a return period of 1:250 years. While the initial work was unconstrained by considerations of cost, final assessments took account of budget limitations advised by SCDC to be in the range £500,000 to £1,000,000. Although from a design perspective the 1:250 year event is considered to be overly conservative given the 50 years design life of the remediation works, given the severity of beach erosion in 2013, the design of schemes based on this extreme event is considered to be prudent.

Having withstood a range of events throughout 2013, albeit with minor damage, there can be little doubt that the Geobags performed at a level beyond the original design. It is noted also that other structures would not have prevented the unprecedented beach erosion associated with the December 2013 storm event and thus the Geobags functioned as effectively as other defence options in this case. Since the remedial works to re-bury the Geobags and restore the beach were undertaken, the site has remained in good condition and resilient to a range of moderate events. Since no evidence can be offered to support a view that the scheme cannot be expected to provide a similar level of protection in the future, the current implementation of Option 1 by SCDC was considered to be worthy of further scrutiny. It was concluded that given the level of protection already demonstrated in December 2013, the Geobags could withstand the impact of a similar event without suffering much damage beyond minor abrasion and percussion effects associated with wave action. However, it is not inconceivable that other events in the future may apply different pressures on the frontage and could, for example, undermine the lower Geobags leading to slope instability and possible failure. While beach erosion required to bring this about would be below all documented historical levels, it is a possibility that must be considered and mitigated.

Option 2, involving proactive maintenance of the beach and existing defence structures, beach monitoring and an emergency plan, aims to maintain the beach to at least the minimum level required to provide efficient natural protection to the shore through recycling of beach sediment. Based on the five years of historical data, it is considered that biennial recharge may be required and a loss of 1m of beach elevation should trigger an assessment. In such an event, a high-level estimate for recharge quantities indicated a shingle volume of between 6,000m^3 to 10,000m^3 may be needed. Ideally this should be placed along the northern part of the frontage so it can be distributed alongshore by natural processes well before critical beach levels are reached. The most serious constraint on Option 2 concerns the source of the donor material and acquiring the necessary permissions and three possible options are identified for further investigation. The cost of Option 2 is estimated to be £223,600 with additional maintenance costs depending on circumstances. Option 2 is open-ended, with no guarantees about whole life costs possible. It is however, a very flexible approach that aims to work responsively with natural processes to provide a good coastal defence function with the least visual impact and minimal disruption to beach access.

The short groynes, or buttresses, constructed of rock (or possibly other materials) in option 5a aim to retain upper beach sediments and lessen the effect of obliquely incident waves that run along the defence line at or around periods of high water. It is though unlikely however, due to the dominance of cross-shore transport, that short rock buttresses will retain sufficient beach material during storm conditions when the combination of high water level and waves are likely to sweep material out from the groyne embayments and lower the beach. This process may also be reinforced by secondary circulations, driven by wave set-up and set-down. The option was therefore not considered viable and consequently has not been costed.

The sheet steel pile wall of Option 9 is intended to provide a backstop function to halt erosion in the event of Phase 1 and Phase 2 Geobag failure. With such a failure, the piled vertical wall would attract considerable wave reflection resulting in further erosion of the beach in front of the structure. This would then require the provision of wave dissipating structure such as rock armour to protect the foundations and would in affect place the frontage in a more vulnerable state than it was in 2010. Maintenance of Option 9 will be required to mitigate potential corrosion. From a practical standpoint, access for construction will be limited and further restricted due to tidal working. The cost of a suitable sheet steel pile wall is estimated to be £511,436.

While a rock revetment structure scored highly against criteria measuring efficacy, sustainability and practicality, it became clear that the cost of a full rock revetment in Option 10a would be too expensive at a cost of £3,887,000. Consequently, a number of lower cost alternative revetment designs to enhance the resilience of the existing Phase 1 and Phase 2 Geobags were developed including:

- Rock toe and rock protection up to Geobag layer 6 (Option 10b); and
- Rock toe protection (Option 10c).

Options 10b and 10c enhance the present resilience of the Phase 1 and Phase 2 Geobags, and provide improve scheme terminations at the northern and southern limits which will mitigate outflanking. Both add further confidence that the existing defences will continue to provide effective coastal erosion protection and conform to the PAR objectives. The cost of options 10b and 10c are estimated to be £1,377,911 and £1,028,223, respectively.

The artificial reef (Option 12) was investigated and its relative merits were explored. However, at a high estimated cost of £3,031,700, and questionable performance as an effective defence, the option not considered to be viable.

Based on the outcome of the appraisal, and on the funds understood to be available for a scheme, Option 1, Option 2 and Option 10c (rock toe protection) are viable options to take forward. It is emphasised that the Phase 1 and Phase 2 Geobags have in the past have exceeded the coastal protection required by the PAR and there is little evidence to support the view that their function will be diminished in the foreseeable future.

It is considered that provided the Geobags remain covered, no further damage to their integrity will occur. In the event of exposure during a severe event, or as a consequence of multiple events and/or a prolonged period of waves from either a north easterly or south easterly direction, the Geobags may again be exposed by beach drawdown and intervention to restore beach levels may be required

(Options 1 and 2). While the need to do this will be reduced if the structural reliance can be enhanced by the toe protection offered in Option 10c, this option will not prevent beach erosion and could potentially leave the Geobags vulnerable to abrasion and percussion damage by waves if they are exposed for a prolonged period.

It is clear from this study that there is no simple solution to the coastal defence issues at Thorpeness. Mott MacDonald (2105) has identified that the efficiency of beach replenishment by alongshore transport processes along the North End Avenue frontage appears to be reduced compared with adjacent locations and for reasons not fully understood at present, incident wave energy can be focussed onto a limited part of the frontage during storms. While these coastal process uncertainties remain and the existing defences continue to provide protection from erosion, it is considered to be unwise to proceed with the construction of further structures that may not stand up to more detailed cost-benefit scrutiny. Instead it should be recognised that a natural beach provides the most effective and sustainable defence solution if the issues regarding sediment recycling can be overcome.

1 Introduction

1.1 Background

In response to a major beach erosion event in 2010, approximately £700k of public and private money was invested between 2010 and 2012 to improve in two phases, protection against erosion of the northern frontage of Thorpeness Village. The resulting Geobag defences were again exposed to high erosion pressure in 2013 and although performing their coastal protection role satisfactorily, there was significant beach erosion to approximately -1 m AOD leading to concerns that the existing defences are not capable of delivering fully the outcome upon which technical approval and funding allocation were based. In addition the geobags also suffered some abrasion damage during this period of exposure, particularly around the mid-level of the stepped structure (Figure 1.1).

Figure 1.1: The seaward edge of the Phase 1Geobag layers showing holing from abrasion.

Source: Terry Oakes Associates, 2010

The Phase 2 Option Appraisal reported here follows on from a Phase 1 study (Mott MacDonald, 2014) concerned with understanding coastal processes and morphodynamics. It identifies options for management of the frontage that are sustainable within the context of the existing management policies and the underlying intent for management as identified within the Suffolk SMP. There is an expectation that the options selected will be sustainable over at least epoch 1 (to 2025), and possibly beyond.

While there is evidence of a capacity for the beach in the vicinity of the defences to rebuild, taking a precautionary approach, the options to be considered must assume further periods of severe erosion over the next decade. Based on historical trends, it might be anticipated that the section of the frontage suffering the greatest erosion since 2010 will become more stable through time and the erosion ‘hotspot’ may shift further north or south. However, simply assuming that this will occur carries a significant risk that requires careful evaluation.

The recent coastal management policy change consultation has raised awareness in the Thorpeness community of erosion risk. There is now pressure to deliver the PAR objectives of the defences installed in 2010-2012. However, the underlying problem remains the same as that pertaining prior to the recent defence installation: i.e. localised severe erosion threatens a significant number of properties due to the continued pressure on the existing defences. Further, the damage to, and further deterioration of, the present defences indicates that they will not maintain the standard of protection required and expected over the next 30 years.

The Phase 1 report (Mott MacDonald, 2014) identifies that in the medium- to long-term, erosion of the coastline will continue irrespective of coastal engineering interventions. The challenge now is to balance management of a naturally evolving shoreline with the Thorpeness community aspirations and to manage risk and the transition from hold-the-line to realignment.

1.2 Literature used to inform the design and appraisal

The information used to assist the development and appraisal of options is drawn from a wide range of sources. Coastal process understanding is based on information provided in: Carr, 1981; Waveney District Council, 1998; Halcrow Group Ltd., 2001a,b,c; HR Wallingford et al., 2002; Environment Agency, 2007, 2011a, 2011b; Pye & Blott, 2006, 2010, 2011; SCDC, 2010; Royal Haskoning, 2009, 2010a, 2010b, 2010c, 2011; and Mott MacDonald, 2014.

The understanding of coastal morphodynamics draws on information from: Birkbeck College/University College, 1999; Brooks 2010; Pontee et al., 2004; BEEMS, 2011, Environment Agency, 2013; Pye et al., 2014; and Mott MacDonald, 2014. Information on hydrodynamic and wave conditions relevant to the Thorpeness frontage is taken from: Dixon & Tawn, 1997; HR Wallingford, 2010; McMillan et al., 2011; Pye & Blott, 2013, 2014; BEEMS, 2013, 2014; and Mott MacDonald, 2014.

1.3 Purpose of the options appraisal

Given that periods of severe local erosion may again occur in the future, the key objective of the options appraisal for the Thorpeness frontage is to identify a means of providing an effective erosion defence to properties over the next 30 to 50 years. To be practical and effective the approach must be affordable and must not interfere with the continued supply of sediment through the area required to maintain adjacent beaches.

2 Basis of Design

2.1 Approach

The basis for design was defined by (a) Mott MacDonald (2014), which identifies the environmental conditions and coastal processes; and (b) the outcomes from the kick off meeting held in Mott MacDonald's Fleet Place office on 25 February 2015. The functional requirements of the proposed structure are based on balancing options and value engineering against realistic capital and revenue budgets.

In the initial work design and options appraisal were undertaken in accordance with the PAR assumptions and conclusions and in compliance with the SMP7 Thorpeness policy.

2.2 Functional Requirements

Initially it was understood that the remediation works must meet the PAR objectives which were developed in line with the SPM2, 2010 (hold-the-line until 2025), Table 2.1.

Table 2.1: PAR objectives

Time	Policy
1st epoch until 2025	Maintained the current alignment at existing defences
2nd epoch (2025 – 2055)	Managed Realignment with review of maintaining the current alignment at existing defences
3rd epoch (2055 – 2105)	Managed Realignment

Source: SPM2, Publication of Policy Development of Zone 5, 2010

Other requirements required that:

- The proposed remediation work should provide an effective erosion defence to properties over the next 30 to 50 years;
- The design of southern termination must address local outflanking which was not included in original construction;
- The scheme design should be resilient against a storm event with similar characteristics to the 2013 storm; and
- The scheme should not interfere with the continued supply of sediment through the area.

2.3 Constraints

The appraisal process reported here has taken into consideration the following constraints:

- A high capital cost option is preferred to high maintenance cost option;
- Public access is valued by residents and visitors;
- The visual impact on the coastal landscape should be as unobtrusive as possible; and
- Some overtopping discharges behind the protection might be allowed providing the impact is quantified and defined in terms of risk, damage & probability of occurrence.

Evidence from 2013 indicated that the design of the terminations at the southern and northern and of the existing defences is critical. The 2013 storm uncovered the gabions and geobags and showed that the termination was not protected and prone to accelerated erosion. While this was most evident at the southern termination, the interface between the Phase 1 geobag scheme and the cliffs to the north also suffered some erosion.

The possibility of using alternative ‘experimental’ solutions was discussed during the kick off meeting. For example, repair of the damaged geobags using polyuria was reviewed. However, it was agreed that the relative novelty of such approaches, combined with the present incomplete understanding of the coastal processes, would make the design and performance assessment of such schemes unreliable.

2.4 Existing Sea Defences at Thorpeness

The coastline at Thorpeness has experienced repeated erosion periods and significant damages. A number of coastal protection structures have been installed over the years. The existing coastal protection comprises a combination of gabions and geobags placed to protect the gabions toe.

Before reporting the options appraisal, it is useful to briefly review the existing defences that include Phase 1 and Phase 2 Geobags installed between 2011 and 2012. Since the gabions installed in the 1970s are now effectively protected by the Geobags, they are not considered further beyond recognising a potential need to repair them as they age and when they suffer storm damage.

It is noted that the Geobags installed in Phase 1 and Phase 2 works are not designed to be exposed for long period. It is therefore a pre-requisite that the beach profile is maintained either by natural processes or my management intervention to a high level to limit any pressure erosion may place on their integrity.

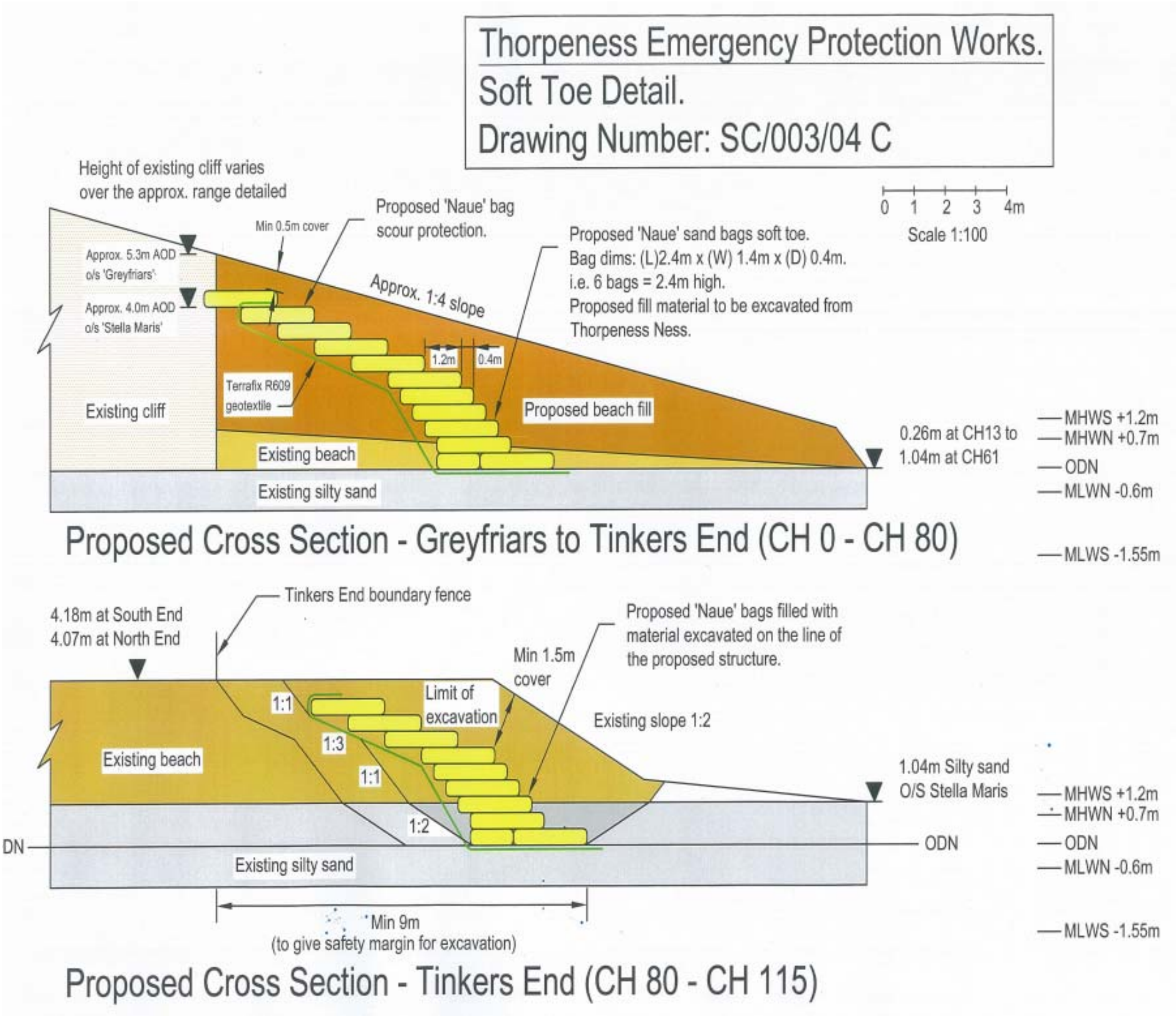
2.4.1 Typical Sections

Protection of the frontage has been undertaken in two phases:

- Phase 1 comprising stacked Naue geotextile bags along approx. 150m of the frontage; and
- Phase 2 comprised Naue geotextile bags placed in front of gabions installed in the early 1970's and approx. 200m in length plus repair of damage to the 1970's gabions.

