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Analysis and Interpretation of Coastal Monitoring Data

Geotechnical Interpretative Report

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Disclaimer

This report is a review of all the available geotechnical information made available by Scarborough Borough Council (SBC) for the proposed scheme. This report presents an initial interpretative analysis of the results of monitoring regimes, (piezometers, inclinometers, walk over surveys, crack monitoring, recession monitoring, etc) desk studies and ground investigation in accordance with the requirements of the Client. The objective of this report is to provide an assessment and review of the relevant background documentation, to analyse and interpret the monitoring data. A full re-appraisal of the whole coastal system and assess the potential capability of this system to provide adequate warnings of potential failures and/of damaging ground movements.

Mouchel has prepared this report on the basis of the available information received from SBC during the study period. Although every realistic effort has been made to obtain all relevant information, all potential contamination, environmental and / or geotechnical constraints or liabilities associated with the sites under analysis may not necessarily have been revealed.

Mouchel has also used reasonable skill, care and diligence in the interpretation of data provided to them for the sites. However, the inherent infinite variation of ground conditions allows only definition of the actual conditions at the location and depths of exploratory holes, while at intermediate locations conditions can only be inferred.

Mouchel accept no responsibility for the content, quality or accuracy of any Third party reports, monitoring data or further information provided either to them by SBC or, via SBC from a Third party source, for analysis under this term contract.

Note on BS EN 14688 and 14689

Soils and rock descriptions in this document have not been executed in accordance with BS EN 14688 and BS EN 14689 as the publication of reports used in the compilation of this document pre-dates the implementation of Eurocode 7 in the UK, in 2007.

In respect of this, Mouchel has used reasonable skill, care and diligence in the interpretation of data provided to them for the sites, where the issue of reports pre-dates current prevailing standards such as Eurocode 7.

Contents

1 Executive Summary

Scarborough Borough Council's (SBC) local coastal monitoring programme extends along the length of its North Yorkshire coast from Staithes in the north to Speeton in the south, a distance of approximately 68 km. Coastal settlements include Runswick Bay, Whitby, Scalby Ness, Scarborough North and South Bay, Knipe Point, Killerby, Filey Town & Brigg and Filey Flat Cliffs, most of which have defended frontages. Some of these coastal defences are now ageing, in poor condition and are subjected to an aggressive wave climate. Furthermore the defences are, for the most part, backed by coastal slopes which show evidence of both instability and climatic denudation. These factors, together with environmental considerations of predicted climate change scenarios and sea level rise, focus the need for constant attention in order to minimise the potential risks to the public and coastal assets of the Borough.

Scarborough Borough Council takes an active approach to coastal monitoring and through their strategic coastal monitoring programme, the Council aims to rationalise and provide synergy with the recommended coastal monitoring as set out in the River Tyne to Flamborough Head Shoreline Management Plan 2, 2007 (SMP2), and various Coastal Strategy studies.

Coastal monitoring equipment has been installed at various locations within the Borough and regular readings have been taken and recorded. Mouchel has reviewed the relevant, available documentation and analysed and interpreted the monitoring data made available and provided by SBC. The objective of this report is to provide information which can be used to appraise the whole coastal monitoring system and assess the true capability of the existing system in order to provide adequate warning of any potentially damaging ground movements. This has been achieved by a process of inspection of monitoring instrumentation in late 2008 and early 2009 and the evaluation and interpretation of the data.

Detailed in the SMP2, the action plan outlines further investigation, studies or works which need to be undertaken or developed in order to implement policies for each of the Management Areas. The action plan identifies the monitoring required from the identification of investigations and studies, more of the need to gain a better understanding of coastal processes, so as to perform coastal management in an effective manner and to feed back into the shoreline management process. The recommendations for monitoring and frequency includes air photography (two yearly), topographic surveys (yearly), defence inspections (after storms/yearly), bathymetric surveys 10m and 20m contours (five and ten yearly), sea bed sediments (ten yearly), cliff face surveys (monthly) and cliff stability (continuous).

The recommended monitoring regimes presented within this report are separate to, but can be amalgamated into, that detailed above in the SMP2. The basis of the monitoring regimes for each of the sites has followed that already in place at the sites of interest. Departures from this are evident where remedial works have not been undertaken at a site, where there are significant 'gaps' in monitoring data from a site and following periods of heavy and prolonged rainfall. In the former two cases, recommendations for future monitoring of installed instrumentation (inclinometers and piezometers) has been to carry out monitoring at monthly intervals for six months, every two months until month twelve and then reverting to bi-annual intervals for the remaining two years monitoring period if no significant movement is detected. Following a period of heavy and prolonged rainfall it is recommended to carry out monitoring one week of the end of the rainfall event and at monthly intervals thereafter for three months. The designation of '***significant movement***' has been proposed as follows, however full quantification of the parameters of 'significant rainfall' was beyond the scope of this study. This will require analysis of historical meteorological data for specific sites and agreement with the response policy with SBC.

Undertake six monthly (bi-annual) monitoring of piezometers and inclinometers, unless there is a significant rainfall event, when the monitoring should be undertaken within one week of the end of the rainfall event and at monthly intervals thereafter for three months. If no significant movement (<10mm) continue with the bi-annual or until the next significant rainfall event.

If significant movement (10 - 20mm) comes from the rainfall event increase the frequency to weekly until the movement reduces <10mm for two consecutive weeks, then resume bi-annual. SBC should be notified.

If movement is 20 - 50mm undertake monitoring on a daily basis, notify SBC and undertake a walkover inspection of the area.

If movement is >50mm continue to monitor hourly. Alert SBC and emergency services and in consultation with SBC warn local occupants to prepare for evacuation.

A summary table of recommended monitoring is presented at the end of each chapter relevant to the sites under analysis. It may be appreciated that there are different scales of monitoring identified for each site. This is reflected in an assessment of the sites generally based upon the amount of relevant monitoring data made available, the significance of the data to the present condition of the sites, any remedial works carried out on site, historic information including previous ground investigation reports and an assessment of the historic and existing problems at each site.

A summary of the observations at each site and the recommended actions is presented in Table 1 below.

Table 1 Summary of Site Observations and Recommendations

Site Title	Principal Observations
Runswick Bay	Remedial measures having positive effect on stability rates, i.e. ground movements arrested.
Whitby West Cliff	Recognise the potential for slope failure present and of ageing slope remedial works.
Scalby Ness	Close proximity of slope failures and cliff crest recession to properties.
Scarborough North Bay	Remedial measures having positive effect on stability rates, i.e. ground movements arrested.
Scarborough South Cliff	Possible failures within inclinometers indicate slope ground movements at the crest of slopes.
Knipe Point	Close proximity of slope failures and cliff crest recession to properties would make this high risk if on SBC land. However risk is on third party landownership of NYCC and the NT
Killerby Cliffs	Active cliff recession, no threat to humans or assets as isolated site at present.
Filey Town	Remedial measures to be undertaken, slope stability analysis indicates slopes are stable at present.
Filey Flat Cliffs	2 No. known failure processes identified, lack of monitoring data puts site as high priority.
Recession Point Sites	Sparse recession data available, aware cliff recession is actively on-going.

2 Introduction

2.1 Summary of the Project

This report relates to a review, analysis and interpretation of existing data held by Scarborough Borough Council in respect of previous plans, strategies, ground investigations, borehole records, laboratory test data, geomorphological mapping and historical monitoring records. An initial analysis and interpretation is to be undertaken based on this data which is to provide:

1) A clear definition and understanding of the problems at each site (in accordance with DEFRA requirements) based upon the existing data;

2) The current and potential risks associated with any ground movements at each site;

3) A series of early warning signs and trigger levels based upon the on-going monitoring of piezometers, inclinometers and visual inspections;

4) A series of appropriate response actions in relation to the findings of the above monitoring;

5) Recommendations for an appropriate regime of continuous monitoring and interpretation, including frequencies, at each site related to the findings of the above monitoring.

2.2 Description of Project

The extent of the monitoring area (Figure 1) to be considered for the analysis is along the full length of the Borough Council's coastline, approximately 68km, from Staithes in the north to Speeton in the south. Through the Shoreline Management Plan 2007 (SMP2) and Coastal Strategy process, several sites within the borough have been identified and are either subject to an on-going monitoring regime or have been monitored in the past.

The sites included for analysis are:

Runswick Bay

Whitby West Cliff

Scalby Ness

Scarborough North Bay

Scarborough South Cliff

Knipe Point

Killerby

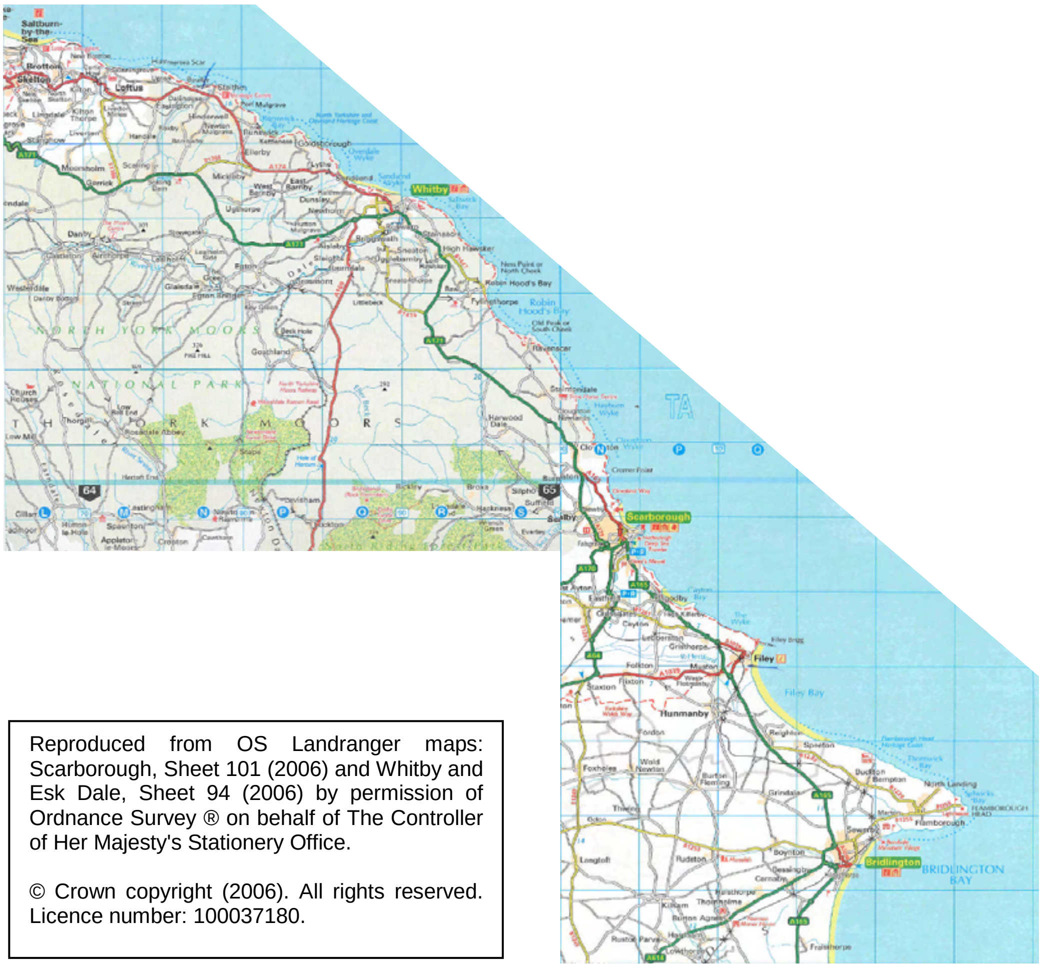
Filey Town and Brigg

Filey Flat Cliffs

15No. Recession Point sites located between Scalby and Speeton

Site plans of the sites are presented as Drawings 1 to 12 in Section 15 and a site plan for Killerby is presented in Section 12.1. The plans illustrate the locations of piezometer , inclinometer and recession points.

Figure 1: Scheme Location



2.3 Background to Data and Monitoring

The Shoreline Management Plan (SMP2) provides the basis for sustainable coastal defence policies along the North Yorkshire coastline. The SMP2 is a non-statutory policy document for coastal defence management planning. It provides a large scale assessment of the risks associated with coastal evolution and presents a policy framework to address these risks to people and the developed, historic and natural environment in a sustainable manner. The SMP2 sets out a development of policy over three epochs (2025, 2055 and 2105) from the present and over the next 100 years. The North Yorkshire coastline is separated into Policy Development Zones (PDZ) which are divided into Management Areas (MA). Each Management Area is sub-divided into Policy Units with an assigned Policy Plan for the succeeding 100 years period. These policies are:

- Hold the line (HTL) by maintaining or enhancing the standard of protection.
- No active intervention (NAI), where there is no investment in coastal defence assets or operations.
- Advance the line (A) by constructing new defences seaward of the existing defences.
- Managed realignment (MR) by identifying a new line of defence and where appropriate constructing new defences landward of the original defences.
- Retreat or Realignment (R) by identifying a new line of defence and where appropriate constructing new defences landward of the original defences.
- Hold the line on a retreated alignment (HR) by identifying a new line of defence and where appropriate constructing new defences landward of the original defences.

The Council's strategic coastal monitoring programme aims to rationalise and provide synergy with the recommended coastal monitoring as set out in the River Tyne to Flamborough Head Shoreline Management Plan, SMP2 (2007), and various Coastal Strategy studies. Coastal monitoring equipment has been installed at specific locations detailed in Section 2.2 within the Borough and regular readings have been taken and recorded.

Mouchel's brief is to review the relevant, available documentation and to analyse and interpret the monitoring data. A re-appraisal of the whole coastal monitoring system is required to assess the true capability of the existing system to provide adequate warning of any future potential risks (i.e. damaging ground movements) and formulate appropriate responses. This is to encompass the processes for inspection as well as monitoring instrumentation and evaluation and, interpretation of the available data.

3 Runswick Bay (Site Code AB01)

The SMP2 details the site (as discussed in Section 2.3) of Runswick Bay as follows:

Policy Development Zone 7							
Management Area		**Policy Unit**		**Policy Plan**			
				2025	2055	2105	Comment
MA21	Cobble Dump to Sandsend Ness	21.1	Runswick Village	HTL	HTL	HTL	-
		21.2	Runswick Bay	NAI	NAI	NAI	Loss of property south of Runswick

3.1 Description of the Site

Runswick Bay is situated on the north east coast of England some 16km north west of Whitby town. It is formed between the headlands of Caldron Cliff to the north and Kettleness to the south and comprises a deeply indented sandy bay approximately 2km in length. The bay is backed mostly by cliffs and steep glacial till coastal slopes. The village of Runswick Bay is developed within the general valley formed by the Runswick and Nettledale Becks. The village straddles the boundary between the glacial till slopes which occupy most of the bay and the Jurassic shale and sandstone cliffs to the north. Most of the village is founded on weathered shale but properties to the southern edge and the access road (Runswick Bank) and car parks are founded on glacial till landslide debris. The village is fronted by four separate sea defences, of varying age and construction, which stretch from Runswick Beck north of Caldron Cliff around to Nettledale Beck to the south.

Figure 2: Site Location

3.1.1 Historic Review of Problems

Runswick Bay has a long history of slope instability, the first recorded slope failures occurred in 1682 when the whole village, located further north than at present, collapsed towards the shore. Successive landslips of varying severity occurred in 1873, 1953 and, in 1958 when the old road was closed twice in one week due to landslides. This road was abandoned in 1961 with the construction of a new access road constructed further to the west between 1961 and 1963, on its present alignment. Around the same time a sea wall extension and new car park were constructed at the base of this road. Landslips and rockfalls were experienced immediately north of the village during the 1970's, including a landslip at Rose Cottage in 1975, resulting in the loss of various, limited assets.

A mass concrete sea-wall constructed in 1970 provided coastal protection to the southern edge of the village, access road and car park areas. Since its' construction, the sea-wall was subjected to a combination of marine and land based erosional mechanisms causing the wall to move in a seaward direction with backwards rotational tilting. Sea-wall deterioration and failure has been caused by earth pressure loading from slope failures behind the wall, beach erosion exposing the toe of the wall and wall toe failure of the fractured and folded shale bedrock.

Three areas of slope instability have been identified within Runswick Bay which have influenced the failure of the previous sea-wall and other sea defences and are still having an effect. These areas are identified in Figure 3 and are described as being:

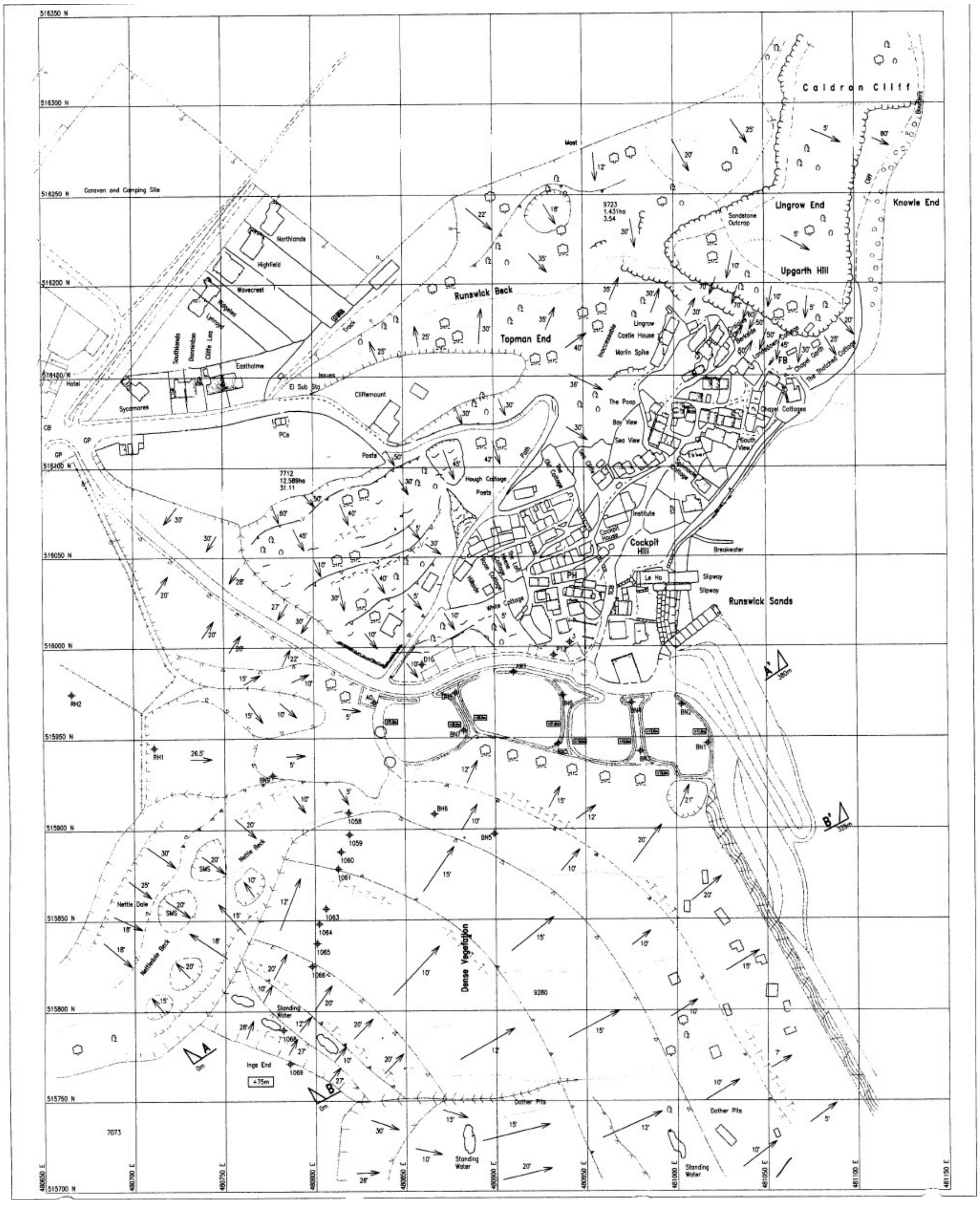
1. Upgarth Hill – The Upper Lias shales and sandstones of the Saltwick Formation forming the cliffs below Upgarth Hill are covered by a thin mantle of glacial clay. Intact cliffs stand at angles of 50 to 70 degrees whereas previous failures have led to slopes of talus debris standing at 20 to 30 degrees with light vegetation cover. The toe of the east facing slopes are protected by a concrete sea-wall and the toe of the south facing slopes are continually being undercut by Runswick Beck which forms an incised valley with over steepened sides to the north east of Runswick village.

2. Topman End – is located immediately north of the village, with heavily vegetated, glacial slopes characterised by a network of scarps and transverse tension cracks behind small superficial failures. Slope angles vary between 30 and 40 degrees, decreasing to 5 to 10 degrees mid-slope. These superficial failures are caused by the entrapment of excessive ground water.

3. Ings End – this area extends from south of Nettledale Beck to Limekiln Beck a distance of approximately 500metres over an area known as Dother Pits. Sub-vertical headscarps, formed in glacial tills, are present below the cliff tops between the two becks. Below this scarp are a series of undulating slopes formed by the retrogressive failure of deep seated basal shear planes along the shale bedrock. The slopes can be divided into three distinct zones characterised by uneven ground, ponding water, irregular springs and streams and dense vegetation. Slope angles vary between 15 and 20 degrees with the crests of individual landslide blocks well defined by breaks of slope at lesser angles of between 5 and 10 degrees. Subsequent failures have been triggered by the destabilising effect of an initial failure caused by undercutting of the leading block by progressive coastal erosion. The back scarp areas of the landslip complex has been found to contain saturated sand layers and lenses which are thought to be supplied by the sandstone present further inland. Groundwater seepages have been experienced, during ground investigations, from the basal backscarp areas and from within disturbed shales immediately below the glacial tills some distance from the slope toe.

Due to the ground movements detailed, it became evident by 1998 that the sea-wall was in danger of imminent collapse which would have lead to large scale landslip failures and loss of amenities in the village. Accelerated movements of the sea-wall, particularly at the southern end, eventually lead to the structure being replaced by a rock armoured revetment and an intermediate compressible buffer zone.

Figure 3: Geomorphological Map of Runswick Village



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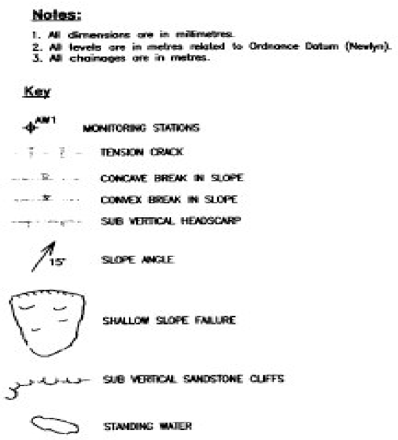


3.1.2 Site Walkover

A site walkover was conducted by a geotechnical engineer from Mouchel on 28th November 2008. The site visit confirmed the condition of the existing borehole instruments as being operable. A series of photographs was also taken of the site picking up salient topographical features such as varying slope angles, back scars, relict slope failures, as well as the remedial works which were completed in 2001 and the sea-wall defences. Selected site photographs are presented in Appendix A.

Features identified during the walk over survey are described below in Section 3.1.3 of this report.

3.1.3 Topography and Geomorphology

The village of Runswick is situated at the foot of a steep, 80metre high bank and has a long history of slope instability. It occupies the northern end of the bay in a confined site bounded by Nettledale Beck to the south and Runswick Beck to the north. The geological structure of the bay is inferred to be derived from a shallow syncline trending north-south and shallowing westwards away from the coastline. This feature forms a buried glacial channel extending some distance inland. The southern side of the village comprises the main access road with car parking facilities beyond as far as Nettledale Beck. This area is founded upon the glacial till deposits which appear actively unstable, based on the surface morphology. Beyond Runswick Beck which forms the northern limit of the village lies sheer cliff headland of Middle Jurassic sandstones and ironstones which lie unconformably on Lower Jurassic shales. These shales form a wave cut platform below the foot of the cliffs at the north end of the bay.

3.1.4 Existing Information

The following reports have been provided by SBC for consultation:

Report No. 089 - ***Runswick Bay Coastal Protection and Cliff Stabilisation Emergency Works***. Document No. H438/R/4, High-Point Rendel Ltd, October 1998.

Report No. 132 - ***Scarborough Strategic Coastal Monitoring (Staithes to Scarborough). Defence Condition Surveys – Volume 1***. Document No. 1540/R/1, High Point Rendel Ltd, March 2002.

Report No. 135 - ***Scarborough Borough Council. Strategic Coastal Monitoring Staithes to Scarborough. Cliff Condition Survey - Volume 2 Slope Proformas. Report No. R/1540/2/1. High Point Rendel Ltd, September 2002.***

Report No. 136 - ***Runswick Bay Coastal Defence Strategy Study, Cauldron Cliff to Kettleness Point***. Document No. R/1321/R/2, High-Point Rendel Ltd, November 2002.

Report No. 186 - ***Scarborough Borough Council. Strategic Coastal Monitoring Programme 2001-2006. Condition Analysis of Coast Protection Assets, Cliffs and Beaches from Staithes to Speeton.*** Halcrow Group Ltd, November 2006.

3.2 Stratigraphy

3.2.1 Soil Profile

The published geological map of the area 1:50,000 British Geological Survey (BGS) Sheet 34 Solid and Drift Guisborough indicate the site is underlain by superficial deposits of glacial till (Boulder Clay). These comprise stiff silty sandy clays, sands and gravels and laminated stiff silty clays. The solid succession of the area is indicated as Middle Jurassic sandstones (Saltwick Formation) and ironstones (Dogger Formation) (rocks of the high cliff headland north of the village) which lie unconformably on Lower Jurassic shales (Whitby Mudstone Formation). The shales are exposed as a wave cut platform, dipping at 2^o in a southerly direction, at the front of the cliffs along the north of the bay. The map indicates a north-south trending fault passing beneath the village and across the upper beach area to the south, with down throw and inclination to the west.

Table 3.2.1 Geological Stratigraphy

Age	Stratum
Quaternary (Pleistocene)	Glacial Till Stiff silty sandy clays, sands and gravels, laminated silty clays
Middle Jurassic	Saltwick Formation Sandstones and mudstones
Middle Jurassic	Dogger Formation Iron-rich sandstones
Lower Jurassic	Whitby Mudstone Formation Silty shales

3.2.2 *Groundwater Regime*

Hydrogeology

The Groundwater Vulnerability Map (Sheet 9) of North East Yorkshire has classified the area as a Non-Aquifer because of their negligible permeability. These formations are generally regarded as containing insignificant quantities of groundwater. However, groundwater flow through such soils, although imperceptible, does take place and needs to be considered in assessing the risk associated with persistent pollutants. Some Non-Aquifers can yield water in sufficient quantities for domestic use. Major and Minor Aquifers may occur beneath Non-Aquifers.

3.2.3 *Laboratory Test Results*

Laboratory test results have not been made available as part of the data provided by SBC.

3.2.4 *Soil Parameters*

A number of site investigations have been carried out within the area of Runswick village, most notably in 1967, 1977, 1981 and 1998. These investigations have encountered the depths of the glacial till / shale bedrock interface.

Soil parameters have been determined or inferred from historic reports detailed in Section 3.1.4 and are presented below in Table 3.2.4. In particular, Report No. 089 (1998) details drained soil parameters for the various units comprising the landslip materials of the glacial till and underlying bedrock. However, there are no further details such as residual soil values or where or how the existing values were derived.

Table 3.2.4 Soil Parameters

Stratum	Effective Cohesion	Effective Angle of Friction
Glacial Till	C' = 5kPa	Ø' = 15
Glacial Sand	C' = 0kPa	Ø' = 35
Glacial Till	C' = 1kPa	Ø' = 15
Glacial Sand	C' = 0kPa	Ø' = 35
Glacial Till	C' = 5kPa	Ø' = 15
Weathered Lias	C' = 3kPa	Ø' = 10
Lias Group	C' = 10kPa	Ø' = 12

3.3 Instrumentation

3.3.1 Definition of Existing Problems

Since the failure mechanisms affecting the old sea-wall and car parks were identified during the late 1990's, remedial works were instigated and completed in 2001.

The reduction in the rate of displacement of the landslipping is evidence that the permanent works comprised of drainage and earthworks, undertaken on the slopes to the north of and at the toe of the slopes below Ings End, have had a positive effect upon increasing slope stability. The greater significance has been the re-orientation of the vector angle of slope movement in a clockwise direction, in a more easterly direction. It is envisaged that following prolonged periods of heavy rainfall, the slopes would continue to fail. However, the probability and risk to village infrastructure of deep seated failures occurring in the future is considered low due to the stabilising effects of the piling and earthworks.

3.3.2 History of Monitoring

Data provided by SBC indicate from reports that there have been several ground investigations undertaken at Runswick including those between 1967 and 1998. However, although details of the specific ground investigations are not available, the locations, depths, general stratigraphy, water regime and general remarks for boreholes drilled have been derived from summary notes (Table C1) within Report No. 089. An extract of this information is presented as Table 3.3.2.

Report No. 136 further details ground monitoring and instrument installations across Ings End. Inclinometer access tubes were installed across Ings End during a ground investigation undertaken in December 1998, have been monitored on a quarterly basis from installation. The monitoring results revealed two distinct planes of movement corresponding to an interface between successive landslide blocks at 16 to 20 metres bgl and a lower basal shear surface of the glacial till and shale bedrock interface at 30 to 33 metres bgl. Ground movements were inferred from the data for each of the shear planes identified. Rates of displacement approximating to 5mm per week orientated at a vector angle of 30 degrees north were detected within the upper shear plane. The basal shear plane recorded movements of <0.5mm per week orientated at a vector angle of 53 degrees north were evident. These rates of displacement apparently correspond well with data obtained from successive surveys carried out over the slope faces of Ings End. These instruments are no longer in service.

A number of survey markers were established on the slopes below Ings End prior to the coast protection and slope stabilisation emergency works being commissioned in March 1999. In early 1999 following a wet winter, average ground movements were measured at 9mm per week, at an average orientation of 46 degrees north. Monitoring was carried out throughout the construction phase of the emergency works and following the completion of the contract. Average ground movements were reduced to 4mm per week during the summer period while construction was on-going with a slight rotation of the vector angle of 1 degree clockwise. Post project rates of ground movements, recorded following prolonged periods of heavy rainfall during the winter of 2000 recorded further reductions to 3mm per week with a change in vector movement of 5 degrees clockwise.

Table 3.3.2 Borehole Database

Runswick Bay - Borehole Database

Investigation of: Runswick Bay Village
Investigation by: John Hastie and Partners
Investigation date: August-67

Borehole Ref	OS Coordinates m E	OS Coordinates m N	Ground Level m OD	Borehole Depth m	Base Level m OD	Rock Depth m	Rock Level m OD	Shear Surfaces Depth m	Shear Surfaces Level m OD	Groundwater Depth m	Groundwater Level m OD	Groundwater Remarks	General Remarks
1	81017	15951	2.96	6.10	-3.14	1.07	1.89	***	***	0.91	2.05	Strike @ 1.13	Shale becoming hard at -0.09m OD
2	81002	15952	6.98	6.55	0.43	2.90	4.08	***	***	0.46	6.52	Strike @ 4.24	
3	81003	15991	3.02	5.49	-2.47	0.84	2.18	***	***	1.07	1.95	Strike @ 1.65	Shale becoming hard at -0.80m OD
4	80992	15986	8.02	6.71	1.31	2.59	5.43	***	***	4.88	3.14		Shale becoming hard at 3.75m OD
5	80913	16085	44.53	10.06	34.47	4.57	39.96	***	***				Sandstone
cont.						9.37	35.16	***	***			Dry	Shale
6	80929	16136	48.53	7.33	41.20	4.42	44.10	***	***			Dry	Sandstone
7	80934	16146	56.05	6.71	49.34	5.49	50.56	***	***	2.74	53.31	Seepage	Sandstone
8	80909	16128	62.06	12.80	49.26	***	***	***	***			Dry	Till to full depth of borehole
9	80877	16136	68.49	21.95	46.54	19.81	48.68	***	***	3.66	64.83	Seepage	Borehole dry on completion
10	80859	16112	76.78	15.85	60.93	***	***	***	***			Dry	Till to full depth of borehole

Investigation of: Runswick Bay Village - Inclinometers
Investigation by: North Yorkshire County Council
Investigation date: ? 1976/7

Borehole Ref	OS Coordinates m E	OS Coordinates m N	Ground Level * m OD	Borehole Depth m	Base Level m OD	Rock Depth m	Rock Level m OD	Shear Surfaces Depth m	Shear Surfaces Level m OD	Groundwater Depth m	Groundwater Level m OD	Groundwater Remarks	General Remarks
R1	80943	15960	18.00	12.75	5.25	10.40	7.60	?	-3.50	***	***		Sheared Inclinometer
R2	80877	15968	25.00	12.90	12.10	11.70	13.30	?	6.00	***	***	No Record	Inclinometer
cont.								?	4.90	***	***		
R3	80884	15995	40.00	18.80	21.20	***	***	***	***	***	***		Inclinometer - virtually no movement in 1977
R4**	80947	15990	17.00	**	**	**	**	**	**	**	**		

Investigation of: Sea Wall Stability
Investigation by: North Yorkshire County Council
Investigation date: May-81

Borehole Ref	OS Coordinates m E	OS Coordinates m N	Ground Level * m OD	Borehole Depth m	Base Level m OD	Rock Depth m	Rock Level m OD	Shear Surfaces Depth m	Shear Surfaces Level m OD	Groundwater Depth m	Groundwater Level m OD	Groundwater Remarks	General Remarks
1	81000	15980	7.20	10.50	-3.30	6.71	0.59	9.21	-1.91	7.16	0.14	Average (tidal)	
2	81011	15934	7.00	13.10	-6.10	10.50	-3.50	***	***	6.72	0.28	Average (tidal)	
3	81004	15982	7.00	10.00	-3.00	6.19	0.81	***	***	6.34	0.66	Average (tidal)	

Investigation of: Staithes / Runswick Bay
Investigation by: Yorkshire Water
Investigation date: April-98

Borehole Ref	OS Coordinates m E	OS Coordinates m N	Ground Level m OD	Borehole Depth m	Base Level m OD	Rock Depth m	Rock Level m OD	Shear Surfaces Depth m	Shear Surfaces Level m OD	Groundwater Depth m	Groundwater Level m OD	Groundwater Remarks	General Remarks
700	80931	15940	22.55	15.00	7.55	***	***	***	***	***	***	Dry	Shear surfaces not specifically recorded.

Investigation of: "Sandside" Rear Retaining Wall
Investigation by: North Yorkshire County Council
Investigation date: June-98

Borehole Ref	OS Coordinates m E	OS Coordinates m N	Ground Level m OD	Borehole Depth m	Base Level m OD	Rock Depth m	Rock Level m OD	Shear Surfaces Depth m	Shear Surfaces Level m OD	Groundwater Depth m	Groundwater Level m OD	Groundwater Remarks	General Remarks
1	80962	16003	15.52	8.65	6.87	2.30	13.22	2.30	13.22	5.45	10.07	Seepage	Shear surfaces not specifically recorded.
cont								5.30	-5.30				Shear surfaces infered from report text only.

Investigation of: Runswick Bay Coastal Landslide
Investigation by: Scarborough Borough Council / Rendel Geotechnics
Investigation date: August-98

Borehole Ref	OS Coordinates m E	OS Coordinates m N	Ground Level m OD	Borehole Depth m	Base Level m OD	Rock Depth m	Rock Level m OD	Shear Surfaces Depth m	Shear Surfaces Level m OD	Groundwater Depth m	Groundwater Level m OD	Groundwater Remarks	General Remarks
01	480780	514942	45.07	42.30	2.77	34.30	10.77	6.07	39.00	5.00	40.07	Main seepage Flow	Sub-Artesian
cont.								8.07	37.00	23.00	22.07	Main seepage Flow	Lower Sand
01-A	480763	515947	47.85	10.00	37.85	***	***	***	***			Dry	
02	480886	515981	24.92	15.30	9.62	8.30	16.62	***	***	1.00	23.92		Sub Artesian
03	480924	515952	22.84	22.10	0.74	13.90	8.94	***	***	0.00	22.84		Artesian
03-A	480923	515966	22.16	2.50	19.66	***	***	***	***				Abandoned in slag drain
04	481007	515943	8.47	15.40	-6.93	9.50	-1.03	***	***	9.05	-0.57	Average (tidal)	Shale becoming hard at -6.36m OD
TP01	480763	519541	47.50	6.00	41.50	***	**	***	***	-2.20	49.70	Slight seepage	** Top of significant saturated sand layer
cont.										-0.70	48.20	Moderate seepage	
cont.										0.80	46.70	Moderate seepage	
cont.										2.10	45.40	Main seepage flow	
TP02	480813	515942	41.33	4.40	36.93	***	***	3.60	37.73	2.00	39.33	Slight seepage	Till landslide debris to full depth
cont.								3.90	37.43	4.40	36.93	Moderate Seepage	
TP03	418023	515954	0.90	1.00	-0.10	0.30	0.60	0.30	0.6	0.20	0.70	Average Tidal	Compression failure to 4m in front of wall

* Estimated from aerial surveys
** Data Unavailable
*** Data Unrecorded

The coast protection and slope stabilisation incorporating remediation works to the sea wall and car park areas was completed by April 2001. In March 2000, 4no inclinometers were installed into piles to a maximum depth of 20metres within bored pile portal frame shear keys. These instruments have been periodically monitored from this date onwards although monitoring records are only available from March 2000 to July 2002 and for 20th November 2008. The instruments may have been monitored through the intervening periods although no data has been made available to confirm this.

