Whitby Coastal Strategy

Sandsend Road PAR Geotechnical Desk Study

Scarborough Borough Council

21 July 2011

Final Report

9W5572

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SUMMARY

The information consulted for this desk study report indicates that the cliffs at Sandsend are potentially at risk from landsliding.

The cliffs consist of glacial till deposits of Pleistocene age overlying Whitby Mudstone Formation rock of Lower Jurassic age. The rockhead at the shoreline is located beneath ground level, though it rises to the south behind the current cliff line. The till cliffs are vulnerable to erosion at the toe of the slopes due to wave action, but are also subject to slippage in the upper parts. This is probably due to water ingress, particularly if layers or lenses of sand or gravel are present within the main mass of the till. The presence of granular soils has been shown in Scarborough to render till cliffs more unstable than where there are no granular deposits present.

At present there is very little geotechnical data available in the area under consideration to enable a full assessment of the current stability of the cliffs and the likelihood of future failure. Thus, a ground investigation is proposed to enable outline design options to be considered in the Project Appraisal Report.

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1 INTRODUCTION

As part of the Whitby Strategy Review being carried out by Royal Haskoning for Scarborough Borough Council, a Project Appraisal Report (PAR) is being prepared for a stretch of coast near Sandsend, north-west of Whitby.

Sandsend is a small village on the North Yorkshire coast about 4 km west-north-west of Whitby. The village is located south-east of the headland of Sandsend Ness. At Sandsend, two streams enter the sea about 350m apart, and the main road from Whitby to Redcar, the A174, passes through the village very close to the shore.

The area under consideration is a stretch of coastline approximately 1km long east of the village. Slopes above the road are unstable, and the seawall and sloping revetments protecting the toe of the slope below the road are becoming damaged and are also unstable.

In order to inform outline design options for the PAR, it is proposed to undertake a ground investigation.

In order to make best use of ground investigation resources, and to mitigate geotechnical risks to the various scheme options, this desk study has been prepared using the available information.

The local geology is summarised and discussed in section 2; coastal stability issues in section 3; and potential geotechnical risks in section 3.3. Recommendations for ground investigation and monitoring are presented in section 4. References are listed in section 5.

This desk study report has been prepared for Scarborough Borough Council and North Yorkshire County Council for the Sandsend Project Appraisal Report only, and should not be used for any other purpose.

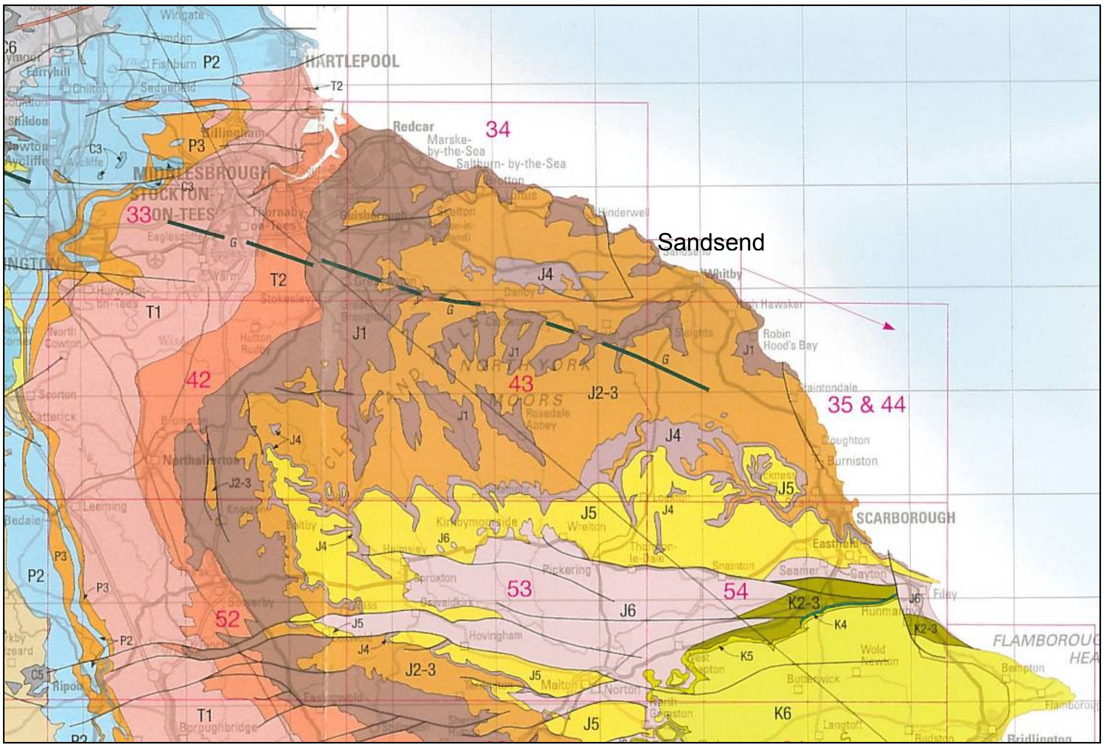
The opinions presented and recommendations made in this note are based on the information available from the consulted sources (as listed in section 5), from informal personal communication and from observations made during a site visit paid to the site on Wednesday 13 July 2011.

