YORK FIELD DEVELOPMENT PROJECT

BEACH EROSION STUDY

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HR Wallingford
Working with water

York Development Pipeline Project

Beach erosion study

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Summary

York Development Pipeline Project

Beach erosion study

Report EX 6577
September 2011

Saipem Ltd has been awarded the EPIC contract by Centrica to install the 16" export pipeline and 3" methanol piggy-back line from the York gas field (North Sea) to the Easington Gas Terminal on the coastline of Holderness. HR Wallingford has examined erosion and sedimentation processes to inform Saipem's project planning for the landfall. This relates to two main issues, firstly the amount of burial required for the pipeline to remain beneath seabed level over the design life and secondly the amount of sediment transport during the month of June when installation of the pipeline is expected to take place.

The York Development Pipeline Project landfall at Easington is on a section of coast that is retreating at an average local rate of about 1.5 m/year. The coastline consists of a system of cliff, beach and clay shore platform that tends to maintain a consistent profile as it retreats. There is a rock revetment at landfall which is designed to prevent cliff retreat, but this will not prevent downwearing of the clay platform from occurring.

The beach at the toe of the cliff consists mainly of medium sand, coarse sand and gravel, with a wide grading. The level of the top of the beach close to the cliff varies by as much as 4 m. At times the mobile beach depth reduces to almost nothing, exposing the shore platform to erosion by waves and currents. The relevant depth of pipeline burial that must be attained to ensure that the pipeline does not become exposed during its design life should, therefore, be measured from the surface of the clay shore platform – not from the beach level at the time of installation – and should be determined using the rate of retreat of the shore platform.

A 2011 cross-shore profile of the top of the clay shore platform was derived from measurements and expert judgment, incuding corrections to levels supplied by Saipem. A future profile in 2037 (allowing 1 year to commission and 25 years for the design life of the pipeline) was estimated by retreating most of the shore platform by 39 m landwards (at the average local rate of retreat of 1.5 m/year). The points representing the base of an infilled channel have not been moved, except where it meets the eroding shore platform, as we consider that it will remain filled in during the lifetime of the project. The level of the top of the pipe must be chosen to be below the anticipated clay shore profile level in 2037 with suitable allowances for inaccuracies in the data and a minimum acceptable depth of cover.

With respect to installation works, construction of a coffer dam and trenching, numerical modelling indicates that most of the longshore sediment transport, with a typical wave climate for the month of June, will occur between the shoreline and the offshore end of the coffer dam (at KP 33.43) and so will be intercepted by the cofferdam. Average wave-induced infill rates of less that 0.05 m per day are expected over most of the shore platform seawards of the cofferdam. The calculated rates of infill may be over-estimates as the pipeline survey identified the seabed to be bedrock with some sediment – so transport rates may be limited by the lack of mobile sediment. Having said that, there will be a general contribution to transport and trench infill from tidal currents that will keep sediment mobile even when waves are small.

Summary continued

The exception to this is with the significantly higher rates of sediment transport predicted around KP 33.35 at the crest of a small sand bar that fills a channel cut through the bedrock. The position and height of the crest of the sand bar will vary in time, which will alter the position and rate of the maximum infill. Nevertheless, a peak average infill rate of about 1 m per week may be expected near the bar crest as the sand bar acts as a conveyor of sediment transport. The depth of the channel is such that the base of the trench is likely to pass through the sand infill at this point – not the clay shore platform. The trench side slopes will have to be lower in sand than in clay, so the trench will be wider at this point.

The sediment transport rates calculated were based on an average wave climate for June. There will be considerable variations in wave height and direction within a month, so daily rates may be considerably higher or lower than the average. Sediment transport calculations are also relatively inaccurate and are often accepted to have error bands of a factor of two.

Contents

Title page *i*
Document Information *ii*
Summary *iii*
Contents *v*

1. Introduction 1
2. Saipem project description 1
3. Scope of work 2
4. Input data 2
   - 4.1 Geomorphology 2
   - 4.2 Waves 3
   - 4.3 Water Levels 3
   - 4.4 Drawings 3
   - 4.5 Sediment 3
   - 4.6 Borehole and Cone Penetration Test data 4
     - 4.6.1 Boreholes 1 to 3 4
     - 4.6.2 Cone Penetration Tests 1 to 4 5
     - 4.6.3 Cone Penetration Tests 32 and 33 5
5. Summary of the site visit 6
6. Geomorphological setting 6
   - 6.1 The platform – beach – cliff system 7
7. Assessment of erosion rates 8
   - 7.1 Cliff retreat rates 8
   - 7.2 Shore platform Location 9
   - 7.3 Shore platform Retreat 11
8. Longshore wave-induced sediment transport to inform trenching 12
9. Summary 15
10. References 17

Tables

Table 1 Drawings supplied by Saipem
Table 2 Average annual source of sediment from erosion of Holderness
Table 3 Gradients of the shoreface ramp and seabed seaward of it for Holderness (Wingfield & Evans, 1998)
Table 4 Cliff Erosion Rates from East Riding of Yorkshire Council
Table 5 2011 and 2037 assumed shore platform levels

Contents continued

Figures

Figure 1	Holderness, Humber and Lincolnshire coastline (HR Wallingford, 2003) showing average coastal retreat rates along Holderness from Valentin (1971)
Figure 2	Particle size distribution from top of beach (2m from revetment toe)
Figure 3	Particle size distribution about 25 m seawards of revetment toe
Figure 4	East Riding Beach Monitoring Profile P111 beach levels (see comment in text on tide levels)
Figure 5	Surveyed seabed levels and levels of top of clay
Figure 6	Present day simplified 2011 profile for clay underlying the seabed profile
Figure 7	Present day simplified profile and future profile of clay (after 25 years from 2012 at 1.5 m/year retreat) (note: the seabed profile has not been changed)
Figure 8	Daily average longshore transport rates during June for 1.77 mm sand
Figure 9	Daily average infill rate for June for 1.77 mm sand

Plates

Plate 1	Made slope, revetment, beach and North Sea in approximate direction of pipeline
Plate 2	Top of the beach, revetment and slope at landfall location (see note on Plate 1)
Plate 3	Minor cliffing and the variations in available sediment sizes at the top of the beach around high tide level
Plate 4	The natural cliff face north of the revetment looking south

1. Introduction

Saipem Ltd has been awarded the EPIC contract by Centrica to install the 16" export pipeline and 3" methanol piggy-back line from the York gas field (North Sea) at KP 0 to the Easington Gas Terminal on the Holderness coast at KP 33.8, as shown in Saipem's York development Project drawing Y49052-PG-DRG-0021 'Field layout'. The location of Easington on the Holderness coastline is shown in Figure 1. HR Wallingford has examined beach erosion and sedimentation processes to inform Saipem's project planning for the landfall.

2. Saipem project description

The work is planned to start in April 2012. The pipeline will be pre-dredged in the nearshore zone up to KP 26.8, and then trenched out to the offshore platform in 43 m of water at KP 0 using a pipeline plough. The 16" and 3" piggyback pipeline trench will be backfilled with seabed material, using the backfill plough, which will be supplemented with rock dump if the pipeline cover is not sufficient.

Steel coffer dams will be installed on the beach in April 2012, as shown in Land & Marine drawing 20504-DRG-DENG-2001 Rev D2 'Construction site layout on beach'. There will be a high cofferdam at the top of the beach, the top surface of which will be above water level and will form the winch platform for pipe pulling. There will also be a low cofferdam running offshore to mean low water (MLW). The low cofferdam will extend 1 m above the existing beach level and will have wing walls at MLW. The top of the low cofferdam will be submerged at high tide along much of its length. Sedimentation may, therefore, occur over the cofferdam into the trench.

The pipeline will be installed through an access shaft from the terminal using micro-tunnelling to reach the intertidal foreshore, as shown in Land & Marine drawing 20504-DRG-DENG-3000 Rev 02, 'G. A. of tunnel and shaft'. On this drawing the access shaft at KP 33.757 is located approximately 69 m landwards of the tunnel exit in the high coffer dam (or winch platform). The approximate line of the tunnel and pipeline route through the cliff and beach is shown in Plate 1, seen from the top of the cliff.

Excavation of the trench through the beach will begin in May 2012. The trench will have a 5 m wide base, 1:1.5 side slopes in the clay / till and 1:3 side slopes through the sand beach. In June 2012 a suction hopper dredger will clean the offshore section of the trench and diggers will clean out the beach section of the trench. It will then take about 2 days in June to lay the pipe pull cable and survey it, a further 2 days to get the lay barge from Rotterdam and a further 2 to 3 days to lay the pipeline. Natural sedimentation during this period of 6 to 7 days will exert a critical influence on installation operations.

3. Scope of work

The HR Wallingford scope of work covers the following items:

Saipem need definition of the minimum backfill cover that would be required to accommodate erosion of the seabed above the pipeline from the tunnel exit (assumed to be at KP 33.681) across the beach to LAT and seawards to KP 32. This information is required in order to set the level of the tunnel exit and to ensure that the pipeline across the beach and nearshore does not become exposed over the 25 year design life.

Saipem also requires information on the likely rates of sedimentation within the pipeline trench during the period of up to 7 days between cleaning of the trench and completion of pipe laying activity.

In order to fulfil the scope of work this report:

- Identifies the input data used in the study;
- Summarises the results from a site visit;
- Describes the geomorphological setting;
- Assesses the rate of erosion at the landfall site;
- Calculates the potential rates of longshore sediment transport that may be expected during a typical seven day period in June; and,
- Summarises the results and discusses the implications.