3.3.3 *Assessment of Monitoring Results*

An assessment of available monitoring data has encompassed the results of inclinometer monitoring of inclinometers A0, D10, P13 and 3 from March 2000 to July 2002 and also November 2008. These instruments were installed within the piles of portal frame shear key systems forming part of slope stabilisation measures. Reference has been made, in Report 136, to the determination of the piles response to loading from successive inclinometer readings. It has not been stated how this has been done or how it is to be achieved. So far, Mouchel Ltd have been made aware by the Client that this information is not available and therefore no further comment can be made other than that of general ground movements indicated by instrument readings.

Inclinometer readings taken from D10 (between March 2000 and July 2002) indicate a maximum cumulative displacement of 7mm in the A-axis and B-axis. This equates to a maximum ground movement of 10mm in a down-slope orientation (southeast direction). Inclinometer readings taken over the same period from instrument A0 indicate a total ground movement of 7mm again in a down-slope orientation (east-southeast direction).

The remaining inclinometers (P13 and 3) show negligible movements over the two years period. This would indicate that these instruments are located in stable ground, relatively unaffected by the prevailing general ground movements active in Runswick village.

Inclinometer readings have not been made available for the interim period between July 2002 and November 2008. The ‘baseline’ readings received from November 2008 do not reflect ground movements until successive readings are taken. These can then be compared to further results for technical interpretation and comment. As such, no further comment can be made of the inclinometer data available.

The location of inclinometers is indicated in Figure 3 and inclinometer data from the two monitoring periods is presented as Figures 4 to 10.

Figure 4: Inclinometer 3 Data

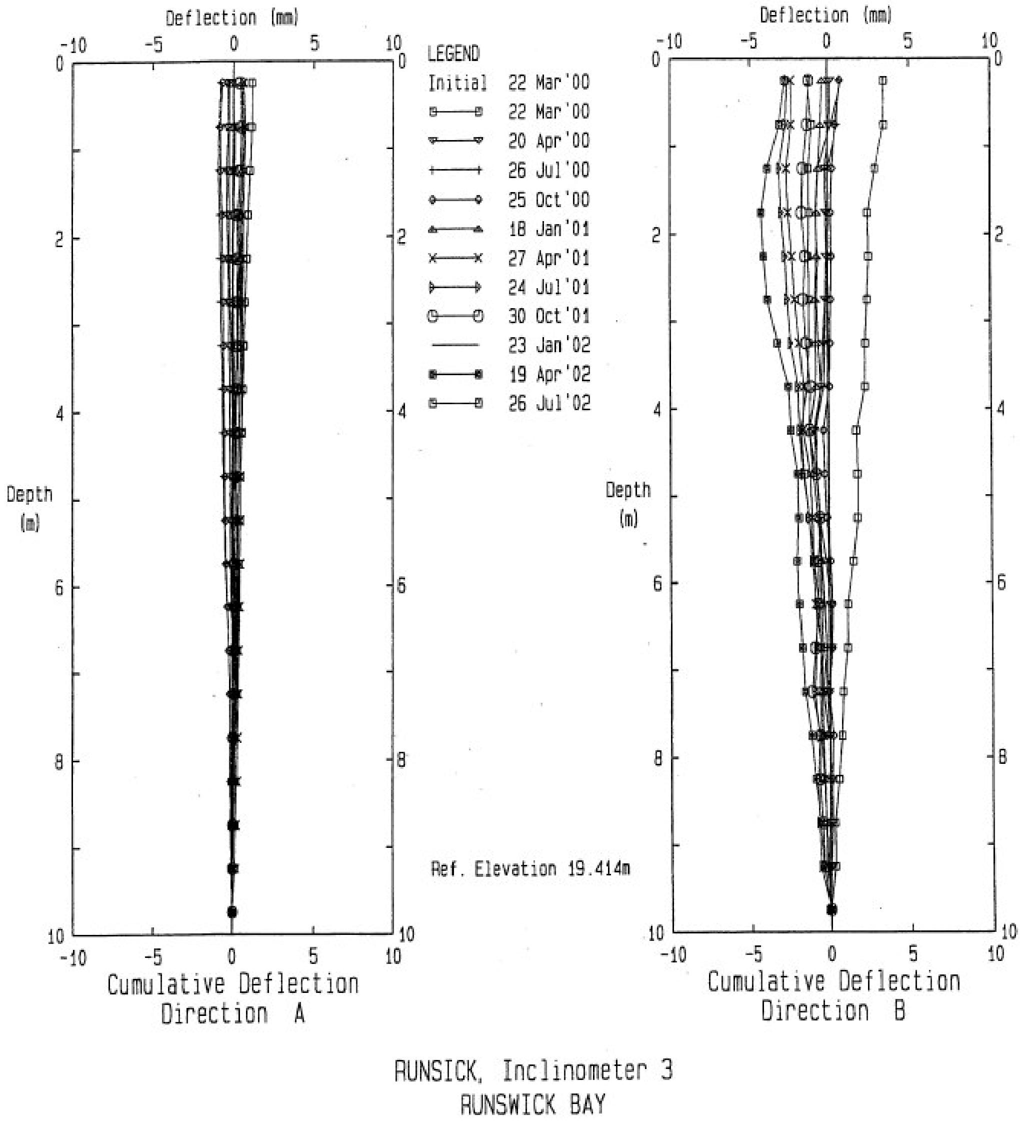


Figure 5: Inclinometer A0 Data

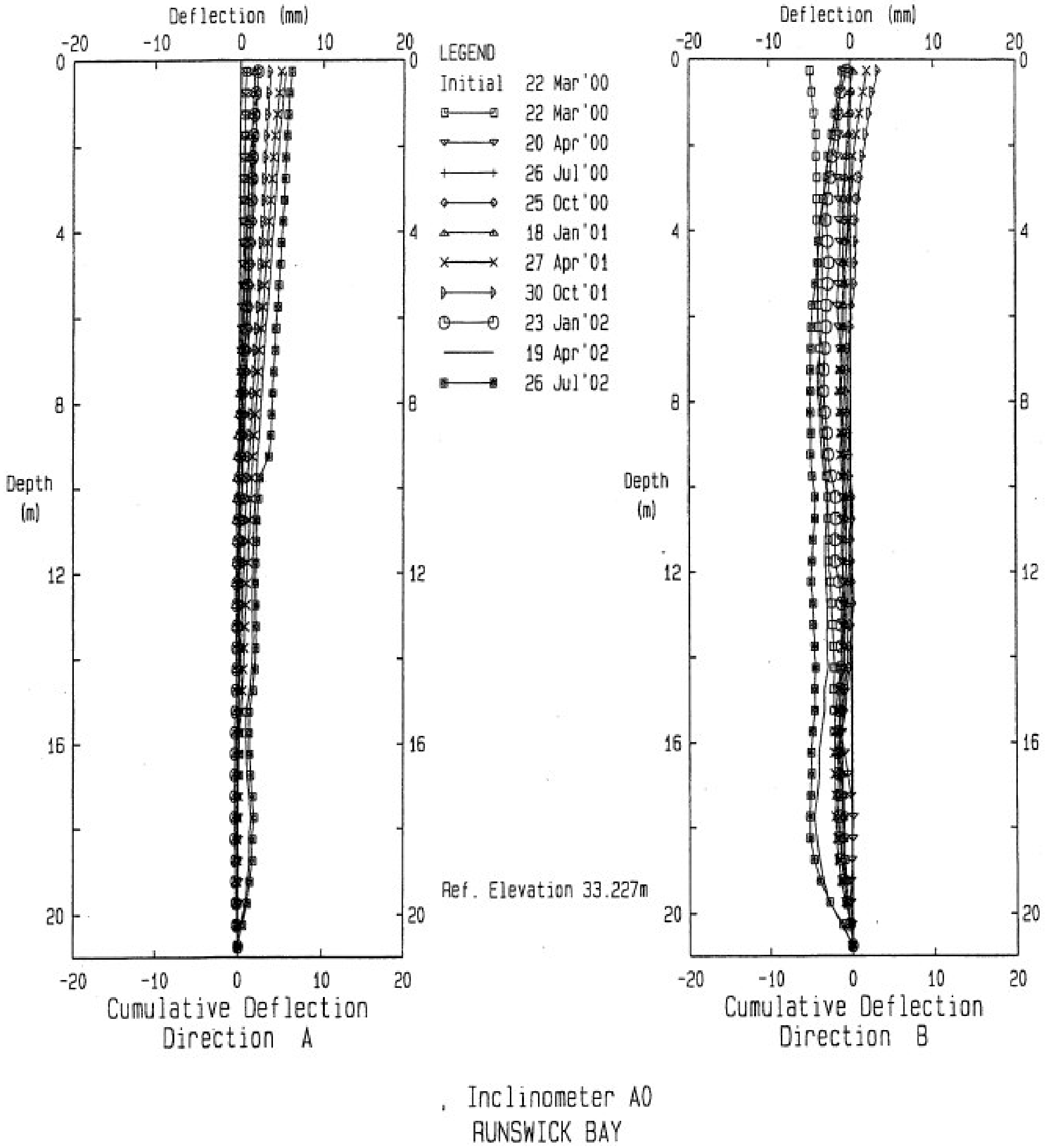


Figure 6: Inclinometer P13 Data

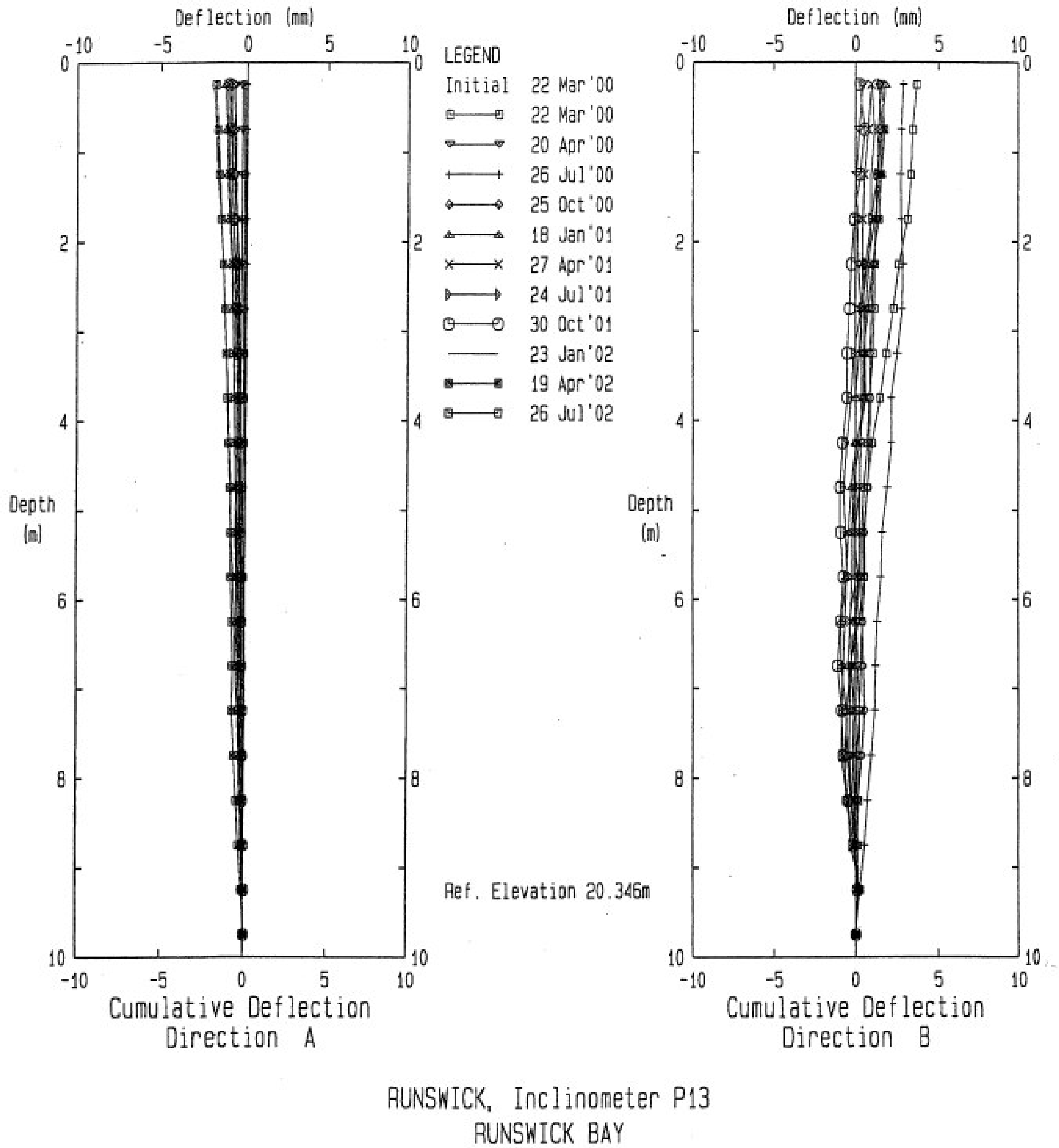


Figure 7: Inclinometer D10 Data

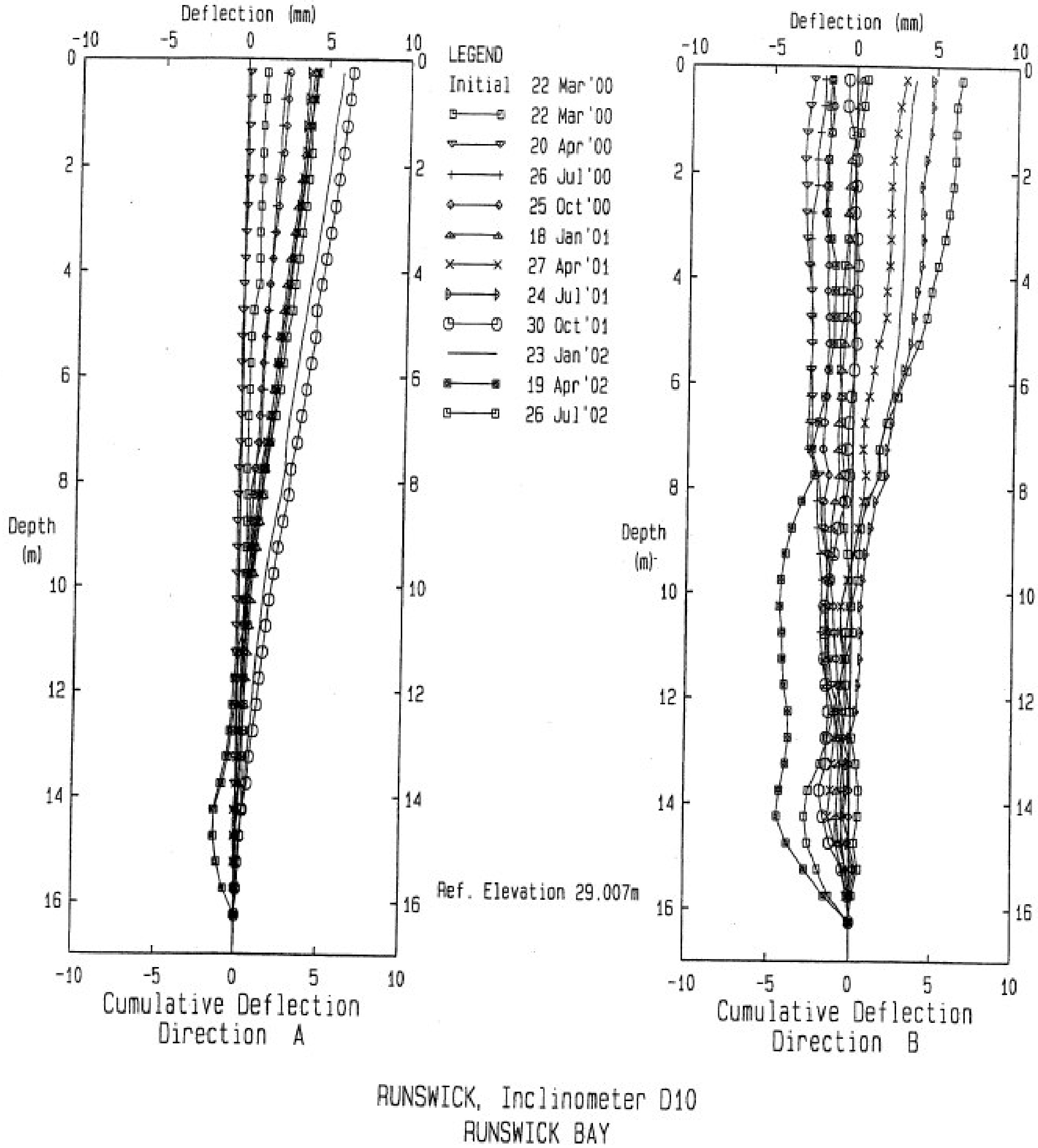


Figure 8: Inclinometer A0 Data

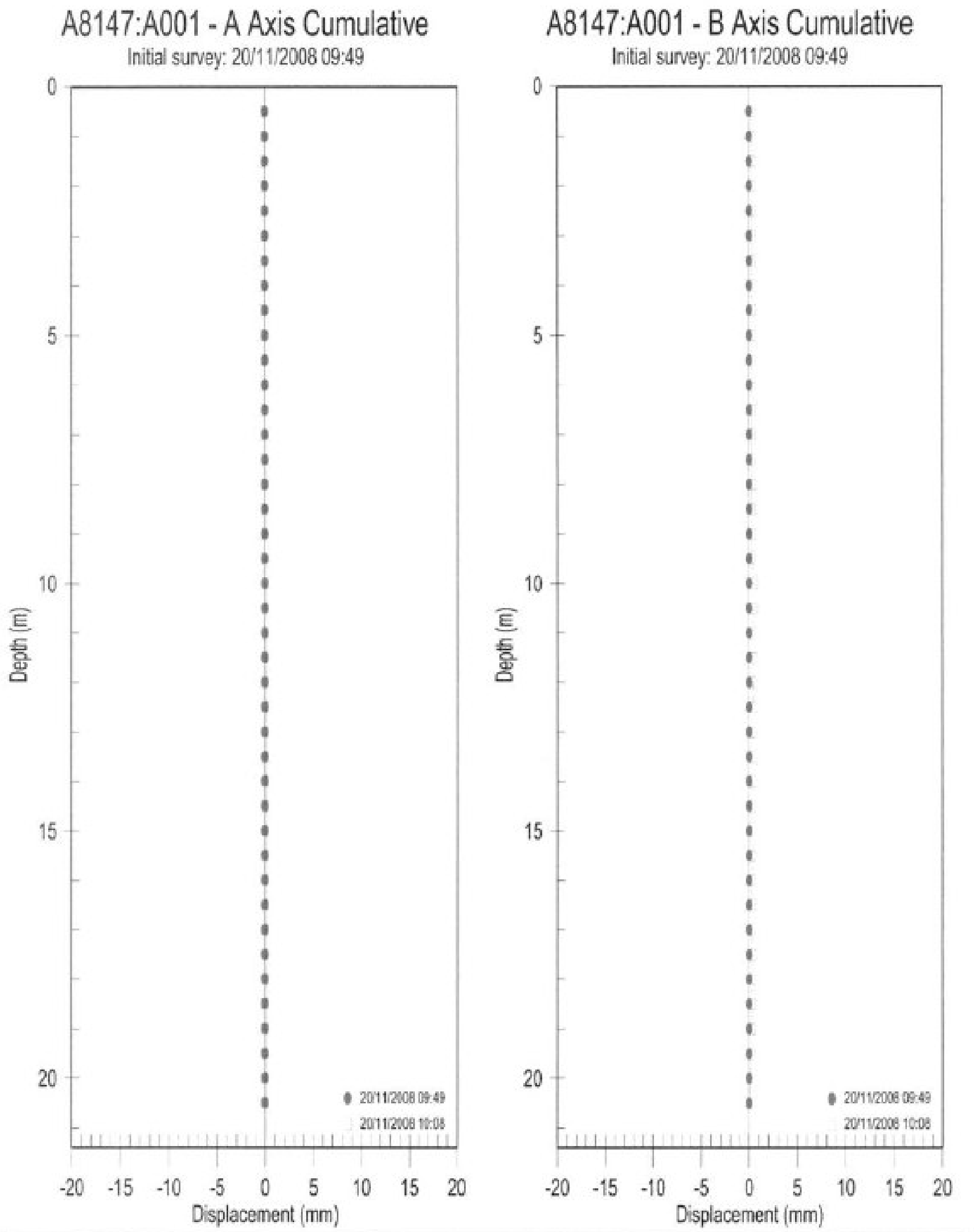


Figure 9: Inclinometer 3 Data

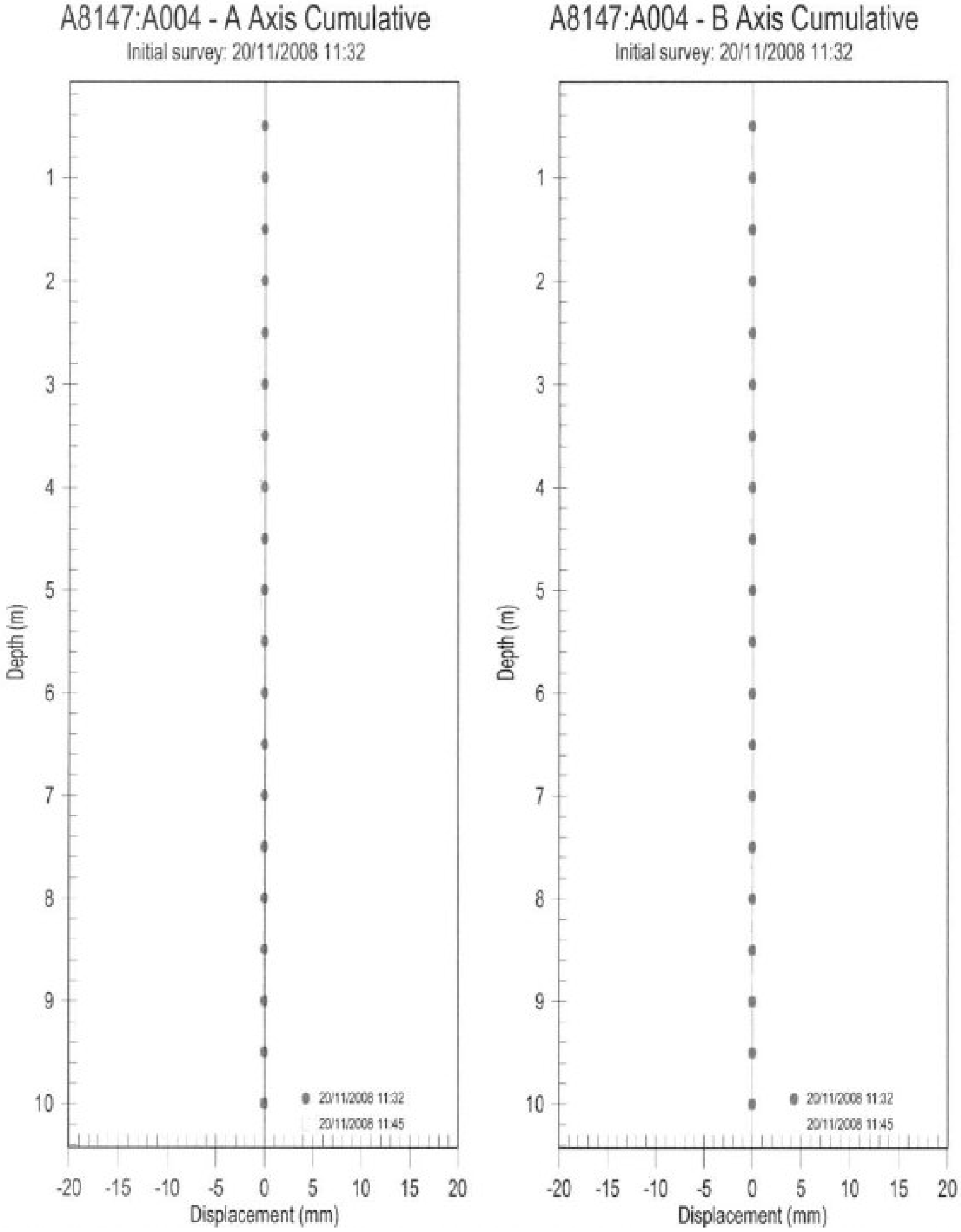
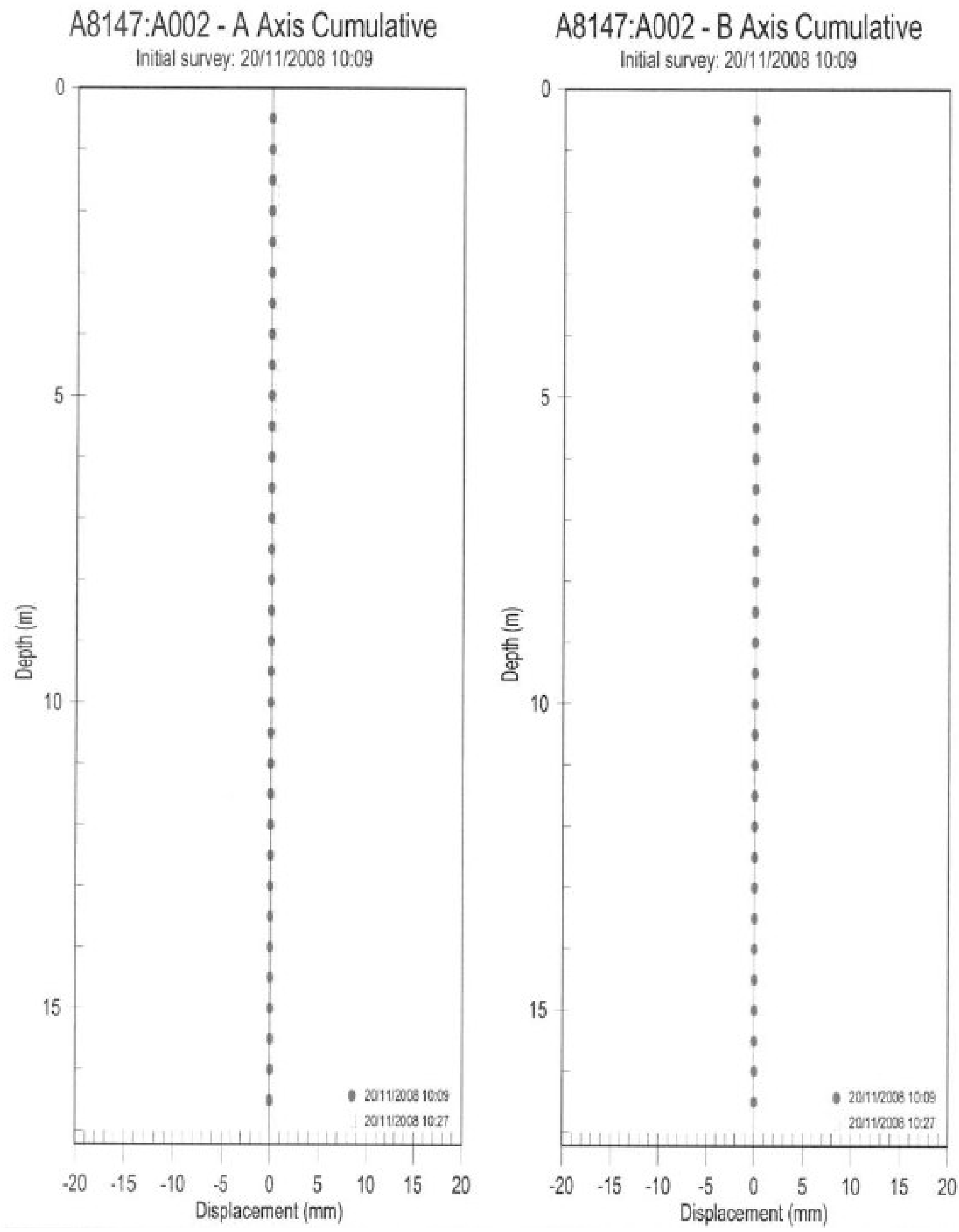


Figure 10: Inclinometer D10 Data



3.3.4 *Stability Analysis*

Not undertaken.

3.4 Re-assessment of Risk Register

3.4.1 Re-definition of Problems

The reduction in the rate of displacement of the landslipping is evidence that the permanent works comprised of drainage and earthworks, undertaken on the slopes to the north of and at the toe of the slopes below Ings End, have had a positive effect upon increasing slope stability. The greater significance has been the re-orientation of the vector angle of slope movement in a clockwise direction. It is envisaged that following prolonged periods of heavy rainfall, the slopes would continue to fail. However, the probability and risk to village infrastructure of deep seated failures occurring in the future is considered low due to the stabilising effects of the piling and earthworks. If equilibrium is to be maintained, then the piles would need to contribute at least 20% of their allowable capacity in terms of pile resistance. The contribution of the load transfer piles when fully mobilised has been to increase the global factor of safety against deep-seated failure by 15%. Future failures are most likely to be shallow and caused by excessive water entrainment. If such failures were to occur then adverse loading of the partially rotated lower landslide blocks would occur resulting in increased loading of the piles. This mechanism could be controlled by slope betterment works and improved surface drainage systems to take ground water away and prevent excess water pressure build-up.

3.4.2 Re-assessment of Risk

Stabilisation works carried out on the adjacent coastal slopes of Ings End as part of the coast protection and slope stabilisation emergency works has had a positive effect on the rate and mechanism of slope movement. Following completion of the emergency works, average rates of surface ground movements measured in the spring 1999 had been reduced by 6mm per week within 2 years. More significantly, it was evident from post construction monitoring that average vector orientation of slope movements had been altered in a clockwise direction. This was due to the stabilising effects of the piling works and the earthworks (toe loading) constructed at the toe of the Ings End slope.

3.4.3 Early Warning / Trigger Levels

Continue with bi-annual monitoring and walk over surveys as detailed in Sections 3.4.5 and 6. Increase periodic surveys during and after periods of heavy or prolonged rainfall for changes in ground water levels. Based on previous inclinometer readings, (between March 2000 and July 2002, a total cumulative movement of 7mm was recorded from Borehole D10), if a total cumulative movement of 10mm or greater is recorded from the existing inclinometers, then the bi-annual monitoring should be increased to monthly readings for a period of two years.

3.4.4 Response Actions

Re-assess the monitoring frequency in accordance with the results of periodic surveys, as detailed in Section 3.4.3. A response would be difficult to apply at this stage without knowing what the event is. However, there should be provision for an emergency response to deal with any arising events.

3.4.5 Future Monitoring and Inspection

It is recommended that a regime of regular monitoring and inspection of Runswick Bay should be undertaken at six monthly intervals (bi-annually). This should be carried out over a period of three years in order to retrieve long term data for analysis in order to determine any seasonal patterns of rainfall, ground water levels and ground movements. The monitoring should encompass the four elements for inspection detailed below.

Coastal slopes monitoring should be carried out by way of walk over surveys and ground surveys accompanied by a photographic record. Defects to record would be tension cracking in pavements and buildings, misalignment of linear features, uneven / bulging ground, surface ponding water, undermining of slope / cliff bases and a visual check of drainage within highways and slopes for functionality (specifically Nettledale Beck).

Beach monitoring should be carried out at low tide conditions to assess beach levels and accompanied by a photographic record.

Sea wall monitoring should be undertaken at low tide conditions to determine any undermining of the base of the sea-wall defences and also to record the general condition, in particular, a record of any outflanking of the northern end of the sea-wall. A photographic record should be taken to accompany a sea wall condition survey to monitor any crack development, concrete spalling, etc.

It is recommended that **inclinometer monitoring** is carried out at the current six monthly (bi-annually) intervals. As well as reading the instruments, a condition examination should be carried out at the same time and any defects recorded and rectified.

The Runswick Bay strategy recommends the construction of a breakwater to the north of the village. This would reduce the scour along the existing defences and allow more minor works to be undertaken in maintaining the walls. The breakwater would reinforce the natural protection of the frontage and is seen as being a basically sustainable approach, protecting the village and essential character of the area without significantly encroaching on the natural coast. Should this work be implemented, the monitoring regime recommended above may need to be modified to take account of any possible improvement in sea defence conditions, changes in beach levels, etc.

3.4.6 Recommendations for Future Instrumentation Installation

It is considered that further instrument installation is not required, the benefits of additional instrumentation do not outweigh the costs as cheaper methods of monitoring are available and have been proposed in Section 3.4.5. The failure mechanisms prevailing at Runswick Bay are well documented and understood. The depths to and the nature of shear surfaces / planes have been well defined from previous ground investigations and installed inclinometers and, the mechanisms of slope failure have been determined through ground investigations and detailed geomorphological mapping. Therefore, regular, detailed walk over surveys and survey monitoring of the area, by an experienced geotechnical engineer, at bi-annual frequencies would be considered adequate measures of monitoring. During periods of heavy or prolonged rainfall the frequency of such surveys should be increased (one week following the event and at monthly intervals for three months) to record the response of groundwater levels to this event.

If future data collection shows abnormalities such as increased ground movements, development of 'new' tension cracks, mal-functioning drainage, etc then the cause of such defects should be investigated further by means of increased frequencies of ground surveys.

3.5 Summary of Recommended Monitoring

Nature of Monitoring and recommended additional instrumentation	Monitoring Frequency	Changes in Frequency following periods of heavy or prolonged rainfall, etc
Walkover survey of Coastal Slopes	Six monthly (Bi-annual) for three years	Increased to one week after event and at monthly intervals thereafter for three months
Beach	Six monthly (Bi-annual) for three years	
Sea Wall	Six monthly (Bi-annual) for three years	
Inclinometers	Six monthly (Bi-annual) for three years	Increased to one week after event and at monthly intervals thereafter for three months

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4 Whitby West Cliff (Site Code AB02)

The SMP2 details the site of Whitby West Cliff as follows:

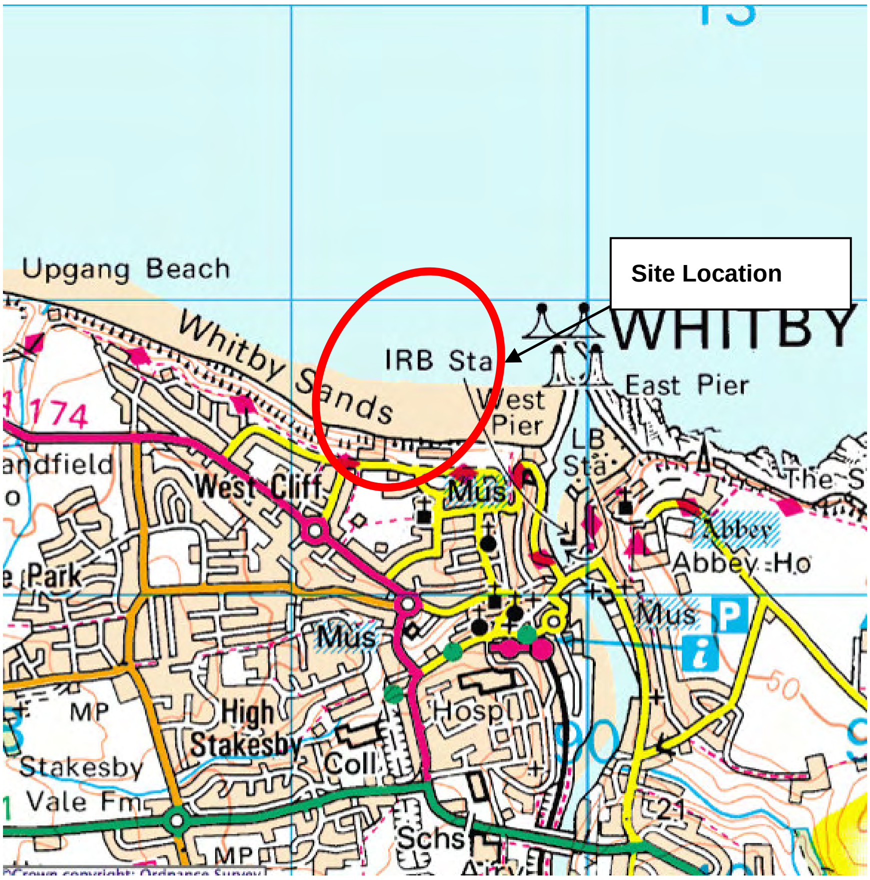
Policy Development Zone 8							
Management Area		Policy Unit		Policy Plan			
				2025	2055	2105	Comment
MA23	Upgang Beck to Whitby Abbey	23.2	West Cliff	HTL	HTL	HTL	-

4.1 Description of the Site

Whitby is located on the north east coast of England approximately 30miles south of the industrial town of Middlesbrough and 20 miles north of Scarborough. West Cliff is part of a long stretch of exposed cliffs running west-east forming protected soft, glacial till cliffs to the west of Whitby harbour and, further west towards Sandsend the coastline is formed of unprotected soft, glacial till cliffs.

The West Cliff site is bounded by The Spa complex to the east and the Cliff Lift towards the west. The natural slope morphology of the protected cliffs has been modified by several phases of slope stabilisation works which included drainage and slope re-profiling that has been undertaken since the 1960's. The slopes attain a height of up to 40-45metres at slope angles of 25 to 35 degrees. Set back approximately 10metres from the crest of the slopes is a main road (North Terrace) and beyond this are large terraced, residential and commercial properties. The faces of the slopes are criss-crossed by pedestrian footpaths which give public access from the top of the cliffs to the beach below. Other features present over the slopes are low retaining walls, gabion walls and relict slip failure scars. At the base of the slopes is a sea wall with a promenade, forming a sea defence, with a wide sandy beach foreshore.

Figure 11: Site Location



4.1.1 Historic Review of Problems

There is evidence of small scale failures along much of the coastal section being investigated, both in the past and at present. The first sections of coastal defences along this stretch of coast were constructed in the 1930's. These defences comprised vertical concrete and masonry seawalls with a promenade, slipways and access ramps to the beach, possibly founded on glacial till materials. Slope stabilisation measures involving slope re-profiling, placement of gabion baskets and drainage improvements have been undertaken over the coastal slopes of West Cliffs in an attempt to reduce the probability of slope instability occurrences since the late 1960's.