2 GEOLOGY

2.1 GENERAL

In North Yorkshire, roughly between Redcar and Filey, the bedrock formations consist of Jurassic-age (208 to 146 million years BP) deposits which are comprised predominantly by marine shales and limestones (see Figure 2-1, below).

Figure 2-1: Extract from 1:625 000 scale geological map of UK – North Yorkshire



Each grid square is 10 km by 10 km (reduced from original scale 1:625 000). Reproduced from 1:625 000 scale map Bedrock Geology North by permission of the British Geological Survey. Licence no. C08/031-CCSL © NERC. All rights reserved.

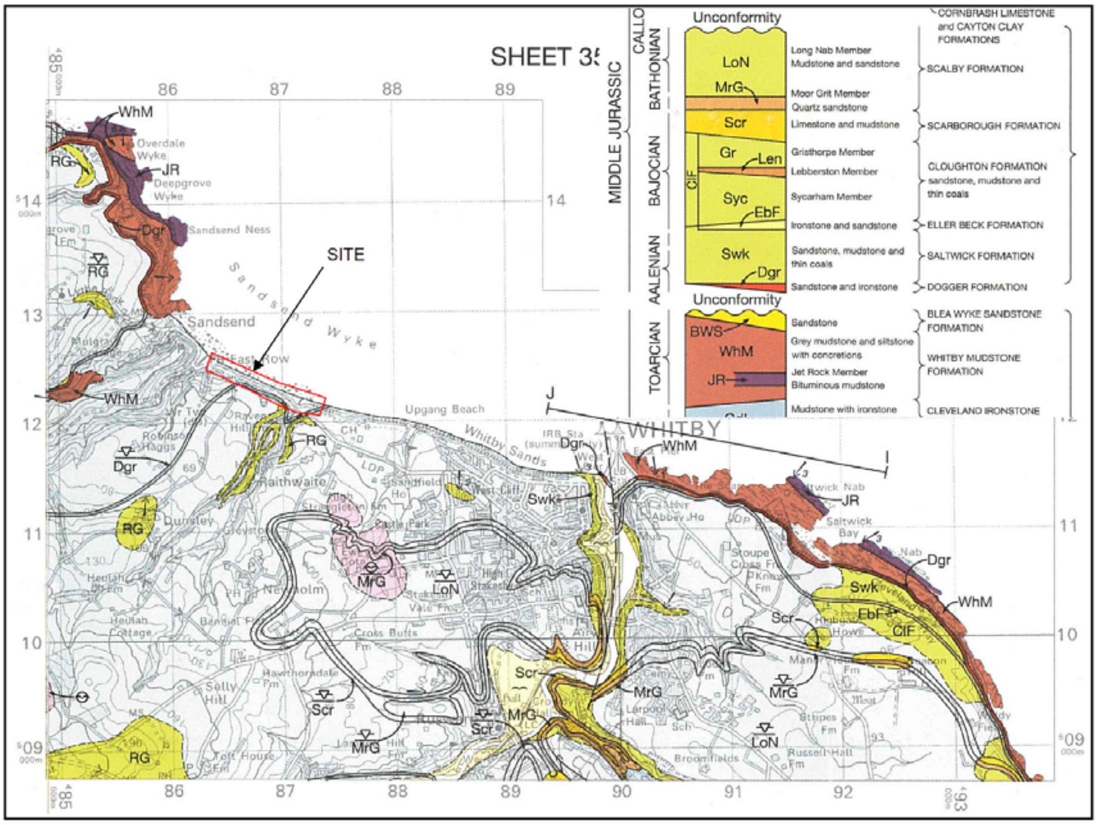
Much of this area was subjected to glacial or periglacial conditions during the Pleistocene period, especially during the last glacial (Devensian) period. As a result there are extensive deposits of glacial till overlying the Jurassic rocks of the North Yorkshire coast and other areas of lower-lying ground. The Cleveland Hills and Yorkshire Wolds tend not to have Devensian glacial deposits, though there are glacial lake deposits in the Vale of Pickering (Kent 1980).