4. Input data

4.1 GEOMORPHOLOGY

Information on the geology, geomorphology and historical coastal evolution has been obtained from:

- Centrica, 2011. York Field Development Project: Preliminary Draft Onshore Environmental Statement. CRL document YO-037-EV-RPT-23 of 13/01/11.
- East Riding of Yorkshire Council, 2004. Easington Beach Management: monitoring final report.
- Halcrow, 2002. Futurecoast [CD ROM] produced for DEFRA, with BGS, ABPmer Ltd., Queen's University of Belfast and University of Plymouth.
- HR Wallingford, 2003. Coastal Behaviour from Easington to Mablethorpe: summary report for Humber Estuary Shoreline Management Plan, Phase 2, by HR Wallingford and BGS.
- HR Wallingford, 2002. Southern North Sea Sediment Transport Study, Phase 2. HR Wallingford Report EX 4526, with Posford Haskoning, CEFAS, UEA and D'Olier.
- Scott Wilson, 2009. Flamborough Head to Gibraltar Point Shoreline Management Plan. Consultation draft for Humber Estuary Coastal Authorities Group. Includes Appendix C: assessment of coastal behaviour and baseline scenarios.
- East Riding of Yorkshire Council, 2010. East Riding Beach Monitoring, combined beach profile results. This includes profile 111, which was also supplied separately.

- East Riding of Yorkshire Council, 2011. Coastal Explorer reports including: 1 Development of the East Riding Coastline, 2 Coastal Processes, 3 Coastal Monitoring, 4 Defending the East Riding Coastline and 5 Spurn Peninsula.
- East Riding of Yorkshire Council, 2011. Coastal explorer data on cliff erosion, including erosion profile details, cliff erosion results and cliff erosion rate bands.
- Royal Haskoning et al., 2007. Understanding and predicting beach morphological change associated with the erosion of cohesive shore platforms. Joint Defra/EA flood and coastal erosion risk management R&D programme, R&D Technical Report FD1926/TR.
- Lee, E.M. and Clarke, A.R., 2002. Soft Cliffs: prediction of recession rates and erosion control techniques. Defra/EA Flood and Coastal Defence R&D Programme, R&D Project FD2403/1302.

The Centrica (2011) and ERYC (2004) reports were supplied by Saipem.

4.2 WAVES

Information on wave climates was obtained from the following report, sent by Saipem:

- Fugro Geos, 2011. York Field Pipeline: Additional Criteria. Report Number C50789/6476/R3 (including Appendices A to P).

4.3 WATER LEVELS

For comparison of datum levels, the values at Spurn Head from the UKHO 2011 tide tables with respect to Chart Datum (CD) and Ordnance Datum Newlyn (OD) are as follows:

Highest Astronomical Tide	7.7 m above CD	3.8 m above OD
Mean High Water Spring Tide	6.9 m above CD	3.0 m above OD
Mean High Water Neap Tide	5.5 m above CD	1.6 m above OD
Mean Sea Level	4.1 m above CD	0.2 m above OD
Ordnance Datum (Newlyn)	3.9 m above CD	0.0 m above OD
Mean Low Water Neap Tide	2.7 m above CD	1.2 m below OD
Mean Low Water Spring Tide	1.2 m above CD	2.7 m below OD
Lowest Astronomical Tide	0.3 m above CD	3.6 m below OD

4.4 DRAWINGS

Saipem provided a range of drawings as pdf files, which are listed in Table 1.

4.5 SEDIMENT

Two samples were taken of the beach sand close to the site of the pipeline landfall. One was taken from approximately 25 m seawards of the toe of the rock revetment and the other was taken approximately 2 m from the toe of the rock revetment, in front of the gas terminal. The latter sample was taken from the surface of the top layer of sand shown in Plate 3 at the top of the trowel. This layer of sand consisted of medium sand with no larger particles and may have been formed by sorting in the swash zone and possibly wind-blown transport. The beach sediment is variable in size and the 2 m sample is not representative of the beach as a whole, which contains a mix of sand and gravel. Therefore the 25 m sample is considered more representative of the mobile beach. The two samples of beach sand were washed, dried and sieved. Their particle size distributions are shown in Figures 2 and 3.

4.6 BOREHOLE AND CONE PENETRATION TEST DATA

Three boreholes and four Cone Penetration Tests (CPTs) were recorded from the cliff top to the lower inter-tidal zone along the revised landfall route in 2011 (Geotechnics Ltd Factual Report "York Field Development Project Soil Investigation 2011", project number PN112532). The three boreholes were sunk by cable percussion tool techniques, standard penetration tests (SPTs) were undertaken at a few depths. The four static cone penetration tests (CPTs) were undertaken to depths of about 12 m below ground level using an 18.5 tonne capacity hydraulic ram set and electric Piezometer equipment. The positions of boreholes 2 and 3 and CPT tests 1 to 4 are shown in Land & Marine drawing 20504-DRG-DENG-2001 Rev D2 'Construction site layout on beach'.

In addition, CPT 33 and CPT 34 were taken along the revised landfall route within the KP range of interest, as reported in Fugro Alluvial Offshore Ltd report "Geophysical Survey and Geotechnical Ground Investigation (York Field Development Project)" Report No 110545-1 (03). Details of the FAOL Borehole and CPT tests are given in the sub-sections below.

4.6.1 Boreholes 1 to 3

Borehole 1 was sunk into the top of the cliff close to the tunnel route. The ground level was 13.27 m OD and the top meter consisted of topsoil and made ground. Below this level the ground consisted of clay with occasional bands of gravelly sand at 3.1 m OD and 0.0 m OD. The borehole extended down to -6.9 m OD. Uncorrected SPT blow counts varied between 16 and 25 for elevations between 4.9 m OD and -5.2 m OD, with higher SPT values at lower levels. Geotechnical tests (appendix 8) confirmed that the ground below the top level consisted of clay. Therefore, we have taken the level of the top of the clay to be 12.3 m OD (but note that this is near the top of the cliff and is not on the wave-cut shore platform).

Borehole 2 was sunk into the upper beach close to the centre of the high cofferdam. The ground level was 1.9 m OD and the top 2.0 m consisted of gravel. From -0.1 m OD downwards the ground consisted of slightly gravelly clay. By a depth of -1.1 m OD the clay was described as very stiff and the ground was described as stiff, very stiff or very high strength down to the borehole base at -10.5 m OD, except for a band of clay described as sandy at -6.3 m OD. Uncorrected SPT blow counts varied between 17 and 24 for elevations between -0.3 m OD and -9.9 m OD, with higher SPT values at lower levels. The exception to this was the highest level at 0.5m OD, where the blow count was greater than 50 and the test was not completed. Geotechnical tests (appendix 8) confirmed that the ground below the top level consisted of clay. We have therefore taken the level of the top of the clay to be -0.1 m OD.

Borehole 3 was sunk into the intertidal beach. The ground level was -0.9 m OD and the top 1.4 m consisted of widely-graded sand. Below the sand was stiff clay, described as very stiff and very high strength by a depth of -3.0 m OD. The clay was described as high strength to very high strength, stiff to very stiff down to the bottom of the borehole at -13.4 m OD. Uncorrected SPT blow counts varied between 18 and 23 for elevations between -2.0 m OD and -11.9 m OD, with higher SPT values at lower levels. Therefore, we have taken the level of the top of the clay to be -2.3 m OD.

4.6.2 Cone Penetration Tests 1 to 4

The CPT data below has been taken from Appendix 5 of Geotechnics Ltd Factual Report "York Field Development Project Soil Investigation 2011", project number PN112532.

CPT 4 is the furthest inshore of the CPT sampling points and was made just offshore from the end of the high cofferdam where the ground level was 0.0 m OD. The ground consisted of loose silt down to -0.4 m OD, overlaying sand down to -0.8 m OD. Below this is stiff clayey silt to silty clay down to -1.8 m OD and silty clay to clay down to -4.9 m OD. The corrected cone resistance reading slowly increases with depth from about 1.6 MPa (at -0.8 m OD) to 3.0 MPa (at -4.8 m OD) which is in the 'stiff' range. The corrected cone resistances gradually increase with depth below the surface (which is common). Therefore, we have taken the top of the clay layer to be at -0.8 m OD.

CPT 1 is the next CPT to be reached on moving down the beach to a stated ground level of 0.7 m OD. However, we consider that due to its position (shown in Land & Marine drawing 20504-DRG-DENG-2001 Rev D2 'Construction site layout on beach') its actual ground level was about -0.7 m OD, as given in Saipem spreadsheet Centrica_York_NearShoreProfiles.xls and have used the latter value in our calculations. The ground consisted of soft, fine-grained material down to -1.0 m OD and very loose silt down to -1.5 m OD. Below this level from -1.5 m OD to -3.8 m OD is a layer of stiff clayey silt to silty clay with corrected cone resistances rising from about 1.7 MPa to 2.3 MPa. From -3.8 m OD to -7.1 m OD is a layer of stiff silty clay with slightly higher corrected cone resistances. Therefore, we have taken the top of the clay layer to be at -1.5m OD.

CPT1 is inshore of Borehole 3, while CPT2 is offshore of it at a stated ground level of 1.0 m OD, which we have taken to be at a level of -1.0 m OD (see drawing 20504-DRG-DENG-2001 Rev D2). The ground consisted of fine-grained material and sand down to -1.8 m OD, with a further layer of sand down to -2.3 m OD. Below this is stiff clay down to -6.2 m OD. The corrected cone resistance readings in the clay layer vary between about 15.6 MPa and 2.6 MPa which is in the 'stiff' range. Therefore, we have taken the top of the clay layer to be at -2.3 m OD.

CPT3 is at the lowest level on the beach (stated in Appendix 5 to be at 2.1 m OD, but taken as at -2.1 m OD - see drawing 20504-DRG-DENG-2001 Rev D2). The ground consists of fine-grained material, loose sand, dense sand and silt down to -3.5 m OD. Below this are a number of layers of stiff clay with different silt contents right down to -12 m OD. The corrected cone resistance readings in the clay layers vary between about 15.6 MPa and 4 MPa which is in the 'stiff' range. Therefore, we have taken the top of the clay layer to be at -3.5 m OD.