4.1.2 Site Walkover

A site walkover was conducted by a geotechnical engineer from Mouchel on 28th November 2008. The site visit confirmed the condition of the existing borehole instrument (BH2) as being operable. A series of photographs was also taken of the site picking up salient topographical features such as varying slope angles, back scars, relict slope failures, the sea-wall defences as well as the remedial works which were carried out on the slopes during 1970's and onwards. Selected site photographs are presented in Appendix B.

Features identified during the walk over survey are described in Section 4.1.3 of this report

4.1.3 *Topography and Geomorphology*

The Whitby coastline lies at the eastern fringe of a dissected plateau which forms the North York Moors. During the last glacial period (Devensian), ice sheets spread south and east across this area to the North Sea. As these ice sheets retreated glacial till was emplaced over the landscape, formed of Jurassic rocks, completely infilling pre-glacial valleys and embayments. West Cliff is part of a long stretch of exposed cliffs running west-east forming protected, soft, glacial till cliffs to the west of Whitby harbour and, further west towards Sandsend the coastline is formed of unprotected, soft, glacial till cliffs. The slopes attain a height of up to 40-45metres at slope angles of 25 to 35 degrees. The faces of the slopes are criss-crossed by pedestrian footpaths which give public access from the top of the cliffs to the beach below. Other features present over the slopes are low retaining walls, gabion walls and relict slip failure scars with thin and bare patches of grasses. At the base of the slopes is a sea wall with a broad promenade, forming a sea defence, with a wide sandy beach foreshore.

4.1.4 *Existing Information*

The following reports have been provided by SBC for consultation:

Report No. 132 - ***Scarborough Strategic Coastal Monitoring (Staithes to Scarborough). Defence Condition Surveys – Volume 1***. Document No. 1540/R/1, High Point Rendel Ltd, March 2002.

Report No. 135 - ***Scarborough Borough Council. Strategic Coastal Monitoring Staithes to Scarborough. Cliff Condition Survey. Volume 2 Slope Proformas. Report No. R/1540/2/1. High Point Rendel Ltd, September 2002.***

Report No. 147 – ***Whitby Coastal Strategy Sandsend to Abbey Cliff. Appendix Report Volume II (Text & Figures) Condition Assessment of the Coastal and River Defences***. Document No. R/932/3/2, High Point Rendell Ltd, July 2002.

Report No. 148 – ***Whitby Coastal Strategy Sandsend to Abbey Cliff. Appendix Report Volume III Coastal Slope Condition and Management***. Document No. R/932/3/3, High Point Rendell Ltd, July 2002.

Report No. 151 – ***Report on a Ground Investigation at Whitby Coastal Strategy***. Document No. F11784. Norwest Holst Soil Engineering Ltd, January 2001.

Report No. 186 - ***Scarborough Borough Council. Strategic Coastal Monitoring Programme 2001-2006. Condition Analysis of Coast Protection Assets, Cliffs and Beaches from Staithes to Speeton.*** Halcrow Group Ltd, November 2006.

Report No. 197 – Summary of Inclinometer Monitoring for Scarborough and Whitby. Ref No. 1308/49/03A/MS, High Point Rendell Ltd, January 2006.

4.2 Stratigraphy

4.2.1 Soil Profile

The 1:50,000 British Geological Survey (BGS) Sheet 35 Solid & Drift, Whitby indicates the site to be underlain by glacial till of Devensian (Quaternary) age. The glacial till is typically comprised of over-consolidated, red-brown sandy silty clays with lenses and discontinuous beds of sands and sandy silts. Within the protected cliffs along West Cliff, there is a persistent mid-slope exposure of fluvio-glacial sand and gravels up to 5metres in thickness. The underlying solid geology is indicated as the Middle Jurassic Scalby Formation, consisting of limestone, sandstone and mudstone.

Table 4.2.1 Geological Stratigraphy

Age	Stratum
Quaternary	Glacial Till Stiff red brown sandy silty clays with sands and gravels.
Scalby Formation Middle Jurassic	Scalby Formation Limestones, sandstones and mudstones

4.2.2 Groundwater Regime

Hydrogeology

The Groundwater Vulnerability Map (Sheet 9) of North East Yorkshire has classified the area as a Minor Aquifer, overlain by soils of intermediate class 1. Soils of class I1 are those possibly able to transmit a wide range of pollutants. Minor Aquifers are variably permeable rocks, usually fractured rocks with a low primary permeability or unconsolidated deposits. They rarely produce large quantities of water for abstraction but often provide important base flow supplies to rivers. Major Aquifers may occur beneath Minor Aquifers.

From a review of historical records, provided by SBC, it has been determined that several ground investigations have been undertaken along this section of coastline since 1983. Ground investigations carried out in 1983, 1985 and 2000 were undertaken to assess the stability of the slopes, provide information for the design of remedial and drainage works and provide soil parameters for slopes design for the Slope Stabilisation and Coast Protection Scheme (1990). It is noted that the 1983 ground investigation was undertaken between Valley Road and White Point Road (which is further west of this site) encountered bedrock at depths varying between 1.10m and 29.10m bgl. Several boreholes failed to encounter bedrock. The locations of the boreholes undertaken for this investigation are detailed in Report No. 148. Subsequent ground investigations of 1985 and 2000 did not encounter bedrock and locations of these ground investigations are also detailed within Report No. 148.

Ground water strikes were experienced within BH3 at 5.50m and 19.00m depth during drilling operations rising to 5.20m (after 10 minutes) and 16.20m (after 5 minutes), respectively. Groundwater was not encountered within the other boreholes.

Table 4.2.2a Levels of Groundwater strikes

Hole ID	Geology	Water Strike Depth (m bgl)	Water Depth After 20 minutes(m bgl)	Flow Rate Remarks
BH3	Glacial Till	5.50	5.20 after 10 mins	Slow
BH3	Glacial Till	19.00	16.40 after 5 mins	Fast

Groundwater levels recorded during fieldworks are presented in Table 4.2.2b. Water levels recorded in BH1 show consistently low values around 18.50m bgl which relates to a level approximately one-third slope height below crest level. The piezometer has been installed into a layer of sand and gravel which outcrops on the slope face. Therefore the low groundwater values are consistent with the hydrostatic pressure expected from an unconfined stratum. The high groundwater levels of BH3 would appear to reflect the high porewater pressures generated from the suspected sandstone strata in which the slip indicator/standpipe is located at 26.00m bgl. The borehole logs indicate the slip indicator/standpipe is installed on a ‘possible boulder’. However, a boulder would not generate the groundwater pressures measured in BH3 and it would seem more logical for the groundwater regime to be attributed to a sandstone strata. The piezometer installed at 19.50m depth has also recorded high groundwater levels within BH3. The readings recorded over an eleven day period following installation recorded groundwater levels between 1.22m and 0.05m bgl. These readings seem to reflect the hydrostatic regime prevailing at that time within the glacial till and may be influenced by the fluvio-glacial horizon which is directly underlying the piezometer tip from 21.50m to 23.10m depth. The observed groundwater level readings may have been subjected to the influence of defective drains, artificially affecting the results. No further readings have been made available for analysis.

Table 4.2.2b Groundwater Monitoring

Hole No	Tip Depth (mBGL)	Reading			
		Date	Water depth (mBGL)	Piezometric Elevation	Installation Type
BH1	19.20	19/11/00	18.57	23.33	Piezometer
BH1	19.20	20/11/00	18.57	23.33	Piezometer
BH1	19.20	23/11/0	18.58	23.32	Piezometer
BH1	19.20	27/11/00	18.55	23.35	Piezometer
BH1	19.20	28/11/00	18.50	23.40	Piezometer
BH3	19.70	17/11/00	1.20	45.43	Piezometer
BH3	26.00	17/11/00	1.76	44.87	Standpipe
BH3	19.70	19/11/00	0.60	46.03	Piezometer
BH3	26.00	19/11/00	0.10	46.53	Standpipe
BH3	19.70	20/11/00	1.22	45.41	Piezometer
BH3	26.00	20/11/00	1.50	45.13	Standpipe
BH3	19.70	23/11/00	0.05	46.58	Piezometer
BH3	26.00	23/11/00	0.05	46.58	Standpipe
BH3	19.70	27/11/00	0.34	46.29	Piezometer
BH3	26.00	27/11/00	1.95	44.68	Standpipe
BH3	19.70	28/11/00	0.05	46.58	Piezometer
BH3	26.00	28/11/00	0.80	45.83	Standpipe

4.2.3 Laboratory Test Results

A review of laboratory testing results has revealed the November 2000 ground investigation provides the only available laboratory testing pertinent to this site. This involved moisture content determinations which were undertaken on samples obtained from the top 5metres from each borehole. These results are presented in Table 4.2.3 below.

4.2.4 Soil Parameters

A number of moisture content values were determined from the 2000 ground investigation and are presented in Table 4.2.3.

Table 4.2.3 Summary of Moisture Content values

Hole ID	Geology	Test Depth Range (m)	M/C value Range (%)	Average M/C value (%)
BH1	Glacial Till	0.50-5.00	13-22	16.6
BH2	Glacial Till	0.50-5.00	5.1-20	15
BH3	Glacial Till	0.50-5.00	17-25	19
BH4	Glacial Till	0.60-5.00	9.8-16	14

4.3 Instrumentation

4.3.1 Definition of Existing Problems

The West Cliff area has been modified by slope stabilisation measures which included the re-grading of slopes and the installation of drainage, carried out during the 1960's and 1970's. These remedial works are now showing signs of distress and appear to be near the end of their design life-cycle. During a site walkover there was evidence of slope instability with visible back scars on the slopes and cracks present in the footpaths; drainage problems were also evident as seepages emanating from retaining walls. However, it is not know whether the seepages were from slope drainage or burst water pipes.

The existing problems on site relate to the instability of the glacial till slopes of West Cliff site which have been the subject of modifications by remedial works over a period of seventy years. The slopes are susceptible to shallow failures of varying size and extent, being 1 to 2metres in depth and up to 5metres in extent. Their size has often been determined by the spacing of vertical drainage. Without remedial measures, small and medium sized slope failures can develop into more serious deep-seated failures which may cause substantial damage and cliff top recession leading to the loss of amenities and possible danger to the public.

4.3.2 History of Monitoring

Report No. 148 details previously known ground investigations in tabulated form. Various details of these investigations are stated although monitoring data is not included or available. The ground investigation of November 2000 was undertaken as part of the Coastal Strategy Study for Scarborough Borough Council to determine groundwater regime, geology and slope stability of the slopes between The Spa and The Metropole Hotel. This section of the West Cliffs slopes had previously not been investigated.

Following the ground investigation of November 2000, an inclinometer was installed in BH2 and piezometers with slip indicators were also installed in BH1 and 3. These instruments were monitored over separate periods. The data for BH1 and 3 only covers groundwater levels recorded during the fieldworks period; there are no readings available for the slip indicators. Groundwater readings from BH1 and 3 are presented in Table 4.2.2b.

BH2 monitoring data detailed in correspondence (dated 01 August 2006) for readings from 27 November 2000 to 24 July 2006.

BH2 monitoring data, extract from Report No. 197. Readings from 22 March 2001 to 28 Nov 2005.

'Baseline' readings provided for BH2 taken on 20 November 2008.

4.3.3 *Assessment of Monitoring Results*

From available readings taken of the inclinometer (BH2) at West Cliff there have been three periods of monitoring undertaken, these are detailed above.

The inclinometer data available for analysis has been provided in PDF and gINT format. A comparison of the two inclinometer data sets shown in Figures 12 and 13 was carried out. It is evident from the two sets of readings that there is little comparison between the two separate traces despite 5No. readings being common to both sets of data. It is possible that the raw data from monitoring visits has been converted using different computer software thus producing separate traces. However, it is possible that the readings from Figure 12 of 23 January 2006 onwards relate to the dark curved line (which shows positive and then negative deflection in Direction A) then these readings illustrate no movement of the inclinometer tube as they all plot an identical trace.

The individual traces of Figure 13 follow a set pattern which shows a total movement of 2.50 mm, although from the quality of the plots it is not clear whether this movement was recovered or represents the most recent reading. Despite this possible anomaly, the results indicate a shear surface at a depth of 1 metre below ground level along which a total movement of 2.50 mm has occurred. This is indicative of creep movement typical of this type of slope geometry.

The latest set of readings (Fig. 14) are ‘baseline’ values and therefore do not indicate ground movements. No further comment is offered.

Figure 12: Inclinometer Data

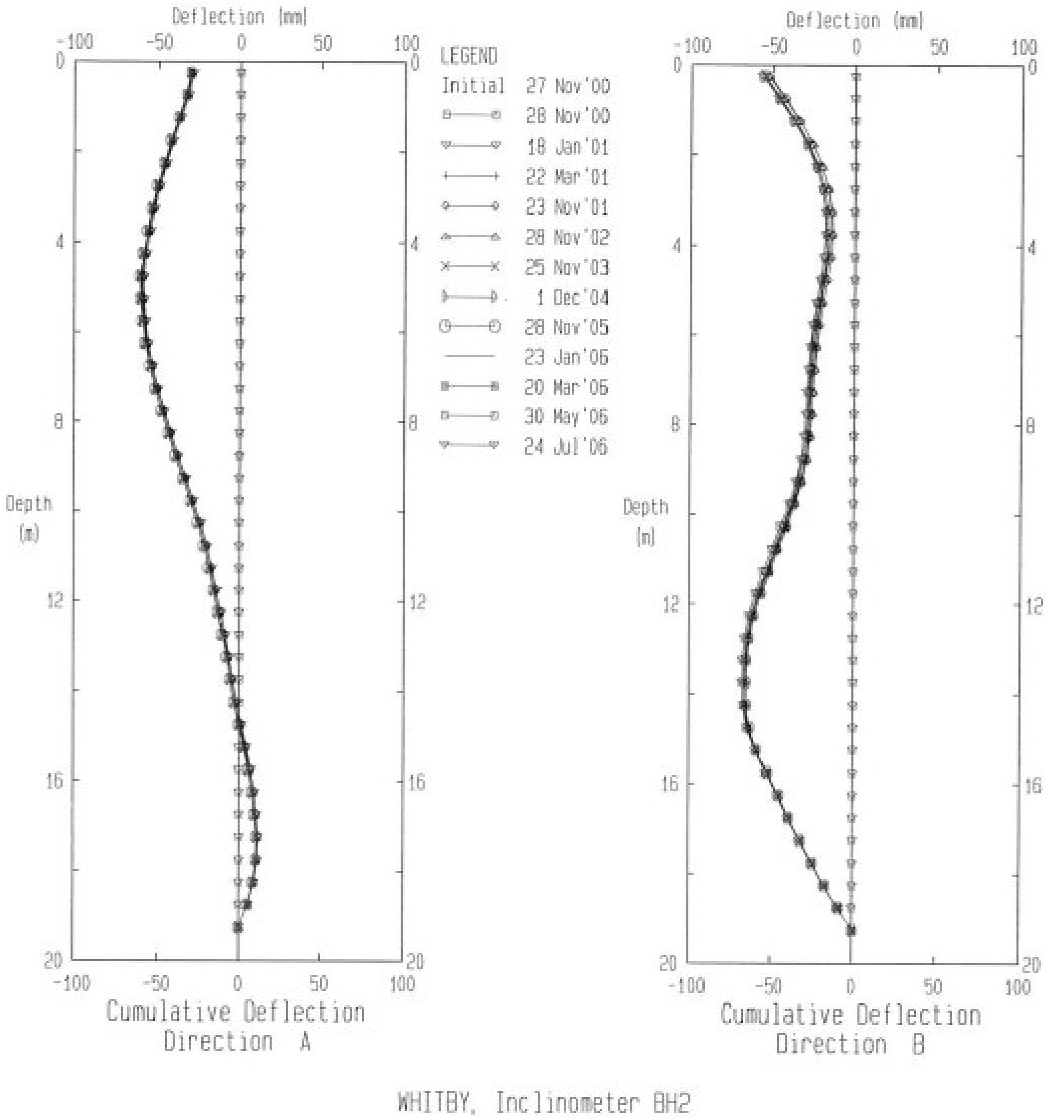


Figure 13: Inclinometer Data

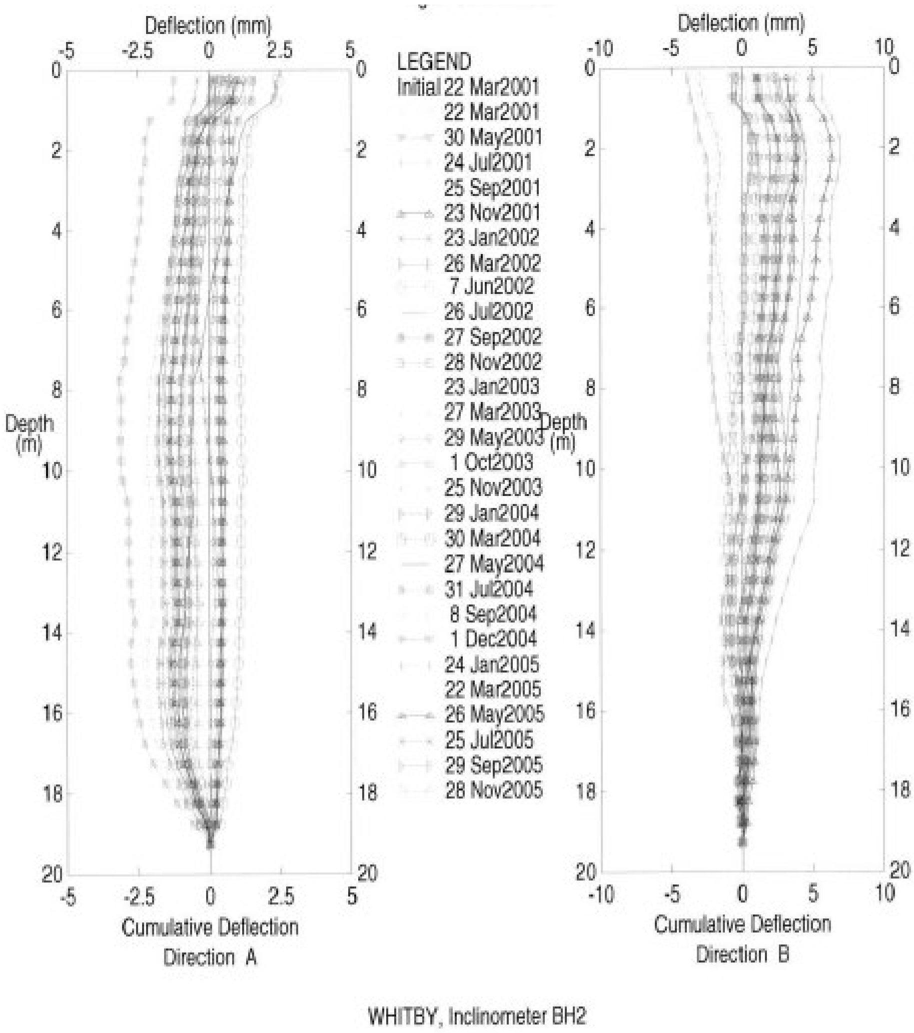
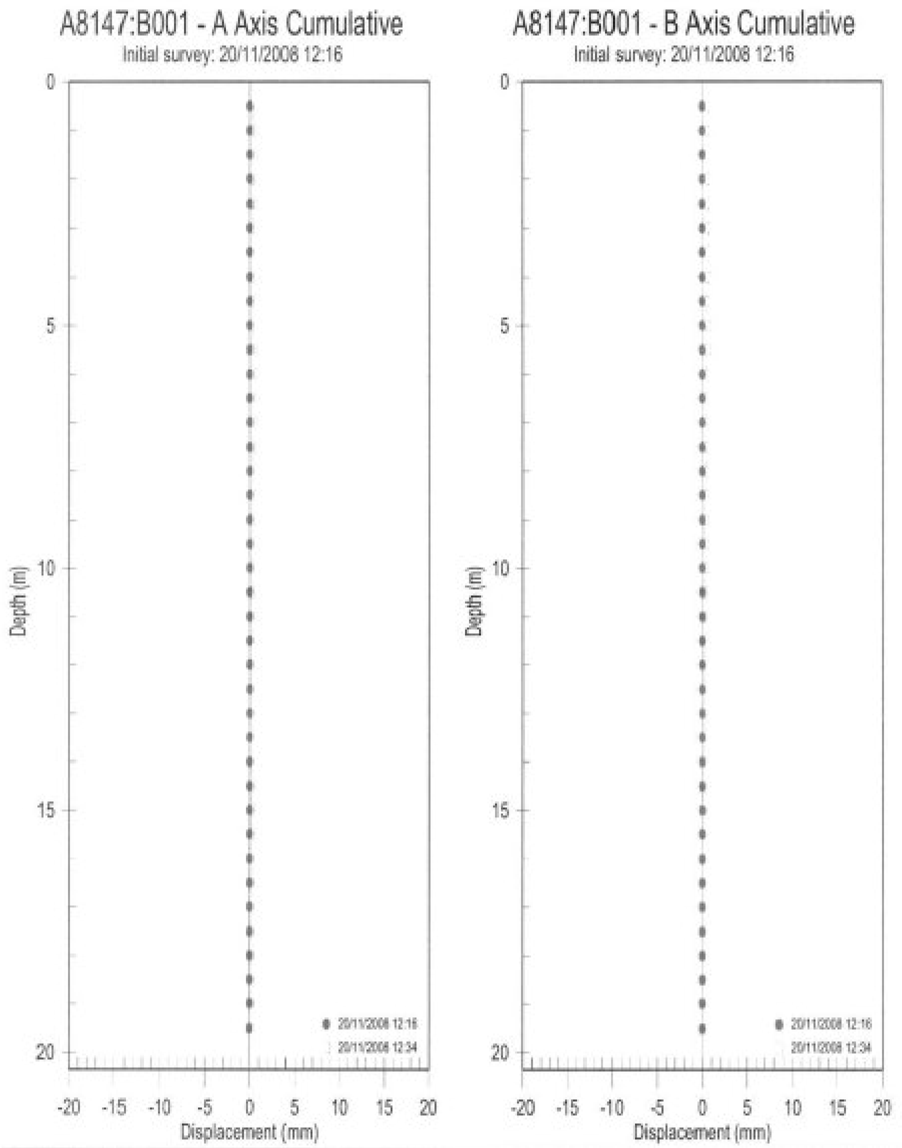


Figure 14: Inclinometer Data



4.3.4 Stability Analysis

Slope stability analysis was undertaken as part of the ground investigation of November 2000. The results of these analyses are detailed more fully within Report No. 148.

The aim of the analysis was to gain information of the most likely slope failure mechanisms, likelihood of slope failure, carry out a comparison of slope stability of the glacial till slopes against composite type slopes and the sensitivity of the slopes to changes in groundwater levels. The analyses were undertaken using SLOPE/W along a section of the West Cliff, in close proximity to The Spa, incorporating BH1 and BH2. The analyses used the Bishop Simplified method for circular failures. Three slope failure scenarios were modelled shallow (<2m deep) planar slides, deep-seated rotational slides and shallow (<2m deep) slides leading to deep-seated rotational slides.

In conclusion of the slope stability analysis, the probability of both shallow and deep-seated slides was considered to be very high if the ground water table was close to the ground surface; with the possibility of such events occurring within the next 60 years. The shear surfaces of deep-seated failures have been calculated as possibly propagating above the sea-wall. There is however the possibility of such shear surfaces day lighting beneath the sea-wall. An analysis of shallow slides also revealed that if shallow slides were allowed to propagate up slope, then the change in slope geometry and resulting removal of slope support would result in a deep-seated landslide. The results reveal that a deep-seated failure is more likely to occur as a result of this mechanism rather than as a result of high groundwater levels.

4.4 Re-assessment of Risk Register

4.4.1 Re-definition of Problems

Several influencing factors have been identified as the causes of slope failures along the West Cliffs site. If small to medium scale failures are not treated they can develop into larger, deep-seated failures leading to more extensive and costly damage.

4.4.2 Re-assessment of Risk

Having carried out a full review of the monitoring data made available, there would seem to be no change in the risks at this site.

4.4.3 Early Warning / Trigger Levels

In consideration of the inconsistent and limited data from the inclinometer instruments and piezometer / slip indicators it is considered that the establishment of early warning / trigger levels for the site would not be meaningful on the basis of existing monitoring data.

4.4.4 Response Actions

Re-assess the monitoring frequency in accordance with the results of the recommended periodic monitoring surveys, as detailed in Section 4.4.5. A response would be difficult to apply at this stage without knowing what the event is. However, there should be put in place provision for an emergency response to deal with any arising events.

4.4.5 Future Monitoring and Inspection

It is recommended that a regime of regular monitoring and inspection of the West Cliff site should be undertaken at six monthly intervals (bi-annually). This should be carried out over a period of three years in order to retrieve long term data for analysis in order to determine any seasonal patterns of rainfall, ground water levels and ground movements. This regime of monitoring should encompass the elements for inspection detailed below.

Coastal slopes monitoring should be carried out by way of walk over surveys and ground surveys accompanied by a photographic record. Defects to record would be tension cracking in pavements and structures, misalignment of linear features, uneven / bulging ground, surface ponding water and a visual check of drainage within the highways and slopes for functionality and seepages.

Beach monitoring should be carried out at low tide conditions to assess beach deposit levels and this should be accompanied by a photographic record.

Sea-wall defence monitoring should be undertaken at low tide conditions to determine any undermining of the base of the sea-wall defences and also to record the general condition of the sea-wall. A photographic record should be taken to accompany a sea wall condition survey to monitor any crack development, concrete spalling, etc.

In addition, it is recommended that **inclinometer monitoring** should be carried out at monthly intervals for six months then every two months until month twelve. If no significant movements are revealed during this twelve month period then monitoring should revert to six monthly intervals (bi-annually) for the remaining two years. Considering the public location of the inclinometer, it is recommended that a condition examination is carried out and any defects recorded and rectified and, ensuring the instrument cover is secure from acts of vandalism.

4.4.6 Recommendations for Future Instrumentation Installation

It is further recommended that a line of survey pins is set-out at regular 5metre intervals down the line of the slope from beyond the crest and in line with the existing inclinometer. The survey pins should be able to provide a semi-permanent, vandal proof record and it is thus suggested they consist of steel pins cast into concrete and marked to distinguish them from their surroundings. The survey pins should be clearly labelled and surveyed to Ordnance Survey co-ordinates in order to reduce mistakes when monitoring data is collected. The survey stations should be measured initially at a monthly frequency for six months to build up base data. If there is no significant movement (<5 mm) at each monitoring event then the frequency can be continued in line with the inclinometer monitoring i.e. on a bi-annual frequency.

If future data collection shows abnormalities such as increased ground movements, development of 'new' tension cracks, mal-functioning drainage, etc then the cause of such defects should be investigated further by means of increased frequencies of ground surveys as detailed below.

4.5 Summary of Recommended Monitoring

Nature of Monitoring and recommended additional instrumentation	Monitoring Frequency	Changes in Frequency following periods of heavy or prolonged rainfall, etc
Walkover survey of Coastal Slopes	Six monthly (Bi-annual) for three years	Increased to one week after event and at monthly intervals thereafter for three months
Beach	Six monthly (Bi-annual) for three years	
Sea Wall	Six monthly (Bi-annual) for three years	
Inclinometer	Monthly intervals for six months then every two months until month twelve. Reverting to bi-annual intervals for remaining two years if no significant movement detected	Increased to one week after event and at monthly intervals thereafter for three months
Install a single line of survey pins down slope at 5 metre intervals in line with BH2	Monthly intervals for six months then reverting to bi-annual intervals for remaining two and a half years if no significant movement detected	Increased to one week after event and at monthly intervals thereafter for three months

5 Scalby Ness (Site Code AB03)

The SMP2 details the site of Scalby Ness as follows:

Policy Development Zone 10							
Management Area		**Policy Unit**		**Policy Plan**			
				2025	2055	2105	Comment
MA26	Hundale Point to Scalby Ness	26.1	Burniston	NAI	NAI	NAI	-

5.1 Description of the Site

Scalby Ness forms a broad promontory to the north of Scarborough North Bay, approximately 3km north of Scarborough. The headland is incised by Scalby Beck which acts as an overflow from the River Derwent when in flood. The beck flows in an east-north easterly direction through Scalby, where at Scalby Mills it changes direction sharply through 90 degrees to flow south easterly at Scalby Ness and outfalls to the sea between Scalby Ness headland and the Sea Life Centre.

A housing development was constructed during the 1970’s and 1980’s on land forming a plateau approximately 25-30m above the beck at Scalby Ness. Over-steepened glacial till cliffs are present on the north west and north east sides of the development falling down towards the beck. The beck contributes to toe erosion of these slopes and is a contributing factor of the mechanism of slope instability. Scalby Mills Road bounds the southern edge of the north east slopes. This road was constructed to give access to the Sea Life Centre on the coast. Part of the works involved re-profiling slopes with toe protection offered by rock outcrops at Scalby Beck and emplaced toe protection around the Sea Life Centre.

Figure 15: Site Location

5.1.1 Historic Review of Problems

A review of the available data detailed in Section 5.1.4 covers previous ground investigations and interpretative report work on the site of Scalby Ness. An interpretation of the over-riding mechanisms acting upon the slopes has identified three landslide behavioural units.

- Behavioural Unit I (North west slopes) – Intermittently active non-circular failure within the glacial till unit, characterised by over-steepened slopes which have been subjected to shallow translational movements accompanied by localised mudslide / debris flows. The head scarp (crest) is undergoing periodic movement giving rise to blocky detachment with cracks forming in mid-slope. Active erosion at the toe is leading to unloading of the slope with a reduction of support for material above.

- Behavioural Unit II (North east slopes, northern part) – This is an episodically active unit characterised by an over-steep head scarp with cracking and shallow surface movements. A mid-slope deep seated, back-tilted block is present across the unit. The location and morphology of this block suggest that it is part of a large, ancient deep-seated translational or rotational landslide. Localised active toe unloading is present within parts of the lower slopes which are also characterised by ponding surface water, tension cracks and hummocky ground. Active toe erosion is taking place by the tidally influenced beck.

- Behavioural Unit III (North east slopes, southern part) – The slopes have been re-profiled during earthworks as part of construction works for the access road into the Sea Life Centre and car park. These slopes show no signs of instability and are currently considered to be stable.

5.1.2 Site Walkover

A site walkover was conducted by a geotechnical engineer from Mouchel on 28th November 2008. The site visit confirmed the condition of the existing borehole instruments and several survey points. A series of photographs was also taken of the site picking up salient topographical features such as varying slope angles, back scars, ponding groundwater, irregular ground features, tension cracks and relict slope failures. Selected site photographs are presented in Appendix C.

Features identified during the walk over survey are described in Section 5.1.3 of this report

5.1.3 Topography and Geomorphology

The site of Scalby Ness consists of a row of houses (Scholes Park Road) built during the 1970's -1980's and bounded by glacial till slopes, up to 30metres in height, to the north west and north east. The headland is incised by Scalby Beck which flows in an east-north easterly direction through Scalby, where at Scalby Mills it changes direction sharply through 90 degrees to flow south easterly to the sea.

The north west facing slopes are composed of a 1metre high vertical face at the crest of the slope. The slope angle decreases below this feature before steepening from the centre of the slope to the base where the slope angles again become shallow at the beck.

The north east facing slopes consist of a deep embayment in glacial till with a back scar and a mid-slope reverse slope bench below this. The slopes steepen below the reverse slope bench suggesting that this is the upper surface of a large back-tilted block. Below this and down to the beck, slope angles vary from 12 to 29 degrees.

5.1.4 *Existing Information*

The following reports have been provided by SBC for consultation:

Report No. 117 – ***Scarborough Borough Council. Report on Ground Investigation at Scalby Ness, Scarborough, North Yorkshire.*** Report No. 16902, Structural Soils Ltd, November 2001.

Report No. 121 – ***Scarborough Borough Council. Factual Report on Supplementary Ground Investigation at Scalby Ness, Scarborough.*** Report No. 40548, Structural Soils Ltd. January 2005.

Report No. 132 - ***Scarborough Strategic Coastal Monitoring (Staithes to Scarborough). Defence Condition Surveys – Volume 1***. Document No. 1540/R/1, High Point Rendel Ltd, March 2002.

Report No. 135 - ***Scarborough Borough Council. Strategic Coastal Monitoring Staithes to Scarborough. Cliff Condition Survey. Volume 2 Slope Proformas. Report No. R/1540/2/1. High Point Rendel Ltd, September 2002.***

Report No. 153 – ***Scarborough Borough Council. Hundale Point to Scalby Ness Coastal Strategy Study. Document No. 1404/R/04, High Point Rendell Ltd. May 2003.***

Report No. 167 - ***Scarborough Borough Council. Hundale Point to Scalby Ness. Scalby Ness Instability Section One – Data Gathering and Analysis***. Report No. R6641, Halcrow Group Ltd. October 2005.

Report No. 174 – ***Hundale Point to Scalby Ness Strategy Review Stage II Report***. Halcrow Group Ltd. August 2006.

Report No. 186 - ***Scarborough Borough Council. Strategic Coastal Monitoring Programme 2001-2006. Condition Analysis of Coast Protection Assets, Cliffs and Beaches from Staithes to Speeton.*** Halcrow Group Ltd. November 2006.

5.2 Stratigraphy

5.2.1 *Soil Profile*

The 1:50,000 British Geological Survey (BGS) Sheets 35 and 44 Solid & Drift, Whitby and Scalby, indicates that the site is underlain by superficial deposits of glacial till of Quaternary age. The underlying solid geology is indicated as the Long Nab Member of the Scalby Formation (Middle Jurassic) characterised by interbedded mudstones, siltstones and sandstones.

Table 5.2.1 Geological Stratigraphy

Age	Stratum
Quaternary	Glacial Till Stiff silty sandy clays, sands and gravels, laminated silty clays
Middle Jurassic	Long Nab Member Scalby Formation Interbedded mudstones, siltstones and sandstones

5.2.2 Groundwater Regime

Hydrogeology

The Groundwater Vulnerability Map (Sheet 9) of North East Yorkshire has classified the northern area of Scalby Ness as a Minor Aquifer, overlain by soils of low leaching potential. Soils of class L are those in which pollutants are unlikely to penetrate the soil layer because either water movement is largely horizontal or because they have the ability to attenuate diffuse pollutants. Minor Aquifers are variably permeable rocks, usually fractured rocks with a low primary permeability or unconsolidated deposits. They rarely produce large quantities of water for abstraction but often provide important base flow supplies to rivers. Major Aquifers may occur beneath Minor Aquifers.

The southern part of Scalby Ness is classified as a Minor Aquifer, overlain by class HU soils. Due to the less reliable nature of data collected in urban areas, the worst case scenario is assumed and soils are classified as having a high leaching potential.

From a review of historical records, it has been determined that several ground investigations have been undertaken at this site since 1995. Following the detection of significant ground movements in September 2000, ground investigations were carried out at the site in 2001 and 2004 to assess the stability of the slopes, provide information for the design of remedial and drainage works and also provide soil parameters for slope stability analysis. A previous ground investigation was carried out for Yorkshire Water in 1995. No further information is available for this ground investigation.

Maximum and minimum groundwater levels recorded at this site are presented in Table 5.2.2.

Table 5.2.2 Maximum and Minimum Groundwater Levels

Piezometer	Maximum GWL		Minimum GWL	
	Reading (mbgl)	Date	Reading (mbgl)	Date
BH P1 Lower	15.31	29/06/04	8.01	04-14/02/05
BH P1 Upper	7.32	25/08/04	8.01	29/06/04
BH P2A Lower	33.45	04 & 28/10/04	33.66	05-08/03/04
BH P2A Upper	6.05	25/08/04	6.82	29/06/04
BH P3	15.93	12/02/05	16.24	15/09/04
BH P4 Lower	4.08	28/08/04	3.92	22/04/05
BH P4 Upper	4.07	29/08/04	3.94	22/04/05
DP1	8.07	30/01/08	8.29	05/08/08
DP2	6.76	30/01/08	7.27	04/02/05
DP3	2.53	30/01/08	6.09	05/08/08
DP6	4.74	30/01/08	8.26	29/11/06
DP9	1.10	04/11/04	6.69	17/06/08
DP10	1.41	02/09/04	5.68	02/04/08
DP11	2.09	02/09/04	3.95	09/11/06
SN4 Upper	2.80	13/08/02	3.27	17/07/02
SN2 Lower	2.80	06/05/04	7.94	18/11/03
SN2 Upper	1.10	06/05/04	Dry	28/10/03 to 30/12/03, 14/12/04, 11/10/06 to 20/12/06

5.2.3 Laboratory Test Results

A summary of the laboratory testing carried out on samples retrieved from ground investigations undertaken in 2001 and 2004 is presented in Table 5.2.3 below.

Table 5.2.3 Summary of Laboratory Testing

Type of test	Test method
Classification/Compaction	
Moisture Content	BS1377: Part 2: 1990; Clause 3
Liquid / plastic limits	BS1377: Part 2: 1990
Particle size distribution	BS1377: Part 2: 1990; Clause 9
Bulk Density	BS1377, (1990) Part 2, clause 7.2
MCV Calibration	BS1377 Part 4 Clause 5.5
Porosity and Dry Density	ISRM (1977)
Strength / Consolidation	
Undrained triaxial (total) strength	BS1377, (1990) part 7
Small Ring Shear (effective strength)	BS1377, (1990) part 7
Unconfined Compressive Strength	ISRM (1977)
Point Load Test	ISRM (1985)
Chemical (tests on soil and groundwater)	
BRE SD1 Suite - Total / water soluble sulphate, pH, Total sulphur, Magnesium, Chloride	TRL Report 447
Contamination (for waste disposal issues)	
Metal suite (As, Cd, Cr, Hg, Pb, Se, Cu, Ni, Zn)	ICP – OES
Speciated Petroleum Hydrocarbons	GC-FID

5.2.4 Soil Parameters

Soil parameters were determined from laboratory testing carried out on samples of glacial till and sandstone / mudstone retrieved from ground investigations undertaken in 2001 and 2004. The soil parameters are presented in Table 5.2.4a and b. The high and low values stated are the highest and lowest values of the range of results determined from laboratory tests.