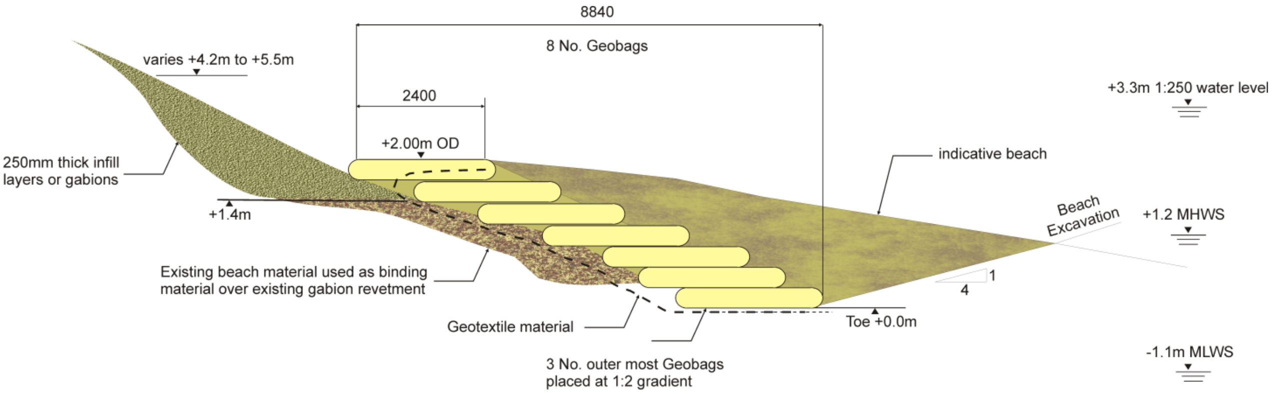
Typical sections of Phase 1 and Phase 2 are shown in Figure 2.1 and Figure 2.2, respectively.

Figure 2.1: Typical Section Phase 1



Source: SCDC

Figure 2.2: Typical Section Phase 2 (scale 1:50)



Source: SCDC/Mott MacDonald

2.4.2 Observed damage attributed to the December 2013 event

Inspection of the defences following the December 2013 storm event showed there was damage to the lower layers of gabions basket above the existing geobags. Further the toe of the structure was exposed and outflanking occurred at both side of the gabions/geobags structure (north termination) and geobags/adjacent unprotected cliff (south termination). Soft cliff erosion was most significant at the northern end of the frontage (Mott MacDonald, 2014).

Inspections have shown that although being of lower abrasion resistance and suffering extensive minor puncturing since installation, the Phase 1 Geobags have fared better than those used in Phase 2 since Phase 2 Geobags bags are in a more exposed position.

Until December 2013 when the beach lowered to -1.0mOD and there was evidence that wave run-up had reached the vegetated crest at the top of the gabions, the Phase 1 Geobags remained partly or fully covered indicating that they may be located in a less aggressive environment. In addition it is possible that their design profile may have contributed further to their resilience when compared with the Phase 2 frontage.

2.4.3 Existing Coastal Protection Conditions

To inform the design process in this study it has been assumed that the conditions of the existing structures forming the coastal protection at Thorpeness are as stated in Table 2.2.

Table 2.2: Existing Structures Conditions

Element	Existing Condition
Phase 1 Geobags	▪ Resisted well the Spring, October and December 2013 erosion events well. ▪ Do not currently require any remediation works to maintain integrity. ▪ Currently (October 2015) covered by beach material after beach repair operations undertaken by SCDC.
Phase 2 Geobags	▪ Suffered some damage during the three 2013 erosion events (torn/ripped bags) but do not require any remediation works to maintain the integrity of the protection. ▪ Currently (October 2015) covered by beach material after beach repair operations undertaken by SCDC.
Gabions	▪ Either buried or exposed to wave attack at the top of the structure. ▪ Damaged during the October and December 2013 erosion events and requiring some repairs to extend their residual life.
South termination	▪ Significant outflanking in 2013. ▪ Beach levels remain high (October 2015) with extensive shingle cover on the unprotected shoreline. ▪ Remediation works may be required to maintain the integrity of the shoreline at this location during events similar to 2013.
North termination	▪ Some cliff retreat may create an outflanking risk. ▪ Remediation works may be required if the integrity of the exposed cliff needs to be maintained.

2.5 Environmental Conditions

2.5.1 Coastal Processes

The beach erosion hotspot along the North End Avenue frontage in 2010 is shown in Figure 2.3. The area is relatively confined reflecting a focus (and possibly reflection of) wave energy along a very limited section of the coastline. Possible causes of this are discussed in Mott MacDonald (2014).

It has been estimated and agreed that the frequency of coastal erosion events is around every 1:10 years (Mott MacDonald, 2014). However, it is clear from historical evidence that the erosion, 'hotspot', presently at North End Avenue, is not permanently fixed and has occurred at different locations along the Thorpeness frontage due to processes that are not fully understood. Evidence in Mott MacDonald (2014) indicates that although the longshore transport of sediment at Thorpeness is relatively small, the beaches are relatively stable under normal conditions and provide an adequate level of protection. However, periods of modest erosion, normally occurring during the winter months can lower the beaches and make them significantly more susceptible to storm impacts. Further, the present defence line is significantly seaward of the natural coastline further limiting the quantity of natural materials available for protection. Thus in the present options appraisal consideration is given to the consequence of options that may extend the defences even further seaward.

Figure 2.3: Beach set-back in front of coastal protection at Thorpeness (prior to the placement of geobags)

Source: Mike Page

2.5.2 Wave climate

Mott MacDonald (2014) reviewed the existing information regarding wave conditions in the vicinity of Thorpeness. The review has shown that the relatively flat and shallow offshore bathymetry determine the wave conditions reaching the beach and defences system and that during storms and/or high water elevation, breaking waves have been observed to reach the toe defence, and in extreme cases run over the Phase 1 and Phase 2 defences and the gabions.

2.5.3 Tidal Currents

Mott MacDonald (2014) and Royal Haskoning (2010) show that peak offshore flood tidal flow is directed towards the coast with a peak velocity of around 1.3 m/s. During the ebb the flow in the offshore area is in the order of 1.5 m/s, and tends to flow slightly to the north-northeast. Closer to the shore, bed friction retards the tidal significantly and near-shore currents are greatly influenced by wave-driven alongshore and cross-shore flows which in turn contribute to processes controlling the morphodynamic behaviour of the beaches.

2.5.4 Beach Profiles

A review of the available beach profiles covering the period 2009-2013 and surveyed biannually (winter profile and summer profile) was reported in Mott MacDonald (2014). Specifically a critical low beach profile was assumed in which:

- The lowest beach level was set to +0.0mOD at the toe of the existing geobags; and
- The approach beach slope was 1:20.

Although Mott MacDonald (2014) shows that the beach level at the toe of the defence typically varies from +1.0mOD to +3.0mOD a level of +0.0mOD was recorded prior to the 2013 storm event and is therefore used in the concept design process.

2.5.5 Water Levels

Tide levels and water levels were reported in Mott MacDonald (2014) for Sizewell, approximately 3.5 km to the north of Thorpeness (Table 2.3 and Table 2.4).

Table 2.3: Still water tidal levels at Sizewell (BEEMS, 2013)

Tide Level	Still Water Level (mAOD)
HAT	+1.62
MHWS	+1.20
MHWN	+0.87

Tide Level	Still Water Level (mAOD)
MLWN	-0.62
MLWS	-1.10
LAT	-1.69

Table 2.4: Extreme still water levels at Sizewell

Return Period (years)	Still Water Level (mAOD)
1	+2.05
5	+2.41
10	+2.57
20	+2.72
50	+2.93
100	+3.09
250	+3.29(*)

(*) Interpolated
Source: Environment Agency, 2007

These still water level data do not include projected Sea Level Rise (SLR) impact. This can be accounted for through use of the UK Climate Projections, assuming a Medium Emission Scenario, which advises a SLR of 117mm for the next 30 years and 232mm for the next 50 years, (2015 base year).

2.5.6 Wave Conditions

Offshore and nearshore wave conditions were reported in Mott MacDonald (2014), and a combination of nearshore wave height and water level is summarised in Table 2.5.

Table 2.5: Return periods of nearshore wave heights at specified water levels

Design Condition		Nearshore Wave (30m from the toe of the structure)	
Wave Height Return Period	Water Level Return Period	Depth (m)	Hs (m)
100	50	4.51	2.73
50	50	4.51	2.73
50	20	4.31	2.62
20	50	4.51	2.72
20	20	4.31	2.61
20	10	4.16	2.53
10	20	4.36	2.60

Design Condition		Nearshore Wave (30m from the toe of the structure)	
10	10	4.16	2.52
10	5	4.00	2.44
5	10	4.16	2.50
5	5	4.00	2.43
5	1	3.64	2.25
1	5	4.00	2.31
1	1	3.64	2.19

Source: Mott MacDonald, 2014

2.5.7 Design Event

2.5.7.1 The 2013 storm event: design water levels

During December 5th and 6th 2013, surge elevations of 1.3m and 2.0m were measured at Harwich and Lowestoft, respectively. The water levels recorded at Harwich and Lowestoft were around +3.5mOD and +3.3mOD respectively (Mott MacDonald, 2014). Analysis of the water levels associated with this event indicates a return period of approximately 1 in 250 years and thus it is a very unusual event.

2.5.7.2 The 2013 storm event: design wave condition

For concept design purposes, determination of the maximum breaking wave characteristics, the *design wave* conditions, assumed a beach profile down to +0.0mOD and a water level of +3.3mOD (i.e. the level recorded at Lowestoft during December 5th and 6th, 2013). Using a combination of environmental conditions with high return period the design maximum wave height and period were determine to be 2.7m and 8s, respectively.

In common with the extreme water level, the *design wave* event has also been conservatively assessed and assumed to have a return period of approximately 1 in 250 years. Such an event has 0.4% probability of being exceeded within any one given year and an18% probability that the *design wave* event will be exceeded over the 50 years design life.

It is noted that for coastal defence schemes the Environment Agency guidelines recommend to design against an event with 39.4% of probability of being exceeded within its design life. The present criteria are therefore highly conservative, and are guided by the conditions pertaining during the 2013 event and by the need to meet the standard of protection in the PAR.

2.5.7.3 Return Period of the Design Event

Having been exposed to significant erosion in the weeks prior to December, 2013, it is understood that the beach levels were already low prior to the December 5th and 6th, 2013 event. A review of the beach profiles covering a 5 years period prior to this event in Mott MacDonald (2014) has shown that a drawn down of more than 2m and a beach level at the toe of the defence at 0.0mOD had not been recorded. However, it is also acknowledged that these levels may have occurred but were not been recorded as beach surveys are infrequent and not event-driven.

Given that the erosion 'hotspot' can occur at other locations along the Thorpeness frontage, it has been assumed for concept design purposes, that these low beach levels could conceivable occur for a period of a few weeks on an annual basis.

2.5.8 Overtopping Limits

Local observation of wave interactions with the defences around the time of high water demonstrate that waves can run up and along the structure whether or not it is covered by beach sediments. The impact of overtopping discharges on the overall stability of the defence system was therefore taken into consideration when developing and reviewing options. In the concept design process, maximum allowable overtopping volumes were taken from the industry-standard Eurotop Manual.

3 Options Appraisal

3.1 Introduction

Given the need to meet the PAR objectives and to provide protection against the kind of event defined in 2.5.7 the initial appraisal approach was financially unconstrained. However, in common with all coastal defence schemes, resources available for design, construction and maintenance are limited and in subsequent stages of the appraisal, SCDC provided guidance on funding limitations and thus refinements to the concept designs recognised that resources would be limited to around £1M. Further, accepting that setting limits on resource availability will inevitably reduce the standard of protection provided, an even lower cost option was desirable with £0.5M defined as the lower limit.

The initial appraisal identified and considered 13 different conceptual options and appraised each against a set of key criteria. Options were developed to meet the primary aims to:

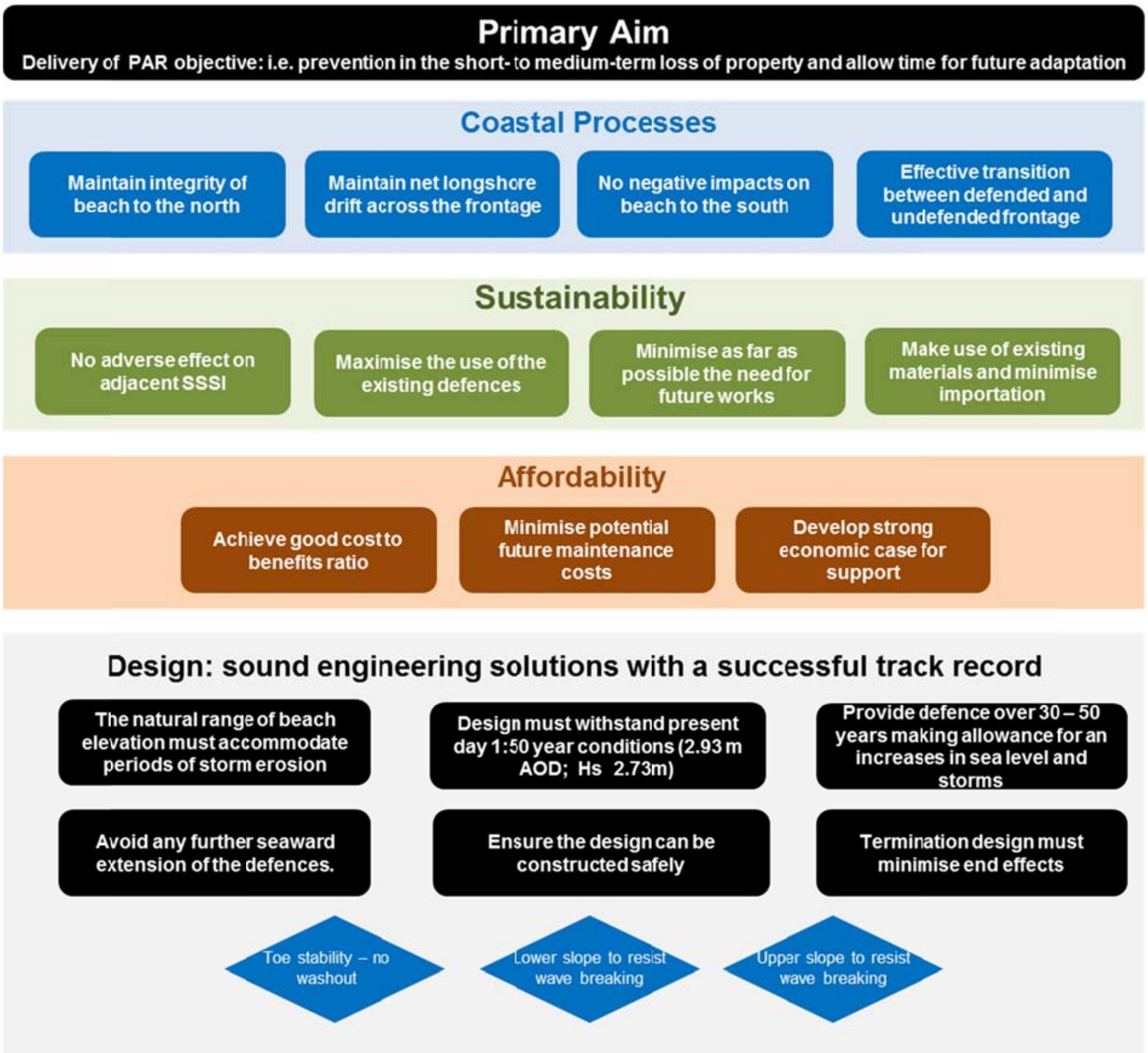
- Prevent loss of property in the short- to medium-term; and
- Allow time for future adaptation.