4.6.3 Cone Penetration Tests 32 and 33

Fugro Alluvial Offshore Ltd report "Geophysical Survey and Geotechnical Ground Investigation (York Field Development Project)" Report No 110545-1 (03) contains details of CPT 33, CPT 34 and vibrocore VC34a taken along the revised landfall route within the KP range of interest. The recorded seabed depths, coordinates and the recorded depth of cover of the clay are shown below. A KP number was associated with each point by calculating the distance from the tunnel exit and subtracting this from the KP number of this position (taken to be 33681 m).

Item	Bed level (m LAT)	mE	mN	Depth of cover (m)	KP (m)
VC34a	-9.7	310595	5949866	0.0	32806
CPT33	-14.7	311335	5950186	0.1	32000
CPT34	-10.3	310591	5949862	0.6	32811

Tunnel exit at 309724mE, 5949468mN
Proposed shaft 309724mE, 5949486mN

5. Summary of the site visit

James Sutherland (JS – HR Wallingford), Robin Howard (RH – Saipem) and Dirk Bauer (DB – Saipem) met at the north car park of Easington Gas Terminal just before 09:00 BST on Thursday 9th June 2011.

JS, RH and DB walked along the public footpath along the seaward side of the gas terminal, above the made slope (where the cliff face had been cut back to stabilise it) and the revetment to the point where the vertical shaft will be installed by Land and Marine. The view towards the York platform from the top of the made slope is shown in Plate 1.

JS, RH and DB then climbed down the made slope and over the revetment to the beach. The top of the beach, revetment and slope are shown in Plate 2. This location is close to Profile line 111, which has been surveyed regularly by East Riding of Yorkshire Council (ERYC) since October 1997. The beach consists of coarse sand, gravel and pebbles largely derived from the erosion of the Holderness coastline between Flamborough Head and Easington over many years. Plate 3 shows minor cliffing and the variations in available sediment sizes at the top of the beach around high tide level.

JS collected two sediment samples. JS, RH and DB walked north along the beach, past the revetment to the location of the access road. The natural cliff face north of the revetment is shown in Plate 4.

6. Geomorphological setting

Easington sits towards the southern end of the curving Holderness coastline, as shown in Figure 1 (HR Wallingford, 2003). The northern limit of the Holderness coastline is the chalk headland of Flamborough Head – the most northerly chalk outcrop in Europe. South of Flamborough the chalk is replaced by erodible glaciogenic cliffs (i.e. a by product of glaciation). This coast is cut into soft glacial till/boulder clay that outcrops at sea level, so the erosion rates are high, forming the smooth curving coastline of Holderness. Cliff recession is known to have continued over hundreds of years and shows no signs of abating. Approximately 1,000 hectares of cliff top land have been lost in the last 900 years. The rock resisting force is less than the assailing force and the cohesive shore platform extends below low water without a break.

Both the cliff and the cohesive shore platform are eroding. The cohesive shore platform has a thin and varying layer of sediment to form a beach at the shoreline overlying till that erodes by abrasion. This till is exposed in the intertidal regions from time to time and in the offshore region is likely to be exposed as there is virtually no sediment cover (except for the extensive sediment accumulation of South Smithic Bank). The youth of the eroded rock means it is unlikely that the surfaces are antecedent from older cycles of sea-level changes. South of about Fraisthorpe (approximately one third of the way from Bridlington towards Hornsea) the predominant direction for nett longshore transport is southwards. General descriptions of the Holderness coastline can be found in many sources, including HR Wallingford (2002, 2003) and Halcrow (2002).

Spurn Head is a coastal spit that lies at the southern end of the Holderness coastline and extends into the mouth of the Humber Estuary. Spurn Head consists of beach deposits and sand dunes above sea level, which rest on gravel deposits (probably not moraine). The material above sea level is vulnerable to erosion and may be removed by wash-over events, but the material below sea level is less likely to be eroded. Spurn Point has extended south-west over the past couple of hundred years (by as much as 7 m/year). Its tip is now at the northern edge of a deep erosional hole, the palaeo-channel of the Humber and it is believed not to be extending as it is constrained by the large tidal discharges into and out of the Humber (HR Wallingford, 2003).

Estimates of the rates of erosion on the Holderness coast have been made in several studies, summarised in Balson, *et al.* (1998). The average rate of erosion from these studies was $3.2\times10^6\ m^3a^{-1}$ and this figure will be used here.

The behaviour of sediment, the transport pathways and the sediment sinks depend on particle size and composition. Although the composition of the till varies along the coast (as does the cliff height and recession rates) the average composition of the basement till (which forms the majority of the eroded till) is given in Table 2 (percentage of source column). The source volume per year was determined from the percentage composition of the till. About $0.1\times10^6\ m^3$ of gravel is released into the sea each year, along with $10^6\ m^3$ of sand (of which about 90 per cent is medium to very fine sand) and about $2.1\times10^6\ m^3$ of silt and clay.

6.1 THE PLATFORM – BEACH – CLIFF SYSTEM

The primary control on the long-term rate of cliff-toe erosion is understood to be the rate of vertical lowering of the beach and cohesive shore platform (Royal Haskoning et al., 2007; Lee and Clarke, 2002). Although cliff erosion is an episodic, local event, when averaged in space and time the rate of cliff retreat is governed by the erosion of the cohesive shore platform. The cliff, beach and shore platform tend to retreat uniformly, in a dynamic equilibrium with the forcing conditions (mainly the wave climate, modulated by tidal levels) and maintain a steady shape.

The dynamically-stable profile shape means that there is a direct relationship between the rate of horizontal cliff retreat, r (m/year) and the rate of vertical platform down-cutting, d (m/year), which is governed by the shore platform slope, α (radians or degrees). This relationship is

$$d = r.\tan(\alpha) \qquad (1)$$

Wingfield & Evans (1998 – quoted from HR Wallingford, 2003) give figures for the average gradients for the shore platform and the seabed seaward along four profiles. The cohesive shore platform extends from a typical elevation of MSL + 3m out to between about 11 m and 14 m below MSL and the seabed seaward of it out to 10 km offshore was included, where the depth was between 24 m and 28 m. These gradients are given in Table 3.

Wingfield and Evans (1998) estimated that only 23 per cent of erosion was from the cliff, 33 per cent from the cohesive shore platform and the remaining 44 per cent from lower levels (out to 10 km from the cliff). Therefore, they estimated that about half the erosion occurs in a strip extending about 2 km out from the coast. However, Balson, *et al.* (1998 – quoted from HR Wallingford, 2003) concluded that cliff erosion supplied about half as much as the erosion of the cohesive shore platform when integrated over the whole of the coastline of Holderness. The relative proportions vary along the coast.

In this case we have long-term observations of the rate of cliff retreat (ERYC, 2011) and have the gradient of the beach profile (using seabed surface levels from the Fugro survey in 2011, taken from the Excel spreadsheet "Centrica_York_NearShoreProfiles.xls" emailed to James Sutherland by Robin Howard on 06/09/2011) and can calculate an expected annual average rate of historic shore platform down-cutting along the cross-shore profile associated with the pipeline alignment. The same rate can be extrapolated forwards for the 25 year lifetime of the project.

Any increase in the future rate of sea level rise would be expected to lead to an increase in the rate of cliff retreat, as higher water levels may lead to higher wave heights along the cross-shore profile.

7. Assessment of erosion rates

7.1 CLIFF RETREAT RATES

In 1951 East Riding of Yorkshire Council (ERYC, 2011) began collecting data on cliff erosion at 123 profiles along the Holderness coastline from Sewerby to the neck of Spurn Point. This data consists of cliff positions from Ordnance Survey (OS) maps between about 1852 and 1998, from GPS profile surveys between 1999 and 2008 and from airborne LiDAR surveys from 2009 to 2010. They have been used to estimate the annual average cliff retreat rate at each of the profiles.

The average rates from the profiles closest to Easington gas terminal are shown in Table 4, where profiles 105 to 109 are north of the gas terminal and 113 and 114 are further south. Profiles 110, 111 and 112 now pass through the revetment in front of the gas terminal. The construction of the revetment and the cutting-back and planting of the cliff face have stabilized it, so it no longer retreats. The results from the retreat rate calculations indicate that the cliffs just north and south of the revetment at Easington have had a long-term retreat rate of 1.5 m/year.

A previous study by Valentin (1971) based on OS maps, gave average rates of erosion as shown below:

- Sewerby (Bridlington) to Earl's Dyke: 0.29 m/year
- Earl's Dyke (Fraisthorpe) to Hornsea 1.10 m/year
- Hornsea to Withernsea 1.12 m/year
- Withernsea to Kilnsea (including Easington) 1.75 m/yr

The ERYC (2011) analysis contains more data and more recent data, so will be used as the primary estimate of retreat rates around Easington. The Valentin (1971) result from Withernsea to Kilnsea will be used as an alternative.

7.2 SHORE PLATFORM LOCATION

In order to determine the retreat of the shore platform and hence the lowering that may be expected, it is first necessary to identify the cross-shore profile of the top of the clay shore platform.

The initial estimate of the profile of the shore platform in 2010 was made using two drawings:

- East Riding Beach Monitoring project drawing 'Profile No. P111 Through north end of gas terminal defences, Easington' (reproduced as Figure 4);
- Gardline Geosurvey drawing 9429.09 Rev. 5, 'Alignment sheet 9 of 9 (KP 29.87 to KP 33.921)'.

The results from the East Riding Beach Monitoring project, shown in Figure 4, reveal that the beach levels in front of the revetment at the gas terminal are highly variable. The elevations on the vertical axis of Figure 4 are levels below Ordnance Datum Newlyn. (The levels of MHWS, MHWN, MLWN and MLWS quoted on the right of Figure 4 are correct, but the corresponding tide lines have been printed at the wrong elevation on the graph.) The difference between the highest beach level and the lowest beach level at a point can be over 4 m within about 60-70 m of the toe of the revetment. These differences reflect seasonal changes and longer-term variations in the volume of sediment in the beach in front of the terminal, often associated with the passage of ords, which are bar-like features on the foreshore. The thickness and variation in thickness of the sediment layer decrease with distance from the toe of the revetment. At approximately 100 m from the revetment toe, the maximum variation in seabed level has reduced to 2 m.