Table 5.2.4a Slope Stability Soil Parameters

Glacial Till	Unit Weight	Effective Stress Parameters		Undrained Shear Strength	Residual Shear Strength (c'r=0)
	KN/m^3	C' (kPa)	Phi' (Degrees)	C_u (kPa)	(Degrees)
Low	17.8	0	26	75	22.5
High	21.0	5	32	150	27.0

Table 5.2.4b Slope Stability Soil Parameters

Sandstone / Mudstone	Unit Weight	Effective Stress Parameters		Unconfined Compressive Strength	Residual Shear Strength (c'r=0)
	KN/m^3	C' (kPa)	Phi' (Degrees)	(MPa)	(Degrees)
Low	17.8	0	30	0.04	-
High	21.0	10	38	50	-

5.3 Instrumentation

5.3.1 Definition of Existing Problems

There is a risk of slope failure on the north west and north east slopes (in Behavioural Unit I and II) of Scalby Ness if groundwater levels were to rise significantly following periods of prolonged heavy rainfall. The presence of more permeable layers of sand and gravel within the glacial tills could lead to localised failures and the possibility of this could be increased if these layers are prevented from draining freely due to slipped soils from above.

The main threat to slope instability and the assets located above results from coastal erosion of the toe and crest erosion from surface water flowing down the slopes.

Behavioural Unit III is considered to be in a stable state since undergoing re-profiling and re-grading works as part of earthworks for the access road to the Sea Life Centre.

5.3.2 *History of Monitoring*

Ground investigations were carried out at Scalby Ness by Structural Soils Ltd in 2001 and 2004. The investigations included the installation of inclinometer and piezometer instrumentation, details are presented in Report No. 117 and 121.

SNI1, SNI3 and SNP2I monitoring data, extract from Report No. 197 (Dated 20 January 2006). Readings from 29 June 2004 to 28 Nov 2005.

Inclinometer monitoring data detailed in correspondence (dated 01 August 2006) for SN1 readings from 12 October 2001 to 24 July 2006 and SNI1, SNI3 and SNP2I from 29 June 2004 to 24 July 2006. Inclinometer data for SN3 was provided from Report No. 167.

Inclinometer data in gINT format I1 29 June 2004 to 18 September 2006

Inclinometer data in gINT format I3 26 June 2004 to 18 September 2006

Inclinometer data in gINT format P2I 29 June 2004 to 18 September 2006

Inclinometer data in gINT format SN1 1 January 2000 to 18 September 2006

There is no data regarding installation dates relating to BH114. However, SBC have provided some data related to this borehole detailing three readings from 11 October to 29 November 2006. This data records water levels of 32.92m to 32.85m depth with a piezometer depth of 40.54m bgl.

A photographic record of the sites covering South Cliffs has been undertaken on a periodic basis since June 2001 onwards. The photographs record damage caused by slope instability including the extent of slip failures, back scars, height of head scarps, mudslides and other topographical features.

Figure 16: Inclinometer Data SN1

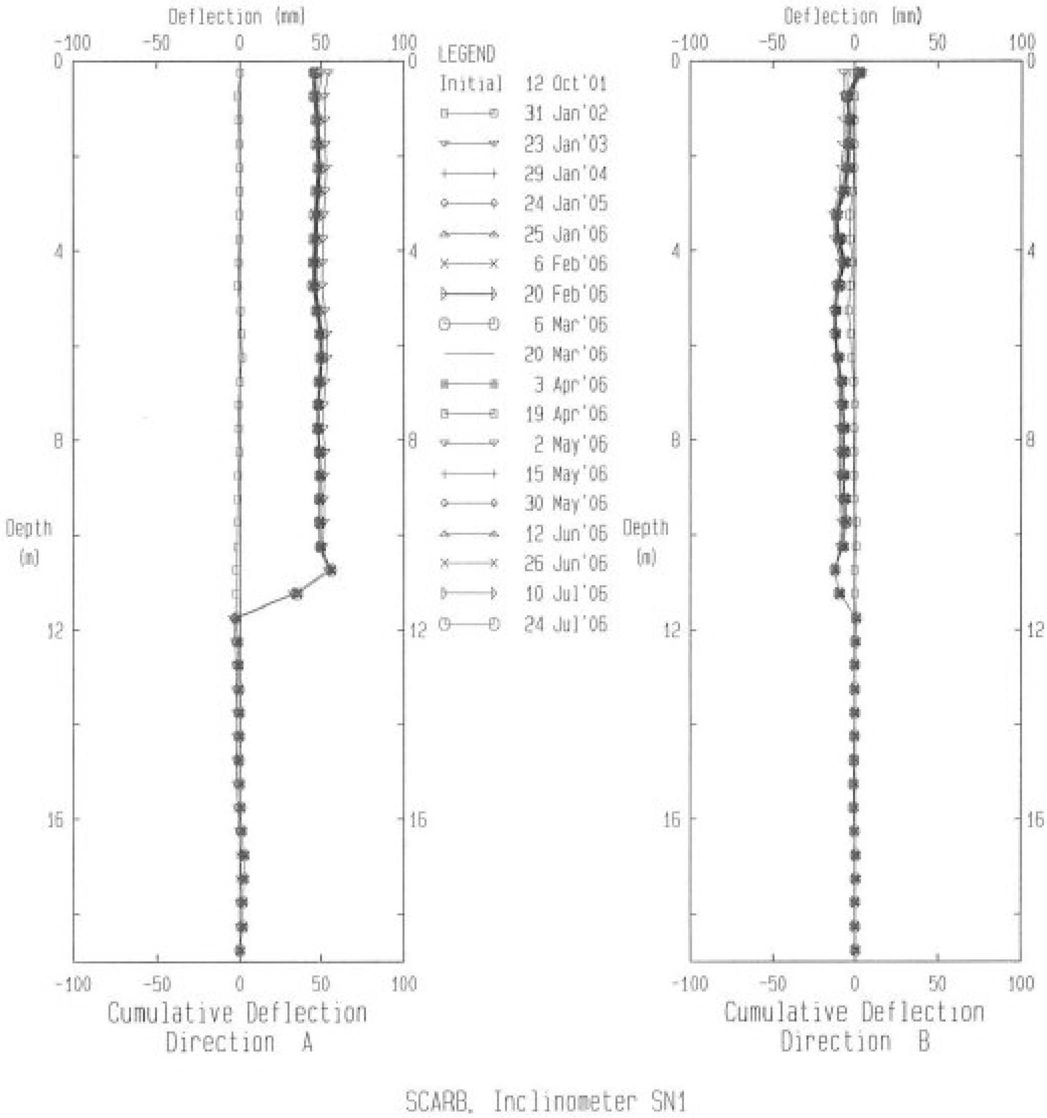


Figure 17: Inclinometer Data SN3

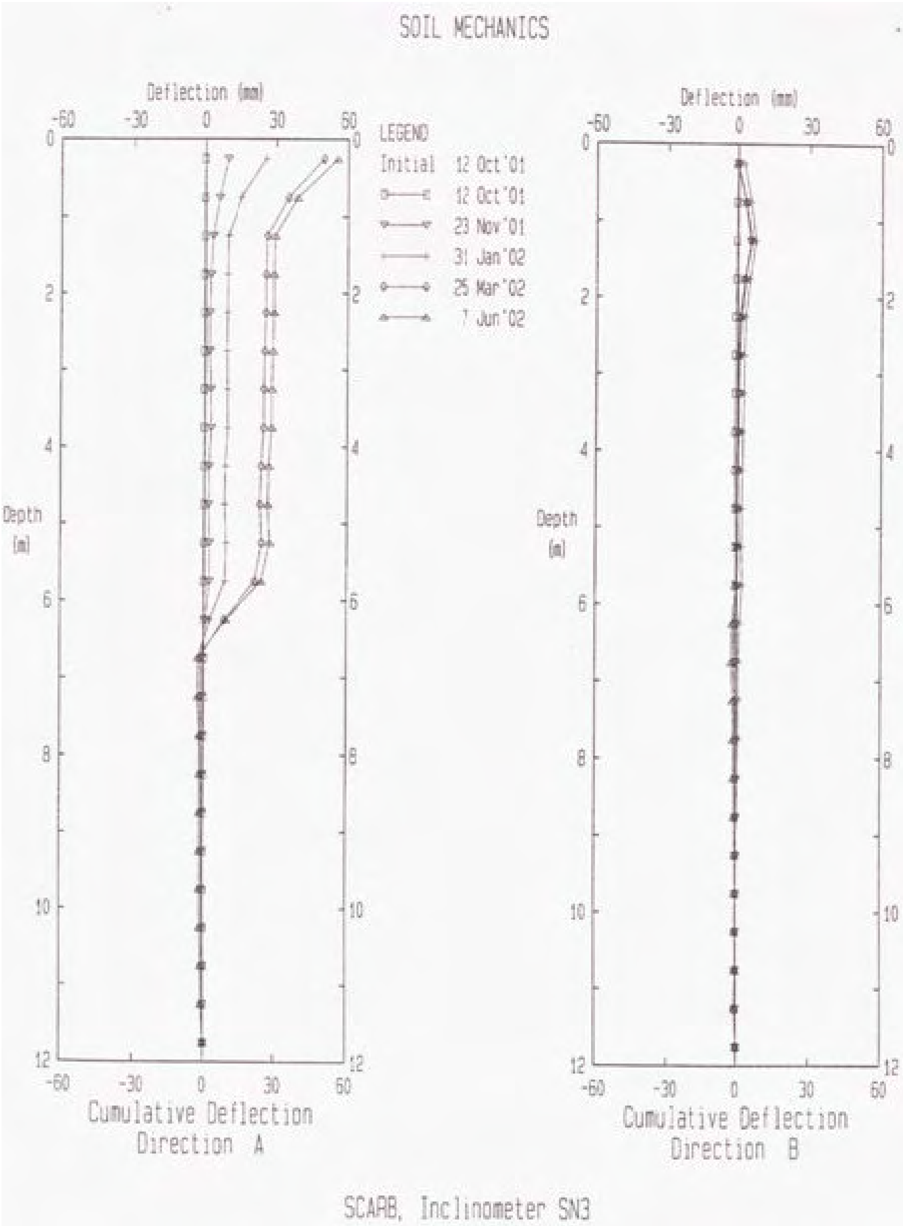


Figure 18: Inclinometer Data SNI1

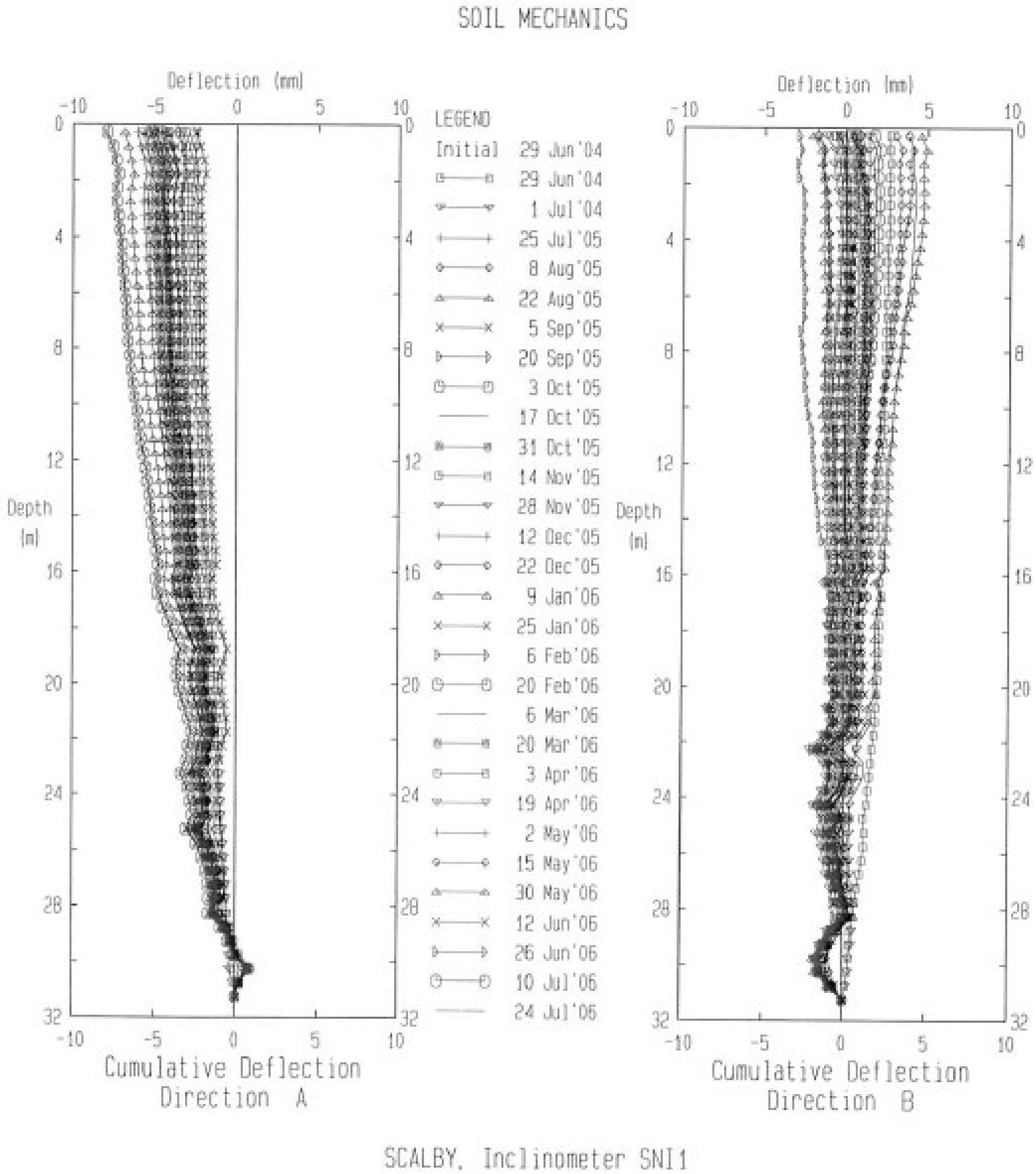


Figure 19: Inclinometer Data SNI3

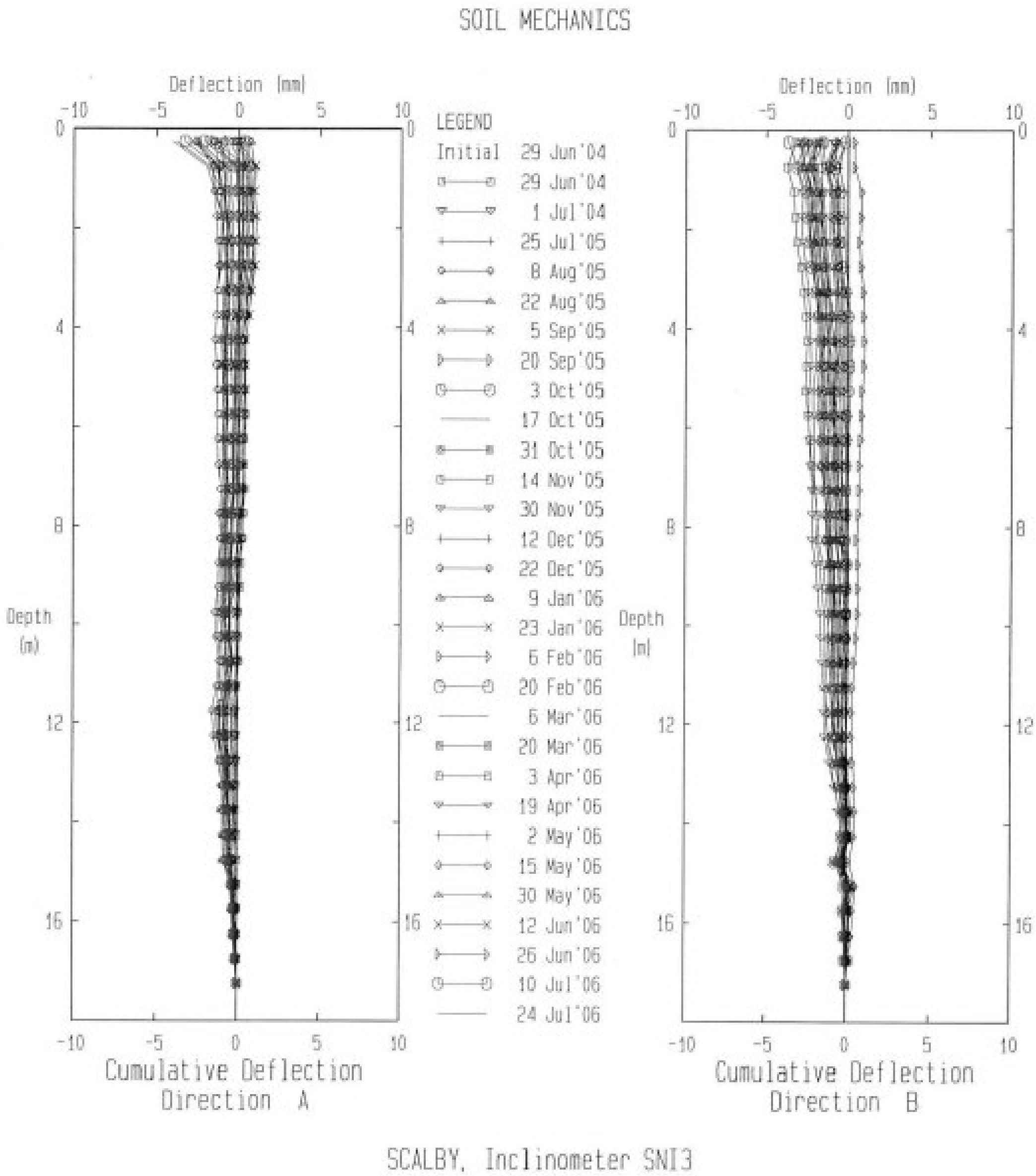
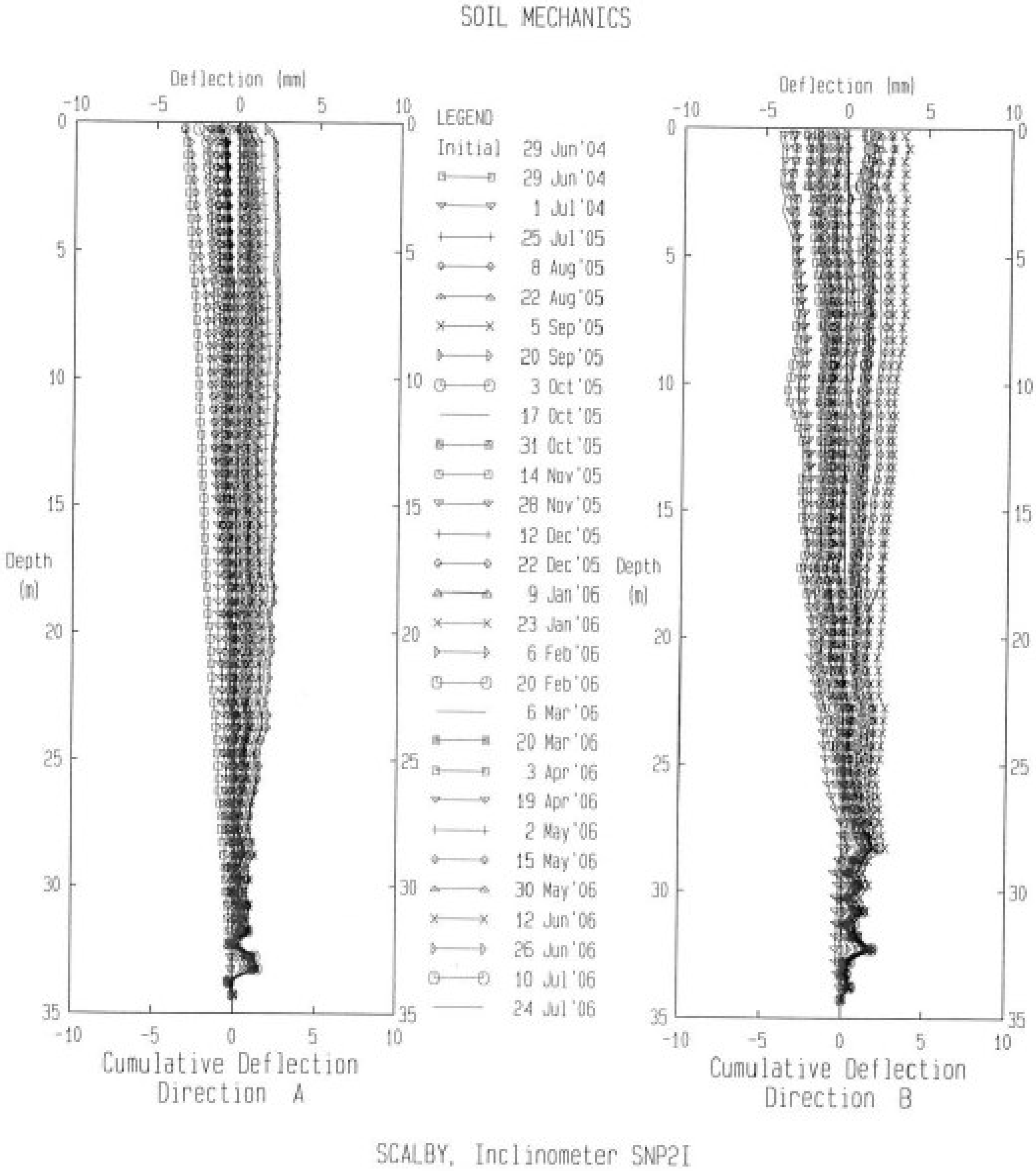


Figure 20: Inclinometer Data SNP2I



'Baseline' readings for I1 (C003) and I3 (C004) taken on 20 November 2008 have been provided in PDF format. No comment is provided on these readings.

5.3.3 *Assessment of Monitoring Results*

Groundwater monitoring, from piezometers at the site, carried out since 2004 has shown that there is perched groundwater present in the glacial tills at varying depths across the site, above a lower groundwater level. During periods of heavy or prolonged rainfall groundwater levels may result in increased porewater pressures leading to slope instability.

Inclinometers SN1 and SN3 were installed in the north east slopes and monitored from October 2001 to September 2006. Data from SN1 revealed ground movements of 50mm, on the back-tilted central block of these slopes, at a depth between 10.8m and 11.7mbgl. Within SN3 the instrument recorded movement at depths of approximately 1.50mbgl of 50mm and between 5.8m and 6.8mbgl of 30mm. A final reading of 7 June 2002 revealed continued movements at depth but failure of the tubing due to surface displacements has left this instrument inoperable.

Inclinometers SNI1, SNI3 and SNP2I were installed at Scalby Ness as part of a second phase of ground investigation in 2004. SNI1 is located behind the crest of the north west slope. SNP2I is located above the crest of the north east slope and SNI3 is positioned towards the lower flanks of the north east slope adjacent to the road. No significant movements have been detected within these instruments although movements at depth have been indicated within SNI1 and SNI3. The displacements are consistent with the movement of the back-tilted block along a pre-existing shear plane within the glacial tills and close to the underlying bedrock.

5.3.4 Stability Analysis

Stability analyses have been carried out on several sections of the north west and north east slopes and are reported separately in Report No. 167 and 174. The analyses applied soil parameters determined from laboratory testing carried out as part of ground investigations at the site in 2001 and 2004. The soil parameters used are presented in Table 5.2.4 above.

A summary of the stability analysis results for the north east slopes indicates that local instability may occur in conditions of high rainfall. A sensitivity analysis showed that there was a risk of localised failure of the upper slopes if groundwater pressures within discrete bands of sand and gravels rose significantly. The potential for such failures would increase if these permeable bands were unable to drain freely due to slips of soil from a higher level. Large-scale failure of the whole slope was analysed by considering failure of the lower block due to high ground water levels, significant toe erosion and residual shear strength parameters. This situation gave a Factor of Safety (FoS) of 1.16 and was considered to be highly unlikely to occur.

A sensitivity analysis of the north west slopes showed that there was a risk of failure should groundwater pressures within the slope rise significantly. Similar to the north east slopes, there is the potential for localised failure in the north west slopes due to the presence of more permeable bands of sand and gravels within the glacial till. The potential for such failures would increase if these permeable bands were unable to drain freely due to slips of soil from a higher level.

5.4 Re-assessment of Risk Register

5.4.1 Re-definition of Problems

There is a risk of slope failure on the north west and north east slopes (in Behavioural Unit I and II) if groundwater levels were to rise significantly following periods of prolonged heavy rainfall. The presence of more permeable layers of sand and gravel within the glacial tills could lead to localised failures and the possibility of this could be increased if these layers are prevented from draining freely due to slipped soils from above

5.4.2 Re-assessment of Risk

The mechanisms of slope failures are still prevalent within this site although to what extent these mechanisms are active is not entirely clear due to the lack of continuous monitoring data available. If a robust regime of monitoring is undertaken over a prolonged period of three years, the data resulting from this would be useful in providing a refined assessment of risk prevailing at Scalby Ness.

5.4.3 Early Warning / Trigger Levels

Given that there are limitations to the monitoring data available for analysis (in terms of incompleteness, continuous readings, incorrect labelling of data sets and a lack of data from parts of the site), it is considered inappropriate to apply trigger levels to this site until such time as sufficient data sets are available for analysis and on which trigger levels could then be based.

5.4.4 Response Actions

It is considered that a programme of response actions or an action plan in relation to significant instability being detected would be inappropriate. A programme of continuous and sustained monitoring and walkover surveys at regular intervals would provide sufficient information on which to formulate the implementation of an action plan.

5.4.5 Future Monitoring and Inspection

It is recommended that a regime of regular monitoring and inspection of Scalby Ness should be undertaken at three monthly intervals. This should be carried out over a period of three years in order to retrieve long term data for analysis in order to determine any seasonal patterns of rainfall, ground water levels and ground movements. This regime of monitoring should encompass the elements for inspection detailed below.

It is recommended that **inclinometer and piezometer monitoring** is undertaken at three monthly intervals, continuing on directly from the 'baseline' readings taken in November 2008. During periods of prolonged or heavy rainfall this interval should be increased in order to provide data of groundwater levels response. It is recommended that a condition examination is carried out and any defects recorded and rectified and, ensuring the instrument covers are secure from acts of vandalism.

At three monthly intervals, **coastal slopes monitoring** should be carried out by way of walk over surveys and ground surveys accompanied by a photographic record. Defects to record would be distances from survey pins installed on slope crests, tension cracking on the slopes, uneven / bulging ground, surface ponding water, undermining of the toe slope at the beck and a visual check of drainage within the highway of Scalby Mills Road for functionality.

5.4.6 Recommendations for Future Instrumentation Installation

Replace or repair inclinometer SN3 which was damaged by shallow ground movements in 2002. This inclinometer was located on the lower, north east slopes, below the mid-slope back tilted block.

It is recommended that a series of survey pins are installed in pairs along the north west and north east crests to monitor recession rates of the slope crests. The pins should be placed one beyond the crest and the other positioned below the crest in the glacial till slopes. The survey pins should be able to provide a semi-permanent, vandal proof record and it is thus suggested they consist of steel pins cast into concrete and marked to distinguish them from their surroundings. The survey pins should be clearly labelled and surveyed to Ordnance Survey co-ordinates in order to reduce mistakes when monitoring data is collected. Monitoring should be undertaken every month following installation for six months and then bi-annually for remaining two and a half years.

5.5 Summary of Recommended Monitoring

Nature of Monitoring and recommended additional instrumentation	Monitoring Frequency	Changes in Frequency following periods of heavy or prolonged rainfall, etc
Walkover survey of slopes	Three monthly intervals for three years	Increased to one week after event and at monthly intervals thereafter for three months
Inclinometers and Piezometers	Three monthly intervals for three years	Increased to one week after event and at monthly intervals thereafter for three months
Replace or repair inclinometer SN3	Monitor every month following reinstatement for six months and then in line with site monitoring	
Install recession points on north west and north east facing crests	Monitor every month following installation for six months and then bi-annually for remaining two and a half years	Increased to one week after event and at monthly intervals thereafter for three months

6 Scarborough North Bay (Site Code AB04)

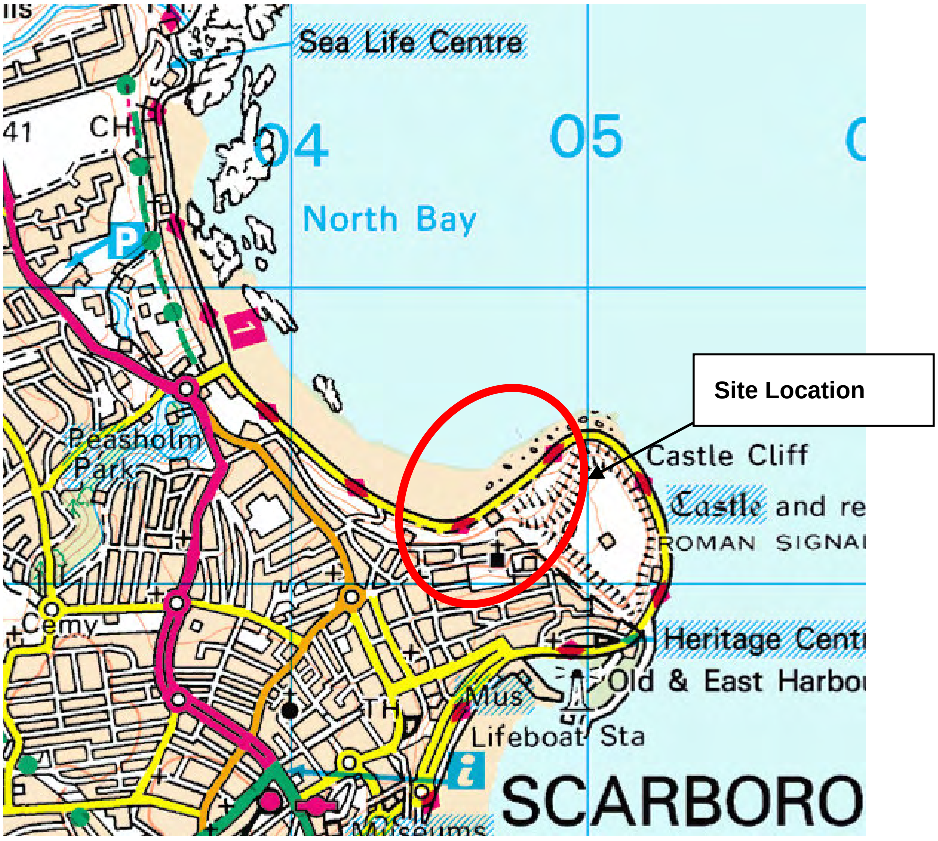
The SMP2 details the site of Scarborough North Bay as follows:

Policy Development Zone 10							
Management Area		**Policy Unit**		**Policy Plan**			
				2025	2055	2105	Comment
MA27	Scarborough North Bay and Castle Cliffs	27.1	North Bay	HTL	HTL	HTL	Detailed strategic appraisal of options required.
		27.2	Castle Headland	HTL	HTL	HTL	

6.1 Description of the Site

North Bay is one of two bays either side of a headland around which the town of Scarborough has developed on the north east coast of Yorkshire. North Bay extends from Castle Cliff northwards to Scalby Ness. The site is known as The Holms, an area of sloping, open parkland between the Castle above and Royal Albert Drive (Marine Drive) along the coast. The parkland consists of open grassed areas with groups of semi-mature trees and shrubs and, meandering tarmac footpaths which increase in steepness from the sea front leading up to the south western flanks of Castle Headland. Discrete rock outcrops are clearly visible across the slopes.

Figure 21: Site Location



6.1.1 Historic Review of Problems

In 2000, a 200mm displacement of the seawall was monitored. These movements were caused by the widespread reactivation of a deep-seated, pre-existing landslide system at The Holms. Although this caused extensive damage to footpaths and cracking of the seawall, movements were relatively minor, with ground displacements of the main landslide body probably in the order of 10's of centimetres. Following this event, a programme of Preventative Emergency Works was undertaken in 2000-2001. This pre-empted the main works of improvement and reconstruction of the seawall defences under the Coastal Protection Scheme.

The underlying landslide system comprises 10 to 17metres of landslide debris overlying intact Scalby Formation of inter-bedded sandstone, siltstone and mudstone. Two units have been identified from ground investigations carried out in 2000.

- An eastern unit, comprising of a deep-seated landslide which 'daylights' close to foreshore level.
- A western unit, composed of a shallower landslide which 'daylights' approximately 1.50m above Marine Drive.

6.1.2 Site Walkover

A site walkover was conducted by a geotechnical engineer from Mouchel on 28th November 2008. The site visit confirmed the condition of the existing borehole instruments as being operable. A series of photographs was also taken of the site picking up salient topographical features such as varying slope angles, back scars, relict slope failures, as well as remedial works which comprise retaining walls and reinforced slope faces. Selected site photographs are presented in Appendix D.

Features identified during the walk over survey are described in Section 6.1.3 of this report.

6.1.3 Topography and Geomorphology

The Holms is an area of public open space laid over to informal gardens with a network of tarmac footpaths which provide access from the sea front to the Castle Headland above. The slopes are heavily terraced, displaying hummocky, irregular ground comprising glacial till and possible landslide debris with a mid-slope bench feature dominating the slopes. The glacial slopes rise from Marine Drive, at approximately 7.0mAOD, at angles of 20-35 degrees to a mid-slope bench and terrace at 35.0mAOD, beyond this plateau the slopes composed of rock debris and scree rise to approximately 50 to 55.0mAOD to near shear cliff faces. These cliff faces rise to the pinnacle (83.31mAOD) of Castle Hill on which the remains of Scarborough Castle are apparent. A thin mantle of top soil, up to 0.17m thick directly overlying bedrock, is present in the mid-slope plateau of the site where glacial till is absent. Glacial till is present over the remainder of the site varying in thickness between 16.0m in the west section and 2.50m-2.95m in the eastern section. Outcrops of the Cornbrash Limestone Formation are prominent on the lower and middle slopes of The Holms.

6.1.4 Existing Information

The following reports have been provided by SBC for consultation:

Report No. 54 – ***Ground Investigation The Holmes, Area L. Holbeck to Scalby Mills Coastal Defence Strategy for Scarborough Borough Council***. Report No. SW/SR/F10849. Norwest Holst Soil Engineering Ltd, January 1998.

Report No. 59 - ***Scarborough Borough Council. Report on a Ground Investigation at Clarence Gardens, Area N, Holbeck to Scalby Mills. Coastal Defence Strategy. Report No. BS/SR/F10849.*** Norwest Holst Soil Engineering Ltd, January 1998.

Report No. 107 - ***Scarborough Borough Council. Report on a Ground Investigation at The Holmes, Scarborough. Photographs. Report No. F11748.*** Norwest Holst Soil Engineering Ltd, January 2001.

Report No. 108 - ***Scarborough Borough Council. Report on a Ground Investigation at The Holmes, Scarborough. Report No. F11748.*** Norwest Holst Soil Engineering Ltd, January 2001.

Report No. 114 - ***Scarborough Borough Council. Report on a Ground Investigation at Warwick Court and The Holmes, Scarborough. Report No. F11858.*** Norwest Holst Soil Engineering Ltd, April 2001.

Report No. 132 - ***Scarborough Strategic Coastal Monitoring (Staithes to Scarborough). Defence Condition Surveys – Volume 1***. Document No. 1540/R/1. High Point Rendel Ltd, March 2002.

Report No. 135 - ***Scarborough Borough Council. Strategic Coastal Monitoring Staithes to Scarborough. Cliff Condition Survey. Volume 2 Slope Proformas. Report No. R/1540/2/1.*** High Point Rendel Ltd, September 2002.

Report No. 170 - ***Scarborough Borough Council Defra. Holbeck to Scalby Mills Strategy Review, Scarborough. Volume 1: Text and Figures. Draft for Consultation. Report No. J2394/1***. High Point Rendell Ltd, July 2005.

Report No. 186 - ***Scarborough Borough Council. Strategic Coastal Monitoring Programme 2001-2006. Condition Analysis of Coast Protection Assets, Cliffs and Beaches from Staithes to Speeton.*** Halcrow Group Ltd, November 2006.

6.2 Stratigraphy

6.2.1 Soil Profile

The 1:50,000 British Geological Survey (BGS) Sheets 35 and 44 Solid & Drift, Whitby and Scalby, indicate that the northeast of the site is underlain by superficial deposits of glacial till of Quaternary age. This directly overlies Scalby Formation deposits of mudstones and sandstones. A north west –south east trending fault and a north – south trending fault gives rise to glacial tills underlying Oxford Clay, which in turn overlies the Hackness Rock Member sandstones of the Osgodby Formation. The Scalby Formation sandstones and mudstones are unconformably overlain by the Cornbrash limestones and the Osgodby Formation. The stratum generally dip at an angle of 7 degrees in a south easterly direction.

Table 6.2.1 Geological Stratigraphy

Age	Stratum
Quaternary	Glacial Till Stiff silty sandy clays, sands and gravels, laminated silty clays
Upper Jurassic	Oxford Clay Formation Grey-green mudstone
Middle Jurassic	Osgodby Formation Calcareous sandstone
Middle Jurassic	Cornbrash Limestone Formation
Middle Jurassic	Scalby Formation Mudstone and sandstone

6.2.2 Groundwater Regime

Hydrogeology

The Groundwater Vulnerability Map (Sheet 9) of North East Yorkshire has classified the area as a Minor Aquifer, overlain by class HU soils. Due to the less reliable nature of data collected in urban areas, the worst case scenario is assumed and soils are classified as having a high leaching potential. Minor Aquifers are variably permeable rocks, usually fractured rocks with a low primary permeability or unconsolidated deposits. They rarely produce large quantities of water for abstraction but often provide important base flow supplies to rivers. Major Aquifers may occur beneath Minor Aquifers.