2.2 SOLID GEOLOGY

In most of the Sandsend area, the 1:50 000 scale geological map shows that the bedrock consists of the Whitby Mudstone Formation of Toarcian (Lower Jurassic) age (BGS 1998). Going south-east, however, towards Whitby, the bedrock becomes younger, with the Dogger Formation and then strata of the Ravenscar Group of Aalenian (Middle Jurassic) age found respectively at rockhead. The geological map indicates that the rockhead is either horizontal or very shallowly dipping in this area (though the dip direction varies where it has been measured). However, it is not clear from the map what the dip direction of the rock is immediately beneath the site.

The geology at the site is shown in Figure 2-2, below, as an extract from sheet 35. The pale blue colour shown overlying the solid geology represents glacial till deposits.

Figure 2-2: Extract from 1:50 000 scale geological map of Whitby



Each grid square is 1km by 1km (reduced from original scale of 1:50 000). Reproduced from 1:50 000 scale Sheet 35 & 44 Whitby and Scalby by permission of the British Geological Survey. Licence no. C08/031-CCSL © NERC. All rights reserved.

The Whitby Mudstone Formation consists of a number of members which have been identified in the region (Kent 1980 and Cope 2006). These comprise (from oldest to youngest):

Grey Shale Member — c. 14m thick. Pale grey shales and siltstones with calcareous and sideritic[1] nodules; locally highly pyritic.

Mulgrave Shale Member — c. 9m thick. The lower part – Jet Rock Member – consists of thinly laminated (up to 20mm thickness) mudstones with high organic content, often bituminous; with layers of calcareous concretions, jet (fossil wood) as hard lenticular masses, and a thin band of hard pyritic limestone (‘Top Jet Dogger’). Ammonites are common and often contain petroleum in their chambers, leached from the surrounding rock.

c. 23m thick. The upper part is less bituminous and lamination is less pronounced. At the top is found a double

[1] Siderite ($FeCO_3$) is an iron mineral in the calcite group.

	band of pyritic nodules containing rare ammonites (*Ovaticerus ovatum*), occasional masses of sideritic mudstone and thin (c. 7cm) bands of limestone formed entirely from belemnites.
Alum Shale Member	up to 37m thick. Soft grey micaceous shales, with the basal 6m hard and almost non-bituminous; and c. 15m of grey pyritic shales. Above these are the main alum-bearing[2] shales, and the top 13-20m consists of limestone with large calcareous nodules, formerly worked for cement manufacture.

It should be noted that rock strata thicknesses as given above may not be applicable to the Sandsend site.

The Alum Shale Member was formerly worked at Sandsend Ness for the manufacture of alum, and as a result much of the upper part of the cliff there is now missing.

An erosional unconformity separates the Whitby Mudstone Formation from the overlying Dogger Formation of Middle Jurassic age. This formation is a thin (1-2m thick) but persistent band of marine sideritic sandstone with sporadic phosphatic pebbles, occurring across the site. The Dogger Formation contains many marine fossils of molluscs, brachiopods and *Opalinum* ammonites.

Above this, on Raven Hill, south of the site, and on the higher ground of Sandsend Ness, are found rocks of the Ravenscar Group. On the geological map around Sandsend they are not differentiated, but the basal Saltwick Formation is found above the Dogger Formation in Whitby. The Ravenscar Group strata consist of fluviatile and deltaic sediments, with the basal Saltwick Formation consisting of cyclothems of argillaceous sandstone, siltstone, underclay[3] and carbonaceous clay or coal.

2.3 DRIFT GEOLOGY

Apart from the headland of Sandsend Ness to the west of Sandsend village, where Jurassic-age rock of the Whitby Mudstone Formation and Dogger Formation are exposed, the cliffs from Sandsend to Whitby consist primarily of glacial till deposits of Pleistocene age (BGS 1998). Most of these deposits are of Devensian age (i.e. from the last period of ice re-advance around 10,000 years ago) and consist of clay with pebbles and lenses of gravel resulting from deposition beneath glaciers to the north of the current coastline (Kent 1980).