The shore platform will erode when the thickness of sediment above it is low or zero and we have assumed that the lowest level recorded by the beach surveys since 1997 represents the level of the top of the clay shore platform at that point in time.

Therefore, we have also assumed that the thickness of mobile sediment will be zero at some times during the 25-year design life of the pipeline. The relevant depth of burial that must be attained to ensure that the pipeline does not become exposed during its design life should be measured from the surface of the clay shore platform – not from the beach level at the time of installation – and should be determined using the rate of retreat of the shore platform.

Release 1 and 2 of this report included results from the drawings noted above. The pipeline route has been moved approximately 125 m north of the route used during the FEED studies and a new set of survey data from 2011 has been supplied. Release 3 (this document) uses data from the following sources to assess the present-day profile of the top of the clay shore platform:

1. Data from Boreholes 2 and 3 and CPT 1, 2, 3 and 4 from Geotechnics Ltd Factual Report "York Field Development Project Soil Investigation 2011", project number PN112532.
2. East Riding Beach Monitoring project drawing 'Profile No. P111 Through north end of gas terminal defences, Easington' (reproduced as Figure 4);
3. Levels of the clay layer under the infilled intertidal channel taken from Gardline drawing 8429.09 Rev 5 of 8 December 2010, called 'Alignment sheet 9 of 9 (KP 29.87 to KP 33.921)'
4. Levels of the top of the clay taken from CPT 33, CPT 34 and VC34a taken from Fugro Alluvial Offshore Ltd (FAOL) report "Geophysical Survey and Geotechnical

Ground Investigation (York Field Development Project)" Report No 110545-1 (03).

5. Seabed surface levels from Fugro survey in 2011, taken from the Excel spreadsheet "Centrica_York_NearShoreProfiles.xls" emailed to James Sutherland by Robin Howard on 06/09/2011.

The borehole and CPT levels from the Geotechnics report were converted from m OD to m LAT by applying the 3.0 m shift specified by Saipem[1]. As these values give a consistent picture of the clay levels they were all used apart from Borehole 1 which gave levels in the cliff, not in the shore platform.

The revised profile location is close to ERYC profile 111. Two sets of elevation and chainage have been extracted from this data (shown in Figure 4):

1. Levels of clay in 1999 out to chainage 138.84 m; and
2. Lowest level recorded during any survey at chainage greater than 138.84 m.

The chainages and elevation from Figure 4 (along profile 111) have been taken to apply to the pipeline route. Chainages have been converted to KP numbers using chainages from Figure 4 and details of the location of Borehole 2 and of the 4 m OD contour on the revetment from drawing 20504-DRG-DENG-2001 r2 of 08/09/2011. The chainage of Borehole 2 was taken as 33668 m. The elevations were also converted into level relative to LAT using the 3.0 m correction supplied by Saipem.

Gardline drawing 8429.09 Rev 5 of 8 December 2010, called 'Alignment sheet 9 of 9 (KP 29.87 to KP 33.921)' shows bathymetry and level data along the original pipeline corridor. This figure includes information about a channel infilled with sand that runs approximately parallel to the coast. We do not consider that this is an active channel feature and anticipate that it will remain filled in for the duration of the pipeline; albeit fill levels may vary in the channel. The levels of the clay at the base of the infilled channel are not clearly given in this drawing. Initially the channel bed levels were taken from the bottom section (of 4) of the Gardline drawing. This has a dashed line under the text 'Channel with Interpreted loose SAND infill' which was taken to be their assessment of the base of the channel (i.e. the top of the clay). Subsequently the numbers in squares in the third section of the drawing were taken to be the depth of clay below seabed level. The squares nearest the old profile indicate clay level of 4 m below seabed at KP 33310 and 33330. The seabed levels along the old profile at these locations is approximately -0.7 m LAT and -1.2 m LAT respectively, which would make the clay levels approximately -4.7 m LAT and -5.2m LAT, which does not agree with the dashed line in the lowest section of the drawing.

In the end the northern square, closest to the new profile, was used. It indicates clay at 4 m below seabed level. From the top section of the drawing the seabed level is between -1.0 m LAT and -1.5 m LAT and is closer to -1.5 than -1.0. If we assume that the seabed level is close to -1.4 m LAT it follows that the clay level is about -5.4 m LAT at about KP 33295. The limits of the channel are at about KP 33225 and 33365 m. A new bathymetry has been inferred for this channel, which goes down to -5.4 m LAT. This is lower than before but it is using the conservative interpretation of the information provided by Gardline. Gardline are best placed to confirm this

[1] This correction is different from that which would be obtained from water level values in Section 4.3

interpretation and we recommend that you contact Gardline as soon as possible for clarification and to see whether they can provide a better profile of the channel along the new profile. The levels from this drawing were subsequently lowered by 0.35 m, following the procedure devised by Saipem to fit the Gardline offshore survey to the Fugro offshore survey.

CPT33 from FAOL (Section 4.6.3) was consistent with the seabed levels from the 2011 Fugro offshore survey so was used to define the depth of clay at KP 32000. The results from VC34a and CPT 34 are not entirely consistent with the results from the 2011 Fugro survey. As CPT 34 indicates a depth of cover of 0.6 m above the clay and VC34a indicates a depth of cover of 0.0 m and as both are in similar positions, a clay level was set at 0.6 m below the 2011 seabed level at the KP calculated for CPT34 and no point was plotted for VC34a.

The levels from the Fugro 2011 survey were used as supplied. The adjusted data from all five sources are plotted in Figure 5. There are gaps in between locations where there is data about the level of the clay shore platform. These can be filled in by assuming that the depth of cover varies slowly in the cross-shore direction. The resulting simplified and interpolated cross-shore profile of the top of the clay shore platform is shown in Figure 6, using data from the 2011 borehooles and vibrocores in preference to the ERYC data from P111 as it represents the most up-to-date data. It would be possible to replace this data with lower points from ERYC P111. The data used to create this profile are listed in Table 5.

7.3 SHORE PLATFORM RETREAT

The shore platform was assumed to retreat by 39 m over 26 years at the historical average rate of 1.5 m/year. A duration of 26 years was used as it will be 1 year to installation and the design life is 25 years. This approach is based on the theory discussed in Section 6 and combined with expert judgment to ensure a smooth realistic profile.

For example, we anticipate that the level of the clay at the base of the 'channel' identified in Gardline Geosurvey drawing 9429.09 Rev. 5 will not change during the lifetime of the project as there will still be a significant coverage of sand over the clay. Therefore, the points representing the channel have not been moved, except where it meets the eroding shore platform. We anticipate that the erosion of the clay will continue inshore and offshore of the channel. It should also be noted that the base of the pipeline trench may be cut through sand at this point, when at all other locations close to the shore the base of the trench will be cut through clay. This will affect the total width of the trench as the side slopes will have to be lower than in clay.

The present day simplified profile and the assumed profile in 2037 are shown in Figure 7. The data are presented in Table 5. The down-cutting rate decreases on moving offshore as the gradient of the shoreface ramp decreases. The elevation differences between the present day profile and the future profile indicate the best estimate of the allowance that should be made for the erosion of clay during the lifetime of the project. This will affect the depth of trench needed. Although the future profile can be used to indicate the likely future level of the top of the clay, care should be taken in doing so, as it is based on a simplified profile and a few of the points have been inferred.

Measurements of platform down-cutting were made between July 2005 and July 2006 at a site a few hundred metres north of the Easington gas terminal (Royal Haskoning et al, 2007). Two transects were measured at levels of about 1 m LAT, which showed erosion rates of 43 mm/year and 40 mm/year, respectively, with standard deviations along the transects of about 14 mm. If erosion was to occur at this rate for 26 years, a decrease in level of 1.04 m would be observed. This is similar to the level of downcutting shown in Figure 6 at this level in the profile. The fact that these measurements were made at this level on the beach profile confirms the point made earlier that the granular beach layer varies in thickness with time, exposing the underlying clay.

8. Longshore wave-induced sediment transport to inform trenching

Longshore sediment transport has been calculated using HR Wallingford's cross-shore profile model COSMOS. The modelling has used the following input datasets:

- Cross-shore bathymetry has been taken from Gardline Geosurvey's drawing 8429.09 Rev. 5, "Alignment sheet 9 of 9 (KP 29.87 to KP 33.921)". The profile extends from KP 31.5 (offshore) to KP 33.662 (onshore). The profile angle measured from the drawing was 64 °N.
- Median sand size has been taken from particle size distribution of the samples taken on the site visit. The sand sample taken about 25 m from the revetment has a median grain diameter of d_{50} = 1.77 mm (Figure 3) and a wide distribution (consisting mainly of medium sand, coarse sand and gravel). The sand sample from the top of the beach had a median diameter of d_{50} = 0.33 mm (Figure 2) and a relatively narrow distribution (it is mainly medium sand) although this is not considered to be representative of the site, which contains a mixture of sand and gravel (Plates 1 to 4).
- Wave conditions are given in Fugro Geos, 2011. York Field Pipeline: Additional Criteria. Report Number C50789/6476/R3 (including Appendices A to P).
- The range of tidal water levels has been taken from the spring tidal range at Spurn Point.

The monthly wave climate for June was given by Fugro in terms of two scatter plots: (i) wave height and period and (ii) wave height and direction. These were combined by assuming that the period and direction were independent, so the fractions of occurrence from the two tables could be multiplied. The offshore wave conditions were taken from the Fugro wave point closest to KP 31.5. The same offshore wave conditions were taken to apply at all water depths. Wave conditions were extracted for significant wave height in 0.4 m high bands, wave period in 4 s bands and wave angle in the 45 ° bands provided. The resulting wave climate consisted of a total of 60 wave conditions.