Table 6.2.1. Groundwater Monitoring following site works

Hole No	Tip Depth (mBGL)	Readings			
		Period	Maximum Water depth (mBGL)	Minimum Water depth (mBGL)	Range (m)
L1	10.00	6/11/97-28/11/00	3.17	2.51	0.66
L1	16.00	6/11/97-28/11/00	6.88	5.97	0.91
L3	20.70	6/11/97-28/09/00	20.5	20.4	0.10
L3	27.40	6/11/97-28/09/00	25.25	12.98	12.27
L5	24.00	6/11/97-28/09/00	24.24	22.27	1.97
L5	33.00	6/11/97-28/09/00	29.25	25.00	4.25
N2	7.30	-	-	-	-
N2	14.00	10/12/98-	14.12	14.01	0.11

		09/07/00			
L7P	-	-	-	-	-
L7P	-	-	-	-	-
L9P	-	-	-	-	-
L9P	-	-	-	-	-

Groundwater monitoring of borehole installations across the site is limited to the results presented in Table 6.2.2 above. The results pre-date the remedial works carried out to The Holms landslide area and coastal defence improvement works. Data from boreholes L7P to L9P has not been made available for analysis.

6.2.3 Laboratory Test Results

A summary of the laboratory tests undertaken and reported in Report No. 59 is presented in Table 6.2.3 below.

Table 6.2.3 Summary of Laboratory Testing

Type of test	Test method
Classification/Compaction	
Moisture Content	BS1377: Part 2: 1990; Clause 3
Liquid / plastic limits	BS1377: Part 2: 1990
Particle size distribution	BS1377: Part 2: 1990; Clause 9
Bulk Density	BS1377, (1990) Part 2, clause 7.2
Strength / Consolidation	
Undrained triaxial (total) strength - Multistage	BS1377, (1990) Part 7
Small Ring Shear	BS1377, (1990) Part 7

6.2.4 Soil Parameters

Soil parameters derived from a schedule of laboratory testing gave the following range of results for glacial till unit:

C_u = 34, phi = 14^0 (From Undrained Triaxial multistage test)

C_u = 0, phi = 30^0 and 18^0 (From Ring Shear test)

Moisture Content = 7.4% to 27%,

Liquid Limit = 27% to 47%,

Plastic Limit = 13% to 18%,

Plasticity Index = 11% to 31%

6.3 Instrumentation

6.3.1 Definition of Existing Problems

Widespread reactivation of a deep-seated landslide system at The Holms occurred during 2000. This caused extensive damage to footpaths and cracking of the seawall. Ground displacements of the main landslide body were in the region of 10's of centimetres although monitoring of the seawall revealed movements of 200mm had occurred.

6.3.2 History of Monitoring

Data provided by SBC from reports indicates that there have been several ground investigations undertaken at The Holms and Clarence Gardens between 1997 and 2001. The four ground investigations are covered by Report No. 54, 59, 108 and 114. A programme of groundwater monitoring and slope movement has been undertaken since approximately 1997 although this has not been carried out continuously from that date. Piezometer and inclinometer monitoring data is detailed in the ground investigation reports and Report No. 170. Inclinometer data available in PDF and gINT format covers the period November 1998 to September 2006.

Inclinometer data (N1, L4, L6, L11 and L12) detailed within Report No. 197 covers the period between November 2000 – July 2001 and November 2001 - December 2005.

'Baseline' readings for L11 (D001) were taken on 20 November 2008. The remaining three inclinometers were not located by the contractor and hence no readings have been made available for analysis.

Topographic surveying has been undertaken at Oasis Café and Clifton Hotel, North Bay. The data provides co-ordinates and elevation readings carried out between 9 February 2001 and 2 October 2003 at the Oasis Café and from 5 July 2004 to 31 January 2007 at the Clifton Hotel.

A photographic record of the sites covering South Cliffs has been undertaken on a periodic basis since June 2001 onwards. The photographs record damage caused by slope instability encompassing slip failures, back scars, cracking in paths, pavements and structural damage to footsteps and retaining walls.

Crack monitoring had been carried out by SBC generally on a monthly basis at The Holms since 2000. Since the completion of Emergency Works 2001, monitoring records demonstrate that there has been a reduction in movement rates.

6.3.3 Assessment of Monitoring Results

Inclinometers have been read since installation, generally from 1997 onwards. Significant reactivation of pre-existing landslides on The Holms site was detected in boreholes L4, L6, L7, L8, L13, L14 and N1 at Clarence Gardens. A summary of this data is presented in Table 6.3.3 below.

Table 6.3.3. Summary of Inclinometer Results: Pre-existing Landslides

Landslide	Inclinometer	Location	Till/Bedrock boundary (m bgl; m AOD)	Interpretation Of Results	Comment
The Holms	L2	Mid slope	2.5m bgl; 16.4m AOD	Bias-shift	No evidence of landslide movement
	L4	Upper slope	No till recorded	Possible shearing	Inclinometer damaged (possible shear surface) at 17m bgl
	L6	Mid slope	-	Possible shearing	Inclinometer obstructed at 10.5m bgl (possible movement)
	L7	Toe	3.0m bgl; 7.60m AOD	Possible shearing	Possible movement at 10m bgl (5-10mm displacement)
	L8	Toe	No till recorded	Possible shearing	Possible movement at 14m bgl (5-10mm displacement)
	L11	Mid slope	-	Bias shift	No evidence of landslide movement
	L12	Mid slope	-	Bias shift	No evidence of landslide movement
	L13	Toe	-	Possible shearing	Possible movement at 10m bgl (5-10mm displacement)
	L14	Toe	-	Bias shift	Possible movement at 14m bgl (5-10mm displacement)
Clarence Gardens	N1	Cliff Top	16.0m bgl; 13.05m AOD	Possible shearing	Possible <5mm movement at 30.0m depth

Crack monitoring had been carried out by SBC generally on a monthly basis at The Holms since 2000. Monitoring records demonstrate that there has been a reduction in ground movement rates since the completion of the 2001 Emergency Works. Monitoring stations were established along Marine Drive in November 2000 to monitor the extent of seawall displacements due to movement of The Holms landslip. The results recorded that seawall displacement of 200mm had occurred between 10 and 27 November 2000. An average displacement measured from 13No. survey stations from November 2000 to November 2001 averaged 17mm movement. Over successive yearly periods, the average measured displacements have been 0.5mm, 4mm and 0.7mm up to 2004.

Topographic surveying has been undertaken at Oasis Café and Clifton Hotel, North Bay over different, three yearly periods. The data provides co-ordinates and elevation values for survey pins / points although it is not clear what the collective data is referenced to.

Groundwater monitoring of borehole installations across the site is limited to results from mid to late 1997 to late 2000. The results pre-date the remedial works carried out at The Holms landslide area and succeeding coastal defence improvement works. Therefore, there is no data to show what impact the remedial works have had on the long term groundwater regime at this site.

6.3.4 Stability Analysis

Stability analysis data has not been made available by SBC for this site.

6.4 Re-assessment of Risk Register

6.4.1 Re-definition of Problems

From analysis of the available inclinometer and borehole data, an established mechanism of failure at this site had been identified as the re-activation of existing slips within strata variously described as slightly to highly weathered, moderately strong to very weak mudstones and siltstones of the Scalby Formation associated with high groundwater levels.

Crack monitoring carried out by SBC showed that movement rates declined at The Holms following the implementation of Preventative Emergency Works in 2000/2001. These works involved the installation of shallow and deep drains across the mid slope bench and rear scarp slopes of The Holms in order to reduce groundwater levels by up to 2metres across the site. In addition to this, bored and cast-in-place large diameter reinforced concrete piles were installed along the landslide toe, on the landward edge of Marine Drive. The piles were installed to provide short to medium-term stability of the landslide area before drainage measures became effective.

Report No. 170, Section 3/10 states - "***As a result of the Emergency Works, road and seawall movements were significantly reduced. Post construction monitoring also indicated that ground water levels had been drawn down by 1.25metres across the central part of the site.***" The source of post construction monitoring is not revealed however, there is little doubt that the drainage measures referred to would have a lowering effect upon groundwater levels at the site. How much of an effect is not proven with monitoring data.

Following the works of 2001, seawall defences along The Holms and Clarence Gardens were improved with the construction of a rock armour revetment on the seaward face of the existing defences and a 1metre high re-curved wall on top of the seawall. The revetment has also provided additional toe loading and has improved stability of the landslide area of The Holms.

6.4.2 Re-assessment of Risk

Inclinometer monitoring data indicates movement has occurred at depth within instruments L4, L6, L7, L8, L13, L14 and N1. Analysis of the readings would indicate that following installation, the great majority of movement, which in some cases had resulted in shearing of the instrument tubing, had ceased by 2002. Therefore it seems reasonable to conclude that the Emergency Works of 2001 and seawall defence works following this have arrested the displacement rates as well as having a stabilising effect on the landslides of The Holms area.

6.4.3 Early Warning / Trigger Levels

Continue with bi-annual monitoring and walk over surveys as detailed in Section 6.4.5. Increase the frequency of the periodic surveys during and after periods of heavy or prolonged rainfall for changes in ground water levels within the piezometer instruments and ground movements from inclinometer data.

6.4.4 Response Actions

It is considered that a programme of response actions or an action plan in relation to significant instability being detected would be inappropriate. A programme of continuous and sustained monitoring and walkover surveys at regular intervals would provide sufficient information to negate the implementation of an action plan.

6.4.5 Future Monitoring and Inspection

It is recommended that a regime of regular monitoring and inspection of North Bay should be undertaken at six monthly intervals (bi-annually). This should be carried out over a period of three years in order to retrieve long term data for analysis to determine any seasonal patterns of rainfall, ground water levels and ground movements. During periods of heavy or prolonged rainfall the frequency of the surveys should be increased in order to record any resulting increases in groundwater levels

Coastal slopes monitoring should be carried out by way of walk over surveys and ground surveys accompanied by a photographic record. Defects to record would be tension cracking in pavements and buildings, misalignment of linear features, uneven / bulging ground, surface ponding water, undermining of slope / cliff bases and a visual check of drainage within highways and slopes for functionality (specifically Nettledale Beck).

Beach monitoring should be carried out at low tide conditions to assess beach levels and accompanied by a photographic record.

Sea wall monitoring should be undertaken at low tide conditions to determine any undermining of the base of the sea-wall defences and also to record the general condition of the sea-wall. A photographic record should be taken to accompany a sea wall condition survey to monitor any crack development, concrete spalling, etc.

There has been a break in the monitoring of the piezometers since 2000 and before the remedial measures were carried out at The Holms. It is recommended that piezometer monitoring is reinstated. **Inclinometer and piezometer monitoring** should be carried out at monthly intervals for six months then every two months until month twelve. If no significant movement is revealed during this twelve month period then monitoring should revert to six monthly intervals (bi-annually). As well as reading the instruments, a condition examination should be carried out at the same time and any defects recorded and rectified.

6.4.6 Recommendations for Future Instrumentation Installation

If the piezometers at The Holms (L1, L3 and L5) are able to be re-commissioned, it would be considered that further instrument installation is not required. The benefits of additional instrumentation do not outweigh the costs as cheaper methods of monitoring are available and have been proposed. The failure mechanisms prevailing at The Holms are well documented and understood. The depths to and the nature of shear surfaces have been defined from previous ground investigations and installed inclinometers and, the mechanisms of slope failure determined through ground investigations and detailed geomorphological mapping. Therefore, regular, detailed walk over surveys and survey monitoring of the area, by an experienced geotechnical engineer, at the stated frequencies would be considered adequate measures of monitoring. During periods of heavy or prolonged rainfall the frequency of the surveys should be increased in frequency in order to record any resulting increases in groundwater levels.

If future data collection shows abnormalities such as increased ground movements, development of ‘new’ tension cracks, mal-functioning drainage, etc then the cause of such defects should be investigated further by means of increased frequencies of ground surveys.

6.5 Summary of Recommended Monitoring

Nature of Monitoring and recommended additional instrumentation	Monitoring Frequency	Changes in Frequency following periods of heavy or prolonged rainfall, etc
Walkover survey of Coastal Slopes	Six monthly (Bi-annual) for three years	Increased to one week after event and at monthly intervals thereafter for three months
Beach	Six monthly (Bi-annual) for three years	
Sea Wall	Six monthly (Bi-annual) for three years	
Inclinometers and Piezometers	Monthly intervals for six months then every two months until month twelve. Reverting to bi-annual intervals for remaining two years if no significant movement detected	Increased to one week after event and at monthly intervals thereafter for three months

7 Scarborough South Cliff (Site Code AB05)

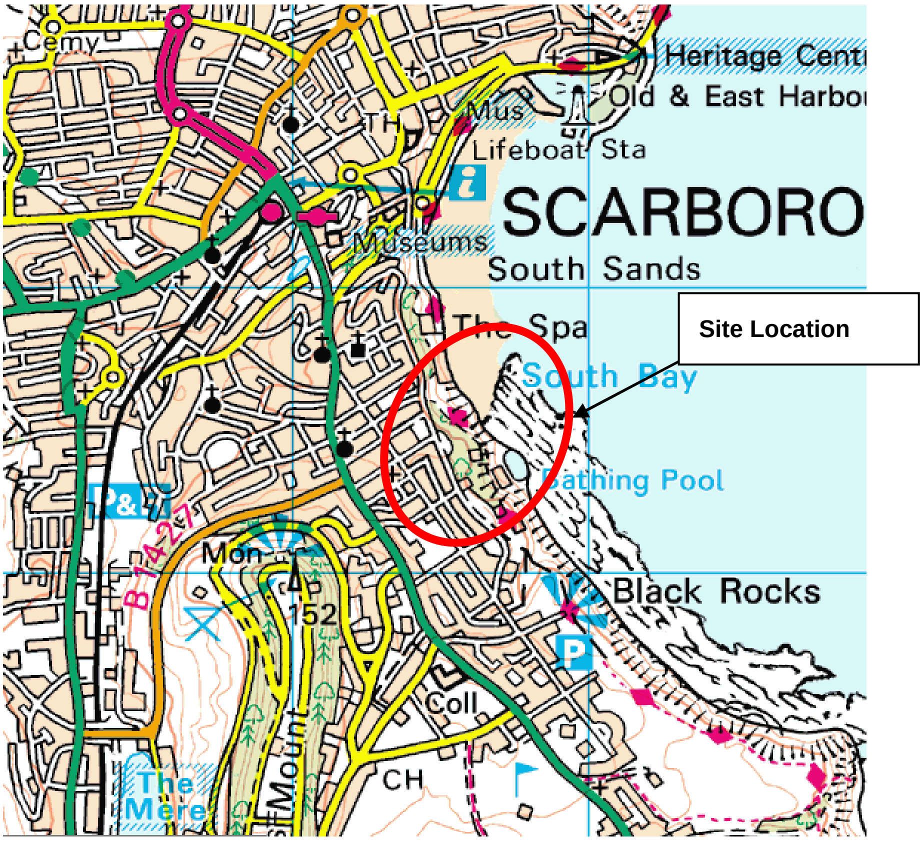
The SMP2 details the site of Scarborough South Cliff as follows:

Policy Development Zone 10							
Management Area		**Policy Unit**		**Policy Plan**			
				2025	2055	2105	Comment
MA28	Scarborough South Sands and Harbour	28.3	Spa and Access	HTL	HTL	HTL	Consider opportunity for advance
		28.4	Cliff Gardens	HTL	HTL	HTL	Minimise impact on foreshore
		28.5	South Cliffs	NAI	NAI	NAI	-

7.1 Description of the Site

Scarborough is a popular sea-side resort located on the north east coast of England. The South Cliff occupies the southern bay of Scarborough town with a gently sweeping coastline from the northern promontory of Castle Hill to the Black Rocks some 2km southwards. The South Cliff site comprises a variety of landscaped gardens stretching from north to south in the following order: Spa Chalet Cliff, Spa Cliff, Prince of Wales Cliff, South Cliff Gardens, Rose Gardens, South Bay Pool Cliff, Holbeck Gardens, Holbeck Cliff and Wheatcroft Cliff. The cliff top is a gently undulating plateau surface with a road, Esplanade Crescent, running parallel to the cliff line. Large houses and hotels line the landward side of the road, set-back generally 30metres, but up to 100metres in places, from the cliff edge.

Figure 21: Site Location



7.1.1 *Historic Review of Problems*

The cliffs of Scarborough's south bay are formed from glacial till slopes of varying thickness, underlain by Jurassic sandstones and siltstones, which are prone to landsliding. All of the cliffs along this section have toe protection provided by seawall / coastal defences, but localised activity on the slopes and head scarps is common. At the Spa Cliffs, South Cliff Gardens and South Bay Pool the cliffs comprise steep rear scarps, forming arcuate embayments up to 200metres in width, with gentle sloping stepped slopes at the base. Geomorphological features such as the steep rear scarps and mid-slope benches, present at these gardens, possibly display the remnants of historic deep-seated retrogressive rotational failures within the glacial tills. At Holbeck Cliff, the 1993 landslide involved a complex series of retrogressive displacements which overwhelmed the seawall and extended 150metres across the foreshore.

The remaining sites present between those mentioned above consist of Spa Chalet Cliff, Prince of Wales Cliff, Rose Gardens, Holbeck Gardens and Wheatcroft Cliff. These sites represent intact coastal slopes which are subjected to localised small-scale shallow slope failures within the glacial tills due in part to increases in porewater pressures which lead to softening of and a decrease in shear strength of the tills. Such failures result in disrupted footpaths and minor damage to other structures and could be expected to occur on a yearly basis.

7.1.2 Site Walkover

A site walkover was conducted by a geotechnical engineer from Mouchel on 27th November 2008. The site visit confirmed the condition of the existing borehole instruments as being operable. A series of photographs was also taken of the site picking up salient topographical features such as varying slope angles, back scars, relict slope failures, retaining walls and tension cracks in structures and pavements. Selected site photographs are presented in Appendix E.

Features identified during the walk over survey are described in Section 7.1.3 of this report

7.1.3 Topography and Geomorphology

Late Devensian age glacial tills have been emplaced across much of the landscape composed of Jurassic sedimentary rocks (predominantly sandstones and siltstones). These tills include stiff silty sandy clays, sands and gravels and, laminated silty clays. At South Cliff, the till has completely in-filled a pre-glacial valley and now the whole cliff profile has developed in these glacial tills attaining a height of between 50m and 65m. The glacial till slopes have been subjected to coastal protection measures, landscaping and drainage improvements since becoming the property of SBC in the late 19th century.

The South Cliff is occupied by a series of terraced gardens developed into glacial till slopes of varying thickness underlain by Jurassic sandstones and siltstones. At the Spa Cliffs, South Cliff Gardens and South Bay Pool the cliffs comprise steep rear scarps, forming arcuate embayments up to 200metres in width, with gentle sloping stepped slopes at the base. At other areas of the garden complex the landscaped slopes attain angles of up to 40 degrees becoming steeper at the base and are criss-crossed by a network of footpaths, bench-cut into the slopes and supported by small walls and revetments. A concrete seawall and promenade has been built along the base of the cliffline from Spa Chalet Cliff to Holbeck Cliff where in the absence of a seawall, a rock armour revetment was constructed to replace the seawall destroyed in 1993 by a landslide. A variety of buildings occupy sites within South Cliff from the Spa Complex and Ocean Ballroom constructed at the base of Prince of Wales Cliff, a cliff railway operating from cliff top down slope to the Spa complex and, a swimming pool and a series of chalets at South Bay Pool Cliff.

7.1.4 Existing Information

The following reports have been provided by SBC for consultation:

Report No. 55 - ***Scarborough Borough Council. Ground Investigation on The Spa, Area H, Scarborough Holbeck to Scalby Mills. Coastal Defence Strategy***. Report No. BS/SR/F10849. Norwest Holst Soil Engineering Ltd, January1998.

Report No. 56 – ***Scarborough Borough Council. Ground Investigation on The Spa, Area H, Scarborough Holbeck to Scalby Mills. Coastal Defence Strategy***. Report No. BS/SR/F10849. Norwest Holst Soil Engineering Ltd, January1998.

Report No. 58 - ***Scarborough Borough Council. Ground Investigation on Wheatcroft Cliff, Area A, Scarborough Holbeck to Scalby Mills. Coastal Defence Strategy***. Report No. SW/SR/F10849. Norwest Holst Soil Engineering Ltd, January1998.

Report No. 60 - ***Scarborough Borough Council. Ground Investigation on The Rose Gardens, Area E, Scarborough Holbeck to Scalby Mills. Coastal Defence Strategy***. Report No. BS/SR/F10849. Norwest Holst Soil Engineering Ltd, January1998.

Report No. 61 - ***Scarborough Borough Council. Ground Investigation on South Cliff Gardens, Area F, Scarborough Holbeck to Scalby Mills. Coastal Defence Strategy***. Report No. BS/SR/F10849. Norwest Holst Soil Engineering Ltd, January1998.

Report No. 62 - ***Scarborough Borough Council. Ground Investigation on South Bay Pool, Area D, Scarborough Holbeck to Scalby Mills. Coastal Defence Strategy***. Report No. BS/SR/F10849. Norwest Holst Soil Engineering Ltd, January1998.

Report No. 63 - ***Scarborough Borough Council. Ground Investigation on Prince of Wales, Area G, Scarborough Holbeck to Scalby Mills. Coastal Defence Strategy***. Report No. BS/SR/F10849. Norwest Holst Soil Engineering Ltd, January1998.

Report No. 87 – ***Scarborough Borough Council. Ground Investigation on Holbeck Gardens, Esplanade Crescent, Scarborough.*** Report No. DEL/LA/F10438. Norwest Holst Soil Engineering Ltd, March 1996.

Report No. 103 – ***Scarborough Borough Council. Scarborough Coastal Defence Strategy Holbeck Gardens Coastal Protection and Cliff Stabilisation. Rapid Risk Assessment. Draft Copy. Report No. R/001247/1/1. High Point Rendell Ltd, July 2001***

Report No. 132 - ***Scarborough Borough Council. Scarborough Strategic Coastal Monitoring (Staithes to Scarborough). Defence Condition Surveys – Volume 1***. Document No. 1540/R/1. High Point Rendel Ltd, March 2002.

Report No. 134 - ***Scarborough Borough Council. Scarborough Strategic Coastal Monitoring (Staithes to Scarborough). Cliff Condition Surveys – Volume 1,*** Text and Figures. Document No. R/1540/2/1. High Point Rendel Ltd, September 2002.

Report No. 135 - ***Scarborough Borough Council. Strategic Coastal Monitoring Staithes to Scarborough. Cliff Condition Survey. Volume 2 Slope Proformas. Report No. R/1540/2/1. High Point Rendel Ltd, September 2002.***

Report No. 186 - ***Scarborough Borough Council. Strategic Coastal Monitoring Programme 2001-2006. Condition Analysis of Coast Protection Assets, Cliffs and Beaches from Staithes to Speeton.*** Halcrow Group Ltd, November 2006.

7.2 Stratigraphy

7.2.1 Soil Profile

The 1:50,000 British Geological Survey (BGS) Sheet 54 Solid & Drift, Scarborough indicates that the site is underlain by superficial deposits of Quaternary glacial till comprising stony clay, underlain by Oxford Clay of up to 36-76m in thickness. This overlies Osgodby Formation calcareous sandstones above undifferentiated strata of the Cayton Clay Formation and Cornbrash Formation consisting of limestones and mudstones. An unconformity separates this stratum from the underlying Scalby Formation mudstones and sandstones. The Scalby Formation is underlain by the Scarborough Formation limestones and mudstones, which outcrop as the Black Rocks of the South Bay foreshore.

Table 7.2.1 Geological Stratigraphy

Age	Stratum
Quaternary	Glacial Till Stiff silty sandy clays, sands and gravels, laminated silty clays
Upper Jurassic	Oxford Clay Formation Grey-green mudstone
Middle Jurassic	Osgodby Formation Calcareous sandstone
Middle Jurassic	Cayton Clay Formation and Cornbrash Formation Limestone and mudstone
Middle Jurassic	Scalby Formation Mudstone and sandstone
Middle Jurassic	Scarborough Formation Limestone and mudstone

7.2.2 Groundwater Regime

Hydrogeology

The Groundwater Vulnerability Map (Sheet 9) of North East Yorkshire has classified the area as a Minor Aquifer, overlain by class HU soils.

Due to the less reliable nature of data collected in urban areas, the worst case scenario is assumed and soils are classified as having a high leaching potential. Minor Aquifers are variably permeable rocks, usually fractured rocks with a low primary permeability or unconsolidated deposits. They rarely produce large quantities of water for abstraction but often provide important base flow supplies to rivers. Major Aquifers may occur beneath Minor Aquifers.

From a review of historical records, provided by SBC, it has been determined that several ground investigations have been undertaken along this section of coastline from Spa Chalets in the north down to Wheatcroft Cliffs near Black Rocks of the South Bay foreshore, from January 1996 onwards.

Groundwater strikes encountered in boreholes during the various fieldworks are detailed below in Table 7.2.2a. An observation of the water strikes, and the response after 20minutes, is that the flows were recorded as being slow to slight seepage. This would indicate that the water strikes are from perched water tables, which have little hydrostatic pressure, within the glacial tills with an underlying water table at depth.

Table 7.2.2a Groundwater strikes from Fieldworks

Hole ID	Geology	Water Strike Depth (m bgl)	Water Depth After 20 minutes(m bgl)	Flow Rate Remarks
I1	Glacial Till	12.30	12.00	-
H4	Glacial Till	5.40	5.40	Slight seepage
A1	Glacial Till	4.70	4.70	Slight seepage
E1	Glacial Till	15.70	15.40	-
E3	Glacial Till	6.90	6.50	-
E5	Glacial Till	18.20	18.20	Slight seepage
F1	Glacial Till	6.25	5.80	-
F1	Glacial Till	10.00	-	-
F1	Glacial Till	19.70	17.20	-
F2	Glacial Till	3.00	2.80	-
F2	Glacial Till	9.00	-	-
F2	Glacial Till	19.50	16.00	-
F5	Glacial Till	5.70	4.50	-
D2	Glacial Till	3.40	2.10	-
G1	Glacial Till	6.20	6.20	-
G1	Glacial Till	16.70	16.70	-
BH1	Glacial Till	19.70	19.15	-
BH3	Glacial Till	12.30	12.00	-

Long term water level monitoring has been carried out at boreholes from across this site, generally from the date of installation up to early August 2008.

A significant number of boreholes had double piezometers (a and b) installed to target groundwater pressures within perched groundwater tables in sandy, granular horizons of the glacial tills and the piezometric pressure at the glacial till / bedrock (mudstone) interface. Groundwater monitoring has indicated a great variation in piezometric pressures at the glacial till / mudstone interface. At times of high rainfall it is likely that the porewater pressures rise within the strata sufficiently to trigger slope instability failures.

7.2.3 Laboratory Test Results

A summary of the laboratory tests undertaken as part of the ground investigations is presented in Table 7.2.3 below.

Table 7.2.3 Summary of Laboratory Testing

Type of test	Test method
Classification/Compaction	
Moisture Content	BS1377: Part 2: 1990; Clause 3
Liquid / plastic limits	BS1377: Part 2: 1990, Clause 4 & 5
Particle size distribution	BS1377: Part 2: 1990; Clause 9
Density	BS1377: Part 2: 1990; Clause 7
Strength / Consolidation	
Undrained triaxial (total) strength-multistage	BS1377, (1990) Part 7, Clause 8 & 9
Shear box (effective strength)	BS1377, (1990) Part 7, Clause 4
Small Ring Shear	Optimal Precedure G.E. July 1997

7.2.4 Soil Parameters

Soil parameters derived from a schedule of laboratory testing gave the following range of results for the glacial till unit:

C_u = 23 to 466kPa, phi = 0 to 14^0 (From Undrained Triaxial multistage test)

C’ = 0kPa, phi’ = 30.5^0 to 35^0 (Triaxial with PWP measurement)

C_r’ = 0kPa, phi’ = 9.5^0 and 31.5^0 (From Ring Shear test)

Peak C’ = 0kPa, Peak phi’ = 33^0 (Small Shear Box)

Residual C’ = 0kPa, Residual phi’ = 0^0 (Small Shear Box)

Moisture Content = 3.7% to 53%,

Liquid Limit = 22% to 79%,

Plastic Limit = 11% to 37%,

Plasticity Index = 1% to 47%

7.3 Instrumentation

7.3.1 Definition of Existing Problems

Existing problems of slope failure along South Cliffs vary between and include both first-time shallow slip failures within the intact slopes and the reactivation of existing deep-seated rotational failures related to increased ground water pressures.

7.3.2 History of Monitoring

Within the various garden areas covered by South Cliffs, a total of 12no. inclinometers and 22no. piezometers have been installed as part of eight ground investigations carried out between January 1996 and January 1998.

Monitoring data for inclinometer instruments has been provided in PDF and gINT format from the instrument installation date until late September 2006. A single set of readings ('baseline') is available for 24-25 July 2006 and November 2008. Both sets of readings represent isolated events, this 'new' data needs to be combined with the previous data in order for it to have any further meaning.

Piezometer data recording groundwater levels across the site has been recorded from the date of instrument installation up to August 2008.

Groundwater levels are available for 5no. piezometer instruments installed around the Spa Ocean Room area. Monitoring data has been recorded from 16 January 2003 until 5 August 2008. However, no further details of ground investigation works, installation details, etc have been made available for analysis.

Crack monitoring was undertaken at several locations at the Prince of Wales Cliff gardens from the installed survey pins (C21A, B and C). This covered the period from 21 June 2000 to 17 January 2006.

A photographic record of the sites covering South Cliffs has been undertaken on a periodic basis since June 2001 onwards. The photographs record damage caused by slope instability encompassing slip failures, back scars, cracking in paths, pavements and structural damage to footsteps and retaining walls.

7.3.3 *Assessment of Monitoring Results*

Several inclinometers have displayed the occurrence of ground displacements of up to 5mm since installation and the readings taken in 2006. Ground movements have been recorded in A1 (Cliff top), D3 (Mid slope), E3 (Cliff top), F4 (Lower slope) and G2 (Cliff top). The data shows that movement had been slow to very slow (<1mm per year) over this monitoring period. Greater movements were recorded over the same period in inclinometers I1 (Cliff top) 20mm at 17m depth, H6 (Cliff top), 25mm at 14m depth and BH2 (Cliff top) 7.5mm at 30m depth.

The succeeding sets of readings for 2006 and 2008 should be considered as stand alone ‘baseline’ readings as they have not been combined into previous data.

However, the readings taken in November 2008 were accompanied by a commentary (from the Contractor) on five inclinometers which were not monitored due to blockages within the tubes. Inclinometers I1, H4, H6, E3 and BH2 (all located at cliff top) were reported as being ‘blocked’. No further comments were made as to the reasons for the blockages or at what depths these instruments were blocked.

Without further information regarding the depth of possible blockages it is speculative, but also reasonable, to assume that the inclinometers have sheared.

Crack monitoring data available from 21 June 2000 to 17 January 2006 revealed yearly movements of <9mm per year at Pin C21A and C21B. Data from C21C is very limited.

7.3.4 *Stability Analysis*

Slope stability analysis was undertaken and included within Report No. 103. The analysis was setup to search for shear planes failures with the lowest Factor of Safety for strata of given strength parameters. The lowest resistance shear planes were found to pass through a weak mudstone horizon. This layer represents the interface between till and underlying bedrock of mudstone. Immediately above the mudstone is a layer of stiff clay; completely weathered mudstone affected by the scour of the glaciers during the last Ice Age. At times of high rainfall it is likely that porewater pressures rise within the strata sufficiently such that slope instability failures occur triggered by small slides within the mudstone. Slope stability analysis indicated that high piezometric levels, close to the slope face at the toe, reduced the overall stability significantly.

7.4 Re-assessment of Risk Register

7.4.1 Re-definition of Problems

The re-activation of pre-existing deep-seated landslides involving significant ground movements are related to periods of heavy or prolonged rainfall that result in excessive groundwater pressures along weak planes of the glacial till and mudstone interface. Ground movements are also associated with blocked and damaged drain runs and water supplies resulting in water seepages and leakages. These can give rise to increased porewater pressures within the glacial tills and result in shallow failures.

7.4.2 Re-assessment of Risk

In light of the findings of the monitoring event of 18-21 November 2008, presented by the Contractor, it is advised that a though inspection of the 'blocked' inclinometers (I1, H4, H6, E3 and BH2) is undertaken to fully understand the mechanisms causing the malfunction of these instruments. It is recommended that this should be accompanied by a monitoring of the inclinometers as soon as practicable in order to provide data for analysis. Following on from this, a re-assessment of the risks prevailing at this site can be assessed in light of the findings.

7.4.3 Early Warning / Trigger Levels

It is not considered realistic to assign trigger levels to the site until the findings detailed in Section 7.4.2 are disclosed.

7.4.4 Response Actions

It is considered that a programme of response actions or an action plan in relation to significant instability being detected would be appropriate. A programme of continuous and sustained monitoring and walkover surveys at regular intervals would provide sufficient information to base the implementation of an action plan. The frequency of inspections and level of response would be dictated by the findings discussed in Section 7.4.2.

7.4.5 Future Monitoring and Inspection

In light of the findings of the previous monitoring event of 18-21 November 2008, it is recommended that a regime of regular monitoring and inspection of the South Cliffs site should be undertaken as soon as practicable, as discussed in Section 7.4.2. The findings of this 'follow-up' monitoring visit will then dictate the future monitoring regime considered appropriate for the site.

Should the further inspection of inclinometers detailed in Section 7.4.2 prove the instruments are functioning correctly, then it would be appropriate to conduct monitoring visits at a frequency of once monthly for six months and then every two months until month twelve. If nothing is revealed during this twelve month period then monitoring should revert to six monthly intervals (bi-annually). This should be carried out over a period of three years in order to retrieve long term data for analysis in order to determine any seasonal patterns of rainfall, ground water levels and ground movements. This regime of monitoring takes into consideration the findings of the possible failure of inclinometers, reported November 2008.

Coastal slopes monitoring should be carried out by way of walk over surveys and ground surveys accompanied by a photographic record. Defects to record would be tension cracking in pavements and structures, misalignment of linear features, development of back scars, uneven / bulging ground, surface ponding water and a visual check of drainage within the pavements and slopes for functionality and seepages.

Beach monitoring should be carried out at low tide conditions to assess beach deposit levels and this should be accompanied by a photographic record.

Sea-wall defence monitoring should be undertaken at low tide conditions to determine any undermining of the base of the sea-wall defences and also to record the general condition of the sea-wall. A photographic record should be taken to accompany a sea wall condition survey to monitor any crack development, concrete spalling, etc.

It is recommended that **inclinometer and piezometer monitoring** is undertaken on the basis detailed above, continuing on directly, as soon as possible, from the 'baseline' readings taken in November 2008. Considering the public location of the instruments, it is recommended that a condition examination is carried out and any defects recorded and rectified and, ensuring the instrument covers are secure from acts of vandalism.

7.4.6 Recommendations for Future Instrumentation Installation

The data collection from a monitoring event, carried out in November 2008, of instruments E3 (AA09), BH2 (AA07), H6 (AA03), H4 (AA02) and I1 (AA01) were interpreted as showing that these inclinometers had 'sheared or blocked' due to ground displacements. There appeared to be little evidence from the inspection event to categorically prove that these instruments had sheared although this assumption is not unreasonable.

It is recommended that a detailed inspection of boreholes E3 (AA09), BH2 (AA07), H6 (AA03), H4 (AA02) and I1 (AA01) is carried out to fully evaluate the operating condition of these inclinometer instruments. Following on from this, it is advised to repair or replace the inclinometers which are inoperable (suspected of being sheared at depth).

It is further recommended that a line of survey pins is set-out at regular 5metre intervals down the line of the slope from beyond the crest and in line with inclinometers AA02, AA09 and AA07. The survey pins should be able to provide a semi-permanent, vandal proof record and it is thus suggested they consist of steel pins cast into concrete and marked to distinguish them from their surroundings. The survey pins should be clearly labelled and surveyed to Ordnance Survey co-ordinates in order to reduce mistakes when monitoring data is collected. The survey stations should be measured at a frequency in line with the inclinometer monitoring i.e. once monthly for six months and then every two months until month twelve and then bi-annually thereafter.

If future data collection shows abnormalities such as increased ground movements, development of 'new' tension cracks, mal-functioning drainage, etc then the cause of such defects should be investigated further by means of increased frequencies of ground surveys.