Capital cost, technical or construction challenges were not taken into consideration at this early stage to ensure the widest range of remediation works were included. Figure 3.1 presents the approach used to develop the options and defines the key criteria against which the options have been reviewed including:

- The primary aim of the scheme;
- Coastal processes;
- Sustainability;
- Affordability; and
- Engineering design.

An initial pass/fail gateway appraisal has been carried out to identify options that would be seen as not acceptable in terms of: capital cost, technical risks, environment impact or stakeholder views. The key criteria were defined based on the performance requirements and the basis of design set out in the preceding sections.

Figure 3.1: Appraisal approach considering the primary aim, coastal processes, sustainability, affordability and engineering design.



Source: Mott MacDonald, 2015

The appraisal has been based on an understanding of the existing conditions of the defences (Table 2.2). Although uncertainties about the potential wider impact of the scheme on the Thorpeness frontage will remain, the appraisal has quantified uncertainties as far as practicable. Following the initial appraisal, six preferred options were identified and further investigated.

3.2 Initial Option Appraisal

The options considered are summarised in the long list Table 3.1 and stem from those suggested in the Mott MacDonald project proposal document and from subsequent discussions with SCDC and a Thorpeness residents representative on 25 February 2015.

Table 3.1: Initial Long List of Options

Option	Description
Option 1	Reactive Management involving: maintenance of the beach and existing defence structures and an emergency plan.
Option 2	Proactive Management involving: management of the beach and existing defence structures, beach monitoring and an emergency plan.
Option 3	*Shingle engine (including near shore re-profiling to simulate a mini Ness accretion feature)*
Option 4	*Timber breastwork / groynes*
Option 5a	Rock buttresses
Option 5b	*Shore-normal rock groynes*
Option 6	*'Fishtail' groynes*
Option 7	*Increase Geobag durability (e.g. polyuria spray)*
Option 8	*Concrete sea wall*
Option 9	Steel sheet pile wall
Option 10	Rock revetment
Option 11	*Offshore breakwater*
Option 12	*Artificial reef + monitoring*
Option 13	*Alternative experimental solution*

Following the process illustrated in Figure 3.1, each of the options identified in Table 3.1 were considered with regards to efficacy, constraints, affordability and impact. As a result options 3, 4, 5b, 6, 7, 8, 11, 12 and 13 were rejected for the reasons stated in Appendix A.

The six remaining options for further investigation include:

- Option 1 (Reactive Management);
- Option 2 (Proactive Management);
- Option 5a (rock buttresses);
- Option 9 (steel sheet pile wall);
- Option 10 (rock revetment); and
- Option 12 (artificial reef).

All these options are investigated in Section 4 where Option 10 is further sub-divided into Option 10a (full revetment meeting PAR objectives), Options 10b (revetment protection to Geobag level 6) and Options 10c (Phase 1 and Phase 2 Geobag toe protection).

4 Concept Options Designs

4.1 Introduction

With the objective of identifying the best defence solution, the appraisal of the six concept option designs identified above considers the options with regards to efficacy, constraints, impacts and costs (Sections 4.2 to 0). In Section 4.7.1 a detailed evaluation of the six options is presented in which each option is compared against Option 1 (do nothing) and considers impacts on processes, sustainability, affordability, stakeholder concerns, design and construction. Section 4.7.1 also provides a table summarising costs and a final commentary of the option judged to provide the best all round performance against all assessment criteria.

4.2 Option 1: Reactive Management

Option 1 involves maintenance of the beach and existing defence structures and the development and implementation of emergency plan to address event-driven erosion pressures. Option 1 is the baseline option against which the advantages of the other options can be judged. It is considered for three reasons:

- It is the present management option implemented by SCDC;
- It enables assessment of whether or not it is acceptable in any respect to continue with this option; and
- It allows comparison with other intervention options presented below with regards to efficacy, constraints, impacts and costs.

While events in 2013 resulted in severe beach erosion and exposure of the Geobags, it is clear that the defences protected the cliffs from erosion. This is also demonstrated by the erosion that occurred to the north and south of the structures at that time. Although the toe of the Phase 1 and Phase 2 structures was exposed, scour did not undermine the foundation and the integrity of the structure was maintained. However, there was some damage to the Geobags attributable to the abrasive and percussive effects of waves charged with coarse sediments, notable on levels 4, 5 and 6. While it might be argued that the structures enhanced beach erosion by reflecting wave energy and causing waves to run along the frontage, there can be little doubt that the Geobags performed to the design requirements. Indeed, the fact that in 2013 the structure withstood prolonged and damaging easterly waves, an autumn storm and a 1:250 year event in December is clear evidence that the scheme is actually performing at a level beyond its original design. It is not unreasonable therefore to expect that the defences will continue to provide protection from erosion in the future. However, it is noted carefully that the standard of protection provided will depend on the severity of future events.

Since the remedial works to re-bury the Geobags and restore the beach to pre-storm levels were undertaken in 2013, the site has remained in good condition and has been characterised by a wide, apparently naturally functioning shingle beach which has remained resilient to a range of moderate events. The scheme is therefore presently performing in accord with the PAR.

With Option 1 there are no constraints, impacts or additional costs and thus only efficacy needs to be considered.

4.2.1 Efficacy and advantages

Understanding and assessing the efficacy of Option 1 can only be guided by the performance of the scheme and beach behaviour since restoration in 2014 and the probability of occurrence of one or more events and/or conditions that may lower beach levels and again expose the Geobag structures. While at present a good level of coastal protection is provided to the frontage, damaging storms cannot be ruled out and it would be unwise to base coastal defences on an assumption that the present situation will continue in the future for the design life of the Phase 1 and Phase 2 schemes.

Given the level of protection provided by the Phase 1 and Phase 2 Geobags to the frontage that has been demonstrated throughout the damaging event in 2013, it is anticipated that the scheme would withstand the impact of a similar event without much damage beyond the minor abrasion effects noted above.

The greatest unknown, and the greatest risks to the Geobag defences, concern the magnitude, duration and frequency of future damaging storm events. Future events will determine the residual life and performance of the scheme and whether or not the defences can be relied upon to continue meeting the PAR objectives is a legitimate question to ask given the resources needed for implementation of any of the options identified in this report. It is considered that the present defences will provide the coastal defence function for which they were designed for the immediate future providing their present structural integrity does not degrade further.

In the meantime, monitoring of the beach behaviour will provide further information to better understand the local coastal dynamics and provide the time required to identify and develop the most appropriate defence strategy for Thorpeness and to seek the resources required. In this respect, the XBand radar presently deployed at the northern end of the frontage will provide valuable data to improve the understanding of wave impacts and beach responses.

While Option 1 carries a risk, it is judged to outweigh the limited advantages that can be provided by a defence scheme that is affordable. With the knowledge that the frontage will be protected against the next event(s), it is therefore not unreasonable to defer a management decision until the occurrence of the next damaging event. The condition of the scheme and its performance can then be re-evaluated and appropriate steps can then be taken.

The design of a suitable emergency response plan to replenish the beach when low levels threaten the existing structures is beyond the scope of this report. However, it is strongly recommended that a plan for a well-resourced and robust response to erosion events in the future be funded and implemented.

4.3 Option 2: Proactive Management

Option 2 involves maintenance of the beach and existing defence structures, monitoring beach levels and the development and implementation of an emergency plan to address event-driven erosion pressures. The primary objective of Option 2 is to maintain the beach to at least the minimum level providing efficient natural protection to the shore and defence structures so that the impact of moderate and extreme events is limited. At the present time, the Geobags are buried and the beach crest is at approximately +4.0mOD with a shallow 1 in 20 slope. In this form it is considered to provide an adequate level of protection. In this restored state beach recharge is not required. However, there is a likelihood that this situation may change in the future and thus account has been taken of some recharge in the costing.

For Option 2 to be effective three requirements must be met:

- A local source of recharge sediment must be identified and the permissions to use it need to be approved;

- Regular beach monitoring must be undertaken to detect erosion trends;
- The ability to rapidly mobilisation of plant to undertake recharge work must be achievable at an acceptable cost.

Beach monitoring is currently being undertaken by the Environment Agency. No additional cost is foreseen. In addition the X-Band radar system deployed at the northern end of North End Avenue in August 2015 will provide daily, high-resolution, coastal monitoring data on beach profiles, nearshore bathymetry, surface currents and waves and thus provide an early warning of changes that may threaten the frontage.

4.3.1 Efficacy and advantages

It is recommended that a drop of 1m in beach elevation should trigger an assessment of the requirement for reactive, event driven, beach nourishment. A high-level estimate for recharge quantities has been undertaken and has identified the required volume of shingle to be approx. 6,000m^3 to 10,000m^3.

It is considered that the most effective beach recharge area is located at the north end of the existing defences. This assumes a net southerly sediment drift that would naturally distributed sediments and contribute to increasing the resilience of the present beach. It would also provide a supply to maintain beach levels to the south of the defences. In the costing provided, the initial investment concerns a recharge at the northern end of the frontage to improve resilience at these locations and to supply sediment towards the south. The quantity of sediments required is based on restoring the beach at this location to the highest recorded elevation.

4.3.2 Constraints and disadvantages

The most serious constraint on Option 2 concerns the source of the donor material and acquiring the necessary permissions. This has implications for both the cost and practicality of the scheme.

The most obvious choice of donor site is the beach to south of Thorpeness on the premise that erosion at the study site is associated with northerly wave energy that moves shingle from the study area southward. However, beach profile analyses suggest that the beaches along the south Thorpeness frontage are in retreat and thus any mass movement of shingle from this area may impact negatively and would require an in depth study to determine the impact of recycling. Unfortunately, it is believed that present data are insufficient to inform such a study without there being considerable residual risks.

The Ness to the north is another potential donor area with different challenges associated with designation and ownership. However, visits to the Ness on three occasions by Mott MacDonald show that the southern part of the Ness is very dynamic and characterised by series of highly mobile, unstable and un-vegetated shingle ridges. Since it is known that sediment supply from Sizewell is very low, accretion on the southern side of the Ness is considered to be related to the delivery of sediments from the south during sustained south-easterly wave conditions. A sediment tracer study could be used to determine provenance and thus prove the sustainability of this site.

Looking further afield the northern Aldeburgh beaches are full and could potentially be a useful recharge resource. A study to examine beach dynamics would be required to offset concerns that are bound to be expressed if mining of beach sediment from this location is proposed.

An effective beach monitoring program will be required to provide an early warning of potential threats to beach resilience and a beach management and emergency plan (BMEP) will be required to mitigate the risks of further coastal erosion.

Option 2 may also require some additional work should the defence structure become exposed and damaged including:

- Limited maintenance of the Phase 1 and Phase 2 Geobags with the extent and frequency depending on events;
- Repairs to gabions (assumed to be1/5 of the overall length) depending on exposure.

These contingencies are included in the costing.

4.3.3 Impacts

Option 2 has low impact on the local environment, landscape and amenity. Infrequent recharge operations may require exclusion of the public from the beach for a short period.

4.3.4 Costs

Based on available costs, Option 2 has a relatively low capital cost of £223,600 and a low maintenance cost of around £50,000 every 5 years (Table 4.1). These costs may be higher if the importation of recharge sediments is required.

4.4 Option 5a: Rock buttresses

Short groynes, or buttresses, constructed of rock (or possibly other materials) have been suggested as a means of retaining protective shingle in front of the Phase 1 and Phase 2 defences. Such structures would lessen the effect of obliquely incident waves that run along the defence line at or around periods of high water. Given their limited cross-shore dimensions, they will not be as effective at retaining sediments and longer structures and will only have a capacity to trap alongshore sediments for a short time during the tidal cycle.

However, given that the amount of alongshore sediment transport is small, and that erosion of the beach sediment is localised and driven primarily by cross-shore transport processes, it is though unlikely that short rock buttresses will retain sufficient beach material during storm conditions, especially given the recent evidence of storm impacts. That said, rock buttresses may act, during fair weather and moderate wave conditions, in a manner that promotes sediment accretion in the embayments, thereby increasing the sediment volume and beach resilience.

4.4.1 Efficacy and advantages

The performance of short rock buttresses depends critically on their ability to trap and retains sediments. If such a scheme can be designed to hold sediment in place, it will likely provide protection from moderate storm events. Specifically, the retention of a good sediment cover adjacent to the defences will enhance beach resilience.

However, the protection afforded to the Phase 1 and Phase 2 structures from an event such as the one in December 2013 may not be that great when the combination of high water level and waves are likely to sweep material out from the groyne embayments and lower the beach. It is also possible that this process will be reinforced by secondary circulations, driven by wave set-up and set-down, when waves are constrained between structures.

Perhaps the strongest argument against Option 5a concerns the dominance of cross-shore sediment transport during erosive conditions. Irrespective of the trapping efficiency of an Option 5a scheme, it would simple be ineffective in preventing material moving offshore and could not prevent subsequent alongshore transport in the narrow surf zone owing to restricted cross-shore extent. The premise that Option 5a could hold the upper beach sediments in place and protect the Phase 1 and Phase 2 Geobags is therefore highly questionable.

4.4.2 Constraints and disadvantages

The design of effective structures must be based on a good understanding of the required height, spacing and orientation of the structures. Numerical modelling may assist this process. However, to reduce the risk of poor scheme performance, a physical model would provide more robust tests, noting that the coarse nature of the beach sediments reduces the scaling problems normally encountered when designing models of this nature.

4.4.3 Impacts

As noted in A.1.2 cross-shore structures will intercept alongshore sediment transport. Given the rock buttress design aims to retain sediments on the upper part of the beach profile where alongshore transport is restricted to times around high water only, the expected disruption to littoral processes is unlikely to be manifest on the down-drift beaches in normal conditions. Access to the upper beach around the time of high water might be restricted by the structures depending on the design.

4.4.4 Costs

Option 5a is not considered to be viable for the reasons outlined above and thus costs are not provided.

4.5 Option 9: Steel sheet pile wall

Option 9 comprises a cantilever steel sheet pile cut off wall driven at the rear of the existing Phases 1 & 2 Geobags and Gabions with a length of 329m and crest level of +2.5m ODN to provide stability to the land behind which supports the existing residential properties. The structure is intended to provide a backstop in the event of failure of the existing seawalls due to the drawdown of shingle/sandy beach to levels and severe damage to the Geobags and gabions due to wave attack and shingle abrasion. Potentially piles could be installed in a manner to render then 'invisible'. However, deployed in this way, pile interactions with the existing defences cannot be predicted and thus poses a risk to structural integrity.

The installation of a steel sheet pile wall is based on the premise that the Phase 1 and Phase 2 Geobag defences will fail and they are intended to act as a backstop to prevent further, damaging, erosion. If we imagine a damaging storm that lowers the beach, undermines the Geobags and results in collapse of the structure and the subsequent destruction of the Geobags, the backstop would indeed prevent further erosion. However, it is conceivable that the resulting conditions (exposed steel sheet pile wall and eroded beach) would place increased erosion pressure on the fronting beach since incident wave would be reflecting from the structure.

4.5.1 Efficacy and advantages

A steel sheet pile wall will provide the desired backstop function to halt erosion in the event of Phase 1 and Phase 2 Geobag failure. The effective lifetime of the piles cannot be guaranteed to function for the expected lifetime of the Phase 1 and Phase 2 Geobags.