The tidal range is so large at Easington that it has a significant effect on where waves break on the beach and hence, where the greatest longshore drift occurs. In order to obtain a reasonable representation of the cross-shore distribution of longshore drift, the wave conditions were modelled at five different levels corresponding to mean high water of spring tides (MHWS), mean high water of neap tides (MHWN), mean sea level (MSL), mean low water of neap tides (MLWN) and mean low water of spring tides (MLWS). The measured water levels at the 'Class A' tide gauge at Immingham for the whole of 2010 were downloaded from the British Oceanographic Data Centre (BODC) in order to determine the relative percentage of time that each water level should be applied for. The tide gauge at Immingham was used as the data were freely available. The water levels from 2010 were sorted into rank order and the percentages of time when water levels were closest to each modelled elevation were calculated and it was assumed that similar percentages would apply at Easington. The percentages of time were MHWS 16 per cent, MHWN 23 per cent, MSL 25 per cent, MLWN 22.5 per cent and MLWS 13.5 per cent.

In order to obtain an average daily longshore sediment transport rate, the 60 representative wave conditions in the wave climate were applied at each of the five water levels and the resulting longshore transport rates were weighted according to their probability of occurrence and converted to a daily rate. Calculations were made for a median grain diameter of 1.77 mm. The model uses a single grain size in its calculations and it is probable that under relatively low wave conditions medium sand may move, even when the coarser sand does not.

Figure 8 shows the cross-shore distribution of the average rate of longshore sediment transport for sand with median diameter of d_{50} = 1.77 mm during June along the pipeline profile. Figure 8 also shows the cross-shore variation in bed level and the cross-shore position of the cofferdam. Separate longshore transport rates were calculated for sediment transport to the south and to the north. The nett transport given is the difference between the two. However, as the trench can fill in from either direction it is the sum of the magnitudes of the transport rates that is important.

Figure 8 shows, for the single bed profile modelled from the surveyed bathymetry, most of the longshore transport from wave breaking is predicted to occur close to the shoreline and landward of about KP 33.45. As the cofferdam will extend out to KP 33.43, most of this longshore transport will be intercepted by the cofferdam walls and will only cause the trench to infill if it can go over the cofferdam walls during high tide. Along most of their length the cofferdam walls will only be 1 m high.

Offshore from KP 33.43 there will be no cofferdams and we have assumed that all of the longshore transport will be trapped by the trench and will cause it to infill. Although it is possible that sediment carried in suspension will pass over the trench, the sand size is relatively large and the inshore wave heights are relatively small, indicating that much of the sediment will travel relatively close to the seabed, making it available to be trapped by the trench.

The peak in the sediment transport rate and the infilling rate offshore from the end of the cofferdam occurs near the top of the small offshore sand bar at about KP 33.31, where the average longshore transport rates to the south and north are 0.6 m^3/m/day and 0.1 m^3/m/day. This implies a cross-shore maximum in the time-averaged total trench infilling rate of about 0.7 m^3/m/day or about 5 m^3 of sediment per metre length of trench during 1 week.

The magnitudes of the longshore transport rates to the north and to the south were added to give a total trench infill rate (m^3/m/day). An average rate at which the trench fills in (m/day) was calculated by assuming that the sediment was distributed evenly across the floor of the trench, which has a 5 m wide base and side slopes of 1:1.5 in clay. The trench infill rates are shown in Figure 9, which also shows the range of cross-shore positions covered by the cofferdam.

Seaward of the cofferdam, the peak in the average trench infill rate occurs at the position of the peak in the average longshore transport rate, where the infill rate was almost 0.14 m/day, which corresponds to just under 1 m in one week. Average infilling rates greater than 0.05 m/day are predicted to occur over a 120 m long section of the trench between KP 33.24 to KP 33.36, while infill rates of greater than 0.1 m/day are predicted to occur over a 40 m long section of the trench between KP33.28 to KP 33.32, using the surveyed bathymetry.

The calculation of the average infill rate assumed that the sediment would spread evenly over the base of the trench, as it filled in. In practice, we would anticipate that the distribution of sediment would not occur evenly across the trench. However, the average infill rate is considered to be a useful statistic as it illustrates, approximately, what proportion of the trench would fill up each day.

The results from the sediment transport modeling are potential transport results. That is to say, they are based on the assumption that the same sediment size is present everywhere at all times. It is necessary to interpret these results in the context of the information provided in the local survey (Gardline Geosurvey drawing 9429.09 Rev. 5, 'Alignment sheet 9 of 9 (KP 29.87 to KP 33.921)'). Section B of this drawing shows the interpreted seabed features below approximately LAT at KP 33.5. This shows that the inshore seabed is interpreted to consist of 'possible bedrock and sand stringers'. However, there is then an area of 'channel infill – SAND' around KP33.3, which coincides with the small offshore sand bar mentioned in the presentation of the sediment transport modelling results, above. Offshore from the sand bar is an area described as 'possible bedrock with sand and gravel stringers.'

It is reasonable to assume that the longshore sediment transport rate, and hence the trench infill rate due to wave-induced transport, in the areas described as bedrock with possible sand (and gravel) stringers will be less than the predicted potential transport rate. This is because we anticipate that there will be locations where there is not enough sand and gravel to be transported. Having said that, there will be a general contribution to transport and trench infill from tidal currents that will keep sediment mobile even when waves are small.

The sand bar at around KP 33.31 fills the 'channel with interpreted loose sand infill' (Section D of Gardline Geosurvey drawing 9429.09 Rev. 5). The sand bar is acting as a conveyor for longshore sediment transport. As the height and position of the crest of the bar will change in time – and it may even disappear for a while – it is not possible to determine in advance where the local peak in longshore transport will be in June 2012. However, it is likely that the channel will be filled with mobile sediment, so that the modelled results give a reasonable indication of the range of infill rates likely to be encountered.

The depth of the channel under the sand bar is such that the base of the trench is likely to pass through the sand infill at this point – not the clay shore platform. Backfill at this location is likely to consist of sand from the channel infill – not clay blocks from trenching through the shore platform. The sand backfill is expected to be more mobile than backfill produced from trenching in the shore platform.

9. Summary

This study has been carried out to inform the design of the York Development Pipeline Project landfall at Easington, which is on a section of coast that is retreating at an average local rate of about 1.5 m/year. The coastline consists of a system of cliff, beach and clay shore platform that tends to maintain a consistent profile as it retreats. There is a rock revetment at landfall which is designed to prevent cliff retreat, but this will not prevent downwearing of the clay platform from occurring.

The beach at the toe of the cliff consists mainly of medium sand, coarse sand and gravel, with a wide grading. The level of the top of the beach close to the cliff varies by as much as 4 m. At times the mobile beach depth reduces to almost nothing, exposing the shore platform to erosion by waves and currents. The relevant depth of pipeline burial that must be attained to ensure that the pipeline does not become exposed during its design life should, therefore, be measured from the surface of the clay shore platform – not from the beach level at the time of installation – and should be determined using the rate of retreat of the shore platform.

A 2011 cross-shore profile of the top of the clay shore platform was derived from measurements and expert judgment, including corrections to levels supplied by Saipem. A future profile in 2037 (allowing 1 year to commission and 25 years for the design life of the pipeline) was estimated by retreating most of the shore platform by 39 m landwards (at the average local rate of retreat of 1.5 m/year). The points representing the base of an infilled channel have not been moved, except where it meets the eroding shore platform, as we consider that it will remain infilled during the lifetime of the project.

The level of the top of the pipe must be chosen to be below the anticipated clay shore profile level in 2037 with suitable allowances for inaccuracies in the data and a minimum acceptable depth of cover.

With respect to installation works, construction of a coffer dam and trenching, numerical modelling indicates that most of the longshore sediment transport, with a typical wave climate for the month of June, will occur between the shoreline and the offshore end of the coffer dam (at KP 33.43) and so will be intercepted by the cofferdam. Average wave-induced infill rates of less that 0.05 m per day are expected over most of the shore platform seawards of the cofferdam. The calculated rates of infill may be over-estimates as the pipeline survey identified the seabed to be bedrock with some sediment – so transport rates may be limited by the lack of mobile sediment. Having said that, there will be a general contribution to transport and trench infill from tidal currents that will keep sediment mobile even when waves are small.

The exception to this is with the significantly higher rates of sediment transport predicted around KP 33.35 at the crest of a small sand bar that fills a channel cut through the bedrock. The position and height of the crest of the sand bar will vary in time, which will alter the position and rate of the maximum infill. Nevertheless, a peak average infill rate of about 1 m per week may be expected near the bar crest as the sand bar acts as a conveyor of sediment transport. The depth of the channel is such that the base of the trench is likely to pass through the sand infill at this point – not the clay shore platform. The trench side slopes will have to be lower in sand than in clay, so the trench will be wider at this point.

The sediment transport rates calculated were based on an average wave climate for June. There will be considerable variations in wave height and direction within a month, so daily rates may be considerably higher or lower than the average. Sediment transport calculations are also relatively inaccurate and are often accepted to have error bands of a factor of two.