7.5 Summary of Recommended Monitoring

Nature of Monitoring and recommended additional instrumentation	Monitoring Frequency	Changes in Frequency following periods of heavy or prolonged rainfall, etc
Walkover survey of Coastal Slopes	Six monthly (Bi-annual) for three years	Increased to one week after event and at monthly intervals thereafter for three months
Beach	Six monthly (Bi-annual) for three years	
Sea Wall	Six monthly (Bi-annual) for three years	
Inclinometers and Piezometers	Monthly intervals for six months then every two months until month twelve. Reverting to bi-annual intervals for remaining two years if no significant movement detected	Increased to one week after event and at monthly intervals thereafter for three months
Install a line of survey pins down slope at 5 metre intervals in line with E3, BH2 and H4	As Inclinometers	

8 Knipe Point

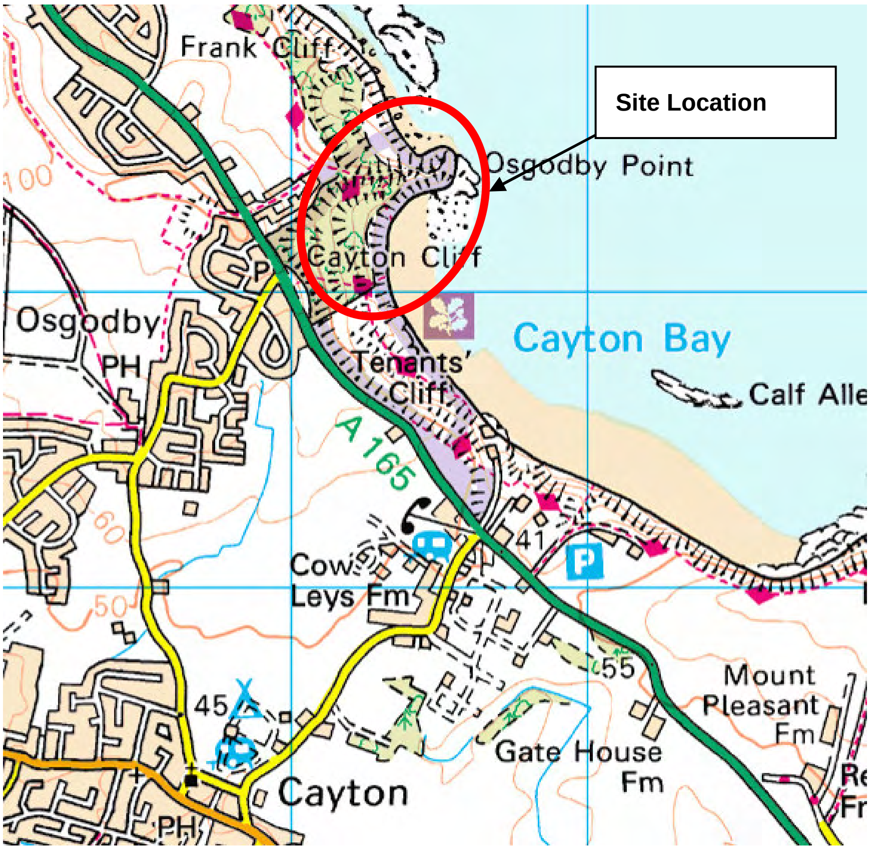
The SMP2 details the site of Knipe Point as follows:

Policy Development Zone 11							
Management Area		**Policy Unit**		**Policy Plan**			
				2025	2055	2105	Comment
MA29	White Nab to Cayton Bay	29.1	Cornellian Bay	NAI	NAI	NAI	-
		29.2	Cayton Bay	NAI	NAI	NAI	-

8.1 Description of the Site

Knipe Point is a promontory located at the north of Cayton Bay, 3.5km south of Scarborough and 7km north of Filey, on the north east coast of England. Set back beyond the promontory the main coastal route (A165) between Scarborough and Filey follows an almost parallel course to the coastline. From the A165, north of Tennants' Cliff, to Knipe Point a series of holiday homes occupies the crest and the southern side of the promontory. The land north of the crest and the holiday homes complex is given over to agriculture. Osgodby Village is located immediately west of the A165.

Figure 22: Site Location



8.1.1 Historic Review of Problems

The landslide complex at Knipe Point abuts the steep sided ridge to the north and Tenants' Cliff landslide complex to the south. The landslide complex comprises a series of retrogressive rotational slides developed primarily in the glacial till deposits, with a deep-seated basal shear surface within the Oxford Clay, and in the toe area, the Kellaway Rocks. A combination of groundwater seepages from granular horizons within the tills and toe erosion by wave action at the base of the cliffs represents the main mechanisms of cliff instability. The landslide complex is active with tension cracks and ground displacements evident over much of the area. Ground movements are degradational and appear to be mostly contained within the existing boundaries of the landslide complex.

8.1.2 *Site Walkover*

A site walkover was conducted by a geotechnical engineer from Mouchel on 1st December 2008. The site visit confirmed the condition of the existing borehole instruments as being operable. A series of photographs was also taken of the site picking up salient topographical features such as varying slope angles, back scars, relict slope failures, mudslides and ponding water. Selected site photographs are presented in Appendix F.

Features identified during the walk over survey are described in Section 8.1.3 of this report.

8.1.3 *Topography and Geomorphology*

The relatively erosion-resistant rock outcrops of the promontory Osgodby (Knipe) Point forms the northern most limit of Cayton Bay. The site is bounded by the steep-sided ridge of Knipe Point to the north and Tenants' Cliff to the south. The crest of the promontory trends south west rising in elevation up to the old coast road (A165) and the village of Osgodby. The crest and southern side of this physical feature are occupied by holiday homes which have been present on this site in some form or other since the 1930's. Immediately south of the holiday village the slopes of Cayton Cliffs are present and are continuously encroaching upon this development at an unpredictable rate. The Cayton Cliff landslide complex is developed in glacial tills, up to 30metres thick, overlying the Oxford Clay and Kellaway Rocks. The area is densely wooded with areas of denudation the results of mudslides and ground movements and, ponded water, springs and other features of poor drainage are also present over the slopes. A combination of groundwater seepages from granular horizons within the tills and toe erosion by wave action at the base of the cliffs represents the main mechanisms of cliff instability.

8.1.4 *Existing Information*

The following reports have been provided by SBC for consultation:

Report No. 122 – ***Scarborough Borough Council. Cayton Bay Coastal Strategy Study. Strategy Report Executive Summary (Final)***. Halcrow Group Ltd, October 2002

Report No. 123 – ***Scarborough Borough Council. Cayton Bay Coastal Strategy Study. Strategy Report Introduction (Final)***. Halcrow Group Ltd, October 2002.

Report No. 124 - ***Scarborough Borough Council. Cayton Bay Coastal Strategy Study. Strategy Report Technical Annexes (Final)***. Halcrow Group Ltd, October 2002.

Report No. 186 - ***Scarborough Borough Council. Strategic Coastal Monitoring Programme 2001-2006. Condition Analysis of Coast Protection Assets, Cliffs and Beaches from Staithes to Speeton.*** Halcrow Group Ltd, November 2006.

Report No. 198 – ***National Trust. Cayton Cliff, Cayton Bay, Stability Report and Cliff Management Plan***. Halcrow Group Ltd, May 2008.

8.2 Stratigraphy

8.2.1 Soil Profile

The 1:50,000 British Geological Survey (BGS) Sheet 54 Solid & Drift, Scarborough indicates that the site is underlain by superficial deposits of glacial till (Quaternary), underlain by Oxford Clay of up to 36-76m in thickness. This overlies 3-13m of Osgodby Formation calcareous sandstone above a thin (1.5-3m) layer of undifferentiated Cayton Clay Formation and Cornbrash Formation consisting of limestones and mudstones. An unconformity is encountered, beneath which is a 60m thick layer of Scalby Formation mudstones and sandstones. Outcrops of strata generally young in a southerly direction, trending northwest-southeast and overlain by glacial till. A fault trending NNW-SSE dissects the point, truncating the aforementioned strata. The tip of the point comprises the Gristhorpe and Lebberston Members (limestones and mudstones) of the Cloughton Formation.

Table 8.2.1 Geological Stratigraphy

Age	Stratum
Quaternary	Glacial Till Stiff silty sandy clays, sands and gravels, laminated silty clays
Upper Jurassic	Lower Calcareous Grit Calcareous sandstone
Upper Jurassic	Oxford Clay Grey-green mudstone
Middle Jurassic	Osgodby Formation Calcareous sandstone
Middle Jurassic	Cayton Clay Formation and Cornbrash Formation Undifferentiated limestone and mudstone
Middle Jurassic	Scalby Formation Mudstone and sandstone
Middle Jurassic	Cloughton Formation Gristhorpe, Lebberston and Sycarham members

8.2.2 Groundwater Regime

Hydrogeology

The Groundwater Vulnerability Map (Sheet 9) of North East Yorkshire has classified the area as a Minor Aquifer, overlain by soils of intermediate class 1. Soils of class I1 are those possibly able to transmit a wide range of pollutants. Minor Aquifers are variably permeable rocks, usually fractured rocks with a low primary permeability or unconsolidated deposits. They rarely produce large quantities of water for abstraction but often provide important base flow supplies to rivers. Major Aquifers may occur beneath Minor Aquifers

From a review of historical records, provided by SBC, it has been determined that a single ground investigation was undertaken at this section of coastline in 1975. Ground water monitoring data has not been made available from this for analysis.

Mills {Mills, (1981). ***Site investigation report Knipe Point, Cayton Bay, North East Yorkshire***, MSc Thesis} carried out a geotechnical investigation at Cayton Cliff which identified three distinct soil units within the glacial tills. No further details of this GI have been made available for analysis.

8.2.3 Laboratory Test Results

Laboratory test results have not been made available by SBC for analysis.

8.2.4 Soil Parameters

Soil parameters have not been made available by SBC for analysis.

8.3 Instrumentation

8.3.1 Definition of Existing Problems

The landslide complex comprises a series of retrogressive rotational slides developed in the glacial till deposits, with a deep-seated basal shear surface within the Oxford Clay, and in the toe area, the Kellaway Rocks. A combination of groundwater seepages from granular horizons within the tills and toe erosion by wave action at the base of the cliffs represents the main mechanisms of cliff instability. The landslide is active, with tension cracks and displaced ground evident over much of the area. These movements are degradational and appear to be restricted to the existing boundaries of the landslip complex, with only minimal failure of the sides and rear scarp.

8.3.2 History of Monitoring

A previous ground investigation was carried out in 1975, as referenced in Report No. 198. This ground investigation comprised four boreholes to various depths across Knipe Point site. The factual report has not been made available, though details of sub- surface geology and hydrogeology were inferred from a MSc. project (Mills, 1981) which included details of this ground investigation. No further details of this GI have been made available for analysis.

Mills (1981) carried out a geotechnical investigation at Cayton Cliff which identified three distinct soil units within the glacial tills. These soils comprised sandy coarse units interbedded with laminated and sandy clay tills. These till units are considered to control the nature and mechanism of landsliding as they are likely to be brittle and prone to progressive failure.

A series of fixed ground marker pins forming part of the National Trust (NT) Monitoring network were installed on 18 April 2008. The survey pins were observed to cover the whole area of instability of Knipe Point and Tenants' Cliff. The survey pins have been monitored since installation although this data has not been made available for analysis or interpretation.

A photographic record of the site covering Knipe Point has been undertaken on a periodic basis since June 2001 onwards. The photographs record damage caused by slope instability encompassing slip failures, back scars, cracking in paths, pavements and structural damage to footsteps and retaining walls.

8.3.3 Assessment of Monitoring Results

Monitoring data has not been made available by SBC for this site.

Scarborough Borough Council commissioned Norwest Holst Soil Engineering Ltd, late 2008, to carry out a ground investigation involving the drilling of boreholes and installation of downhole instrumentation. The results of this ground investigation have not been made available to Mouchel Ltd at the time of compiling this report.

8.3.4 Stability Analysis

Stability analysis data has not been made available by SBC for this site.

8.4 Re-assessment of Risk Register

8.4.1 Re-definition of Problems

During early 2008 the main landslide complex at Knipe Point became reactivated resulting in the retreat of the headscarp up to existing property boundaries. The increased development of the headscarp eventually led to the demolition of several properties and the distinct possibility that more properties could be similarly affected. A detailed ground investigation over this site was implemented

It is envisaged that a re-definition of the problems experienced at Knipe Point can be assessed in light of the current ground investigation. The findings of this GI have not been made available at the time of compiling this report.

8.4.2 Re-assessment of Risk

In early 2008, large scale collapse of the south east facing slopes began with the imminent threat of loss of assets becoming realistic. It was estimated that approximately 8.50metres of cliff recession had occurred during six months since the initial reactivation of the landslide complex in January 2008.

8.4.3 Early Warning / Trigger Levels

An early warning / trigger level system would give warnings of ground movements that could lead to the potential damage and loss of assets at Knipe Point. Monitoring of survey pins at the site would give an indication of the nature, rates and directions of ground movements. If the current ground investigation involves the installation of instrumentation for ground movement determination, data from these can be used as a basis for the formulation of an early warning system and trigger levels. The monitoring data from survey pins should also be made available to refine the assessment of trigger levels.

8.4.4 Response Actions

As Section 8.4.3.

8.4.5 Future Monitoring and Inspection

Based upon the assumption that the current ground investigation at Knipe Point will incorporate the installation of at least two piezometers and inclinometers, the following is considered valid.

It is recommended that a regime of regular monitoring and inspection of Knipe Point be undertaken at two monthly intervals. This should be carried out over a period of three years in order to retrieve long term data for analysis in order to determine any seasonal patterns of rainfall, ground water levels and ground movements. The monitoring should encompass the elements of inspection detailed below.

Coastal slopes monitoring should be carried out by way of walk over surveys and ground surveys accompanied by a photographic record. Defects to record would be tension cracking of the crest and in pavements and buildings, cliff recession rates, misalignment of linear features, uneven / bulging ground, mudslides, surface ponding water, undermining of slope / cliff bases and back scarp heights.

Beach monitoring should be carried out at low tide conditions to assess beach levels and the occurrence of beach run-out debris from landslips and this should be accompanied by a photographic record.

It is recommended that **inclinometer and piezometer monitoring** is carried out at monthly intervals for six months then every two months until month twelve, reverting to bi-annual intervals for the remaining two years if no significant movement detected. During periods of prolonged and heavy rainfall this interval should be increased to provide data of groundwater levels response. As well as reading the instruments, a condition examination should be carried out at the same time and any defects recorded and rectified.

8.4.6 Recommendations for Future Instrumentation Installation

Based upon the assumption that the current ground investigation at Knipe Point will incorporate the installation of at least two piezometers and inclinometers accompanied by a regime of regular monitoring, the following is considered valid.

Given the large scale instability and known mechanisms of failure of the slopes at Knipe Point, it is recommended that the data from the current ground investigation is analysed and evaluated before consideration is given to providing analysis and interpretation on soil parameters, slope stability analysis, groundwater levels or ground displacement monitoring.

Scarborough Borough Council has no land ownership in the area of Knipe Point. The land is in private ownership and that residents, North Yorkshire County Council (NYCC) and the National Trust (NT) are the current land owners.

8.5 Summary of Recommended Monitoring

Nature of Monitoring and recommended additional instrumentation	Monitoring Frequency	Changes in Frequency following periods of heavy or prolonged rainfall, etc
Walkover survey of Coastal Slopes	Two monthly intervals for three years	Increased to one week after event and at monthly intervals thereafter for three months
Beach	Two monthly intervals for three years	
Inclinometers and Piezometers	Monthly intervals for six months then every two months until month twelve. Reverting to bi-annual intervals for the remaining two years if no significant movement detected	Increased to one week after event and at monthly intervals thereafter for three months

9 Killerby

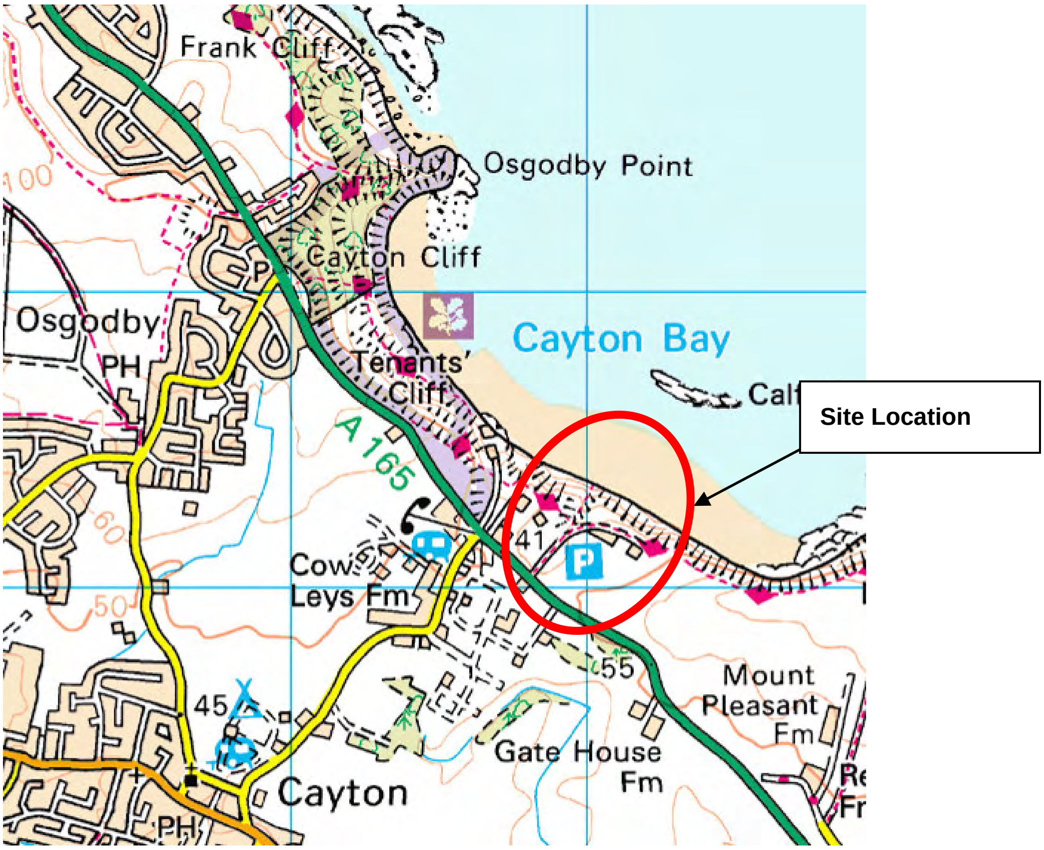
The SMP2 details the site of Killerby as follows:

Policy Development Zone 11							
Management Area		**Policy Unit**		**Policy Plan**			
				2025	2055	2105	Comment
MA29	White Nab to Cayton Bay	29.2	Cayton Bay	NAI	NAI	NAI	-

9.1 Description of the Site

Killerby lies within Cayton Bay mid-way between Osgodby Point to the north and Lebberston Cliffs in the south. The coast line is composed of steep, unprotected glacial till cliffs up to 40metres in height. The cliffs are prone to slumping with the regression of a steep head scarp (approximately 3metres high) and toe erosion from marine influences. Beyond the cliff crest the ground is relatively flat with a row of houses some 200metres back from the cliff edge. Further set back beyond this the A165, the main coastal route between Scarborough and Filey, follows an almost parallel route to the coastline.

Figure 23: Site Location



9.1.1 *Historic Review of Problems*

Killerby Cliffs are composed of glacial tills characterised by a near vertical head scarp of generally 3metres in height. The slopes below become less steep at angles of approximately 22 to 30 degrees down to beach level where the slope toe is eroded by wave action to form low near vertical till cliffs. Localised slumping of till materials are evident across the upper and lower slopes caused by the build-up of excess groundwater pressures developing in sandy granular horizons, resulting in the collapse of the slopes and the landward recession of the cliff top edge. Recent slippages have occurred in the ravine area, which affords pedestrian access from cliff top to the beach, just north of this site.

9.1.2 *Site Walkover*

A site walkover was conducted by a geotechnical engineer from Mouchel on 1st December 2008. The site visit confirmed the condition of the existing borehole instruments as being operable. A series of photographs was also taken of the site picking up salient topographical features such as varying slope angles, tension cracks, back scars and relict slope failures. The recession points indicated by SBC as being present at this site were not located. Selected site photographs are presented in Appendix G.

Features identified during the walk over survey are described in Section 9.1.3 of this report.

9.1.3 *Topography and Geomorphology*

The cliff top along this stretch of coast is relatively level maintaining heights of approximately 40metres. The cliff tops are vegetated with thick grasses and there is an absence of trees and shrubs. The cliffs are composed of glacial tills attaining angles of between near vertical at the crest with a head scarp of generally 3metres. Below this feature, the slopes become less steepened at angles of approximately 22 to 30 degrees down to beach level where the slope toe is eroded by wave action to form low near vertical till cliffs. Localised slumping of till materials are evident across the upper and lower slopes where excess groundwater pressures develop in sandy horizons resulting in the collapse and recession of cliff top edge.

9.1.4 *Existing Information*

The following reports have been provided by SBC for consultation:

Report No. 122 – ***Scarborough Borough Council. Cayton Bay Coastal Strategy Study. Strategy Report Final (Executive Summary)***. Halcrow Group Ltd, October 2002

Report No. 123 – ***Scarborough Borough Council. Cayton Bay Coastal Strategy Study. Strategy Report Final (Introduction)***. Halcrow Group Ltd, October 2002.

Report No. 124 - ***Scarborough Borough Council. Cayton Bay Coastal Strategy Study. Strategy Report Final (Technical Annexes)***. Halcrow Group Ltd, October 2002.

Report No. 132 - ***Scarborough Strategic Coastal Monitoring (Staithes to Scarborough). Defence Condition Surveys – Volume 1***. Document No. 1540/R/1. High Point Rendel Ltd, March 2002.

Report No. 135 - ***Scarborough Borough Council. Strategic Coastal Monitoring Staithes to Scarborough. Cliff Condition Survey. Volume 2 Slope Proformas. Report No. R/1540/2/1. High Point Rendel Ltd, September 2002.***

Report No. 186 - *Scarborough Borough Council. Strategic Coastal Monitoring Programme 2001-2006. Condition Analysis of Coast Protection Assets, Cliffs and Beaches from Staithes to Speeton.* Halcrow Group Ltd, November 2006.

9.2 Stratigraphy

9.2.1 Soil Profile

The 1:50,000 British Geological Survey (BGS) Sheet 54 Solid & Drift, Scarborough indicates that the site is underlain by superficial deposits of glacial till underlain by Oxford Clay. This overlies the Osgodby Formation of calcareous sandstone above a thin layer of undifferentiated clays of the Cayton Clay Formation and, Cornbrash Formation consisting of limestones and mudstones. The Cornbrash Formation unconformably overlies the Scarborough Formation (mudstones and limestones). This Formation outcrops as the Calf Allen Rocks in Cayton Bay. The geological map indicates a normal fault trending north-south immediately west of the site.

Table 9.2.1 Geological Stratigraphy

Age	Stratum
Quaternary	Glacial Till Stiff silty sandy clays, sands and gravels, laminated silty clays
Upper Jurassic	Oxford Clay Grey-green mudstone
Middle Jurassic	Osgodby Formation Calcareous sandstone
Middle Jurassic	Cayton Clay Formation and Cornbrash Formation Undifferentiated limestone and mudstone
Middle Jurassic	Scarborough Formation Limestone and mudstone

9.2.2 Groundwater Regime

Hydrogeology

The Groundwater Vulnerability Map (Sheet 9) of North East Yorkshire has classified the area primarily as a Major Aquifer, overlain by soils of intermediate Class 1. Soils of Class I1 are those possibly able to transmit a wide range of pollutants. Major Aquifers are highly permeable rocks, usually with a known or probable presence of significant fracturing. They may produce large quantities of water and be able to support large abstractions for public supply and other purposes. The Osgodby Formation immediately along the coastline is classified as a Minor Aquifer (Class 1). Minor Aquifers are variably permeable rocks, usually fractured rocks with a low primary permeability or unconsolidated deposits.

They rarely produce large quantities of water for abstraction but often provide important base flow supplies to rivers. Major Aquifers may occur beneath Minor Aquifers.

Information on ground water levels at this site has not been made available by SBC.

9.2.3 Laboratory Test Results

Laboratory test results have not been made available by SBC for this site.

9.2.4 Soil Parameters

Soil parameters have not been made available by SBC for strata at this site.

9.3 Instrumentation

9.3.1 Definition of Existing Problems

The presence of confined granular strata within the glacial till slopes may result in excess groundwater pressures to develop resulting in the collapse and recession of the head scarp and cliff crest.

9.3.2 History of Monitoring

A regime of crack monitoring has been initiated at this site. This has apparently been undertaken between 1999 and 2005.

9.3.3 Assessment of Monitoring Results

Crack monitoring rates have been determined from a series of survey pins established away from the cliff edge at 4No. locations at Killerby. The crack monitoring points were not found during a walk-over survey undertaken in November 2008. Data provided by SBC provided 135 monitoring results from 21 June 2000 to 17 January 2006. The data relates to a base reading and successive readings illustrate how much movement, if any, has occurred during the interim periods. A distance of +4.13mm was experienced at Pin A between 21 June 2000 and 17 January 2006. At the other three pins (Pin B, C and D) a change in distance of between -0.84mm, -0.4mm and -1.45mm, respectively was measured over the same time frame. The readings show that there is very little to no change in the cliff crack regime and therefore the cliffs are not displaying any signs of retreat.

9.3.4 Stability Analysis

Stability analysis has not been undertaken for this site.

9.4 Re-assessment of Risk Register

9.4.1 Re-definition of Problems

The problems determined at this site are associated with cliff top recession and landward retreat of the coastline. This is the result of confined granular strata within the glacial till slopes which result in excess groundwater pressures developing resulting in small-scale translational and rotational slips and mudslides on the cliff face.

9.4.2 Re-assessment of Risk

Localised slumping of till materials are evident across the upper and lower slopes of the cliffs caused by the build-up of excess groundwater pressures developing in sandy granular horizons. This results in the collapse of the slopes and the landward recession of the cliff top edge.

9.4.3 Early Warning / Trigger Levels

Given the lack of monitoring information available from the field instrumentation at the site, it is considered inappropriate to formulate an early warning / trigger levels until such time that sufficient data from monitoring and walkover surveys has been collected and an informed opinion can be reached.

9.4.4 Response Actions

In the event of significant slope movements being detected, it is considered unnecessary to implement an action plan. Given the relatively remote location and lack of assets that would be adversely affected by an event of slope instability, it is considered that the recommended regime of walk-over surveys and monitoring would be sufficient.

9.4.5 Future Monitoring and Inspection

It is recommended that the exercise of crack monitoring be re-introduced to monitor the behaviour of the cliffs at Killerby. In line with future instrumentation detailed in Section 9.4.6, it is recommended that the survey pins are monitored on a bi-annual basis along with **coastal slopes monitoring**. This should be carried out by way of walk over surveys and ground surveys accompanied by a photographic record. Defects to record would be distances from survey pins installed on slope crests, tension cracking on the slopes, heights of head scarps, uneven / bulging ground particularly at the toe and evidence of toe erosion rates due to marine influences. The surveys should be carried out over a period of three years in order to retrieve long term data for analysis in order to determine any seasonal patterns of rainfall and ground movements.

9.4.6 *Recommendations for Future Instrumentation Installation*

It is recommended that a series of survey pins are installed in pairs along the cliffs to monitor recession rates of the slope crests. The pins should be placed one beyond the crest and the other positioned below the crest in the glacial till slopes. The survey pins should be able to provide a semi-permanent, vandal proof record and it is thus suggested they consist of steel pins cast into concrete and marked to distinguish them from their surroundings. The survey pins should be clearly labelled and surveyed to Ordnance Survey co-ordinates in order to reduce mistakes when monitoring data is collected.

9.5 Summary of Recommended Monitoring

Nature of Monitoring and recommended additional instrumentation	Monitoring Frequency	Changes in Frequency following periods of heavy or prolonged rainfall, etc
Walkover survey of Coastal Slopes	Six monthly (Bi-annual) for three years	Increased to one week after event and at monthly intervals thereafter for three months
Crack Monitoring	Six monthly (Bi-annual) for three years	
Install survey points	Six monthly (Bi-annual) for three years	

10 Filey Town and Brigg

The SMP2 details the site of Filey Town and Brigg as follows:

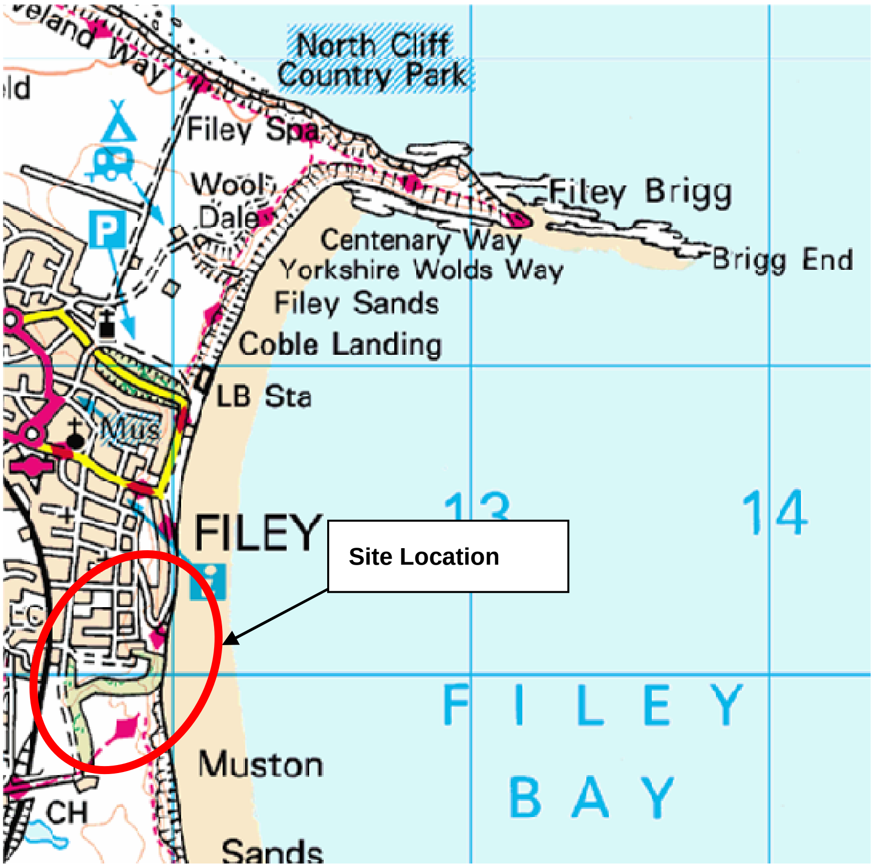
Policy Development Zone 11 and 12							
Management Area		**Policy Unit**		**Policy Plan**			
				2025	2055	2105	Comment
MA31	Filey Brigg to Muston Sands	31.1	North of Filey	NAI	NAI	NAI	Affected by works to stop outflanking of Filey
		31.2	Filey	HTL	HTL	HTL	Looking to long term overall management

10.1 Description of the Site

The site is located to the south and east of Filey town centre, a popular holiday resort, on the north east coast of England.

Martin’s Ravine is a steep sided valley to the south of Filey, through which a footpath leads, sloping downwards from a car park to the southern end of Royal Parade and the sea. Royal Parade is a flat esplanade along the sea front extending from the south at the base of Martin’s Ravine, northwards to where The Crescent approaches from above, and continues north towards Filey town centre and Church Ravine. To the rear of Royal Parade is a line of small chalets behind which is a steep slope rising up to a level grassed area (Glen Gardens). The northern edge of this area is bounded by Crescent Hill which leads off The Crescent, from the top of the recreation grounds, and winds down to join Royal Parade. A number of footpaths criss-cross the slopes allowing pedestrian access from the cliff top to the beaches below.

Figure 24: Site Location



10.1.1 Historic Review of Problems

The severe adverse impacts of an intense period of prolonged and extremely heavy rainfall, in July 2007, resulted in considerable and widespread flooding to parts of Filey. The resulting rainwater run-off caused slope failures and scour damage to riffles and bridge abutments in a stream within Martin's Ravine. Existing drain runs were damaged due to excessive rainwater around Glen Gardens and this also caused drainage to collapse leading to slope instability behind Royal Parade chalets and Crescent Hill.

10.1.2 Site Walkover

A site walkover was conducted by a geotechnical engineer from Mouchel on 27th November 2008. The site visit confirmed the condition of existing borehole instruments as being operable. A series of photographs was also taken of the site picking up salient topographical features such as varying slope angles, back scars, hummocky ground, mudslides, as well as man-made features and the sea-wall defences. Selected site photographs are presented in Appendix H.

Features identified during the walk over survey are described in Section 10.1.3 of this report

10.1.3 *Topography and Geomorphology*

During the last glacial period (Devensian), ice sheets spread south and east across this area to the North Sea. As these ice sheets retreated glacial till was emplaced over the landscape, formed of Jurassic rocks, completely infilling pre-glacial valleys and embayments. Filey is part of a long stretch of exposed cliffs running north-south forming protected, soft, glacial till cliffs between Church Ravine and Martin's Ravine and, further south towards Reighton the coastline is formed of unprotected, soft, glacial till cliffs. The slopes attain a height of up to 30metres at slope angles of 25 to 35 degrees. The faces of the slopes are criss-crossed by pedestrian footpaths which give public access from the top of the cliffs to the beach below. Other features present over the slopes are benched, viewing points and relict slip failure scars with thin and bare patches of vegetation. At the base of the slopes is a sea wall with a broadwalk, forming a sea defence, with a wide sandy beach foreshore.

Martin's Ravine is bounded by steeply sided sloping edges (1v:1.5h to the north and 1v:1h to the south) and slopes downwards from a car park in the west to the sea front in the east. The side slopes measure about 12m in height at their highest point. The toe of the slope has been scoured by recent floodwater leading to more extensive slope failure at isolated locations. There is evidence of past instability at the toe of the slopes with remnants of rock armouring present in the stream bed. The presence of sheet piles, low retaining walls and lengths of culvert indicates past erosion / stability problems within the Ravine.

The eastern most edge of Glen Gardens slopes steeply (>1v:2h) down to the back of chalets along Royal Parade; the slope is 15-18m high with upper slope angles steeper than at the toe. The steep slope separating Glen Gardens and Crescent Hill has an estimated height of 14metres and both are crossed by stepped footpaths ascending the slopes. The road at Crescent Hill slopes gently down to the sea front.

10.1.4 *Existing Information*

The following reports have been provided by SBC for consultation:

Filey Flood Damage Reinstatement Works, Geotechnical Interpretative Report. Document No. 785871/001/GIR/02/FINAL, Mouchel Ltd, December 2008.

Report No. 125 – ***Scarborough Borough Council. Filey Bay Coastal Strategy Study. Executive Summary (Final)***. Halcrow Group Ltd, October 2002.

Report No. 126 – ***Scarborough Borough Council. Cayton Bay Coastal Strategy Study. Strategy Report (Final)***. Halcrow Group Ltd, October 2002

Report No. 127 – ***Scarborough Borough Council. Filey Bay Coastal Defence Strategy Study. Strategy Report (Final) Technical Annexes.*** Halcrow Group Ltd, October 2002.

Report No. 134 – ***Report on a Ground Investigation for Filey Flood Damage Reinstatement Works***. Document No. F15272, Norwest Holst Soils Engineering Ltd, September 2008.

Report No. 175 - *Scarborough Borough Council. Coastal Monitoring Programme 2001-2002. Filey and Cayton Bay Cliff Inspection and Condition Assessment, Halcrow Group Ltd. Mat 2002.*

Report No. 186 - ***Scarborough Borough Council. Strategic Coastal Monitoring Programme 2001-2006. Condition Analysis of Coast Protection Assets, Cliffs and Beaches from Staithes to Speeton.*** Halcrow Group Ltd, November 2006.

10.2 Stratigraphy

10.2.1 The 1:50,000 British Geological Survey (BGS) Sheet 54 Solid & Drift, Scarborough indicates that the site is underlain by superficial deposits of glacial till (Boulder Clay) composed of stony clay. The solid succession at depth in the area is indicated as solid strata of the Kimmeridge Clay Formation of Upper Jurassic age. This typically comprises bituminous clays.

Table 10.2.1 Geological Stratigraphy

Age	Stratum
Quaternary (Recent)	Glacial Till Stiff silty sandy clays, sands and gravels, laminated silty clays
Upper Jurassic	Kimmeridge Clay Formation Bituminous Clays

10.2.2 Groundwater Regime

Hydrogeology

The Groundwater Vulnerability Map (Sheet 9) of North East Yorkshire has classified the area as a Non-Aquifer because of their negligible permeability. These formations are generally regarded as containing insignificant quantities of groundwater. However, groundwater flow through such soils, although imperceptible, does take place and needs to be considered in assessing the risk associated with persistent pollutants. Some Non-Aquifers can yield water in sufficient quantities for domestic use. Major and Minor Aquifers may occur beneath Non-Aquifers.

Groundwater strikes experienced during field works (See Table 10.2.2) reflect the existence of perched ground water tables at various levels within granular horizons of the glacial till. The water strikes showed that there was no significant hydrostatic pressure within the granular layers. The water strike in BH02 may have been influenced by ground drainage from the slopes above rather than reflecting high groundwater pressures at that location.

Table 10.2.2 Levels of Groundwater strike

Hole ID	Geology	Water Strike Depth (m bgl)	Water Depth After 20 minutes(m bgl)	Flow Rate Remarks
BH01	Glacial Till	14.90	14.90	Slight
BH02	Glacial Till	1.70	0.50	Fast
BH03	Glacial Till	8.00	8.00	Seepage
BH04	Glacial Till	9.00	9.00	Seepage
BH06	Glacial Till	21.80	21.70	Seepage

Groundwater readings were taken during and after the completion of site works, up to early October 2008. The recorded readings over this period showed little, if any, change in ground water levels indicating a static water regime at this site.

10.2.3 Laboratory Test Results

A summary of the laboratory tests undertaken is presented in Table 10.2.3 below.