A further concern relates to the situation, however unlikely, of severe damage to the Phase 1 and Phase 2 Geobags so that the steel sheet pile was is exposed for all or part of its length. In such circumstances, the structure would have no support on the seaward face and potentially very high pressure on the landward face due to the mass of material and water table. It is unclear how the structure would respond to these conditions, especially if the piles have relatively short foundations in poorly consolidated material as seems the case. This possibility is flagged here as carrying a very high risk, since failure of the structure could lead to failure of the cliff.

4.5.2 Constraints and disadvantages

Constraints identified include access for construction and unknown ground conditions. It also remains unclear how piles can be driven without damaging either the gabions or the Phase 1 and Phase 2 Geobags.

Option 9 will only be effective as a protection once the existing defences are breached and/or damaged in part or whole. With such a failure, the piled vertical wall would attract considerable wave reflection resulting in further erosion of the beach in front of the structure subsequently requiring the provision of wave dissipating structure such as rock armour in front. Unlike a rock structure, where minimal maintenance is required, maintenance of Option 9 will be required to mitigate potential corrosion.

With access being unlikely from land at the rear of the existing seawall for installation of piling (gardens of properties), a large crane (with extended boom) is required for piling from foreshore in front of the existing seawall. Access will be limited due to tidal working

With top of finished pile being 1.5m – 2.0m lower than the ground level, the piles may either be driven from existing ground, requiring longer piles than required and would need to be left in place (too costly to excavate and trim pile) or the required length of pile is driven from excavated trench at the top down to, say +2.0m ODN. The latter would be more expensive due to the need to excavate and this method is unlikely to be acceptable to the residents.

Borehole ground investigation and material testing is required to ascertain the properties of the underlying soil to design the cantilever piling (pile length & required penetration for fixity). The sheet pile cannot be accessed or viewed to ascertain its condition for future maintenance. It is noted that while the WP150 silent piler (or similar) potentially offers a practical solution, a crane will be required to supply the machine and access from the beach or from North End Avenue properties may be restricted.

4.5.3 Impacts

Beyond the immediate impacts of construction, which could be small if a system such as the WP150 silent piler is employed, other impacts mainly concern unknown damage to the existing structures as the piles are pushed into the ground.

4.5.4 Costs

Based on the recent piling by a WP150 at 'Seadune' on North End Avenue using 5m U-section 'Larssen' interlocking piles, the cost is around £800/m including mobilisation1. It is the opinion of Mott MacDonald that 7.5m long SSP type AZ 14 piles would be suitable along a total length of 329m. Consequently the total cost has been estimated to be £511,436 (£1555/m), Table 4.1, which includes mobilisation/demobilisation of the piling plant (e.g. Giken Pile Press), contingency, a 6m-wide piling platform along the pile run for the attendant crane, supply of the piles, handling, pitch and drive and excavation (1.5m deep approx.) to the top of the piling and backfill.

4.6 Option 10: Rock revetment

Being the most reliable hard structure for on-shore defences, rock revetment options were included in the final set of selected options. Three designs have been examined and costed:

- **Option 10a** - Full revetment meeting PAR objectives with sufficient resilience to protect to Geobag structures against events similar to December 2013;
- **Option 10b** - Revetment protection to level 4, 5 and 6 of the Phase 1 and Phase 2 Geobag schemes to prevent collapse and protect the most vulnerable Geobag layers from wave action; and
- **Option 10c** - Phase 1 and Phase 2 Geobag toe protection to prevent collapse.

4.6.1 Option 10a: Full rock revetment

The first concept design for a full rock revetment to be investigated included the existing Geobags. However, the footprint of the revetment was considered to be too large and the option was re-evaluated. In order to limit the scheme footprint, the Geobags were removed to accommodate a 1 in 2 slope rock revetment.

[1] Mike Chandler, personal communication.

The Option 10a design comprises a full-height rock revetment with crest level up to +4.4m ODN to limit significant overtopping discharge and to limit potential damage to the gabions and the cliff. The resulting scheme design covers the length of the frontage and is extended southwards by 86m south. The toe of the revetment has been set at -1.1mOD to allow for the beach drawdown observed during the 2013 event. Rock sizing calculations were carried out using the design wave and the required standard grading was found to be 3,000 to 6,000kg. It is envisaged that in a few locations gabions may be exposed to waves and thus may need limited maintenance. A typical cross-section through the Option 10a design is shown in Figure 4.1.

4.6.1.1 Efficacy and advantages

Although it would ensure a significant level of protection to the frontage, Option 10a may also restrict beach access and encroach further cross-shore than the existing defences unless these were removed. High variability in beach level known to exist here would require a deep toe to ensure structural stability and increase the scheme cost as well as its footprint. Option 10a may also be responsible for a significant change in beach sediment dynamics which are presently unknown. Virtually no maintenance would be required to the rock revetment. The structure form (voids) would encourage beach build up.

4.6.1.2 Constraints and disadvantages

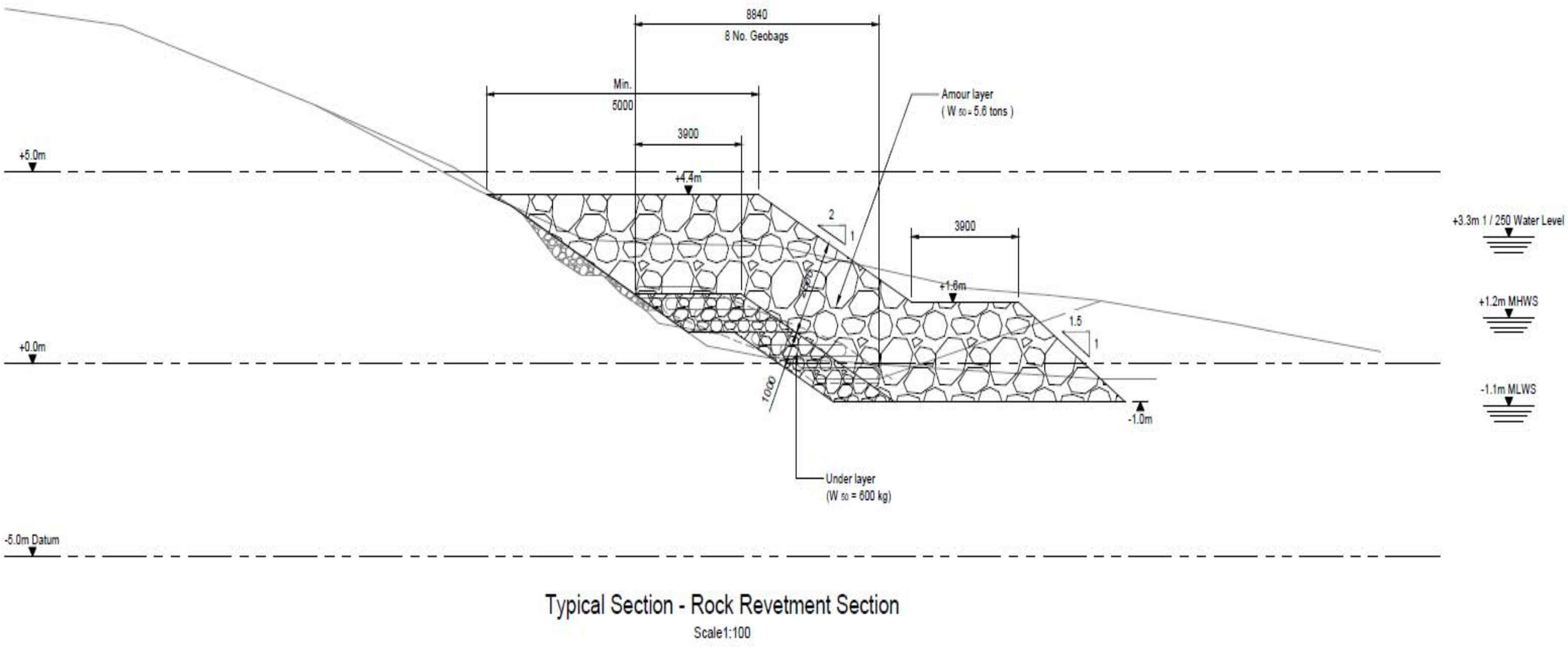
While Option 10a offers a significant level of protection to the frontage, it extends a long way cross-shore. High variability in beach levels known to exist here would require a deep toe to ensure structural stability and increase the scheme cost as well as its footprint. Option 10a will be a significant construction requiring excavation and careful rock placement. Beach access will be restricted.

4.6.1.3 Impacts

Assuming a revetment scheme is built following removal of the Geobags, the footprint would be similar to the Phase 1 and Phase 2 Geobag schemes and thus impacts might be expected to be similar.
Costs

In an initial appraisal the total cost of the Option 10a scheme was estimated to be £3,887,000, with an additional £20,000 required to cover structural surveys over the 50 year life, Table 4.1. This cost was subsequently revised down to around £2.8M by reducing rock size and volume. **However, in both cases the cost of Option 10a is judged to be too high and thus it is considered not to be viable**.

Figure 4.1: Option 10a Full rock revetment - typical cross section of revised design.



Source: Mott MacDonald

4.6.2 Option 10b - Revetment protection to level 6 of the Phase 1 and Phase 2 Geobag schemes

Option 10b is essentially a scaled-down version of Option 10a providing rock armour revetment protection with crest level up to + 2.4m ODN and +2.0m ODN along the Phase 1 and Phase 2 frontages respectively against draw down of the existing shingle/sandy beach to levels immediately following 2013 storm event (0.0m ODN). It is designed also to mitigate damage to the Geobags and gabion baskets due to wave attack and shingle abrasion. Rock cover is provided up to Geobag layer 6 (Phase 1). Option 10b also includes an extension roundhead termination around the groyne at the northern end of the Geobag scheme. The total scheme length is 391m.

A plan view of the scheme is shown in Figure 4.2 and typical cross-sections at locations A, B, C and D (Figure 4.2) are shown in Figure 4.3, Figure 4.4, Figure 4.5 and Figure 4.6.

4.6.2.1 Efficacy and advantages

Option 10b will provide good toe protection to ensure structural integrity of the Phase 1 and Phase 2 Geobags is maintained if beach levels drop during an erosion event. Extension of the scheme around the terminal Geobag groyne at the northern end of the existing defences will provide a significant improvement to the present termination. Rock cover over the Phase 1 and Phase 2 Geobags will reduce significantly wave action that may damage exposed Geobags up to level 6.

Rock armour would provide protection to the Geobags from direct wave attack by dissipation of the waves within the rock voided structure. Construction work can be readily carried out entirely from foreshore which can be easily accessed. The rock armour of size specified could be easily sourced locally or imported from Europe. Most of the structure is buried in beach at most times with revetment rock only being exposed during drawdown during storm. The structure form (voids) would encourage beach build up.

4.6.2.2 Constraints and disadvantages

Option 10b will be a significant construction requiring excavation and carful rock placement and the entire structure would require tidal working. The new works would extend approximately 11m seaward (cross-shore) of the existing seawall toe. Structural costs of Option 10b are marginally more (20%) than Option 10c. Some restrictions to access on the upper part of the beach (15-width) will occur during beach draw down events. There is a risk to the existing Geobags during construction which should be mitigated by careful placement of under-layer rock. A toe trench formation level below MLWS will be required to ensure adequate support to the existing seawall toe and provide a fully-buried toe. The difficulty of low level toe construction (below MLWS) could be mitigated by the construction of the toe in short lengths (up to 10m).

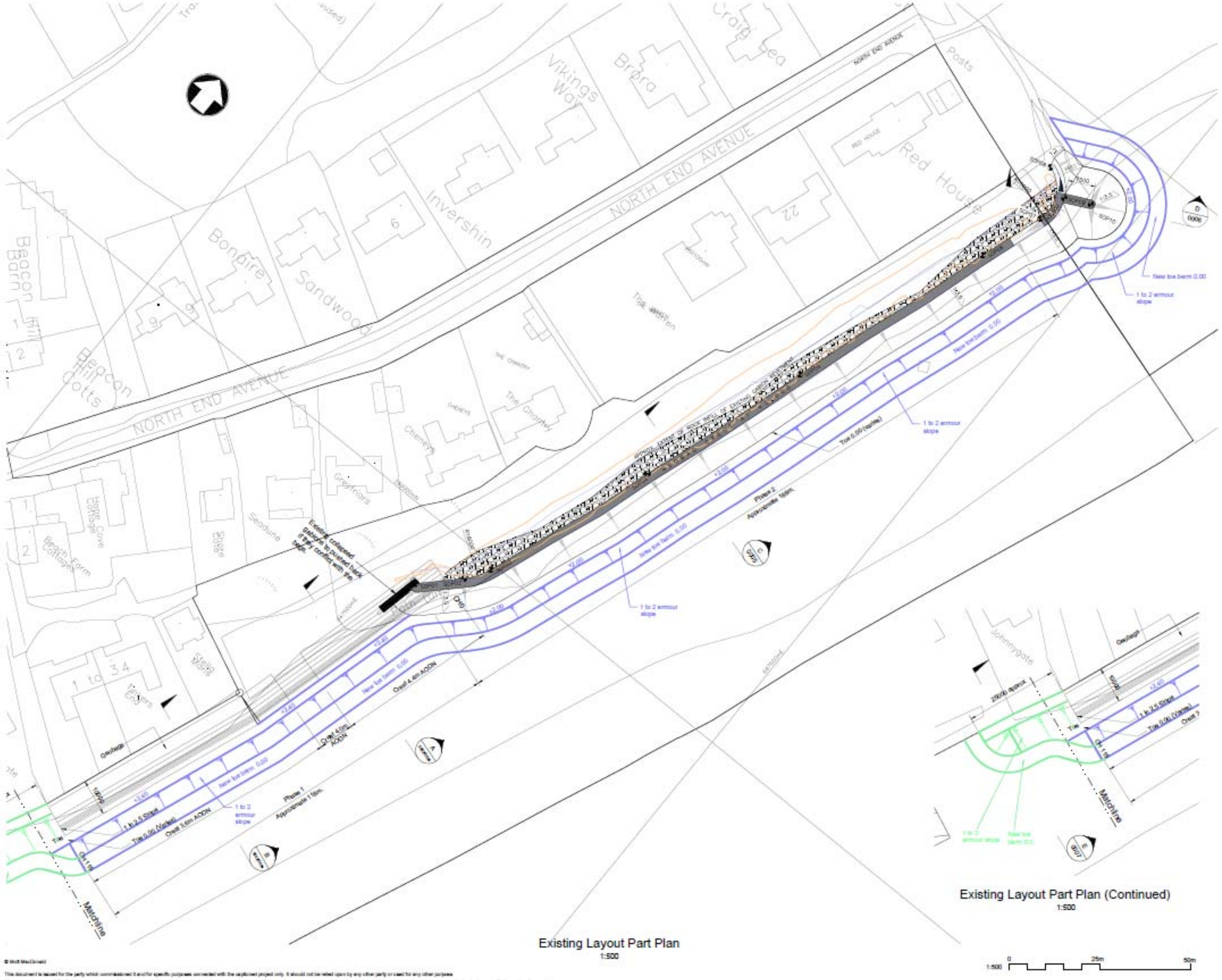
4.6.2.3 Impacts

Alongshore sediment transport will be affected owing to the larger footprint of the scheme. Providing the scheme remains buried, no other impacts are anticipated.