10. References

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Tables

Table 1 Drawings supplied by Saipem

Title	Drawing Number	Rev.
Shore Approach	J08435B-K-DW-21034	D2
Typical shore approach/landfall arrangement	J08435B-K-DW-21056	D2
Overall field layout	J08435B-K-DW-21150	D5
On-shore survey	SAIL-11-SK-13-0003.01	01
Pipeline route responsibility diagram	SAIL-11-SK-13-0006.01	01
16" gas pipeline & 3" methanol piggybacked pipeline route alignment sheet 10 to 10	J08435B-K-DW-21044	D2
York project FEED (Easington option) temporary construction areas & site establishment options	J8435B-S-DW-18018	D1
York pipeline S355 Shore Pull Sequence.	SAIL-10-BID-13-0009.01	01
Alignment sheet 9 of 9 (KP 29.87 to KP 33.921)	8429.09	5
Field layout	Y49052-PG-DRG-0021	B1
Platform approach	Y49052-PG-DRG-0022	B1
Shore approach	Y49052-PG-DRG-0023	B1
Pipeline G.A. for tunnel & shaft	Y49052-PG-DRG-0029	B1

Table 2 Average annual source of sediment from erosion of Holderness

Material	Percentage of source	Source volume per year ($\times 10^3\, m^3/a^{-1}$)	Sinks and temporary stores*
Gravel	3.5	112	Binks, New Sand Hole, Spurn Head
Very Coarse Sand	1.5	48	Binks, New Sand Hole, Spurn Head
Coarse Sand	2	64	Mainly as above, some as below
Medium Sand	5.5	176	Sandwaves*
Fine Sand	13.5	432	Sandwaves* and Donna Nook
Very Fine Sand	8	256	Donna Nook
Silt and clay	66	2112	Humber, Wash, North Sea

Table 3 Gradients of the shoreface ramp and seabed seaward of it for Holderness (Wingfield & Evans, 1998)

	Barmston	Hornsea	Tunstall	Dimlington
Gradient of shoreface ramp	1:133	1:118	1:179	1:78
Base of shoreface ramp (m)	-11	-14	-13	-14
Width of shoreface ramp (km)	1.9	2.0	2.9	1.3
Gradient of seaward seabed	1:708	1:833	1:476	1:708

Table 4 Cliff Erosion Rates from East Riding of Yorkshire Council

Profile Number	OS eastings (m)	OS northings (m)	Cliff top elevation (mOD)	Average cliff retreat rate (m/yr)
105	538474.4	422400.8	24.5	1.35
106	538652.6	422004.7	23.4	1.26
107	538957.8	421608.6	35.4	1.17
108	539262.9	4321212.6	27.7	1.56
109	539568.1	420816.5	23.0	1.50
110 - 112	Easington Revetment			
113	540501.8	419058.4	7.9	1.50
114	540711.2	418604.4	6.8	1.58
115 – 117	Easington / Kilnsea SSSI		Dunes	

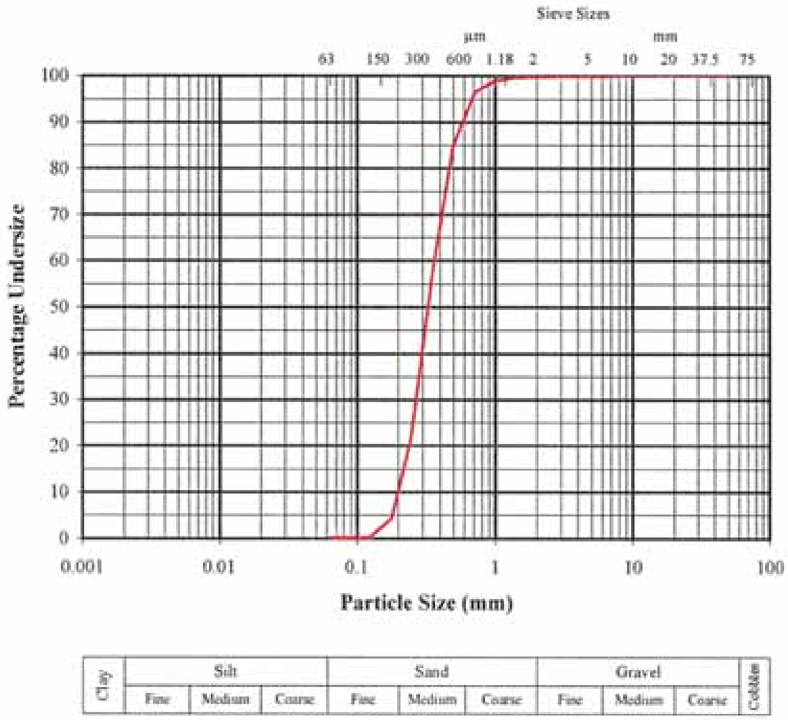
Table 5 2011 and 2037 assumed shore platform levels

Source	2011 KP (m)	2011 Level (mLAT)	2037 KP (m)	2037 Level (mLAT)
CPT33	32000	-14.8	32039	-14.8
inferred	32150	-14.8	32189	-14.8
inferred	32485	-13	32524	-13
CPT34*	32811	-10.1	32850	-10.1
inferred	33225	-4.4	33225	-4.94
inferred	33260	-5.3	33260	-5.3
8429.09	33295	-5.75	33295	-5.7
inferred	33330	-5.3	33330	-5.3
inferred	33365	-3.5	33404	-3.5
CPT3	33521	-0.5	33560	-0.5
CPT2	33572	0.7	33611	0.7
BH3	33578	0.7	33617	0.7
CPT1	33621	1.5	33660	1.5
CPT4	33644	2.2	33683	2.2
BH2	33668	2.9	33707	2.9

Note: correction from ODN to LAT made using Saipem's specified value of 3 m
CPT34* value based on CPT depth of cover and Fugro seabed level

Figures

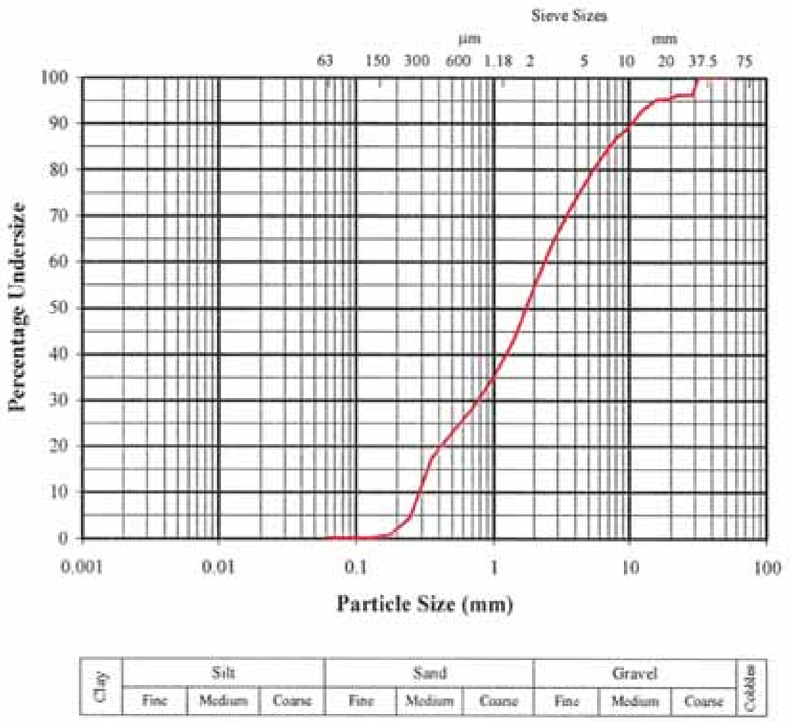
Figure 1 Holderness, Humber and Lincolnshire coastline (HR Wallingford, 2003) showing average coastal retreat rates along Holderness from Valentin (1971)



Sieve Size mm	% Undersize	Sieve Size mm	% Undersize	Sieve Size mm	% Undersize	Sieve Size mm	% Undersize
50.800		4.000	99.909				
47.630		2.800	99.879				
44.450		2.000	99.804				
41.280		1.400	99.594				
38.100		1.000	99.009				
34.930		0.710	96.462				
31.750		0.500	84.851				
28.580		0.355	57.868				
25.400		0.250	21.705				
22.230		0.180	4.226				
19.050		0.125	0.205				
15.880		0.090	0.053				
12.700		0.063	0.035				
9.520							
8.000	100.000						
5.600	99.909						

D_{90} (mm)	0.593	**Description:** WES job no. PSD04_11 17th June 2011
D_{50} (mm)	0.332	HR job no : DDM6677 James Sutherland
D_{10} (mm)	0.203	PSD analysis of upper beach sample

Figure 2 Particle size distribution from top of beach (2m from revetment toe)



Sieve Size mm	% Undersize	Sieve Size mm	% Undersize	Sieve Size mm	% Undersize	Sieve Size mm	% Undersize
50.800		4.000	73.410				
47.630		2.800	64.715				
44.450		2.000	54.416				
41.280		1.400	42.777				
38.100		1.000	35.040				
34.930		0.710	28.250				
31.750	100.000	0.500	22.902				
28.580	96.274	0.355	17.319				
25.400	96.274	0.250	4.503				
22.230	96.274	0.180	0.722				
19.050	95.300	0.125	0.110				
15.880	95.300	0.090	0.045				
12.700	93.242	0.063	0.029				
9.520	88.755						
8.000	86.871						
5.600	80.472						
D_{90} (mm)	10.402	**Description:** WES job no. PSD04_11				17th June 2011	
D_{50} (mm)	1.772	HR job no : DDM6677				James Sutherland	
D_{10} (mm)	0.295	PSD analysis of lower beach sample					