A visit to site showed the till to consist of stiff fissured brown sandy gravelly clay. Lenses or layers of red-brown medium to coarse sand were also noted in places in the lower cliff below the road. Where not covered by vegetation, the cliffs appear reddish-brown in colour.

Very large boulders (glacial erratics) have been noted in the till at Upgang, further east along the coast towards Whitby (Hemingway and Riddler 1980), and one was tentatively

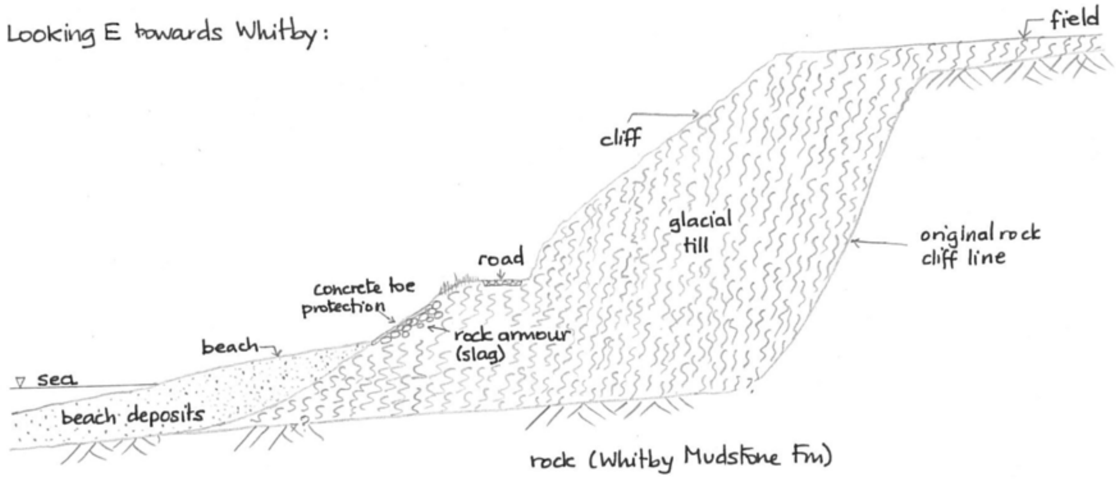
[2] Alum is a potassium aluminium sulphate mineral, previously used as a mordant (fixative) for dyes.

[3] Underclay – fine grained sediment immediately beneath a coal seam, generally with no bedding and strongly leached, causing a high kaolinite content.

identified on site in the upper cliff above the road at the western end of the study area. These large boulders, or 'rafts', are thought to have been ripped off the underlying rock by ice during glacial advance and later deposited amongst the finer material.

A schematic of the possible cliff morphology is shown in Figure 2-3, below.

Figure 2-3: Schematic of possible cliff morphology (not to scale)



(It should be noted that this cross-section represents only one of numerous alternatives of the likely cross-sections through the cliff, and that the geometry and the presence of the buried rock cliff shown does not necessarily represent the site conditions, which will be established through ground investigation and back-analysis of the slopes.)

The surface of the underlying rock is likely to have been weakened, due to the effects of glacial processes such as ice-shattering and weathering under periglacial conditions. It may be possible that the rock surface was abraded by the passage of ice over it, and thus the surface may be smoothed.

2.4 BGS BOREHOLE LOG DATA

Only a few borehole records are available from the BGS online GeoIndex database in the area, four of which are close to the site. The remaining three are located in the west of Whitby or on what is now Whitby Golf Course at Upgang. Details of these boreholes are given in Coordinates are reported to the nearest 10m, except where asterisked, where the precision of measurement is only to the nearest 100m. Records for NZ 81 SE 1 and NZ 81 SE 4 are identical.

Table 2-1 and their locations shown in The two boreholes which did extend into rock did so at quite different levels, since they were drilled about 2km apart, and at differing distances from the shore.

Up to 2.2m thickness of made ground, consisting of road construction material (granular sub-base material and granular sandstone fill) and re-worked glacial till (brown silty sandy slightly gravelly clay) was found in NZ 81 SE 5. However, made ground was not identified in any of the other exploratory holes.