4.6.2.4 Costs

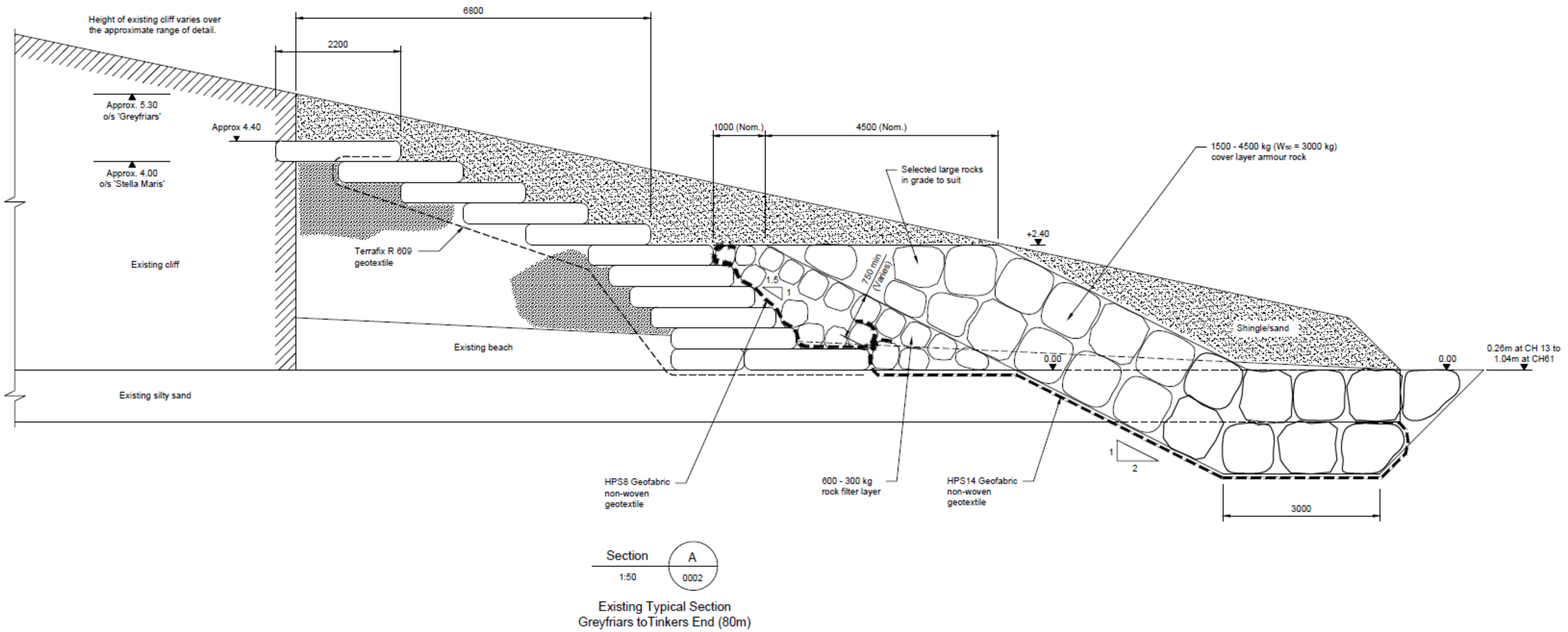
The total cost of the scheme is estimated to be £1,377,911 (Table 4.1). This includes design costs, contracts, procurement and site supervision, construction and contingency. It also includes provision of a full height heavy rock armour revetment termination at the southern end of the scheme (Figure 4.14).

Figure 4.2: Option 10b - Rock toe and revetment protection to Phase 1 and Phase 2 Geobags.



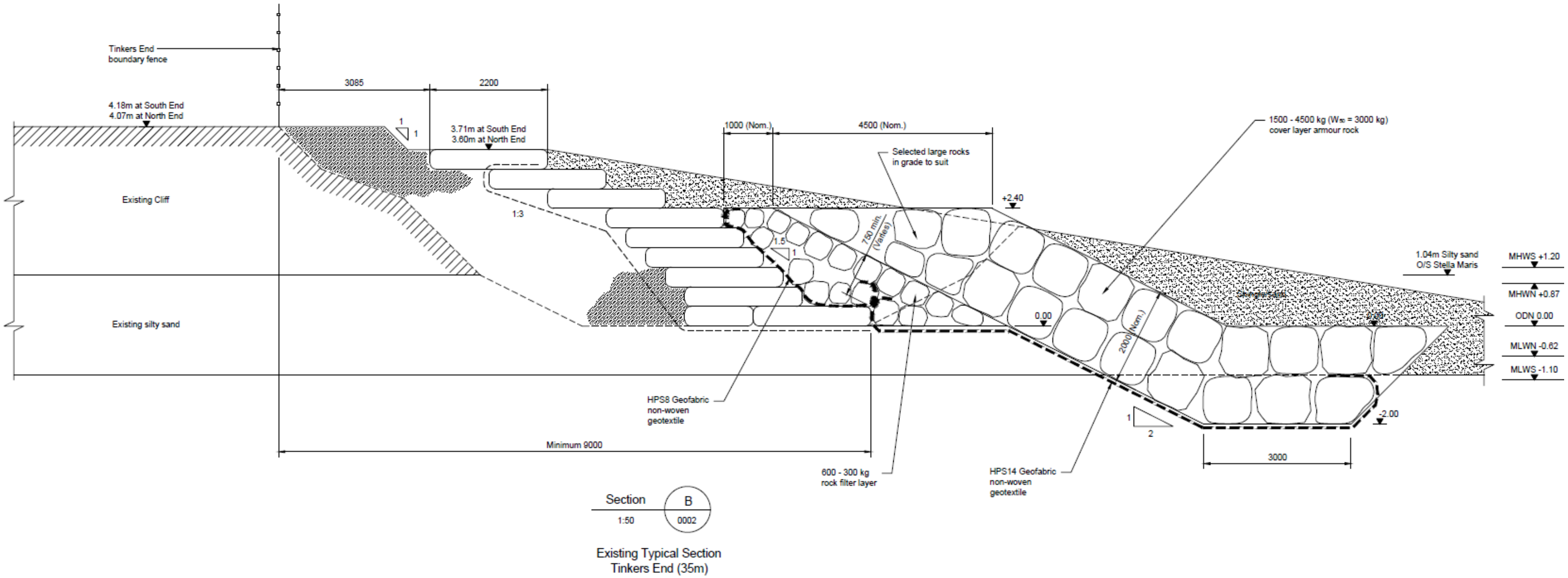
Source: Mott MacDonald

Figure 4.3: Option 10b – Section A



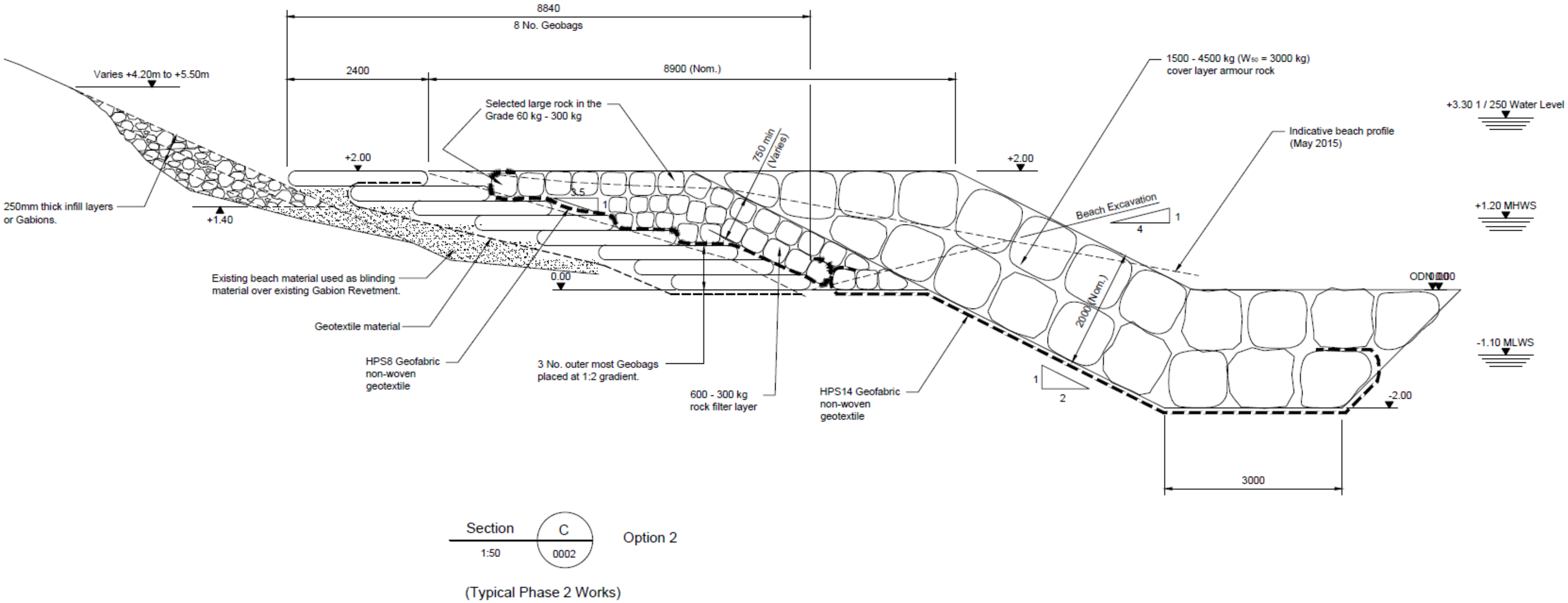
Source: Mott MacDonald

Figure 4.4: Option 10b: Section B.



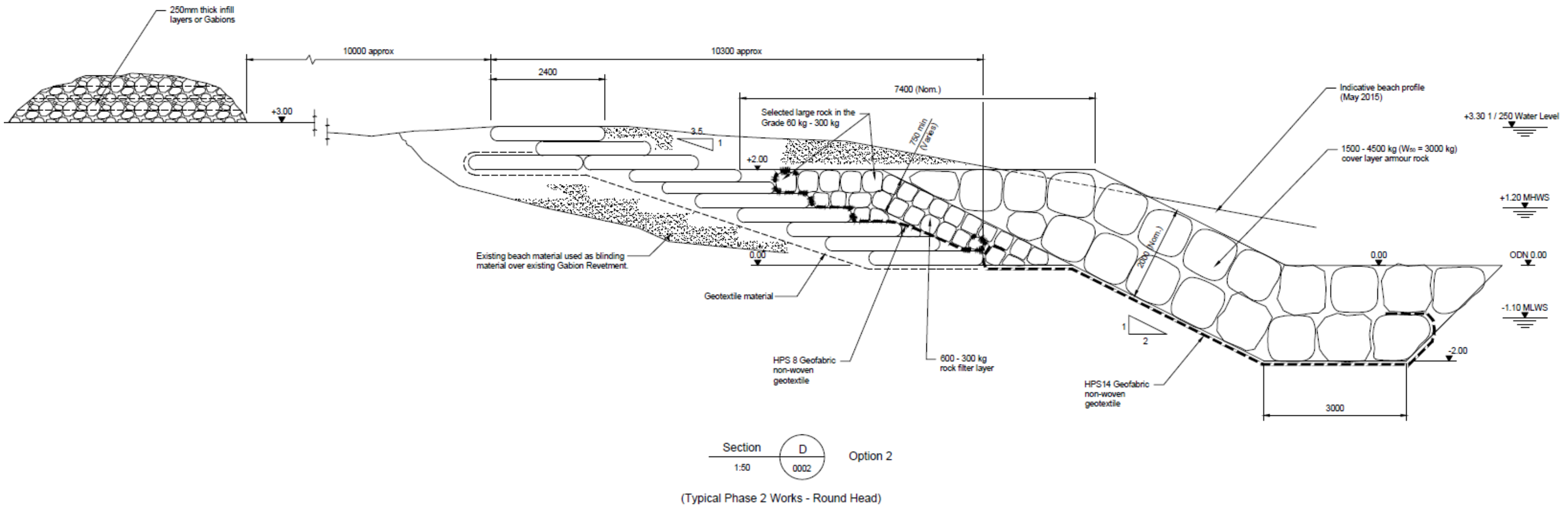
Source: Mott MacDonald

Figure 4.5: Option 10b – Section C.



Source: Mott MacDonald

Figure 4.6: Option 10b: Section D.



Source: Mott MacDonald

4.6.3 Option 10c – Phase 1 and Phase 2 Geobag toe protection.

Option 10c provides rock armour toe protection to the Phase 1 and Phase 2 Geobags with crest level up to +1.2m ODN to stabilise the existing structure against draw down of the existing shingle/sandy beach to levels immediately following the 2013 storm event (0.0m ODN). Option 10c also includes an extension roundhead termination around the groyne at the northern end of the Geobag scheme. The total scheme length is 366m.

A plan view of the scheme is shown in Figure 4.7 and typical cross-sections at locations A, B and D (Figure 4.7) are shown in Figure 4.8, Figure 4.9, Figure 4.10 and Figure 4.11.

In addition a cross-section through a design for a southern termination (Section E, Tinkers End) is shown in Figure 4.12.

4.6.3.1 Efficacy and advantages

Option 10c will provide good toe protection to ensure structural integrity of the Phase 1 and Phase 2 Geobags is maintained if beach levels drop during an erosion event.

In the present design, the scheme is extended around the terminal Geobag groyne at the northern end of the existing defences. The need for this groyne should be re-evaluated at a later design stage and if found to be ineffective it should be removed and replaced by a simple curved termination to the cliff line. This will have a cost saving of around £140,000 (50m length).

The seaward extent (cross-shore) of the new structure is marginally less than Option 10b (1.0m approx.). Works can be readily carried out entirely from foreshore which can be easily accessed. The rock armour of size specified (1.5t-4.5t) could be easily sourced either locally or imported from Europe. The structure is fully buried in beach at most times with toe rock being exposed only during storm beach drawdown. It is considered that the structure form (voids) would encourage beach build up. The construction cost of the structure is marginally less (20%) than Option 10b.

4.6.3.2 Constraints and disadvantages

Option 10c will be a significant construction requiring excavation and carful rock placement. Geobags will not be protected from damage by wave attack and/or shingle abrasion if they are exposed and may require continual maintenance involving repairs. The new works would extend approximately 10m seaward (cross-shore) of the existing seawall toe. The construction of the entire structure would require tidal working. Some restrictions to access on the upper part of the beach (12m width) will occur during beach draw down. The low toe trench formation level below MLWS will be required to ensure adequate support to the existing seawall toe and provide a fully buried toe. The difficulty of low level toe construction (below MLWS) could be mitigated by the construction of the toe in short lengths (up to 10m)

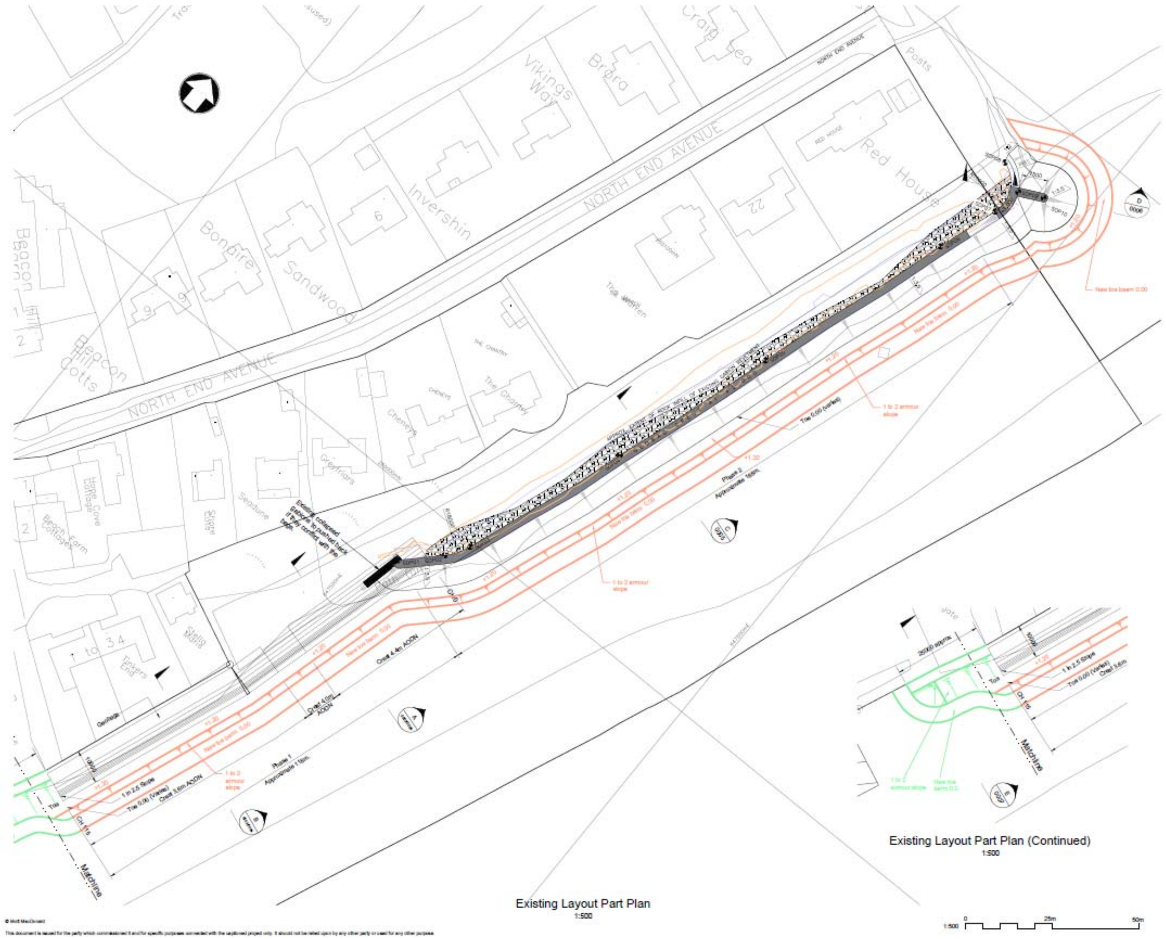
4.6.3.3 Impacts

Providing the scheme remains buried, no impacts are anticipated.