Figure 3 Particle size distribution about 25 m seawards of revetment toe

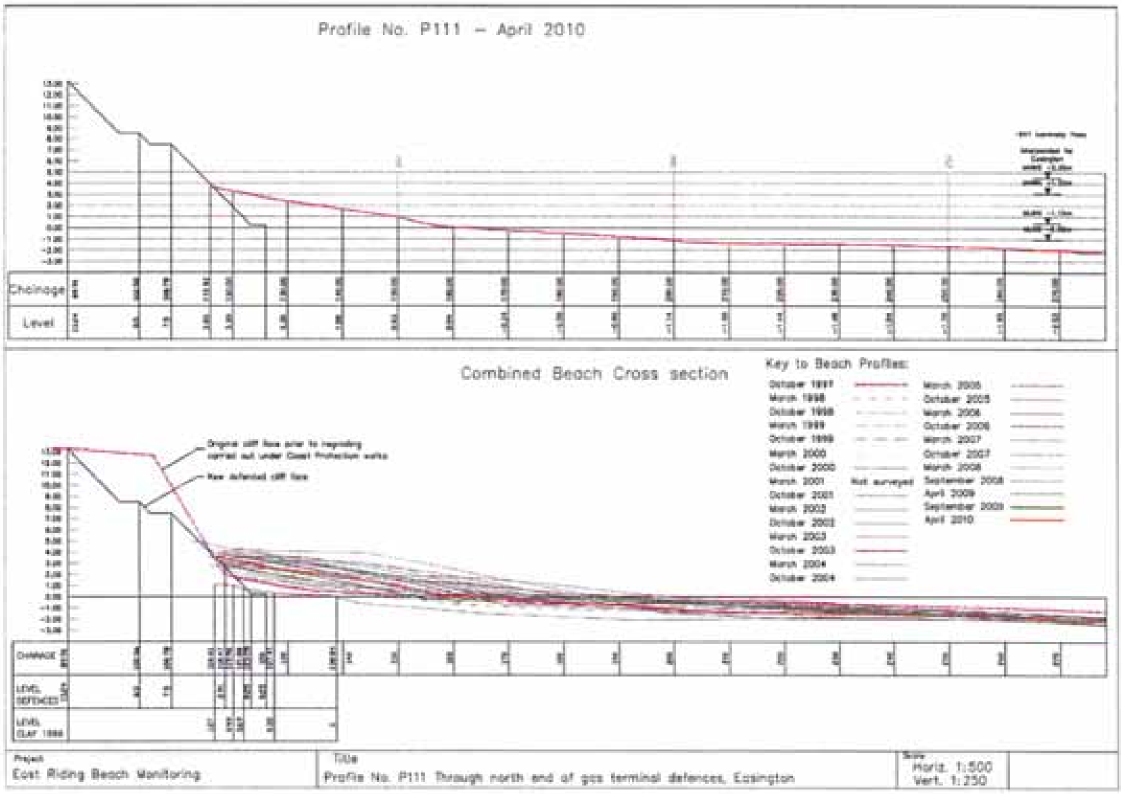


Figure 4 East Riding Beach Monitoring Profile P111 beach levels (see comment in text on tide levels)

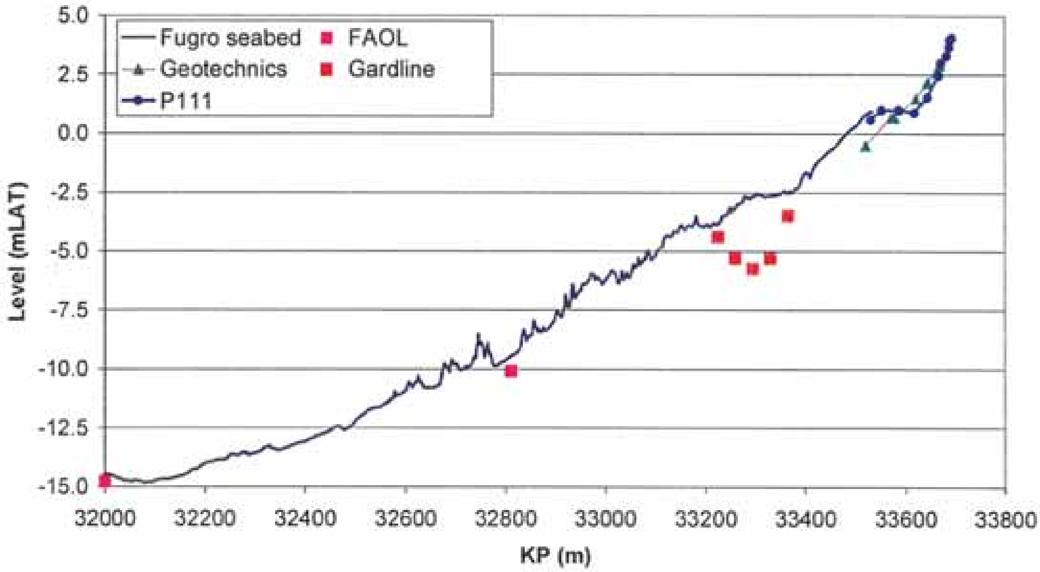


Figure 5 **Surveyed seabed levels and levels of top of clay**

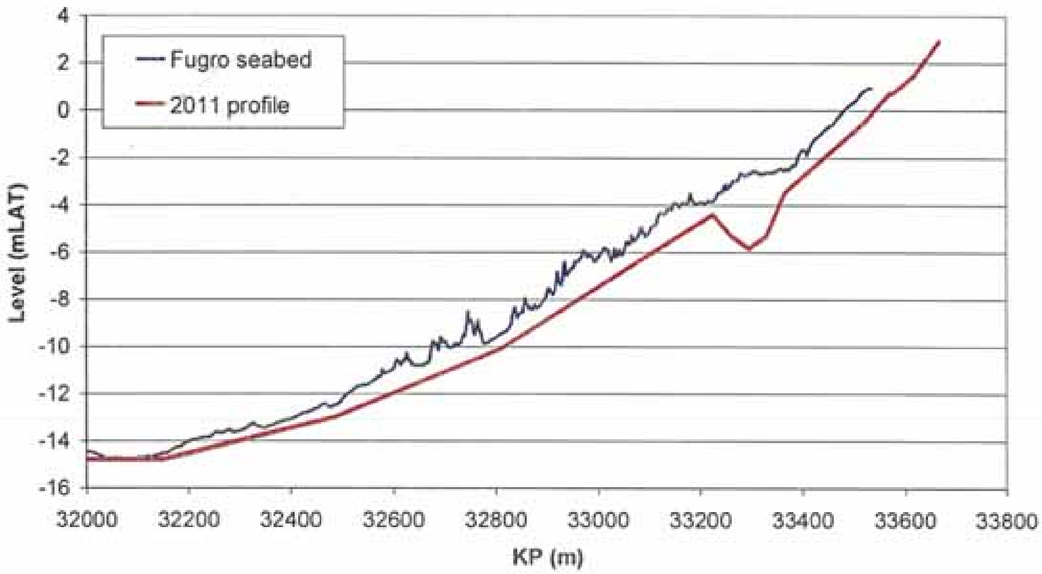


Figure 6 **Present day simplified 2011 profile for clay underlying the seabed profile**

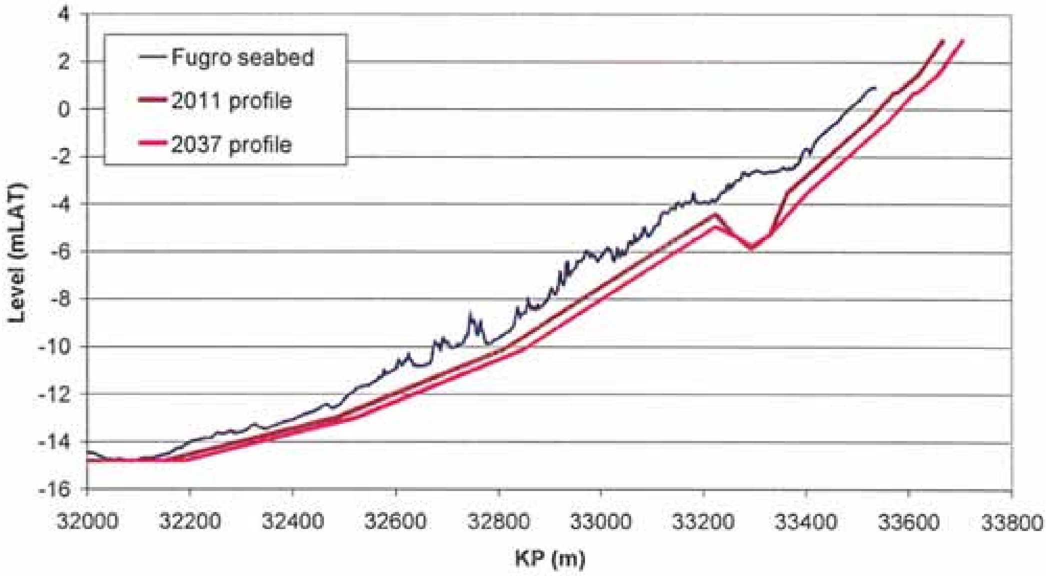


Figure 7 Present day simplified profile and future profile of clay (after 25 years from 2012 at 1.5 m/year retreat) (note: the seabed profile has not been changed)