The trial pit and boreholes undertaken closest to the shore (NZ 81 SE 5, 6 and 7) encountered beach deposits consisting of slightly gravelly sand of up to 2.2m thickness.

In NZ 81 SE 6 and 7, a layer of interbedded and interlaminated clayey silt and fine sand of between 1.2 and 2.5m thick was found directly above the till. A horizon of medium-coarse sand was also noted in this layer in NZ 81 SE 7. In boreholes NZ 81 SE 31 and 32, firm and stiff brown sandy gravelly clay layers were found above glacial till.

Glacial till deposits were found in all the boreholes except the trial pit NZ 81 SE 5, though they were not always clearly described (NZ 81 SE 70 records the strata above rockhead solely as "Drift", and thus soil other than till may be present at this location). In NZ 81 SE 1, the till deposits were found to consist predominantly of gravelly clay, but layers of gravel, silty sand and clay were also found, together with some very large boulders over 5m in size.

Where the glacial till was described in detail in the logs, it was characterised as a stiff red-brown or brown sandy slightly gravelly clay. Where rockhead was encountered in the boreholes, the till was between 26.5m (NZ 81 SE 1) and 36.6m (NZ 81 SE 79) thick. A thick (1.5m) layer of coarse gravel ("ballast") was noted at about 1m above rockhead in NZ 81 SE 1, which may or may not be water bearing.

Figure 2-4, on page 8.

Coordinates are reported to the nearest 10m, except where asterisked, where the precision of measurement is only to the nearest 100m. Records for NZ 81 SE 1 and NZ 81 SE 4 are identical.

Table 2-1: BGS borehole records in area referred to in this desk study report

BGS reference	Easting	Northing	Borehole depth (m bGL)	Estimated rockhead level (m OD)
Sandsend:				
NZ 81 SE 1 (& 4)	486280	512200	60.96	+19.2
NZ 81 SE 5	486250	512620	3.00 (trial pit)	unknown
NZ 81 SE 6	486250	512630	8.25	unknown
NZ 81 SE 7	486240	512660	7.63	unknown
West Whitby:				
NZ 81 SE 31	488410	511790	3.00	unknown
NZ 81 SE 32	488430	511800	3.00	unknown
Upgang:				
NZ 81 SE 79	488200*	511800*	1305.20	−14.8

Borehole NZ 81 SE 2 is close to borehole NZ 81 SE 79, but the record only details the Permian evaporite deposits at depth (between 719.3m and 1305.15m), and gives no detail of the overlying strata. Thus this record has been ignored for the purposes of this desk study.

The two boreholes which did extend into rock did so at quite different levels, since they were drilled about 2km apart, and at differing distances from the shore.

Up to 2.2m thickness of made ground, consisting of road construction material (granular sub-base material and granular sandstone fill) and re-worked glacial till (brown silty sandy slightly gravelly clay) was found in NZ 81 SE 5. However, made ground was not identified in any of the other exploratory holes.