Table 10.2.3 Summary of Laboratory Testing

Type of test	Test method
Classification/Compaction	
Moisture Content	BS1377: Part 2: 1990; Clause 3
Liquid / plastic limits	BS1377: Part 2: 1990
Particle size distribution	BS1377: Part 2: 1990; Clause 9
Determination of dry density/moisture content relationship (2.5 kg hammer)	BS1377, (1990) Part 4
Recompacted California Bearing Ratio	BS1377, (1990) Part 4, Clause 7.4
MCV Calibration	BS1377 Part 4 Clause 5.5
Strength / Consolidation	
Undrained triaxial (total) strength	BS1377, (1990) Part 7
Small Shear box (effective strength)	BS1377, (1990) Part 7, method 4
Consolidated undrained triaxial (effective) strength	BS1377, (1990) Part 7, method 4
1-D oedometer	BS1377, (1990) Part 5, method 3
Chemical (tests on soil and groundwater)	
BRE SD1 Suite - Total / water soluble sulphate, pH, Total sulphur, Magnesium, Chloride	TRL Report 447

10.2.4 Soil Parameters

Soil parameters derived from a schedule of laboratory testing gave the following range of results for the glacial till unit:

C_u = 21 to 136, phi = 0^0 to 7.1^0 (From Undrained Triaxial multistage test)

C' = 2 to 57, phi' = 9^0 to 29^0 (Triaxial with PWP measurement)

Peak C' = 72kPa, Peak phi' = 23^0 (Small Shear Box)

Residual C' = 53kPa, Residual phi' = 21.5^0 (Small Shear Box)

Moisture Content = 13% to 17%,

Liquid Limit = 24% to 43%,

Plastic Limit = 12% to 25%,

Plasticity Index = 13% to 20%

Liquidity Index = -0.08 to 1.50

10.3 Instrumentation

10.3.1 Definition of Existing Problems

The prevailing problems at Filey would seem to originate from the inadequacy of the existing drainage systems to cope with heavy and / or prolonged periods of rainfall. Surface water is constricted by a railway embankment trending north-south, to the west of the site. Surface water east of the embankment flows towards the coast where it is channelled and concentrated within the ravines. The erosive potential of the waters is increased by flowing down the steep gradients of the ravines resulting in undercutting of the bed of the streams and slopes and the eventual collapse of the slopes. This is coupled with surface water run-off flowing over the slopes

10.3.2 History of Monitoring

Standpipe piezometers were installed in BH01 at 14.00m and BH04 at 9.00m in cohesive boulder clay, in BH02 at 2.00m in non cohesive boulder clay and in BH05B at 6.45m in made ground. Groundwater readings were taken during and after the completion of site works, up to early October 2008.

A photographic record of the sites covering Filey Town and The Brigg has been undertaken on a periodic basis since June 2001 onwards. The photographs record damage caused by slope instability encompassing slip failures, back scars, cracking in paths, pavements and structural damage to footsteps and retaining walls.

10.3.3 *Assessment of Monitoring Results*

Groundwater readings were taken during and after the completion of site works, up to early October 2008. The recorded readings over this period showed little, if any, change in ground water levels indicating a static water regime at this site.

Inclinometer casings were installed in BH03 and BH06 at 29.70m and 30.00m depth, respectively. On installation, a base reading was taken followed by seven successive weekly readings. In BH03 a total ground movement of 15.6mm, in a southerly direction (178 degrees), was measured and in BH06 at total movement of 3mm in a northerly direction (230 degrees) was recorded. The recorded movement is indicative of ambient temperature fluctuations and also some soil creep typical of this area of high coastal cliffs where boulder clays overlie bedrock at depth. The readings, so far recorded from monitoring visits, do not indicate any unfavourable ground movements of the slopes.

10.3.4 *Stability Analysis*

Outline designs for slope stability analysis (Drained case) were modelled with ***Slide v5.036*** Analysis using soil parameters determined from the site investigation and laboratory testing results. Back analysis of the slopes at Martin's Ravine was carried out using soil parameters derived from laboratory testing and provided Factor of Safety (FoS) values of 1.017 for the upper section and 0.597 for the lower section. The back analyses were used to verify the parameters to use in proposed remedial design works (scheduled for early 2009). Ground water was modelled at a level encountered during site works (June-July 2008) and also at 1metre higher to reflect flood conditions. The FoS remained the same for the two models which indicated the independence of the slope stability to changing ground water levels at the base of the slope. The slope analysis modelled proposed remedial solutions of 2metre high basal gabion baskets with soil nailing techniques applied to the slopes above. Soil nailing was been modelled with 8metre length nails, spaced at 1.5m intervals at an inclination of 10degrees to the horizontal.

After applying the remedial measures to the model, the FoS for the whole slope was increased to an acceptable value of 1.167. This value is lower than would normally be accepted. However, since the slopes have been stable for over twelve months, the known mode of slope failure was due to solifluction with the transportation of slope materials by excessive surface rainwater run-off and a circular slope failure not considered a realistic failure mechanism. As a consequence of these factors, the FoS of 1.167 was considered acceptable. Regrading of the slope and the establishment of vegetation would increase the Factor of Safety.

Outline designs for slope stability analysis (Drained case) were modelled with ***Slide v5.036*** Analysis using soil parameters derived from the site investigation and laboratory testing results. Further modelling was been undertaken for the slopes on Crescent Hill and behind Royal Parade chalets where slope failure had also occurred. Perched ground water levels were modelled within the sand and gravel layer in the upper reaches of the boulder clay deposits evident from BH03 at 8.00mbgl. The FoS of 1.001 is identical to that derived for the lower water level case which had been modelled at a level 5metres lower. However, the high water level case gave rise to a deeper more expansive potential failure surface compared to that of the lower water level case.

10.4 Re-assessment of Risk Register

10.4.1 Re-definition of Problems

The severe adverse impacts of an intense period of extremely heavy rainfall, in July 2007, lead to considerable and widespread flooding to parts of Filey. The resulting rainwater run-off caused slope failures within the south slopes at the base of the stream and scour damage around riffles and bridge abutments at stream level within Martin's Ravine. Slope failures were experienced above and below pedestrian footsteps on the south side of this ravine.

10.4.2 Re-assessment of Risk

A programme of slope stabilisation works are to be commissioned for the damaged slopes around south and east of Filey in early 2009. The remedial works are to comprise the emplacement of gabion baskets to prevent slope toe erosion and provide toe loading, slope stabilisation measures using soil nailing techniques and re-grading of slopes, removal of slumped materials and in-filling with granular fill and Terra mat. Slope surfaces are to be re-seeded.

The proposed remedial works were designed to improve slope stability of the slopes damaged by groundwater run-off and failed drainage runs. The proposed design works were accompanied by recommendations for further works which were suggested in order to enhance the remedial works. The main recommendations centred around up-grading of drainage runs, regular maintenance of drains top ensure functionality and increase the diameter of culverts to improve capacity and ability to cope with increased groundwater flows at times of flooding. The implementation of these recommendations would greatly enhance the effects of the remedial works and reduce the probability of further slope failures occurring in similar weather conditions as experienced in July 2007.

10.4.3 *Early Warning / Trigger Levels*

Given the lack of monitoring information available from the field instrumentation at the site, it is considered inappropriate to formulate an early warning / trigger levels until such time that sufficient data from monitoring and walkover surveys has been collected and an informed opinion can be reached.

10.4.4 *Response Actions*

It is considered that a programme of response actions or an action plan in relation to significant instability being detected would be inappropriate. A programme of continuous and sustained monitoring and walkover surveys at regular intervals would provide sufficient information to negate the implementation of an action plan.

10.4.5 *Future Monitoring and Inspection*

It is recommended that a regime of regular monitoring and inspection of Filey should be undertaken at six monthly intervals (bi-annually). This should be carried out over a period of three years in order to retrieve long term data for analysis in order to determine any seasonal patterns of rainfall, ground water levels and ground movements. The frequency of walkover surveys and instrument monitoring should be increased following periods of heavy and prolonged rainfall. The monitoring should encompass the elements of inspection detailed below.

Coastal slopes monitoring should be carried out by way of walk over surveys and ground surveys accompanied by a photographic record. Defects to record would be tension cracking in pavements and structures, misalignment of linear features, uneven / bulging ground, surface ponding water, undermining of slope / cliff bases and a visual check of drainage within highways and slopes for functionality (specifically around Crescent Hill slopes).

Beach monitoring should be carried out at low tide conditions to assess beach levels and accompanied by a photographic record.

Sea wall monitoring and rock armour should be undertaken at low tide conditions to determine any undermining of the base of the sea-wall defences and also to record the general condition, in particular, a record of any outflanking of the southern end of the rock armour defences. A photographic record should be taken to accompany a sea wall condition survey to monitor any crack development, concrete spalling, etc.

It is recommended that **inclinometer and piezometer monitoring** is carried out at the current six monthly (bi-annually) intervals. As well as reading the instruments, a condition examination should be carried out at the same time and any defects recorded and rectified.

10.4.6 Recommendations for Future Instrumentation Installation

It is considered that the present instrumentation installed at this site is sufficient to provide adequate data for the long term monitoring of the slopes at Filey. The inclinometers have been installed along the seafront glacial till cliffs to record and monitor any ground movements within these slopes. Accompanying piezometers have also been installed at strategic locations to record groundwater levels within the tills.

10.5 Summary of Recommended Monitoring

Nature of Monitoring and recommended additional instrumentation	Monitoring Frequency	Changes in Frequency following periods of heavy or prolonged rainfall, etc
Walkover survey of Coastal Slopes	Six monthly (Bi-annual) for three years	Increased to one week after event and at monthly intervals thereafter for three months
Beach	Six monthly (Bi-annual) for three years	
Sea Wall	Six monthly (Bi-annual) for three years	
Inclinometers and Piezometers	Six monthly (Bi-annual) for three years	Increased to one week after event and at monthly intervals thereafter for three months

11 Filey Flat Cliffs (Site Code AB06)

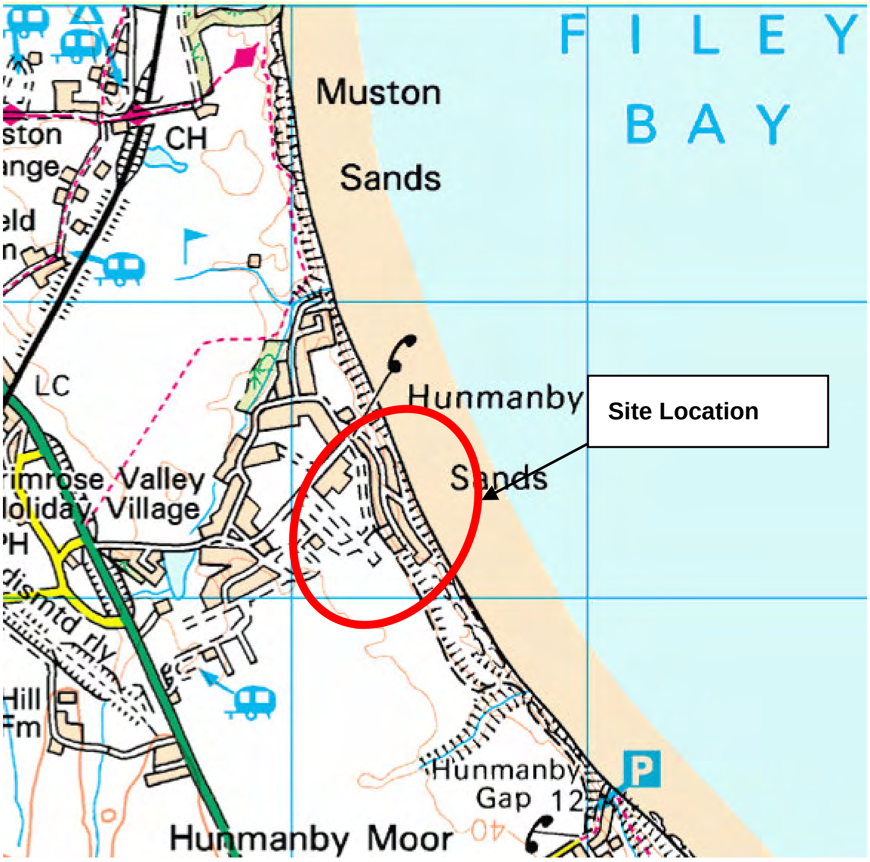
The SMP2 details the site of Filey Flat Cliffs as follows:

Policy Development Zone 12							
Management Area		**Policy Unit**		**Policy Plan**			
				2025	2055	2105	Comment
MA32	Muston Sands to Speeton	32.1	Hunmanby Sands	NAI	NAI	NAI	Consideration of the long term management of frontage, access and hinterland

11.1 Description of the Site

Filey Flat Cliffs is situated near Primrose Valley Holiday Park, 2km south of Filey town centre on the north east coast of England. The site comprises steep unprotected coastal slopes of glacial till on which holiday homes and static caravans have been constructed with narrow tarmac access roads. The site is bounded to the north, west and south by the holiday park and to the east by the cliffs.

Figure 25: Site Location



11.1.1 Historic Review of Problems

At Flat Cliffs there is evidence of active slope erosion, cliff-top recession and slope instability. Slope instability is particularly apparent at this site where an active landslip (rotational failures forming a benched slope profile) now threatens to breach the only vehicle access route into the area.

11.1.2 Site Walkover

A site walkover was conducted by a geotechnical engineer from Mouchel on 27th November 2008. The site visit confirmed the condition of the existing borehole instruments as being operable. A series of photographs was also taken of the site picking up salient topographical features such as varying slope angles, back scars, relict slope failures, tension cracks and tilting structures. Selected site photographs are presented in Appendix I.

Features identified during the walk over survey are described in Section 11.1.3 of this report

11.1.3 *Topography and Geomorphology*

The coastal cliffs are entirely composed of glacial till with solid rock formations dipping below sea level. The glacial till deposits comprise a highly variable mixture of clays, silts and, sands and gravels. They are easily eroded by wave action and are susceptible to groundwater effects and mass movements. Complex landslides are present at Flat Cliffs, large-scale, deep-seated failure of the glacial till cliffs has occurred. At the north end of Flat Cliffs, the surface morphology indicates rotational failure of the glacial till has occurred. At Flat Cliffs (south), large undercliffs have formed which appear from the surface morphology to be formed by translational failure of the glacial till slopes, possibly founded upon or within weathered bedrock at depth.

11.1.4 *Existing Information*

The following reports have been provided by SBC for consultation:

Report No. 115 - ***Report on a Ground Investigation at Primrose Holiday Village, Filey (Draft)***. Document No. F11848, Norwest Holst Soils Engineering Ltd, June 2001.

Report No. 116 - ***Report on a Ground Investigation at Primrose Holiday Village, Filey (Final)***. Document No. F11848, Norwest Holst Soils Engineering Ltd, July 2001.

Report No. 125 – ***Scarborough Borough Council. Filey Bay Coastal Strategy Study. Executive Summary (Final)***. Halcrow Group Ltd, October 2002.

Report No. 126 – ***Scarborough Borough Council. Cayton Bay Coastal Strategy Study. Strategy Report (Final)***. Halcrow Group Ltd, October 2002.

Report No. 127 – ***Scarborough Borough Council. Filey Bay Coastal Defence Strategy Study. Strategy Report (Final) Technical Annexes.*** Halcrow Group Ltd, October 2002.

Report No. 175 - *Scarborough Borough Council. Coastal Monitoring Programme 2001-2002. Filey and Cayton Bay Cliff Inspection and Condition Assessment, Halcrow Group Ltd. Mat 2002.*

Report No. 186 - ***Scarborough Borough Council. Strategic Coastal Monitoring Programme 2001-2006. Condition Analysis of Coast Protection Assets, Cliffs and Beaches from Staithes to Speeton.*** Halcrow Group Ltd, November 2006.

11.2 Stratigraphy

11.2.1 *Soil Profile*

The 1:50,000 British Geological Survey (BGS) Sheet 54 Solid & Drift, Scarborough indicates that the site is underlain by superficial deposits of glacial till (Quaternary), overlying the Speeton Clay Formation. This formation overlies the Kimmeridge Clay Formation.

Table 11.2.1 Geological Stratigraphy

Age	Stratum
Quaternary (Recent)	Glacial Till Stiff silty sandy clays, sands and gravels, laminated silty clays
Cretaceous	Speeton Clay Formation Clay with limestone and phosphate concretions
Upper Jurassic	Kimmeridge Clay Formation Bituminous mudstones

11.2.2 Groundwater Regime

Hydrogeology

The Groundwater Vulnerability Map (Sheet 9) of North East Yorkshire has classified the area as a Non-Aquifer because of their negligible permeability. These formations are generally regarded as containing insignificant quantities of groundwater. However, groundwater flow through such soils, although imperceptible, does take place and needs to be considered in assessing the risk associated with persistent pollutants. Some Non-Aquifers can yield water in sufficient quantities for domestic use. Major and Minor Aquifers may occur beneath Non-Aquifers.

A ground investigation was carried out at Primrose Holiday Village, Filey during the period February to April 2001. The field works involved the installation of three inclinometers and two piezometers, to various depths, to monitor possible ground displacements and the groundwater regime at the site.

Groundwater strikes recorded during field works are presented in Table 11.2.2a. The driller noted that drilling within the glacial till was 'dry'. However, water seepages were recorded within granular bands and lenses of the glacial till. Groundwater rises were not recorded.

Table 11.2.2a Levels of Groundwater strike

Hole ID	Geology	Water Strike Depth (m bgl)	Water Depth After 20 minutes(m bgl)	Comment
BHA2	Clay	13.10	NR	
BHA2	Clay	14.50	NR	
BHD2	Made Ground	3.10	NR	

Piezometers were read in March 2001 during field works and in July 2001. The latter readings show a slight increase in groundwater levels. Although it is more likely that these are 'average values' and that during periods of prolonged and heavy rainfall groundwater levels may be higher.

Table 11.2.2b Levels of Groundwater strike

Borehole	Piezometer Reading (m bgl)	
	March 2001	July 2001
A3	18.0	17.0
B1	4.0	3.6
D1	Not Read	12.5

11.2.3 Laboratory Test Results

A summary of the laboratory tests undertaken is presented in Table 11.2.3 below.

Table 11.2.3 Summary of Laboratory Testing

Type of test	Test method
Classification/Compaction	
Moisture Content	BS1377: Part 2: 1990; Clause 3
Liquid / plastic limits	BS1377: Part 2: 1990
Particle size distribution	BS1377: Part 2: 1990; Clause 9
Strength / Consolidation	
Shear box (effective strength)	BS1377, (1990) part 7, method 4

11.2.4 Soil Parameters

Soil parameters derived from a schedule of laboratory testing gave the following range of results for the glacial till unit:

Peak C' = 10 to 38kPa, phi' = 25^0 to 32^0 (From Shear Box test)

Residual C' = 5 to 14kPa, phi' = 25^0 to 31^0 (From Shear Box test)

Moisture Content = 9.1% to 15%,

Liquid Limit = 20% to 34%,

Plastic Limit = 14% to 26%,

Plasticity Index = 2% to 16%

11.3 Instrumentation

11.3.1 Definition of Existing Problems

The presence of confined granular strata within the glacial till slopes may result in excess groundwater pressures to develop resulting in the collapse and recession of the head scarp and cliff crest.

11.3.2 History of Monitoring

During the ground investigation undertaken at Flatt Cliffs in 2001, two inclinometers (A2 and D2) and three piezometers (A3, B1 and D1) were installed as part of this fieldwork. The location of the instrumentation is presented on Drawings No. 11 and 12 in Section 15. Following a review of data submitted by SBC, monitoring details have not been made available for the two inclinometers. However, data has been made available for the three piezometers installed at this site during a ground investigation in 2001. The readings start from the earliest date of March 2001 up to September 2008. Ground water level readings have also been provided from the inclinometer tube instruments (A2 and D2) from February-May 2003 to October 2004.

11.3.3 Assessment of Monitoring Results

Inclinometer monitoring results have not been assessed as the data represents initial 'base line' readings and no follow-up readings have been made available.

Piezometer data from A3 (tip at 30.50m depth) recorded groundwater levels of between 18.21 and 19.77 m bgl. The results show little, if any, variation in water levels over the monitoring period which may well be a reflection of the true groundwater level. The other boreholes, B1 and D1, have installations at higher levels of 24.90m and 20.50m, respectively. The fluctuating readings would seem to illustrate seasonal trends reflecting changing rainfall amounts although without yearly rainfall records it is not possible to comment in any detail on the attenuation of the ground to varying rainfall levels.

11.3.4 Stability Analysis

Slope stability analysis was carried out on two sections of cliffs at Flat Cliffs, this reported in detail and included as part of Report No. 127.

11.4 Re-assessment of Risk Register

11.4.1 Re-definition of Problems

Stability analysis (detailed in Report No. 127) has shown the sensitivity of Flatt Cliffs to the continued effects of erosion and retreat of the sea cliffs. The natural removal of materials from the compound landslide blocks that form the sea cliffs can only cause a reduction in the stability of the coastal slopes. Stability analysis has also shown that a rise in groundwater levels of only a few metres may be sufficient to reduce the factor of safety of this area below unity. As such, it is probable that ground movements in this area will be greatest during periods of prolonged and heavy rainfall.

11.4.2 Re-assessment of Risk

The geomorphological interpretation and ground investigation (2001) provides evidence that Flatt Cliffs comprises a range of landslide mechanisms of contrasting age and degrees of activity which are sensitive to rising ground water levels resulting from increased ground porewater pressures.

11.4.3 Early Warning / Trigger Levels

Given the lack of monitoring information available from the field instrumentation at the site, it is considered inappropriate to formulate an early warning / trigger levels until such time that sufficient data from monitoring and walkover surveys has been collected and an informed opinion can be reached.

11.4.4 Response Actions

It is considered that a programme of response actions or an action plan in relation to significant instability being detected would be inappropriate at this time. A robust programme of continuous and sustained monitoring and walkover surveys at regular intervals would provide sufficient information on which to base an action plan. The information collated from these surveys and monitoring visits would then provide a basis on which to formulate an action plan.

11.4.5 Future Monitoring and Inspection

It is recommended that a regime of regular monitoring and inspection of Flat Cliffs should be undertaken at monthly intervals for six months and then every two months until month twelve. If no significant movement is revealed during this twelve month period then monitoring should revert to six monthly intervals (bi-annually). Monitoring should be carried out over a period of three years in order to retrieve long term data for analysis in order to determine any seasonal patterns of rainfall, ground water levels and ground movements. During periods of heavy or prolonged rainfall the frequency of the surveys should be increased in order to record any resulting increases in groundwater levels. The monitoring should encompass the elements for inspection detailed below.

Coastal slopes monitoring should be carried out by way of walk over surveys and ground surveys accompanied by a photographic record. Defects to record would be tension cracking in pavements and buildings, misalignment of linear features, uneven / bulging ground, surface ponding water, undermining of slope / cliff bases and a visual check of drainage within highways and slopes for functionality (specifically the access road into Flat Cliffs).

It is recommended that **piezometer and inclinometer monitoring** is carried out at the frequency detailed above. As well as reading the instruments, a condition examination should be carried out at the same time and any defects recorded and rectified.

11.4.6 Recommendations for Future Instrumentation Installation

Further ground investigation is recommended to supplement the information retrieved from a previous investigation carried out in 2001. Although the ground investigation provided evidence of a variety of slope failure mechanisms of different age and activity, the restricted scope of the previous ground investigation works (2001) still leaves uncertainties with respect to the sub-surface geometry. This was reflected in the limited number of boreholes undertaken and also the poor recovery of core samples of the glacial tills from the previous investigation.

11.5 Summary of Recommended Monitoring

Nature of Monitoring and recommended additional instrumentation	Monitoring Frequency	Changes in Frequency following periods of heavy or prolonged rainfall, etc
Walkover survey of Coastal Slopes	Six monthly (Bi-annual) for three years	Increased to one week after event and at monthly intervals thereafter for three months
Inclinometers and Piezometers	Monthly intervals for six months and then every two months until month twelve. Reverting to bi-annual intervals for remaining two years if no significant movement detected	Increased to one week after event and at monthly intervals thereafter for three months
Further ground investigation within this area is recommended		

12 Recession Points

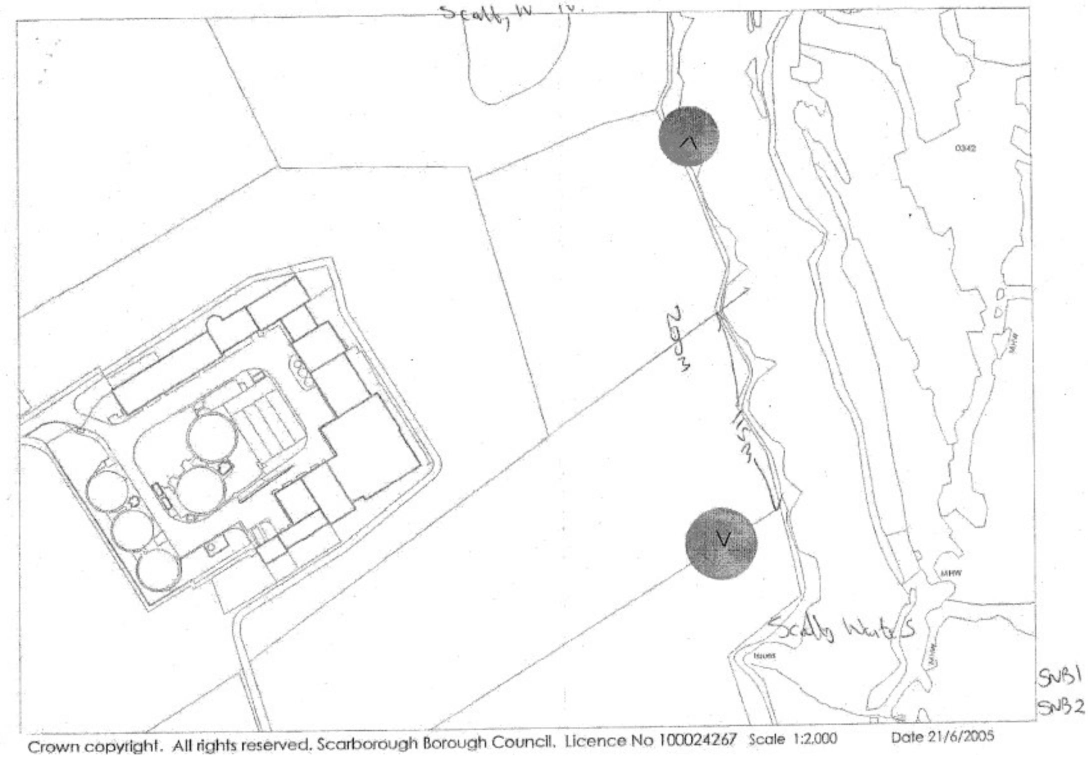
The SMP2 details the recession point sites along the north east coast between Scalby in the north and Reighton in the south as follows:

Policy Development Zones 10, 11 & 12							
Management Area		**Policy Unit**		**Policy Plan**			
				2025	2055	2105	Comment
MA26	Hundale Point to Scalby Ness	26.1	Burniston	NAI	NAI	NAI	-
MA27	Scalby Ness to Castle Cliff	27.1	North Bay	HTL	HTL	HTL	Detailed strategic appraisal of options required
MA29	White Nab to Cayton Bay	29.1	Cornellian Bay	NAI	NAI	NAI	-
		29.2	Cayton Bay	NAI	NAI	NAI	-
MA31	Filey Brigg to Muston Sands	31.1	North of Filey	NAI	NAI	NAI	Affected by works to stop outflanking of Filey
		31.2	Filey	HTL	HTL	HTL	Looking to long term overall management
		31.3	Muston Sands	NAI	NAI	NAI	Affected by works to stop outflanking of Filey
MA32	Muston Sands to Speeton	32.1	Hunmanby Sands	NAI	NAI	NAI	Consideration of long term management of frontage, access and hinterland.
		32.2	Hunmanby Gap	NAI	NAI	NAI	Consideration of long term management of frontage
		32.3	Reighton	NAI	NAI	NAI	Consideration of long term management of frontage

12.1 Description of the Sites

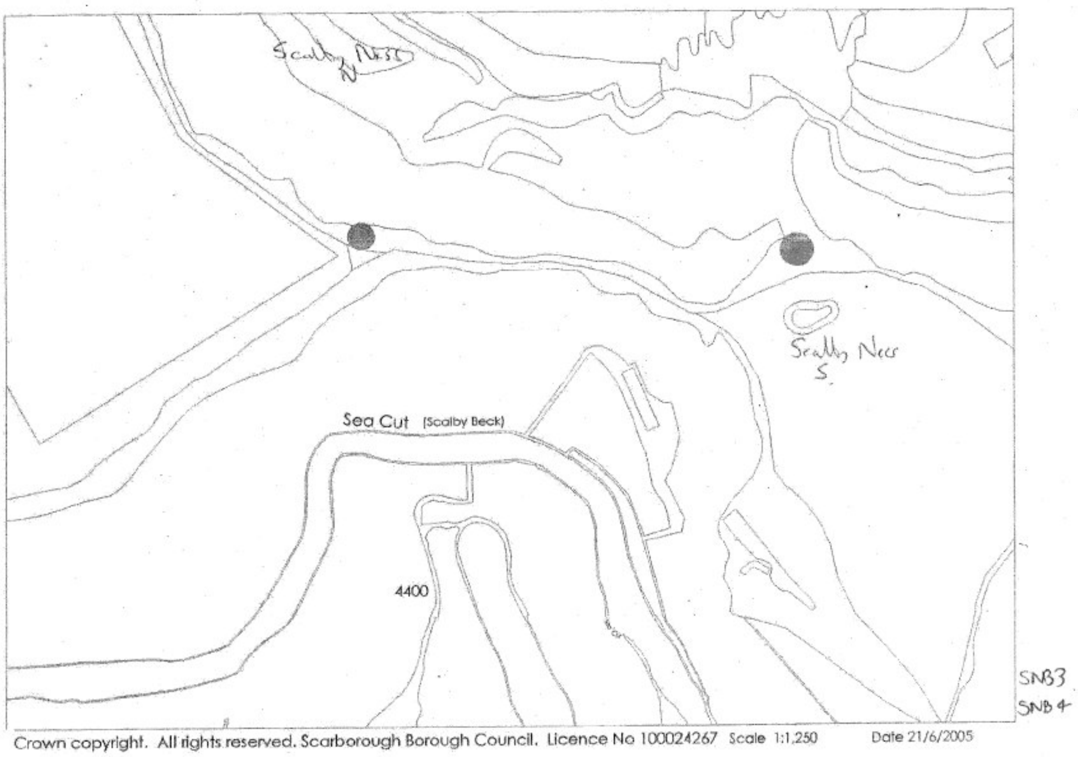
Ref. No.	Location	Grid Reference
SNB1	Scalby WWTW Nth	TA 02863 92419
SNB2	Scalby WWTW Sth	TA 02886 92201
SNB3	Scalby Ness North	TA 03411 91129
SNB4	Scalby Ness South	TA 03559 91123

The sites at Scalby are covered under Policy Units 26.1 and 27.1.



Recession Points at Scalby Ness (SNB1 and 2).

Scalby Ness forms a broad promontory to the north of Scarborough North Bay, approximately 3km north of Scarborough. The headland is incised by Scalby Beck which acts as an overflow from the River Derwent when in flood. The beck flows in an east-north easterly direction through Scalby, where at Scalby Mills it changes direction sharply through 90 degrees to flow south easterly at Scalby Ness and outfalls to the sea between Scalby Ness headland and the Sea Life Centre.

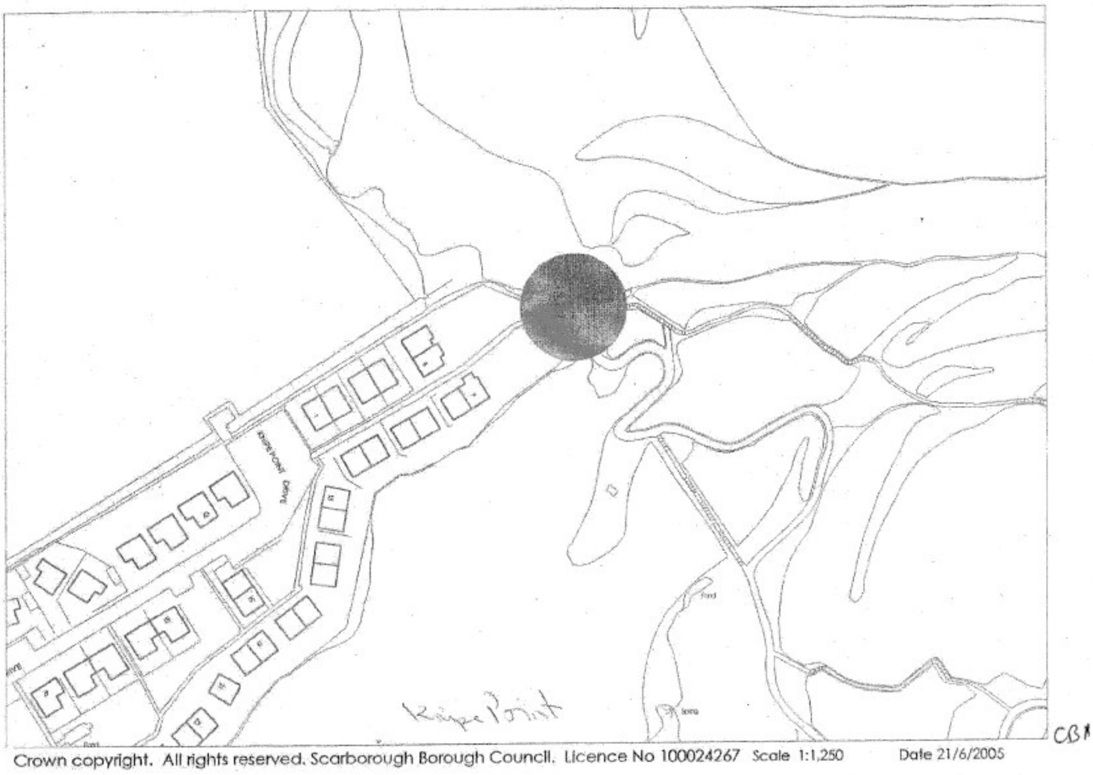


Recession Points at Scalby Ness (SNB3 and 4).

A housing development was constructed during the 1970's and 1980's on land forming a plateau approximately 25-30m above the beck at Scalby Ness. Over-steepened glacial till cliffs are present on the north west and north east sides of the development falling down towards the beck. The beck contributes to toe erosion of these slopes and is a contributing factor of the mechanism of slope instability. Scalby Mills Road bounds the southern edge of the north east slopes. This road was constructed to give access to the Sea Life Centre on the coast. Part of the works involved re-profiling slopes with toe protection offered by rock outcrops at Scalby Beck and emplaced toe protection around the Sea Life Centre.

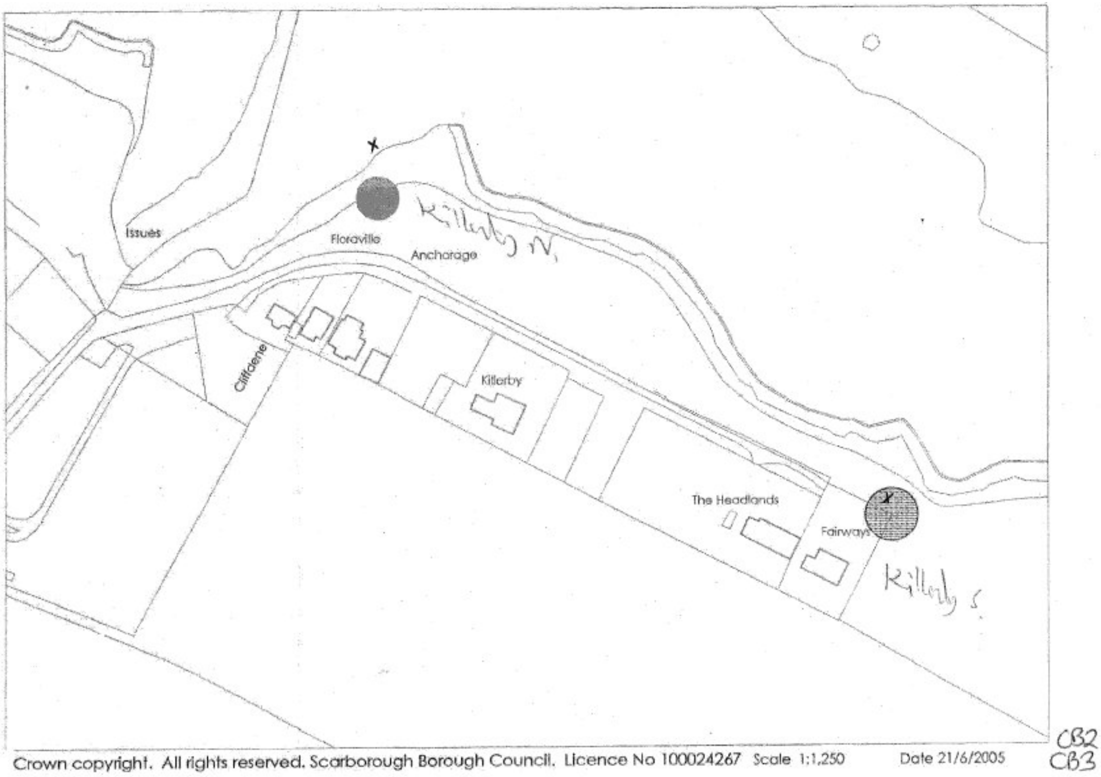
Ref. No.	Location	Grid Reference
CB1	Knipe Point	TA 06109 85390
CB2	Killerby Cliff Nth	TA 07025 84241
CB3	Killerby Cliff Sth	TA 07193 84126

The sites of Knipe Point and Killerby are covered under Policy Units 29.1 and 29.2.



Recession Point at Knipe Point (CB1).

Knipe Point is a promontory located at the north of Cayton Bay, 3.5km south of Scarborough and 7km north of Filey, on the north east coast of England. Set back beyond the promontory the main coastal route (A165) between Scarborough and Filey follows an almost parallel course to the coastline. From the A165, north of Tennants' Cliff, to Knipe Point a series of holiday homes occupies the crest and southern side of the promontory. The land north of the crest and the holiday homes complex is given over to agriculture. Osgodby Village is located immediately west of the A165.