4.6.3.4 Costs

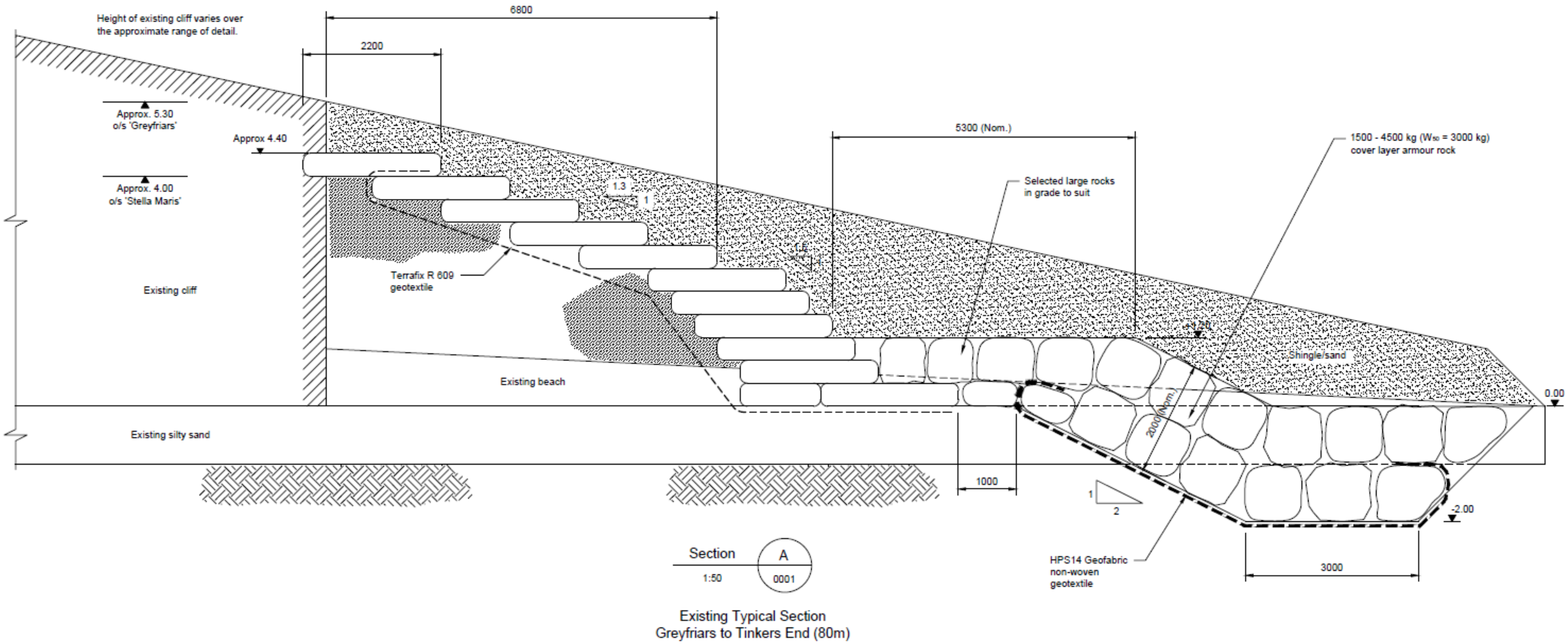
The total cost of the scheme is estimated to be £1,028,223 (Table 4.1). This includes design, contracts, procurement and site supervision, contingency and construction costs. It also includes provision of a full height heavy rock armour revetment at the southern end of the scheme (Figure 4.12).

Figure 4.7: Option 10c - Rock toe protection to Phase 1 and Phase 2 Geobags.



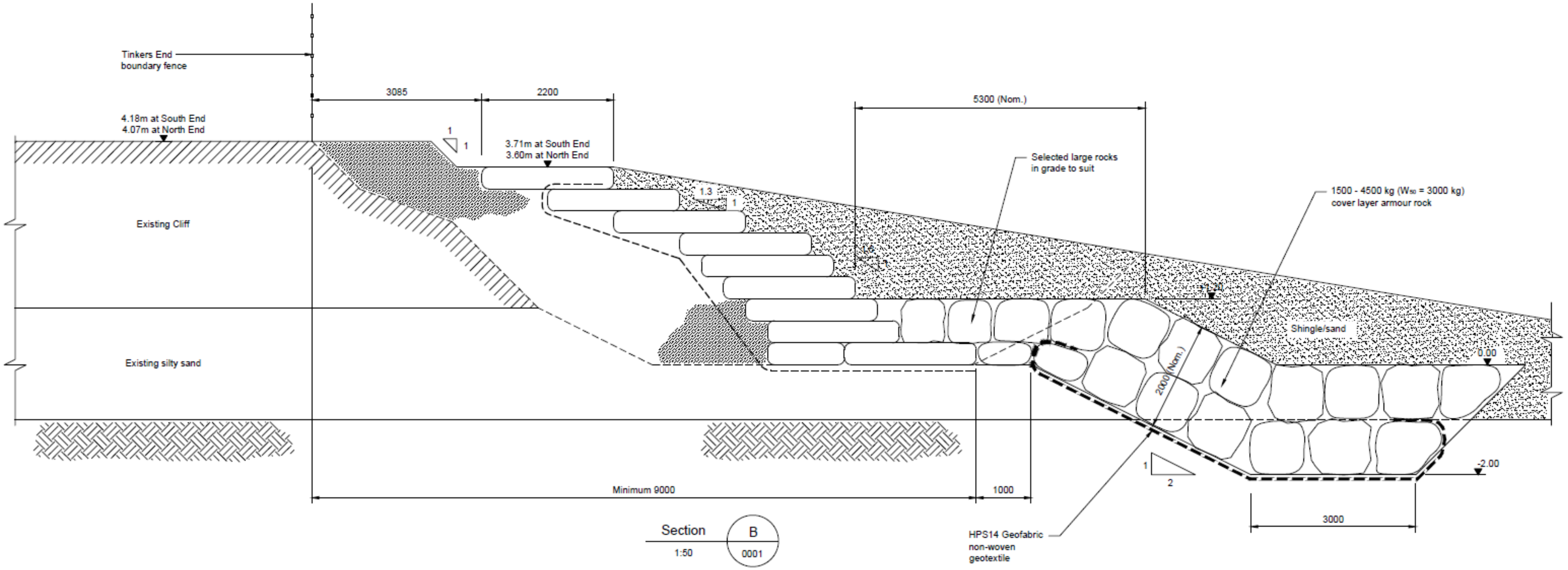
Source: Mott MacDonald

Figure 4.8: Option 10c – Section A.



Source: Mott MacDonald

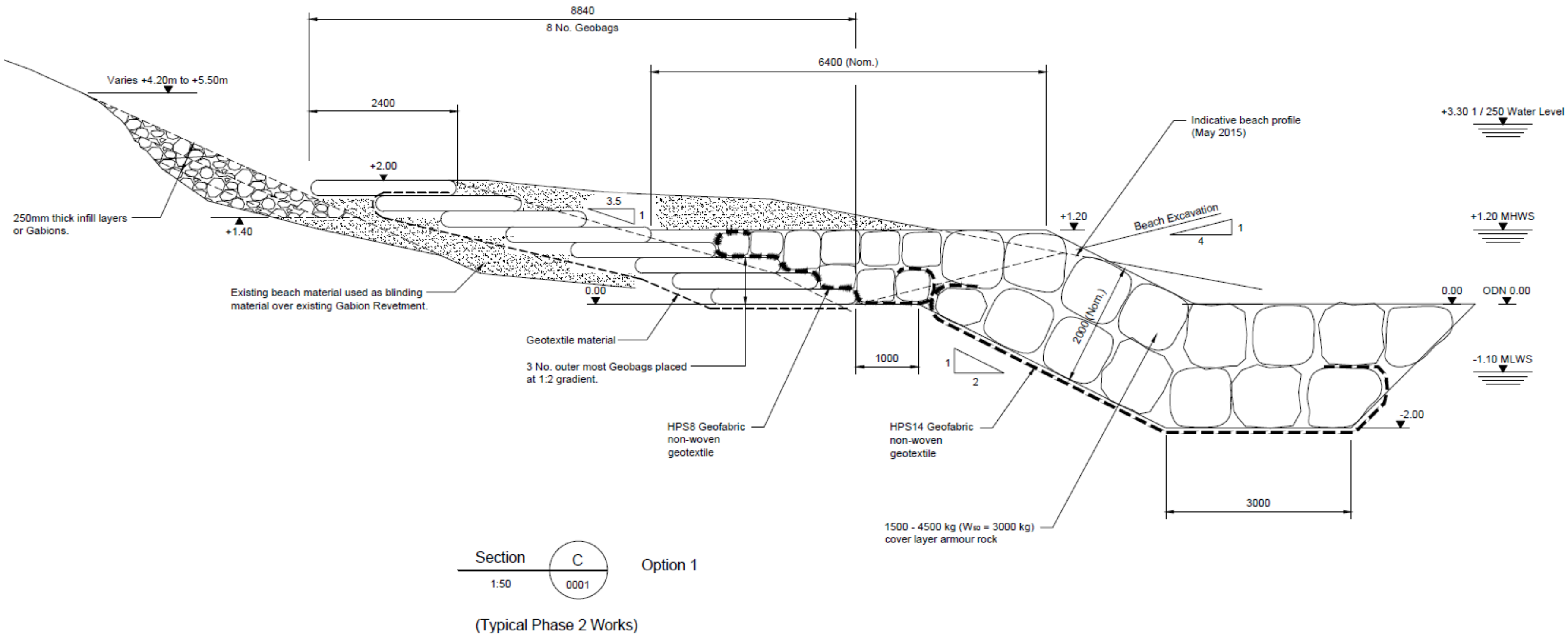
Figure 4.9: Option 10c – Section B.



Existing Typical Section
Tinkers End (35m)

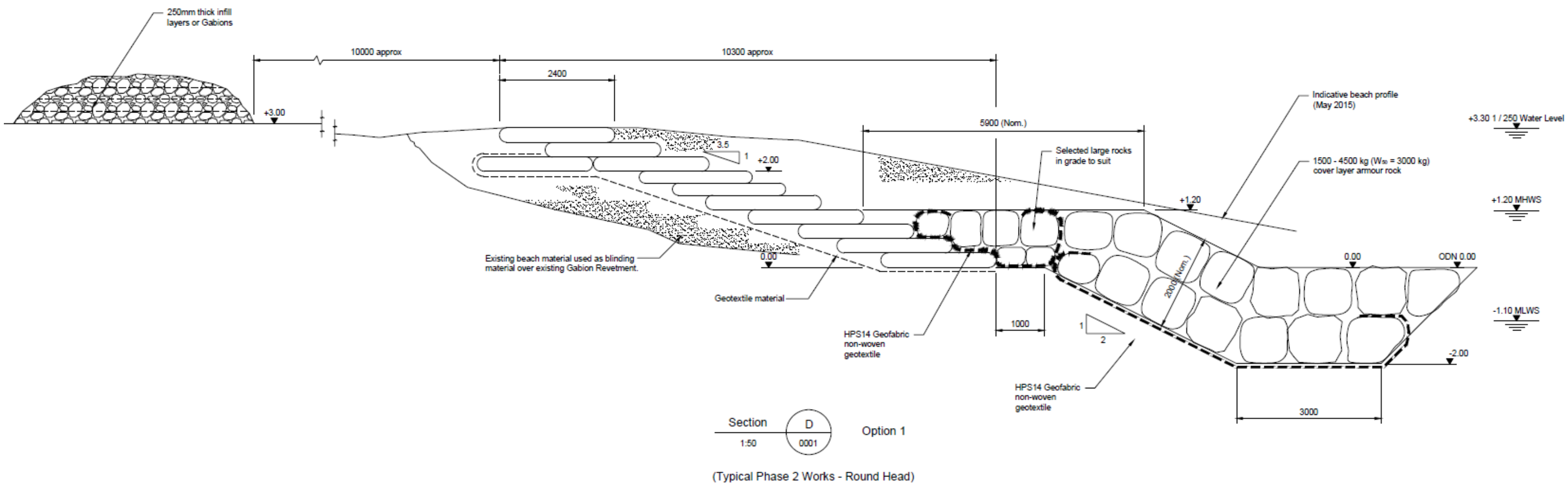
Source: Mott MacDonald

Figure 4.10: Option 10c – Section C



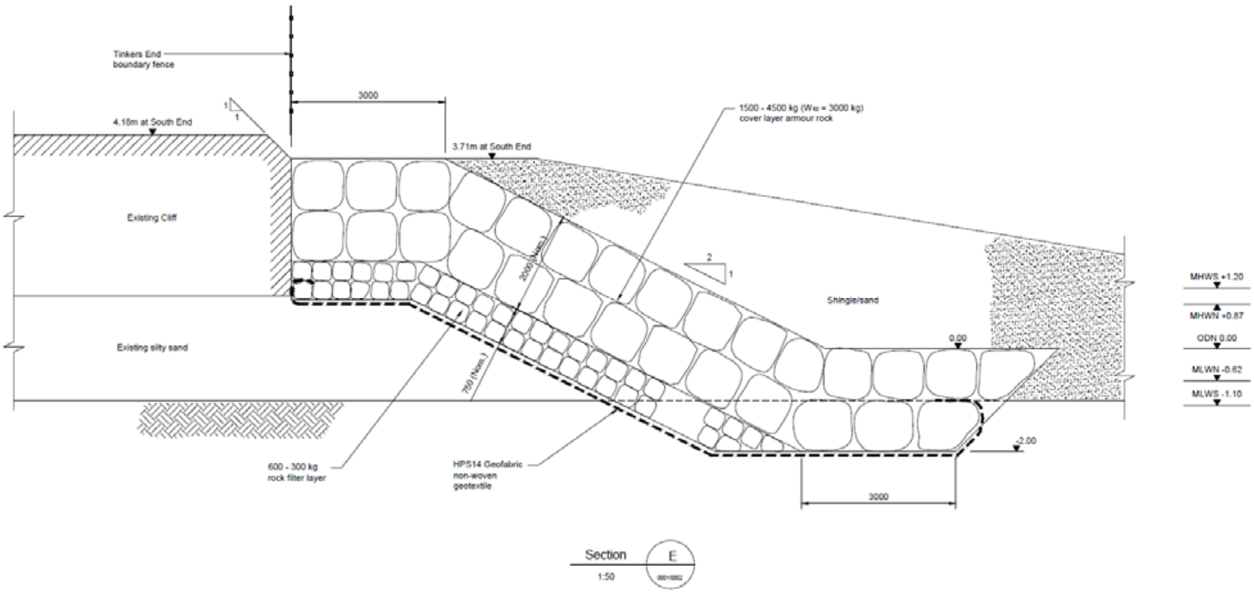
Source: Mott MacDonald

Figure 4.11: Option 10c – Section D.