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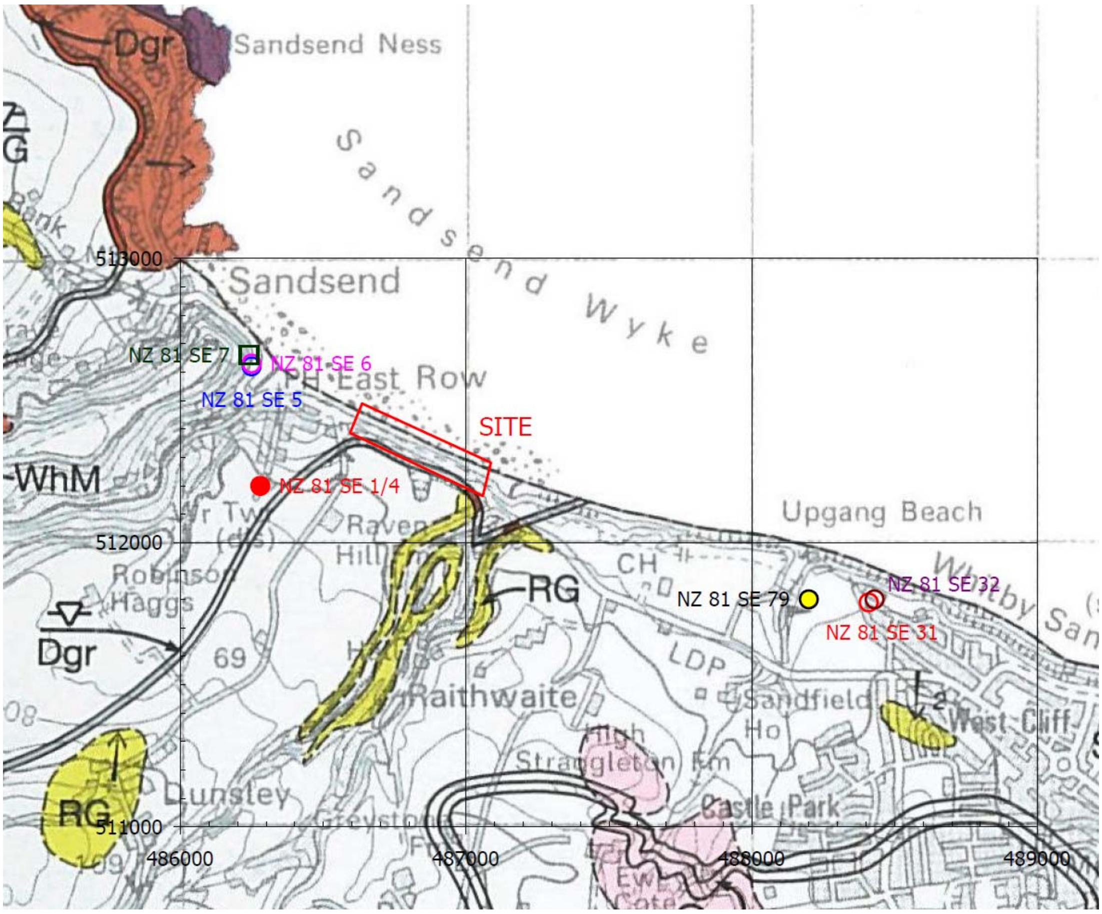
Figure 2-4: Approximate locations of BGS boreholes referred to in this note



Map reproduced from 1:50 000 scale Sheet 35 & 44 Whitby and Scalby by permission of the British Geological Survey. Licence no. C08/031-CCSL © NERC. All rights reserved. Each grid square is 1km x 1km.

There were no water strikes noted in any of the borehole logs, but this should not be taken as confirmation of its absence from the site.

3 COASTAL INSTABILITY

3.1 INTRODUCTION

The glacial till cliffs of the Yorkshire coast are known to be unstable, with the Holderness coast from Flamborough Head to Spurn Head eroding at significant rates. Failures are also known in slopes protected from marine erosion, such as the 1993 landslide at Holbeck Hall in Scarborough (West 1994). In these cases, instability is largely instigated by the ingress of water into the slopes through granular layers within the till deposits (Lee 2009).

At Whitby's West Cliff, east of the site, unstable cliffs of glacial till were remediated by cutting back the slope to 28°, and forming an earth buttress around the toe of the slope which is around 20m high and 400m long (partly shown below in Figure 3-1). Granular basal and intermediate drainage was also installed (Clark & Fort 2009).

Figure 3-1: Cliff stabilisation at West Cliff, Whitby

The above photograph also shows the difference in the cliff line between the stabilised area on the left (east) and the unprotected area on the right (west).

3.2 COAST AT SANDSEND

At Sandsend, rockhead is found at varying depths below beach level. There is a wave-cut platform of rock of Whitby Mudstone Formation at Sandsend Ness which is visible at most tide states except high water, but this disappears beneath the beach deposits eastwards towards Whitby. At Upgang, east of the site, rockhead is as low as −15m OD, but there is insufficient data to indicate whether this represents a buried valley, or whether the rockhead is consistently low in this area. Informal information received during a site visit on 13 July 2011 suggests that rock is about 1-2m below mean sea level, though this has not been confirmed.

The coastal cliffs at Sandsend are protected at the toe of the slope by armour consisting of boulders of blast furnace slag which are overlain by a skin of un-reinforced concrete. The concrete is continuously eroded by the sea and often spalls off in large sheets, leading to yearly patch repairs having to be made.

Above the main road, the upper slopes tend to be heavily vegetated, and have been variously remediated, generally by re-grading and installation of drainage fans. However, this has been done piecemeal and not all of the cliffs are stable. At the top of the cliffs, the land is relatively level and appears to be used as pasture for a nearby farm. On the day of the site visit, cattle were grazing in these fields, and hoofprints were noted in the exposed soil of the upper slopes.