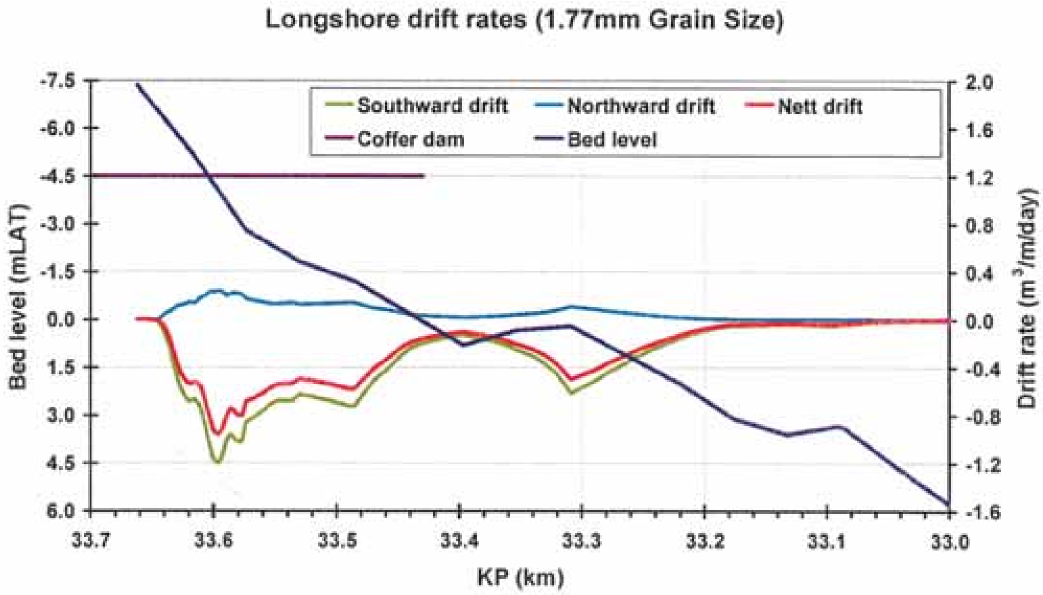


Figure 8 Daily average longshore transport rates during June for 1.77 mm sand

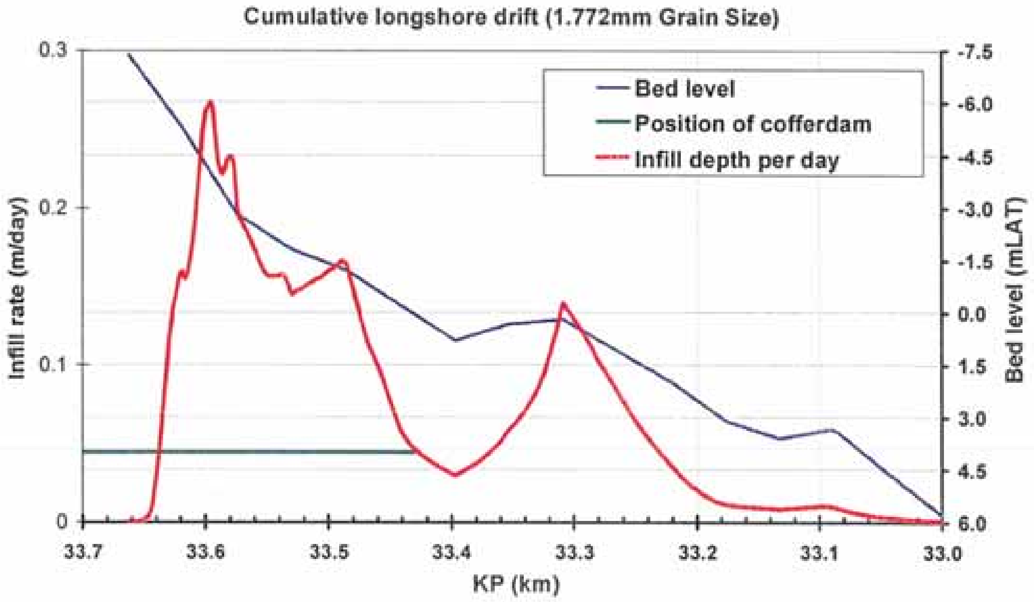


Figure 9 Daily average infill rate for June for 1.77 mm sand

Plates

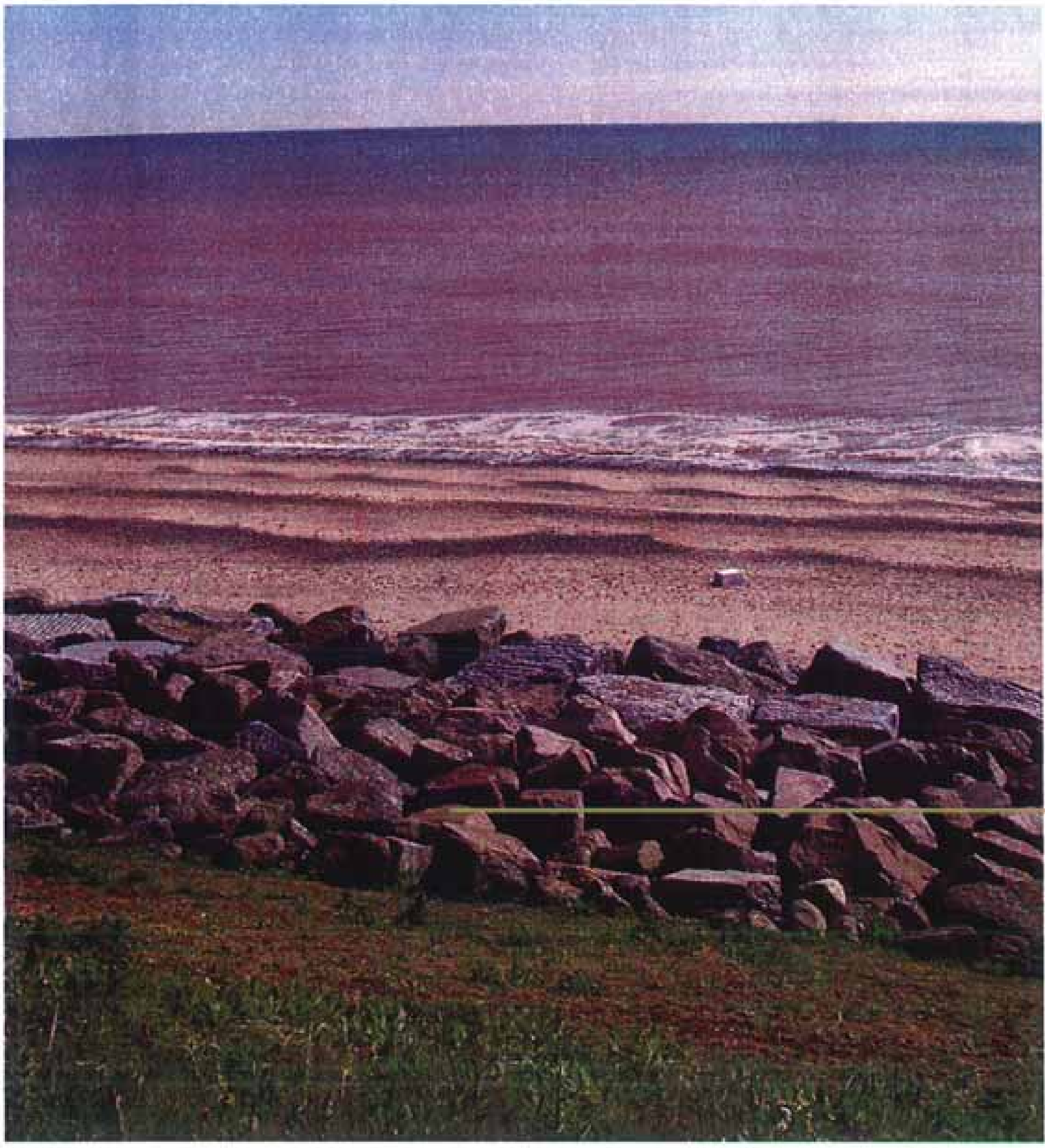


Plate 1 Made slope, revetment, beach and North Sea in approximate direction of pipeline
(note: this location is within 100 m alongshore from the currently defined landfall location)

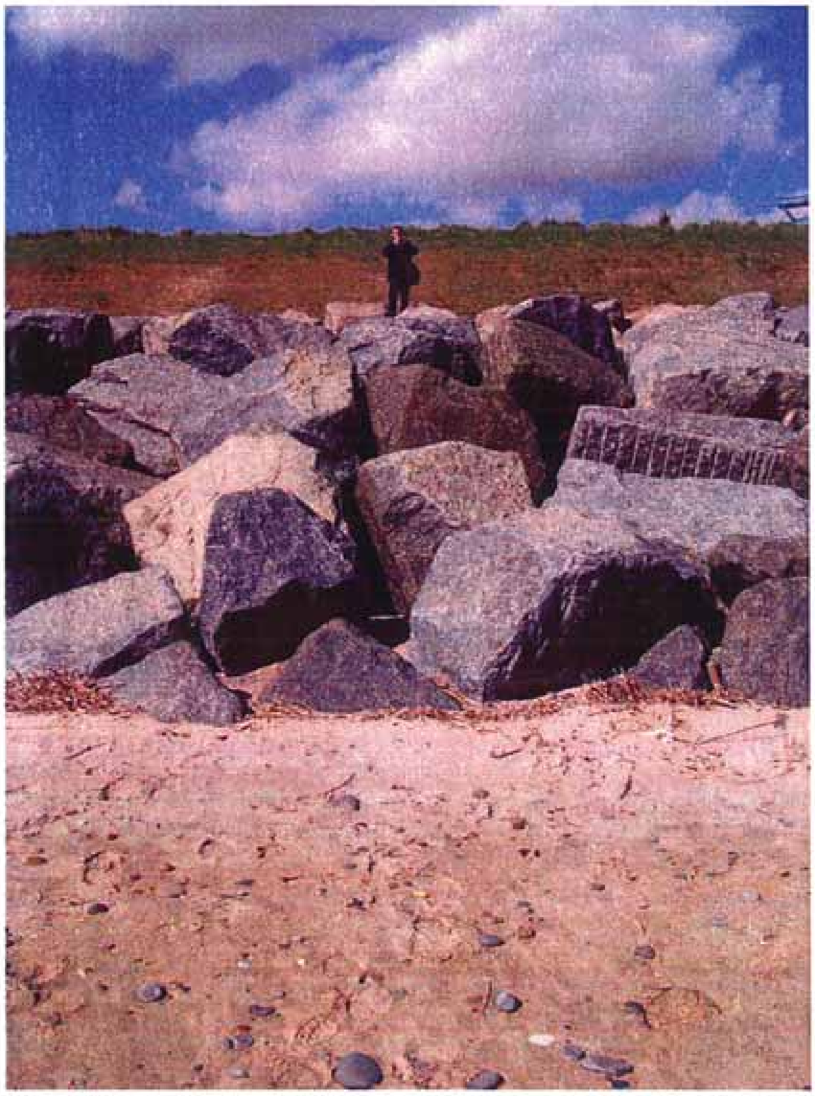


Plate 2 Top of the beach, revetment and slope at landfall location (see note on Plate 1)

Plate 3 **Minor cliffing and the variations in available sediment sizes at the top of the beach around high tide level**
(note: overall length of wooden handle about 90 mm)

Plate 4 The natural cliff face north of the revetment looking south

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