Source: Mott MacDonald

Figure 4.12: Option 10c – southern termination – Section E.



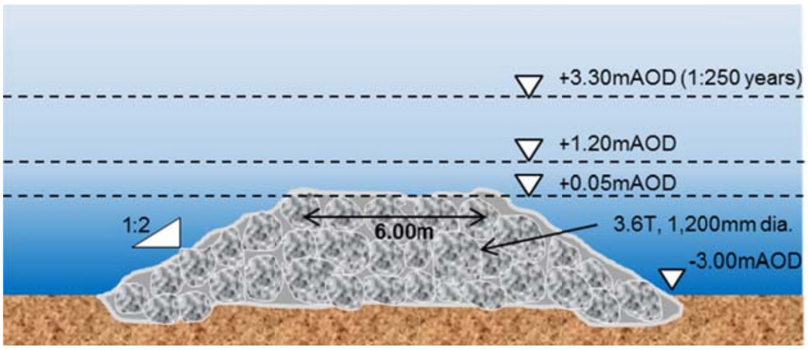
Source: Mott MacDonald

4.7 Option 12 Artificial Reef

The Thorpeness Coastal Erosion appraisal (Mott MacDonald, 2014) has identified wave energy focus on the frontage as being one of the main causes of extreme erosion during storm events. An artificial reef, constructed using suitable materials[2] could significantly limit wave energy on the frontage with a limited impact on the adjacent areas. To be effective the reef would need to be: (a) at an appropriate distance offshore; (b) immobile in all wave conditions; and (c) remain below water at all states of the tide. Artificial reefs have been deployed at a number of locations around the world and found to effectively reduce beach erosion. In many cases they have been observed to actually promote accretion in their lee.

A 250m artificial submerged reef option would reduce wave energy reaching the shoreline and therefore would moderate beach erosion. A typical reef cross section is shown in Figure 4.13.

Figure 4.13: Typical reef cross-section



Source: Mott MacDonald, 2015

[2] rock, sand 'sausages', castings, re-cycled vehicle tyres etc.

The rock size grading was assessed as a standard 3,000 to 6,000kg and the crest level set as +0.05mOD. The reef would therefore be submerged most of the time. The rock rubble mound structure concept design was developed based on the existing information.

4.7.1 Efficacy and advantages

Reefs act to dissipate the energy of shoreward propagating waves and thus reduce the incident energy on the beach face and reduce erosion. In normal conditions they have very little impact on waves owing to the shallow wave base of smaller waves. However, they can act to force larger waves to break and thus become more effective as a defence in more extreme conditions.

Reefs have an additional advantage of providing new habitats for marine life (e.g. oyster reefs and reef balls) and thus make a positive contribution to biodiversity and populations. This solution also avoids any restriction to beach access and has no visual impacts.

4.7.2 Constraints and disadvantages

Construction of a reef could not be undertaken from the beach adding significantly to costs. The design and construction must be carefully executed to balance the local wave shelter effect and associated accretion afforded by the reef with the need to allow alongshore transport to proceed unhindered once the now beach geometry is established. This is likely to be challenging and may require reef modifications in sit to adjust performance adding significantly to costs.

4.7.3 Impacts

It is anticipated that a reef would promote the development of a salient in its wave with dimensions and orientation governed by the geometry of the structure, alongshore and cross-shore sediment supply and the incident wave climate.

4.7.4 Costs

The artificial reef option is costly but significantly less expensive and intrusive than a surface piercing offshore breakwater. Nevertheless the cost is estimated to be £3,031,700 with additional £20,000 for structural surveys over the lifetime of the scheme (assumed to be 50 years), Table 4.1.

4.8 Quantitative Options Appraisal

4.8.1 Cost

For comparative purposes a summary of the high-level costs for the options above is provided in Table 4.1. Setting aside Option 1, Table 4.1 shows that Option 10a is the most expensive and Option 2 is the least expensive. It should be noted that the costs quoted are in addition to costs of the baseline Option 1 response currently implemented by SCDC.

On the basis of guidance from SCDC regarding potential funding availability of between approximately £500,000 and £1,000,000, Table 4.1 indicates that the only affordable options are Options 2, 9 and 10c.

It should be noted carefully that no provision in these costs has been made for decommissioning that may be required in the future. It would be prudent to add a further 50% to the costs to cover this. In addition it would be advisable to set aside funds for all options to cover the cost of maintenance (£50,000 for Option2 every 5 years and £20,000 for Options 9, 10a, 10b, 10c and 12 over 30 years) plus £11,000 for gabion repairs.

Table 4.1: High-level costing of defence options including design, contract procurement & site supervision and construction elements based on 2015 prices.

Remediation Works	Option 2	Option 9	Option 10a	Option 10b	Option 10c	Option 12
Total length	**-**	**329**	**410**	**391**	**366**	**-**
Cost/metre	**-**	**£1,554**	**£9,480**	**£3,524**	**£2,809**	**-**
Total Cost	**£223,600**	**£511,436**	**£3,887,000**	**£1,377,911**	**£1,028,223**	**£3,031,700**

4.8.2 Performance

In addition to the financial appraisal, a detailed evaluation of the six options was also carried out by comparing the performance of each option against Option 1 and considering impacts on processes, sustainability, affordability, stakeholder concerns, design and construction. The evaluation followed an objective quantitative approach frequently used in assessments of this nature, with appraisal criteria given a score of 10, 8, 6, 4, 2 and 0 to reflect very good, good, neutral, poor, very poor and bad performance, respectively. In addition a weighting was given to individual criteria to reflect the relative importance with regards to scheme performance and impacts. The detailed scoring is shown in Table 4.2.

Omitting the assessment of Option 1, the evaluation in Table 4.2 shows that the preferred option is Option 2 which combines soft protection measure and minimum cost. Option 10c (Phase 1 and Phase 2 Geobag toe protection) ranks 2 with Options 10b, 10a, 5a and 12 ranked 3, 4, 5 and 6 respectively. **While scores allocated in Table 4.1might be disputed, it is considered that Option 2 would remain the preferred option given its significantly higher overall score (i.e. around 20% more that Option 10c ranked at 2).**

Table 4.2: Quantitative Options appraisal using weighted key parameters. The sum is calculated by the addition of option score in a given criteria multiplied by the weighting.

		Weight	Option 2	Option 9	Option 10a	Option 10b	Option 10c	Option 12
Primary Aim	Prevent short to medium term loss of property		Pass	Pass	Pass	Pass	Pass	Pass
Processes	Maintain integrity of beach	20	10	8	8	8	8	10
	Maintain net longshore drift	20	10	6	6	8	8	8
	No negative impacts on beach to the south	20	10	6	4	6	6	8
	Effective transition between defended and undefended frontage	20	8	6	6	6	6	8
Sum			760	520	480	560	560	680
Rank			**1**	**5**	**6**	**3**	**3**	**2**
Sustainibility	No adverse effect on SSSI	10	8	8	8	8	8	10
	Maximise the use of the existing defences	10	10	10	2	6	8	10
	Mnimise as far as possible the need for future works	10	0	6	10	8	8	8
	Make use of existing materials and minimise importation	10	6	2	0	0	0	0
Sum			240	260	200	220	240	280
Rank			**3**	**2**	**6**	**5**	**3**	**1**
Affordability	Capital Cost (against "Do Nothing")	100	10	2	0	0	2	0
	Minimise potential future mainteance costs	50	2	4	10	8	8	8
	Develop strong economic case for support	20	8	6	0	2	4	0
Sum			1260	520	500	440	680	400
Rank			**1**	**3**	**4**	**5**	**2**	**6**
Stakeholder	Maintain Access	10	10	6	6	8	8	10
	Visual Impact	10	10	4	4	6	6	6
Sum			200	100	100	140	140	160
Rank			**1**	**5**	**5**	**3**	**3**	**2**
Design	Design Risk & uncertainties	20	4	6	8	8	8	4
	Natural range of beach elevations to accomodate storms	10	10	6	8	8	6	8
	Design withstands present day 1:50 event	10	8	10	10	10	10	10
	Provide defence over 30 - 50 years and allowance for SLR	10	8	10	10	10	10	10
	Avoid any further seaward extension of the defences	20	10	4	0	4	6	4
	Termination design	10	8	10	10	8	8	0
	Reduce sudden collapse risk	100	8	8	10	10	10	2
	Track record of solution	20	8	6	10	8	8	6
Sum			1580	1480	1740	1760	1780	760
Rank			**4**	**5**	**3**	**2**	**1**	**6**
Construction	Safety and Impact on Stakeholders during construction	50	10		4	6	6	6
Sum			500	0	200	300	300	300
Rank			**1**	**6**	**5**	**2**	**2**	**2**
Total			**4540**	**2880**	**3220**	**3420**	**3700**	**2580**
Rank			**1**	**5**	**4**	**3**	**2**	**6**

5 Conclusions

5.1 Conclusion

Options for management of the frontage that are broadly sustainable within the context of the policies and underlying intent for management as identified within the Suffolk SMP have been identified and assessed. Further, in accordance with the outcomes of the project kick off meeting, a design event has been developed that conforms to the PAR objectives as well as reflecting as far as practicable the series of damaging events throughout 2013 that culminated in the December 2013 event that had an estimated return period of 1:250 years.

The study has used all available information to identify the best means of providing an effective erosion defence to properties over the next 30 to 50 years in a manner that is acceptable economically and does not interfere with the continued supply of sediment through the area while at the same time addressing the recurrence of periods of severe local erosion.

In the study 13 different conceptual options have been appraised against a set of key criteria agreed with SCDC. Options have been developed to meet the primary aim of preventing, in the short- to medium-term, loss of property and allow time for future adaptation.

On the basis of the initial appraisal, six options have been identified for further more detailed investigation and high-level costing. These include:

- Option 1 (reactive management);
- Option 2 (proactive management);
- Option 5a (rock buttresses);
- Option 9 (steel sheet pile wall);
- Option 10 (rock revetment); and
- Option 12 (artificial reef).

It should be noted carefully that:

- No option can guarantee retention of the beach currently providing protection;
- Defences cannot prevent erosion of the beach sediments;
- There will be impacts on the adjacent coastline; and
- Management and monitoring is required adding to whole life costs.

In common with the December 2013 event, the design event examined for each option has a return period of approximately 1 in 250 years. Based on available information, this event has 0.4% probability of being exceeded within any given year, and an 18% of probability that the design event will be exceeded during the 50 years design life. It is noted that the Environment Agency guidelines recommend that designs for coastal defence schemes should be able to accommodate an event with 39.4% of probability of being exceeded during the design life. Thus while the design event developed to assess the concept design can be seen as overly conservative, given the 50 years design life of the remediation works, it is considered to be necessarily precautionary given the recent history of the frontage.

Concluding remarks about each of the six options considered in this report are now provided.

5.1.1 Option 1: Reactive Management

The Phase 1 and Phase 2 Geobag structures have thus far protected the North End Avenue frontage successfully, albeit at the expense of some minor damage. Give the occurrence of a series of damaging events throughout 2013 including prolonged easterly wind in the spring, an autumn storm, and the 1:250 year event in December, this demonstrates performance over and above the original design specification and indicates that the structure could probably withstand similar events in the future and deliver the PAR objectives.

The greatest unknown, and the greatest risks to the Geobag defences, concern the magnitude, duration and frequency of future damaging storm events. Although it is argued above that the Geobags will continue to provide a coastal defence function, it remains unclear exactly what the residual life of the scheme is at present, and how the scheme might perform in the future. However, whether or not the defences can be relied upon to continue meeting the PAR objectives is a legitimate question to ask given the resources needed for implementation of any of the options identified in this report. On the basis of available evidence, and on the balance of probability, it is considered that the present defences will provide the coastal defence function for which they were designed providing their present structural integrity does not degrade further.

In the meantime, monitoring of the beach behaviour will provide further information to better understand the local coastal dynamics and provide the time required to identify and develop the most appropriate defence strategy for Thorpeness and to seek the resources required. In this respect, the XBand radar presently deployed at the northern end of the frontage will provide valuable data to improve the understanding of wave impacts and beach responses.

While Option 1 carries a risk, it has been effective to date and is judged to outweigh the limited advantages that can be provided by a defence scheme that is affordable. With the knowledge that the frontage will be protected against the next event(s), it is therefore not unreasonable to defer a management decision until the occurrence of the next damaging event. The condition of the scheme and its performance can then be re-evaluated and appropriate steps can then be taken.

An effective beach monitoring program will be required to provide an early warning of potential threats to beach resilience and a beach management and emergency plan (BMEP) will be required to mitigate the risks of further coastal erosion.

5.1.2 Option 2: Proactive Management

A beach recharge option follows on logically from Option 1 by careful monitoring of beach levels and providing a means of restoring the beach to a healthy condition in the event of erosion pressure. For the option to be viable it will be necessary to obtain permission to exploit a donor site and to undertake a study to assess the wider implications to the coast. Further, the practical aspects of the option concerned with mobilising sufficient resources to undertake the work, at what might in the event be short notice, might prove to be both challenging and expensive. However, this can be mitigated through monitoring so that an early warning of falling beach levels can be provided ahead of a critical erosion event and actions taken to address the problem.

An effective beach monitoring program will be required to provide an early warning of potential threats to beach resilience and a beach management and emergency plan (BMEP) will be required to mitigate the risks of further coastal erosion.

5.1.3 Option 5a: Rock buttresses

Since cross-shore sediment transport dominates the beach dynamics during erosive conditions, irrespective of the trapping efficiency of an Option 5a scheme, it would be ineffective in preventing material moving offshore. Further, such a scheme could not prevent subsequent alongshore transport in the narrow surf zone owing to restricted cross-shore extent. Option 5a is also likely to have impacts on the down-drift beach during periods favouring accretion in the buttress embayments. The premise that Option 5a could hold the upper beach sediments in place and protect the Phase 1 and Phase 2 Geobags is therefore highly questionable and consequently is not considered viable.

5.1.4 Option 9 (Steel Sheet Pile Wall)

While a steel sheet pile wall will provide the desired backstop function to halt erosion in the event of Phase 1 and Phase 2 Geobag failure[3]. The lifetime of the piles cannot be guaranteed and they may not be effective for the expected lifetime of the Phase 1 and Phase 2 Geobags. A further concern relates to exposure of the piles in the unlikely event of failure of the Phase 1 and Phase 2 Geobags Option 9 will only be effective as a protection once the existing defences are breached and/or damaged in part or whole. With such a failure, the piled vertical wall would attract considerable wave reflection resulting in further erosion of the beach in front of the structure subsequently requiring the provision of wave dissipating structure such as rock armour in front. Unlike a rock structure, where minimal maintenance is required, maintenance of Option 9 will be required to mitigate potential corrosion.

With access being unlikely from land at the rear of the existing seawall for installation of piling (gardens of properties), a large crane (with extended boom) is required for piling from foreshore in front of the existing seawall. Access will be limited due to tidal working

With top of finished pile being 1.5m – 2.0m lower than the ground level, the piles may either be driven from existing ground, requiring longer piles than required and would need to be left in place (too costly to excavate and trim pile) or the required length of pile is driven from excavated trench at the top down to, say +2.0m ODN. The latter would be more expensive due to the need to excavate and this method is unlikely to be acceptable to the residents.

5.1.5 Option 10: Rock Revetment

Being the most reliable hard structure for on-shore defences a rock revetment option was included in the final set of selected options.