3.3 POTENTIAL GEOTECHNICAL RISKS

The main risks to the site are seen to be the following:

- Ongoing instability of upper cliffs above road leading to slumping and falls of soil onto the road.
- Seepage of water into tension cracks within and behind the cliff face, leading to softening and weakening of the soil mass, and consequent landsliding.
- Unknown presence of gravel bands or lenses within the glacial till which could act as conduits for water seepage, leading to slippage of the soil.
- Presence of large boulders within the glacial till which could act as conduits for water seepage, leading to slippage of the soil; the boulders could also cause serious damage if a slip occurred which loosened the material around the boulder.
- Dip of rock towards the sea, acting as a preferential failure plane for deep-seated rotational failure of the cliff, including damage to the road.
- Weakening of rock at rockhead level due to ice shattering and other glacial processes, leading to loss of cohesion and contribution to slippage; may also act as weak zone for deep-seated failure.
- Erosion by wave action at the toe of the slope washing out material behind the armour and thus losing toe weighting protection against slippage of the whole cliff.
- Erosion by wave action at the toe of the slope washing out material beneath the road and consequent voiding, leading to damage to the road;

Ground investigation to inform design options for the mitigation of these risks is listed in section 4, next page.

4 RECOMMENDATIONS FOR GROUND INVESTIGATION

4.1 GROUND INVESTIGATION

In order to determine the likelihood of the risks listed in section 3.3, and thus to enable a suitable management strategy to be determined, a ground investigation is recommended to be carried out, consisting of the elements listed below in Table 4-1. It should be noted that these recommendations are for preliminary ground investigations, and that a more comprehensive investigation will be required for the final design stage.

Table 4-1: Proposed essential ground investigation

Location	Investigation
At the toe of the slope, on the beach*	Four number window sample holes, two at each end of the affected section and all roughly equally spaced along the beach. The window sample holes should attempt to reach rock, and to retrieve samples of the overlying strata. * Restrictions are known to apply with respect to access to the beach.
On the main road	Three number boreholes at roughly equal spacing in the outer (parking) lane of the road and in the lane closest to the upper cliff to determine the depth and type of infill beneath the road, and the composition and behaviour of the deposits beneath this down to rockhead. The presence of voids or the degree of compaction of the fill beneath the road should be determined, if possible.* Piezometers should also be installed to allow regular and long-term monitoring of the water level in the cliff. * Boreholes may need to be terminated if boulders or other obstructions are found beneath the road.
On the crest of the cliff	Three number deep boreholes to rockhead at roughly equal spacing along the top of the cliff to determine the thickness of the glacial till and take samples for testing, to determine the depth to rockhead and its condition. The presence of sand or gravel bands should be clearly identified. Piezometers should also be installed to allow regular and long-term monitoring of the water level in the cliff.

Laboratory testing should be undertaken on samples retrieved from the exploratory holes. This should include classification testing, strength and consolidation testing, residual strength testing (e.g. by ring shear tests) and contamination testing (for waste acceptance criteria).

In addition, the ground investigation listed in Table 4-2, next page, would be desirable, but not essential:

Table 4-2: Proposed desirable investigation

Location	Investigation
On the upper slope of the cliff	Two boreholes to a depth of 10m below rockhead to determine the composition and thickness of the glacial till, and the depth to rockhead, with coring of rock, sampling of soil and rock, and installation of piezometers for water level monitoring in the cliff.
All boreholes listed in Table 4-1	Extension of boreholes into rock by 10m with coring of rock, sampling and testing.
In the road	Three or four trial pits to determine the composition and degree of compaction of the fill beneath the road.

Further investigation will also be required to enable detailed design of the proposed works. This may include installation of inclinometers or additional piezometers, but will depend on the strategy chosen.

4.2 MONITORING PROGRAMME

Groundwater monitoring should be undertaken on a regular basis in the piezometers installed in the cliff. The groundwater surface and its behaviour before, during and after rainfall and storm events should be mapped. Daily rainfall on site should also be recorded.

Regular and semi-continuous readings can be provided by installing electronic 'divers' in standpipes, from which data can be transmitted or regularly downloaded. Given the rapid rate with which till cliffs can fail, it is recommended that readings are recorded at no less than hourly intervals.

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