[3] Thought to be unlikely given past performance (5.1.1)

However, although it would ensure a significant level of protection to the frontage it may also restrict beach access and encroach further cross-shore than the existing defences unless these were removed. High variability in beach level known to exist here would require a deep toe to ensure structural stability and increase the scheme cost as well as its footprint. It may also be responsible for a significant change in beach sediment dynamics which are presently unknown. As it offers the best level of protection against outflanking it is believed at this stage that this option is likely to be the best option for the northern end of the frontage.

5.1.5.1 Option 10a

Option 10a will meet all defence requirements with minor down-drift impacts. However, at a cost of at least £2.8M, this option is not viable.

5.1.5.2 Option 10b

Option 10b provides toe protection to the existing structure and armours the lower Geobags against wave action thereby adding resilience with minimal impacts. It provides improved scheme terminations at the northern and southern ends of the defences. However, the cost of option 10b is beyond the upper budget limit of £1M.

5.1.5.3 Option 10c

Option 10c will improve Phase 1 and Phase 2 Geobag performance in the event of low beach levels by proving support for the structures and preventing terminal scour. It provides also improved scheme terminations at the northern and southern ends of the defences.

5.1.6 Option 12: Artificial Reef

The artificial reef is ruled out on cost grounds.

5.2 Final remarks

It is clear from this study that there is no simple solution to the coastal defence issues at Thorpeness. With budget constraints and local coastal process uncertainties in mind, and with the likelihood that the existing defences will continue to provide protection from erosion, it is considered that structural enhancements to the existing Geobags will deliver only limited benefits that may not stand up to a detail cost-benefit analysis. Instead it should be recognised that a maintained beach, either by Option 1 or 2, provides the most effective and sustainable defence solution for the time being providing the issues regarding sediment recycling can be overcome. This course of action will provide further time to develop options and possibly secure additional resources.

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Appendices

Appendix A. Initial options appraisal

A.1 Commentary on rejected options.

A.1.1 Option 3: Shingle engine

The 'shingle engine' follows the same principle as the 'sand motor' implemented in the Netherlands in 2011 comprising a volume of 21,000,000m^3 of sand in an area of 128 ha. The intention of the project, which so far has performed as predicted, is to nourish the shoreface via natural sand dispersal from this source and thereby avoid the annual or biannual works of the past.

A.1.1.1 Efficacy and advantages

The Shingle engine approach would be a pilot project to test the effectiveness and efficiency of a local mega-nourishment as a measure to account for local erosion problems the anticipated increased coastal recession in this century. In concept it is proposed that a single mega-nourishment, once every 20 years, will be more efficient and effective in the long-term than traditional beach and shoreface nourishments, presently being used with typically a three to five year interval.

A.1.1.2 Constraints and disadvantages

The approach would be highly experimental and untested for shingle which has very different behaviour to sand. The source of the sediment may be distant adding greatly to costs and there is uncertainty about its capacity to offer the standard of coastal protection required for Thorpeness for the next 30 years.

A.1.1.3 Impacts

The impacts are unknown. However, it might be anticipated that material from the mega-nourishment would be transported alongshore over time contribute to coastal protection at other locations. Equally, the transport of sediments to other areas may impact on navigation and habitats.

A.1.1.4 Costs

Very high capital cost is the primary reason for rejecting this option. For example a concept scheme design for Slaughden investigated HR Wallingford would require 2,000,000m^3 of sediment to provide a sediment 'engine' with a maximum width of 200m and length of 1.8km at a cost of £14M. For Thorpeness although less sediment may be required, the cost is still likely to be in the region £8M-£10M.

A.1.2 Option 4, 5b and 6: Groynes

Here for simplicity we address the three groyne options together as they have a common function and have similar impacts and costs. These include: (a) Option 4 (timber groynes); (b) Option 5b (shore-normal rock groynes); and (c) Option 6 ('fishtail' groynes).

Shore-normal timber groynes are a familiar sight on many UK beaches and in many places they are relatively effective. Increasingly the use of expensive hardwood for groyne construction is being replaced by the use of rock which is less expensive and much more resilient. Rock groyne designs range between straight, shore-normal structures to more complex 'fishtail' shapes which may be orientated at an angle to the coast in such a way as to enhance their ability to trap and retain sediments in a given prevailing wave climate and tidal regime.

As an example of a large, complex scheme, 23 'fishtail' groynes were installed along the Clacton frontage over a two year period with beach nourishment to complete the scheme in October 2015. The scheme covered a 5km stretch of coastline and cost £36M, of which £27M was FDGiA. The project provides protection against coastal erosion to over 3000 properties.

Irrespective of the construction materials or the detailed design, groynes work by intercepting alongshore sediment transport and holding the beach *in situ*. Often, beach recharge is used to fill newly installed groyne embayments.

It is noted that a number of major coastal schemes of this nature have been implemented at sites in the region over recent years. These include South Felixstowe in 2008, Central Felixstowe in 2010 and the Clacton to Holland-on-Sea defences noted above. All of these schemes involved the installation of rock groynes and subsequent beach recharge to supplement the depleted beach levels at the sites.

A.1.2.1 Efficacy and advantages

The efficacy of groynes is entirely dependent on their ability to trap and retain beach sediments. They have little control on cross-shore sediment transport processes and thus sediments can 'leak' seawards and be lost from groyne embayments leading to beach erosion, especially during storms. In many cases groynes only act to modify the alongshore transport processes and frequently high beach levels are developed at one end of a groyne embayment, while at the other end, beach levels may be very low. In this situation, sediments moving alongshore by natural processes can effectively bypass the groynes.

A.1.2.2 Constraints and disadvantages

The primary constraint for the Thorpeness frontage concerns accommodation space for groynes owing to the reduced beach width. To be effective, groynes would need to span most of the intertidal beach width. The present lack of understanding of medium- to long-term coastal processes at Thorpeness, combined with the relevant footprint of the scheme, and their poor performance in storms when effective beach protection is most required, makes all groyne options unviable.

A.1.2.3 Impacts

The most significant impact which cannot be quantified without an in-depth study, concerns impacts on adjacent beaches. While it is understood that net alongshore sediment transport is relatively low along the Thorpeness frontage, any disruptions will impact the down-drift beaches and could potentially lead to erosion. Mitigating these effects could potentially add unforeseen maintenance cost. A secondary, but nevertheless significant impact, concerns beach access, which would be greatly restricted and would probably require accommodating in any design, adding further to cost.

A.1.2.4 Costs

A single hardwood timber groyne typically cost around £230,000. Since at least four would be required at Thorpeness, this takes the total cost to around £1M. Further, in the Central Felixstowe Scheme protecting the coast from Cobbolds Point to The Pier, 20 rock groynes have been installed over a 1.6km length of coast with beach nourishment placed to complete the project. The works cost £10M and were justified by protecting 1400 properties against coastal erosion. While a more modest scheme for Thorpeness may comprise only 5 groynes and nourishment, the cost is likely to be in the region of £3M and thus unaffordable. Further, it is highly unlikely that such a scheme would be supported through Flood and Coastal Resilience Partnership Funding.

A.1.3 Option 7: Increase Geobag durability

It has been suggested that the use of polyuria spray or another suitable coating on the Geobags may increase their resilience against abrasion should they again be exposed.

A.1.3.1 Efficacy and advantages

The efficacy of increasing durability has not been tested or demonstrated and remains merely a suggestion. Issues identified below indicate that efficacy is likely to be low.

A.1.3.2 Constraints and disadvantages

Geobag strengthening by whatever means is experimental and cannot be guaranteed to improve resilience. Further, any such techniques can only be undertaken when the Geobags are exposed either through excavation or by natural processes thus adding further to the risk of damage to the existing Geobags.

A.1.3.3 Impacts

It is considered that the application of a hard coating to the Geobags would constrain bags mobility and reduce the capacity of the Geobags scheme to flex with wave action. A ridged structure of this nature could potentially be pulled apart in energetic conditions if one part of it begins to move. A coating would also greatly reduce the permeability of the Geobags and could result in higher wave pressures on the structure if it is exposed.

A.1.3.4 Costs

Owing to the undesirable potential impacts and the constraints outlined above, this approach has not been costed. However, it is likely to be the cheapest option.

A.1.4 Option 8: Concrete sea wall

A seawall, whether vertical, curved or stepped, works by reflecting incident wave energy thereby reducing the energy and erosion which the coastline would otherwise be subjected to. In addition to their unsightly visual appearance, seawalls have two specific weaknesses:

Wave reflection induced by the wall may result in scour and subsequent lowering of the fronting beach; and

Seawalls can accelerate erosion of adjacent, unprotected coastal areas affecting the littoral drift process. In extreme cases, seawalls can be outflanked.

The design and type of seawall that is appropriate depends on aspects specific to the location, including the surrounding erosion processes.

A.1.4.1 Efficacy and advantages

Sea walls provide a strong, fixed line protection to the coastline and are frequently employed to protect high value assets. As a seawall is a static feature it will conflict with the dynamic nature of the coast and modify significantly the exchange of sediment between the land and the sea.

A.1.4.2 Constraints and disadvantages

Installation of a sea wall would require removal of the Geobags and gabions and involve major construction works that would probably require very restricted beach access during the works. Waves can scour material at the base of the wall causing them to become undermined unless they have deep foundations.

A.1.4.3 Impacts

It is considered that over time, given the relatively low rates of net alongshore sediment transport, that cross-shore sediment transport by wave reflection effects would progressively lower the fronting beach as well as impacting on sediment supply to the down-drift beach.

A.1.4.4 Costs

Sea walls are very expensive to construct. For the Thorpeness frontage the cost is estimated to be around £5M.

A.1.5 Option 11: Offshore breakwater

Breakwaters, also called bulkheads, reduce the intensity of wave action in inshore waters and thereby reduce coastal erosion. The dissipation of energy and relative calm water created in the lee of the breakwaters often encourage accretion of sediment (as per the design of the breakwater scheme). Breakwaters can be either emerged or submerged or may be submerged for some part of the tidal cycle.

Breakwaters are normally positioned offshore in the range 100 m to 600 m from the shoreline and may be single or multiple. They may be either fixed or floating, and impermeable or permeable to allow sediment transfer shoreward of the structures, the choice depending tidal range and water depth. Breakwaters are normally constructed using large rocks weighing up to 16T and their design is influenced by the angle of wave approach and other environmental parameters. Breakwater construction can be either parallel or perpendicular to the coast, depending on the shoreline requirements.

A.1.5.1 Efficacy and advantages

Breakwaters, when designed well, can provide a good level of protection to the coastline from wave action, and can promote accretion that will add further resilience to the shoreline.

A.1.5.2 Constraints and disadvantages

Due to the complexity of the coastal system dynamics its design also involves some significant risks in terms of performance and impact to the frontage. Breakwaters are also subject to damage, and overtopping in severe storms events.

A breakwater scheme would require careful and potentially expensive investigation, using for example, a physical model. Although used extensively in Europe, there are relatively few examples of offshore breakwaters in the UK, where high tidal ranges make their design even more challenging. The nearest to Thorpeness are the 8 breakwaters built in the 1990’s at Sea Palling, Norfolk and at Jaywick, Essex in 2008.

A.1.5.3 Impacts

In some cases breakwaters can lead to excessive salient build up, leading to tombolo formation reducing longshore drift (e.g. Sea Palling, UK). This trapping of sediment can cause adverse effects down-drift of the breakwaters leading to beach sediment starvation and increased erosion. This may then lead to further engineering protection being needed down drift of the breakwater development.

A.1.5.4 Costs

Of all the options considered the offshore breakwater is likely to be the most expensive scheme. For example the offshore breakwater scheme installed at Jaywick, near Clacton consisted of one additional breakwater, the extension of the 2 “fishtail” groynes and beach recharge. In total scheme cost £9M in 2008, roughly 50% of this was required for the breakwater.

A.1.6 Option 13: Alternative experimental solutions

Other experimental solutions have not been identified. However, given the requirement for a scheme to offer a good standard of coastal protection for the next 30 years makes it unlikely that a risk-free alternative will be identified.

Table A1. Options appraisal summary

Option	Description	Advantage	Disadvantage	Comment
Option 1	Do nothing + monitoring	Minimum cost. Assessment of the beach capacity to recover naturally. Enhanced understanding of the coastal processes by monitoring.	Emergency plan to be developed and ready to be implemented. Potential risk of failure if not carried out on time	To be considered further
Option 2	Beach recharge at the north end + monitoring + emergency plan	Build the resilience of the beach. Protection at the north end of the frontage. Low cost. Minimum impact on coastal processes. Minimal impact on access/view.	Emergency plan to be developed and ready to be implemented. Potential maintenance and emergency costs. (beach recharge or remedial works for the existing geobags) Potential risk of failure if emergency measures not carried out on time but could be managed by monitoring the beach levels and defining a critical beach level.	To be considered further
Option 3	Shingle engine (including near shore re-profiling to simulate a mini Ness accretion feature)	Build the resilience of the beach. No impact on access/view	Performance risk - Regional scale coastal erosion structure. High cost. Uncertain sediment source. Design risk due to uncertainties regarding the coastal processes taking place.	Not considered further due to performance risk.
Option 4	Timber breastwork / groynes	Build the resilience of the beach. Hard structure satisfying stakeholder expectations in terms of long term coastal protection scheme.	Medium High capital cost. High whole life cost. The groynes are designed to allow the beach material to be trapped to raise the beach profile. The uncertainties regarding the coastal processes may lead to inefficient design. Potential impact on longshore sediment drift. Impact to access/view.	Not considered further due to cost, performance risk and unknown impact on sediment transport.
Option 5a	Rock Buttresses	Have a potential to hold beach sediments in place on the upper part of the profile.	Medium High capital cost. Medium whole life cost.	To be considered further
Option 5b	Rock Groynes	Build the resilience of the beach. Minimum maintenance requirements. Hard structure satisfying stakeholder	High capital cost. The groynes are designed to allow the beach material to be trapped to raise the beach profile. The	Not considered further due to cost, performance risk and unknown impact on sediment transport.

Option	Description	Advantage	Disadvantage	Comment
		expectations in terms of long term coastal protection scheme.	uncertainties regarding the coastal processes may lead to inefficient design. Impact on longshore sediment drift. Impact to access/view.	
Option 6	Fishtail Groynes	Build the resilience of the beach. Minimum maintenance requirements. Hard structure satisfying stakeholder expectations in terms of long term coastal protection scheme.	High capital cost. Performance risk - usually in place for sandy beach (as opposed to gravel)	Not considered further due to cost, performance risk and unknown impact on sediment transport.
Option 7	Higher durability geobags (polyuria spray)	Minimum capital cost Maximum use of existing defences	Untested solution. Performance and design life risks.	Not considered further at present due to performance risk. In situ test of durability recommended.
Option 8	Concrete sea wall	Hard structure satisfying stakeholder expectations in terms of long term coastal protection scheme. Minimal failure risk.	Promote beach erosion. High Capital Cost. Construction practicality. Negative down-drift impacts possible.	Not considered further due to cost and beach erosion promotion.
Option 9	Steel sheet pile wall	Hard structure satisfying stakeholder expectations in terms of long term coastal protection. Failure risk low.	Promote erosion. High Capital Cost. Construction practicality. Aesthetical impact	To be considered further.
Option 10	Rock Revetment	Hard structure satisfying stakeholder expectations in terms of long term coastal protection. Failure risk low. Provides good protection to the north end	High capital cost. Encroach further on the beach with a risk to impact the longshore drift.	To be considered further
Option 11	Offshore breakwater	Reduce wave energy. Builds the resilience of the beach.	High capital cost. Design must be based on good understanding of the coastal process.	Not considered further due to cost
Option 12	Artificial Reef + Monitoring	Reduce wave energy - builds the resilience of the beach. Minimum impact on longshore drift. Limited impact on access/view. Sustainable solutions available (oyster reefs, reef balls)	High capital cost but lower than the offshore breakwater option. Significant design required. Construction from the sea needed. Natural England approval.	To be considered further.

Option	Description	Advantage	Disadvantage	Comment
Option 13	Alternative experimental solution	None identified yet.	Untested solution, performance and design life risks.	Design and performance risks not acceptable.