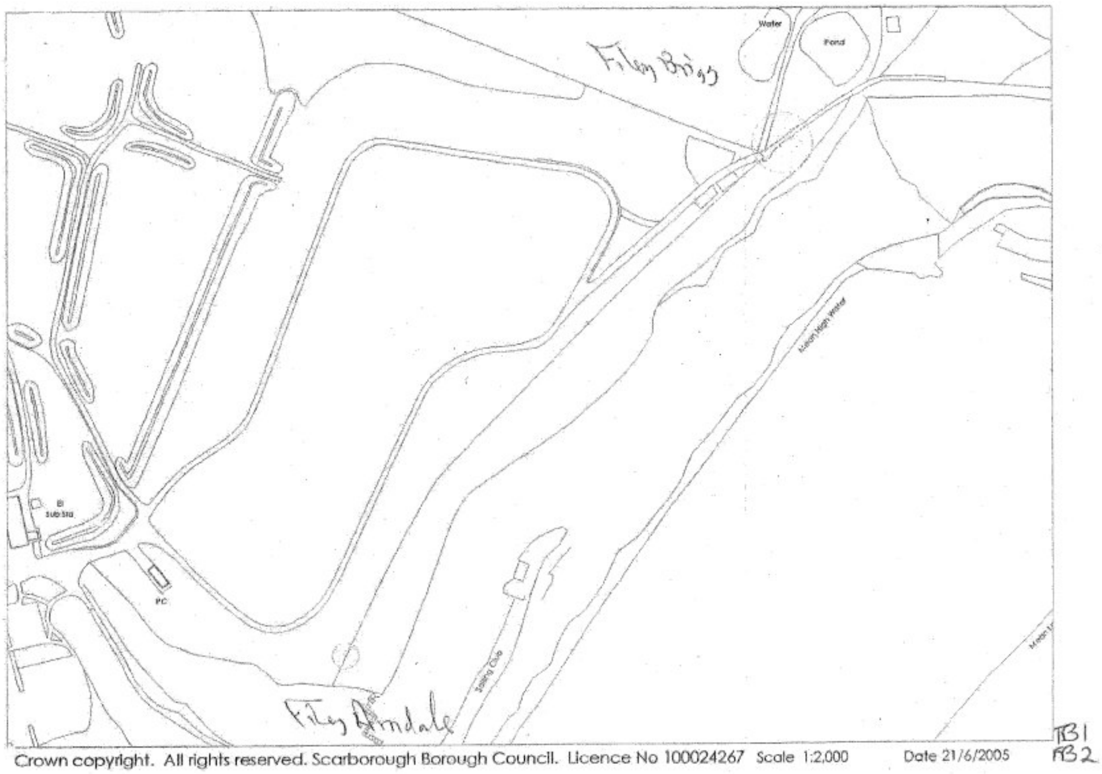


Recession Points at Killerby Cliffs (CB2 and 3).

Killerby Cliff lies within Cayton Bay mid-way between Osgodby Point to the north and Lebberston Cliffs in the south. The coast line is composed of steep, unprotected glacial till cliffs up to 40metres in height. The cliffs are prone to slumping with the regression of a steep head scarp (approximately 3metres high) and toe erosion from marine influences. Beyond the cliff crest the ground is relatively flat with a row of houses some 200metres back from the cliff edge.

Ref. No.	Location	Grid Reference
FB1	Filey Brigg	TA 12399 81608
FB2	Filey Arndale	TA 12188 81357
FB3	Filey Church Ravine	TA 12045 81018
FB4	Filey, Filey GC	TA 12045 81018

The sites at Filey are covered under Policy Units 31.1, 31.2 and 31.3.

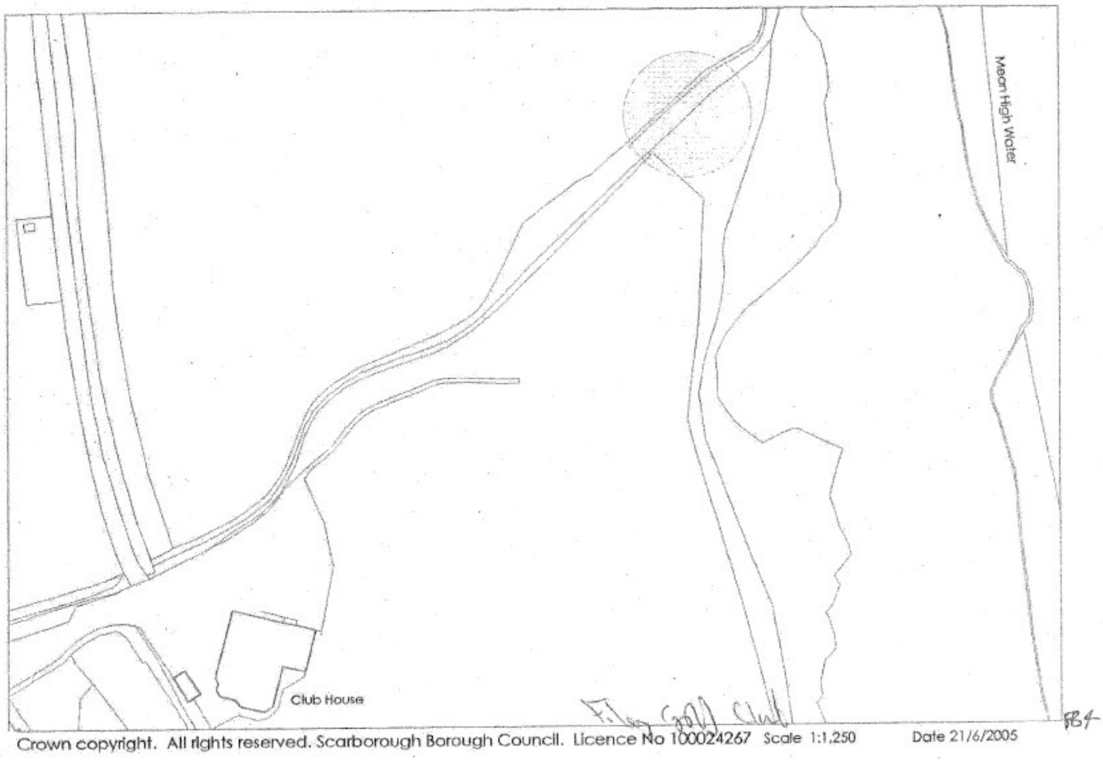


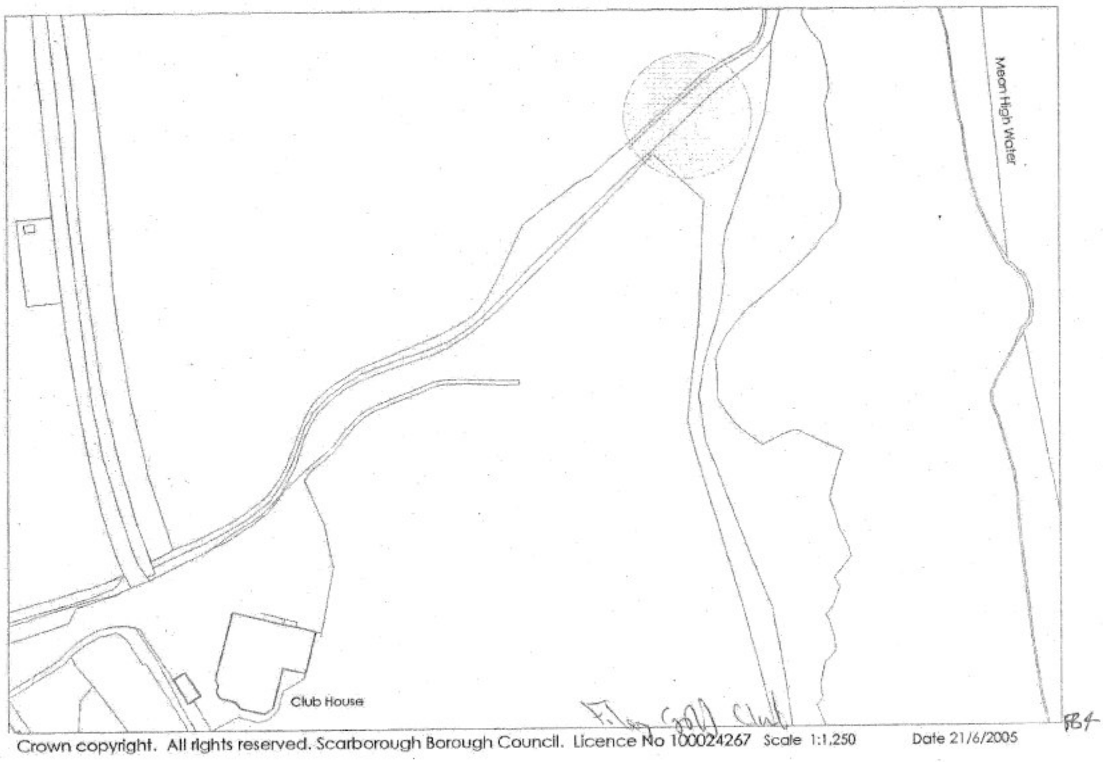
Recession Points at Filet Brigg and Filey Arndale (FB1 and 2).

The composite cliffs of Filey Brigg form a distinctive headland feature at the northern limit of Filey Bay. The cliffs are unprotected and comprise up to 10metres of Jurassic rocks overlain by 20 to 25metres of glacial till deposits which are prone to erosion from groundwater run-off leading to distinctive gullying features and mudslides. Around the bay towards Filey Arndale, the cliffs are composed of glacial tills with the underlying rocks dipping below sea level. Filey Country Park is located above the cliff top with actively unstable coastal slopes.

Recession Point at Filey, Church Ravine (FB3).

Church Ravine is a deep valley formed entirely in glacial tills at the north end of Filey town. The ravine extends from the cliff top down to the beach below where the northern extent of the sea wall and promenade are present. Further north from this point the cliffs are unprotected, and the coastline arcs round eastwards to the promontory of Filey Brigg. The coastal cliffs attain heights of up to 55metres from Church Ravine reducing to 30metres at the Brigg.



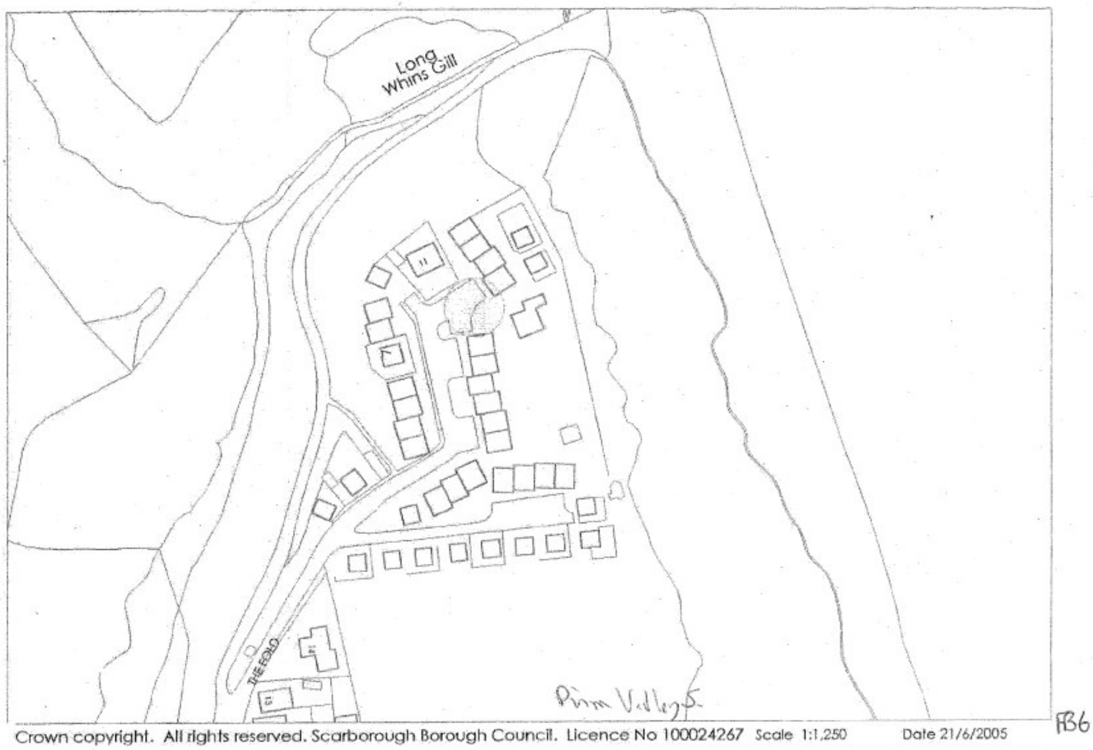


Recession Point at Filey Golf Club (FB4).

The slopes along this stretch of coastline are unprotected glacial till cliff type, approximately 35metres in height, prone to toe erosion at the base from marine influences and translational landslides and mudslides due to high groundwater pressures and rainwater run-off. The land beyond the cliff crest is generally level, laid over to short grassland with gorse and shrubs and, a golf course.

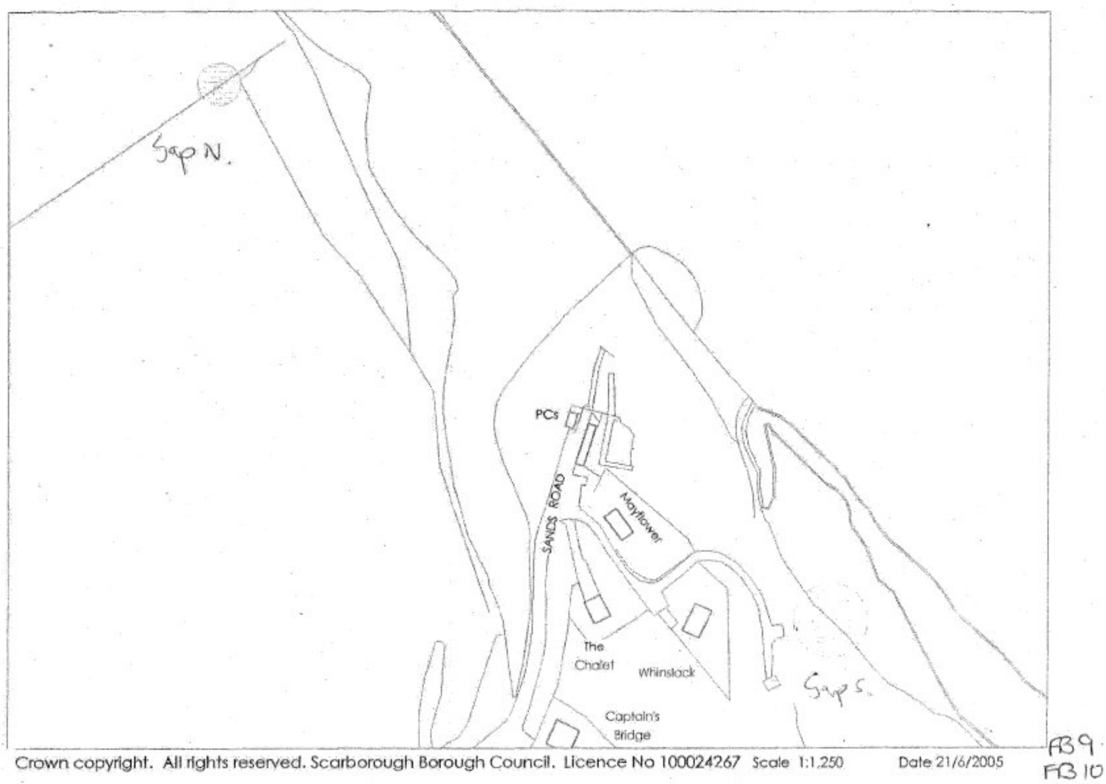
Ref. No.	Location	Grid Reference
FB6	Primrose Valley Sth	TA 12059 78961
FB9	Hunmanby Gap Nth	TA 12919 77415
FB10	Hunmanby Gap Sth	TA 13123 77235
FB11	Reighton	TA 13123 77235

The site of Primrose Valley, Hunmanby and Reighton are covered under Policy Units 32.1, 32.2 and 32.3.

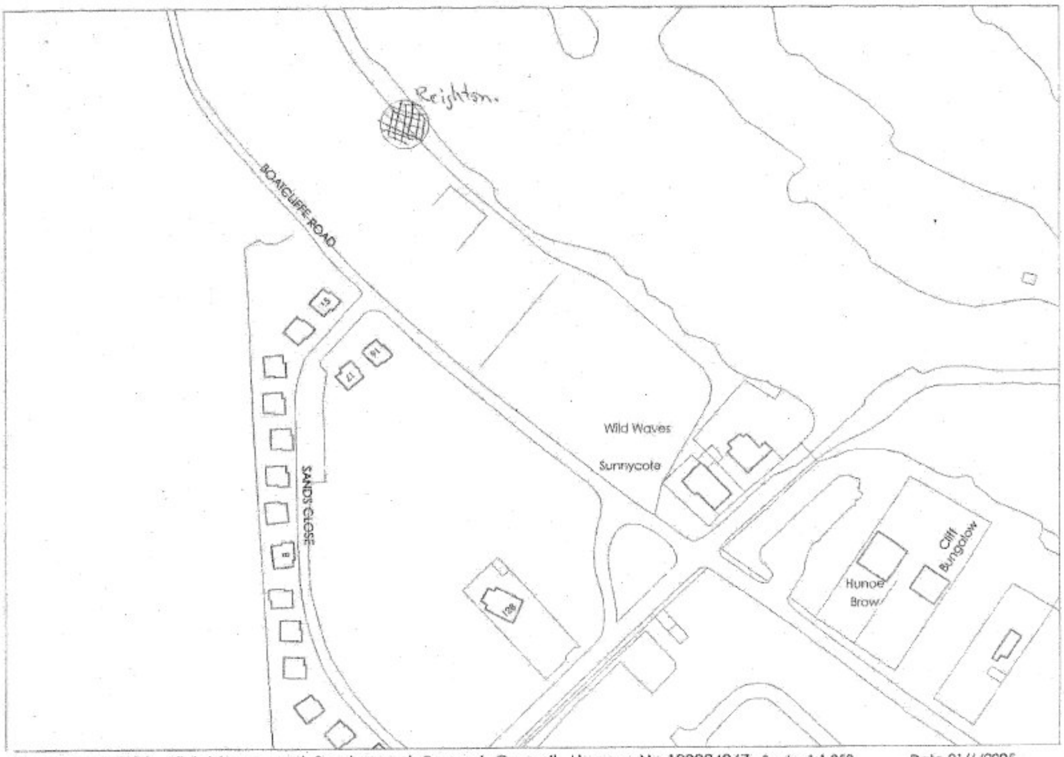


Recession Point at Primrose Valley South (FB6).

Primrose Valley is located 2km south of Filey town centre on the north east coast of England. The site comprises steep unprotected coastal slopes of glacial till, up to 40metres in height, on which holiday homes and static caravans have been constructed with narrow tarmac access roads. The site is bounded to the north, west and south by a holiday park and to the east by the cliffs. Continuing south around Filey Bay, Hunmanby Gap is encountered. The coastal slopes are similar to Primrose Valley development with evidence of incipient cliff instability and cliff retreat. Further south, the cliff profile continues to be composed of glacial tills undulating in height between 30 and 40metres, again evidence of slope instability is prevalent along the coastline.



Recession Points at Hunmanby Gap (FB9 and 10).



 Scale 1:1,250 Date 21/6/2005 FB11

Recession Point at Reighton (FB11).

12.1.1 Historic Review of Problems

At all of the sites presented for analysis of cliff recession rates, the prevailing aspect of these investigations is of continuous observation of cliff behaviour and monitoring cliff recession rates. In respect of the collapse of cliff faces (failures), generally the most frequently occurring mode of failure at the sites is that of mudslides, rotational landslips and translational landslips. Clifff top recession develops, due to pressure relief within the slopes, as cracks open along the cliff crest. During periods of rainfall the cracks fill with groundwater and the tills soften leading to the eventual collapse of the cliff face. Toe erosion is also a contributing factor to the destabilising of cliffs which are solely composed of glacial tills. Scalby Ness and Filey Brigg are exceptions to this mechanism of erosion where Jurassic rocks outcrop above the sea level at both locations.

At Filey Brigg (Carr Naze) ground water run-off has resulted in gullying within the glacial tills at surface level where rainwater run-off flows over the surface and erodes into the soft clays. The clays are softened by groundwater to a point where mudslides and slumping of the tills develops with retreating headscarps.

12.1.2 *Site Walkover*

A site walkover of several of the recession point sites was conducted by a geotechnical engineer from Mouchel on 27th and 28th November and 1 December 2008. A series of photographs was also taken of some of the sites picking up salient topographical features such as tension cracks, varying slope angles, hummocky and irregular ground, surface ponding water, back scars and relict slope failures. Selected site photographs are presented in Appendix C, F, G, H and I.

Features identified during the walk over survey have been described in previous sections of this report.

12.1.3 *Topography and Geomorphology*

The topography and geomorphology of the recession sites has been detailed previously in the relevant chapters (with the exception of Filey Brigg and Speeton detailed below) covering these sites as follows:

Scalby – Chapter 5, Section 5.1.3

Knipe Point – Chapter 8, Section 8.1.3

Killerby – Chapter 9, Section 9.1.3

Filey – Chapter 10, Section 10.1.3

Flat Cliffs – Chapter 11, Section 11.1.3

Filey Brigg –Filey Bay comprises mostly glacial till cliffs of varying height which are underlain by Upper Jurassic rocks from the northern extent down to Speeton in the south. The northern limit of the Bay is marked by Filey Brigg a natural headland formed of Upper Jurassic limestones and Corallian Grits which outcrop above sea level.

Glacial tills cap the exposed Jurassic and Cretaceous rocks in the northern and southern extent of the Bay and where the solid strata dips below sea level, the cliffs are formed entirely of glacial till. The glacial till along this coastal section comprise variable mixtures of clay, silts, sands and gravels which are easily eroded by wave action at the cliff toe and are also highly susceptible to groundwater effects and mass movements.

12.1.4 *Existing Information*

The following reports have been provided by SBC for consultation:

Filey Flood Damage Reinstatement Works, Geotechnical Interpretative Report. Document No. 785871/001/GIR/02/FINAL, Mouchel Ltd, December 2008.

Report No. 115 - ***Report on a Ground Investigation at Primrose Holiday Village, Filey (Draft)***. Document No. F11848, Norwest Holst Soils Engineering Ltd, June 2001.

Report No. 116 - ***Report on a Ground Investigation at Primrose Holiday Village, Filey (Final)***. Document No. F11848, Norwest Holst Soils Engineering Ltd, July 2001.

Report No. 122 – ***Scarborough Borough Council. Cayton Bay Coastal Strategy Study. Strategy Report Final (Executive Summary)***. Halcrow Group Ltd, October 2002

Report No. 123 – ***Scarborough Borough Council. Cayton Bay Coastal Strategy Study. Strategy Report Final (Introduction)***. Halcrow Group Ltd, October 2002.

Report No. 124 - ***Scarborough Borough Council. Cayton Bay Coastal Strategy Study. Strategy Report Final (Technical Annexes)***. Halcrow Group Ltd, October 2002.

Report No. 125 – ***Scarborough Borough Council. Filey Bay Coastal Strategy Study. Executive Summary (Final)***. Halcrow Group Ltd, October 2002.

Report No. 126 – ***Scarborough Borough Council. Cayton Bay Coastal Strategy Study. Strategy Report (Final)***. Halcrow Group Ltd, October 2002

Report No. 127 – ***Scarborough Borough Council. Filey Bay Coastal Defence Strategy Study. Strategy Report (Final) Technical Annexes.*** Halcrow Group Ltd, October 2002.

Report No. 132 - ***Scarborough Strategic Coastal Monitoring (Staithes to Scarborough). Defence Condition Surveys – Volume 1***. Document No. 1540/R/1. High Point Rendel Ltd, March 2002.

Report No. 134 – ***Report on a Ground Investigation for Filey Flood Damage Reinstatement Works***. Document No. F15272, Norwest Holst Soils Engineering Ltd, September 2008.

Report No. 135 - ***Scarborough Borough Council. Strategic Coastal Monitoring Staithes to Scarborough. Cliff Condition Survey. Volume 2 Slope Profomas. Report No. R/1540/2/1. High Point Rendel Ltd, September 2002.***

Report No. 175 ***- Scarborough Borough Council. Coastal Monitoring Programme 2001-2002. Filey and Cayton Bay Cliff Inspection and Condition Assessment, Halcrow Group Ltd. Mat 2002.***

Report No. 186 - ***Scarborough Borough Council. Strategic Coastal Monitoring Programme 2001-2006. Condition Analysis of Coast Protection Assets, Cliffs and Beaches from Staithes to Speeton.*** Halcrow Group Ltd, November 2006.

Report No. 198 – ***National Trust. Cayton Cliff, Cayton Bay, Stability Report and Cliff Management Plan***. Halcrow Group Ltd, May 2008.

12.2 Stratigraphy

12.2.1 Soil Profile

The geology of the coastline extending from Scalby in the north to Speeton encompasses Middle Jurassic rocks to Cretaceous clays of the Speeton Clay Formation. The geology is presented in tabulated format for ease of interpretation for the four separate areas of Scalby, Knipe Point / Killerby, Filey and Flat Cliffs / Speeton.

Table 12.2.1a Geological Stratigraphy of Scalby Area

Age	Stratum
Quaternary	Glacial Till Stiff silty sandy clays, sands and gravels, laminated silty clays
Middle Jurassic	Long Nab Member of the Scalby Formation Interbedded mudstones, siltstones and sandstones

Table 12.2.1b Geological Stratigraphy of Knipe Point / Killerby Area

Age	Stratum
Quaternary	Glacial Till Stiff silty sandy clays, sands and gravels, laminated silty clays
Upper Jurassic	Lower Calcareous Grit Calcareous sandstone
Upper Jurassic	Oxford Clay Grey-green mudstone
Middle Jurassic	Osgodby Formation Calcareous sandstone
Middle Jurassic	Cayton Clay Formation and Cornbrash Formation Undifferentiated limestone and mudstone
Middle Jurassic	Scalby Formation Mudstone and sandstone
Middle Jurassic	Cloughton Formation Gristhorpe, Lebberston and Sycarham members

Table 12.2.1c Geological Stratigraphy of Filey Area

Age	Stratum
Quaternary	Glacial Till Stiff silty sandy clays, sands and gravels, laminated silty clays
Upper Jurassic	Kimmeridge Clay Formation Bituminous clays
Upper Jurassic	Upper Calcareous Grit Formation Siltstone and sandstones
Upper Jurassic	Coralline Oolite Formation Oolitic limestone and sandstone
Upper Jurassic	Lower Calcareous Grit Formation Calcareous sandstone
Upper Jurassic	Oxford Clay Formation Grey green mudstones
Middle Jurassic	Osgodby Formation Calcareous Sandstone

Table 12.2.1d Geological Stratigraphy of Flat Cliffs / Speeton Area

Age	Stratum
Quaternary	Glacial Till Stiff silty sandy clays, sands and gravels, laminated silty clays
Cretaceous	Speeton Clay Formation Clay with limestone and phosphatic concretions
Upper Jurassic	Kimmeridge Clay Formation Bituminous clays

12.2.2 Groundwater Regime

Hydrogeology

The Groundwater Vulnerability Map (Sheet 9) of North East Yorkshire has classified the area as a Non-Aquifer because of their negligible permeability. These formations are generally regarded as containing insignificant quantities of groundwater. However, groundwater flow through such soils, although imperceptible, does take place and needs to be considered in assessing the risk associated with persistent pollutants. Some Non-Aquifers can yield water in sufficient quantities for domestic use. Major and Minor Aquifers may occur beneath Non-Aquifers.

12.2.3 Laboratory Test Results

Non undertaken.

12.2.4 Soil Parameters

Non undertaken.

12.3 Instrumentation

12.3.1 Definition of Existing Problems

Recession points have been installed at the selected locations in order to measure and record the rates of cliff recession taking place. The monitoring consists of measuring from a fixed point (usually a steel pin set into concrete outside the influence of cliff erosion rates) to the cliff edge and recording this distance using a 30metre tape. The locations selected for cliff recession rate determinations are entirely glacial till or of a composite type (glacial till overlying rock succession) coastal slope profile. Generally the cliff slopes are unprotected by man-made structures or coastal defences, the exception being Filey Town where the glacial till slopes are protected by seawall defences which extend from Coble Landing south to Martin's Gill and beyond this to Muston Sands by rock revetment emplaced at the base of the till slopes.

12.3.2 History of Monitoring

Recession points have been installed at the locations detailed in Section 12.1 between Scalby Ness and Reighton. It has been reported by SBC that the monitoring points were installed in 2001 and apparently monitored on a bi-annual basis up to 2004. However, recession data so far provided by SBC only extends from 12 March 2004 to 12 September 2005.

12.3.3 Assessment of Monitoring Results

Very limited recession data has been made available by SBC for the fifteen sites. Data made available for the recession sites spans a period from 12 March 2004 to 12 September 2005. The data from this period covers a maximum of 5No. readings. Some of the readings for individual pins (SNB1 to 4) are missing and there is only one reading available from this period. At another site, a recession pin (CB1) was replaced and again there is little data from this for any prolonged length of time.

12.3.4 Stability Analysis

Slope stability analysis has been undertaken at several of the sites and is reported on under the relevant Chapters of Scalby Ness (Section 5.3.4), Filey (Section 10.3.4) and Flat Cliffs (Section 11.3.4) within this report.

12.4 Re-assessment of Risk Register

12.4.1 Re-definition of Problems

Insufficient data is available to make a judgement on the problems affecting the sites in question other than cliff erosion is an on-going natural event. A robust regime of regular monitoring of the recession points is required to be put into action in order to build a database on which to evaluate and make a judgement of the problems at each site.

12.4.2 Re-assessment of Risk

A re-assessment of the risks at the sites covered by the recession points would be invalid at this stage. There is insufficient monitoring data available for analysis on which to make a valid judgement at this point. However, it is recognised that the recession points have been installed at sites where the retreat of cliff lines has and continues to have an adverse impact upon the natural environment and near-by assets.

12.4.3 Early Warning / Trigger Levels

It is considered imprudent to attempt to provide or formulate a regime of Early warning / Trigger levels, at this stage, based upon the limited monitoring data so far made available. Any future assessment should be based on at least three consecutive readings from the sites in order to get an idea of any seasonal or other influences affecting the recession rates prevailing at these sites.

12.4.4 Response Actions

Re-assess the monitoring frequency in accordance with the results of periodic surveys, as detailed in Section 12.4.5. A response would be difficult to apply at this stage without knowing what the event is. However, there should be provision for an emergency response to deal with any arising events.

12.4.5 Future Monitoring and Inspection

It is recommended that a robust regime of regular monitoring and inspection of these sites should be undertaken at six monthly intervals (bi-annually). This should be carried out over a period of at least three years in order to retrieve long term data for analysis in order to determine any seasonal patterns of rainfall, ground water levels and ground movements.

12.4.6 Recommendations for Future Instrumentation Installation

Install or re-install recession points at the locations and begin a robust regime of monitoring on a six monthly (bi-annual) basis for at least a three year period. Following periods of prolonged and heavy rainfall there may be the requirement to increase the frequency of monitoring events in order to record the behaviour, extent and nature of any ground movements as a consequence of the weather events.

12.5 Summary of Recommended Monitoring

Nature of Monitoring and recommended additional instrumentation	Monitoring Frequency	Changes in Frequency following periods of heavy or prolonged rainfall, etc
Monitor recession points and walkover survey of Coastal Slopes	Six monthly (Bi-annual) for three years	Increased to one week after event and at monthly intervals thereafter for three months
Install or re-install recession points where required or where they have been lost	Six monthly (Bi-annual) for three years	Increased to one week after event and at monthly intervals thereafter for three months

13 References

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BS 6031: (1981) Code of Practice for Earthworks. British Standard Institution.

BS 8002: (1994) Code of Practice for Earth Retaining Structures. British Standard Institution.

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Tomlinson, M. J. (2001) Foundation Design and Construction - 7th Edition. Longman Ltd.

14 Drawings

Drawing No. 1 – Site Plan of Runswick Bay (Inclinometers)

Drawing No. 2 – Site Plan of Whitby West Cliff (Inclinometer)

Drawing No. 3 – Site Plan of Scalby Ness (Piezometers)

Drawing No. 4 – Site Plan of Scalby Ness (Inclinometers)

Drawing No. 5 – Site Plan of Scarborough North Bay (Piezometers)

Drawing No. 6 – Site Plan of Scarborough North Bay (Inclinometers)

Drawing No. 7 – Site Plan of Scarborough South Bay (Piezometers)

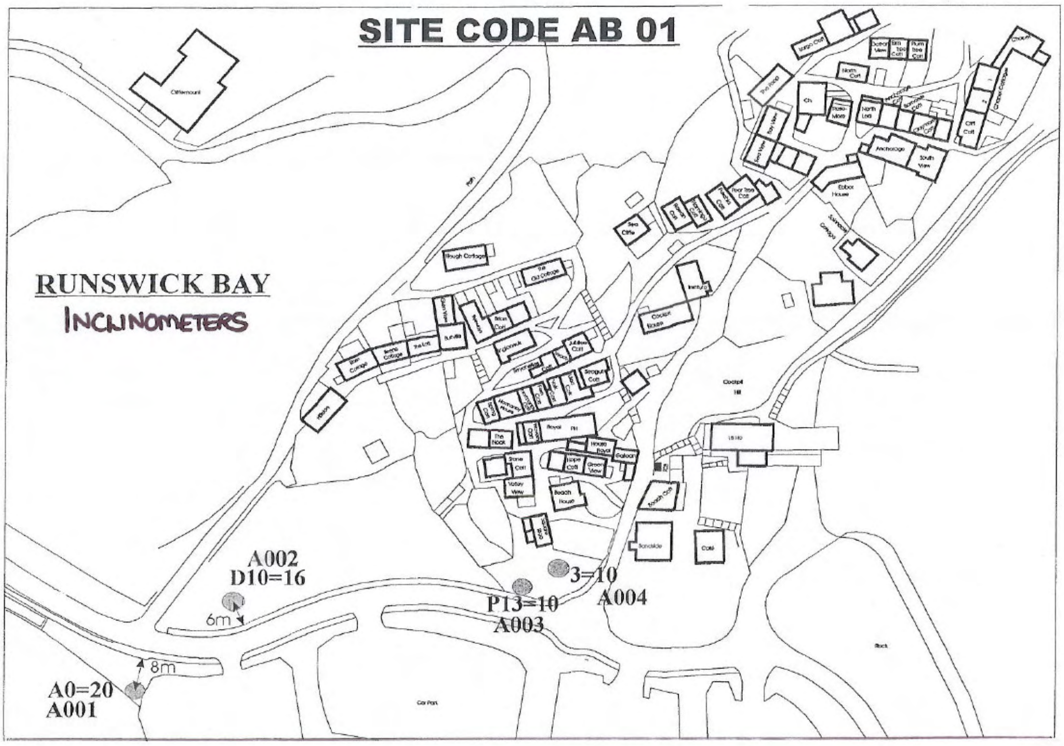
Drawing No. 8 – Site Plan of Scarborough South Bay (Inclinometers)

Drawing No. 9 – Site Plan of Proposed G.I. Plan Cayton Cliff, North Yorkshire (Provisional)

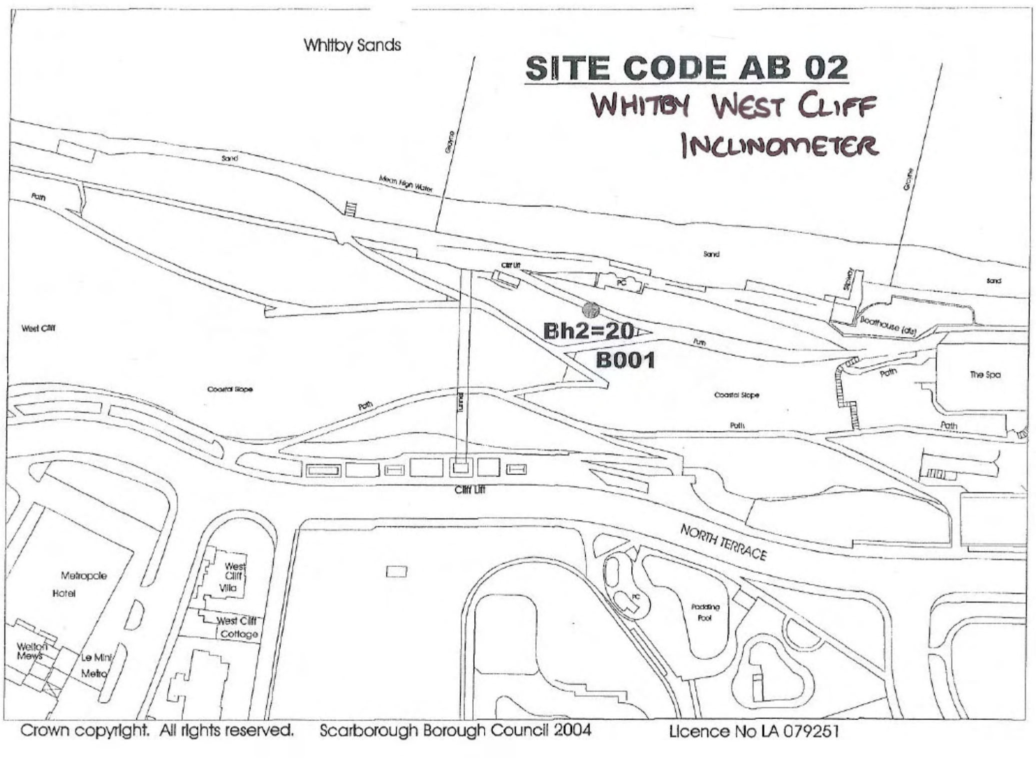
Drawing No. 10 – Site Plan of Filey (Piezometers and Inclinometers)

Drawing No. 11 – Site Plan of Flat Cliff (Piezometers)

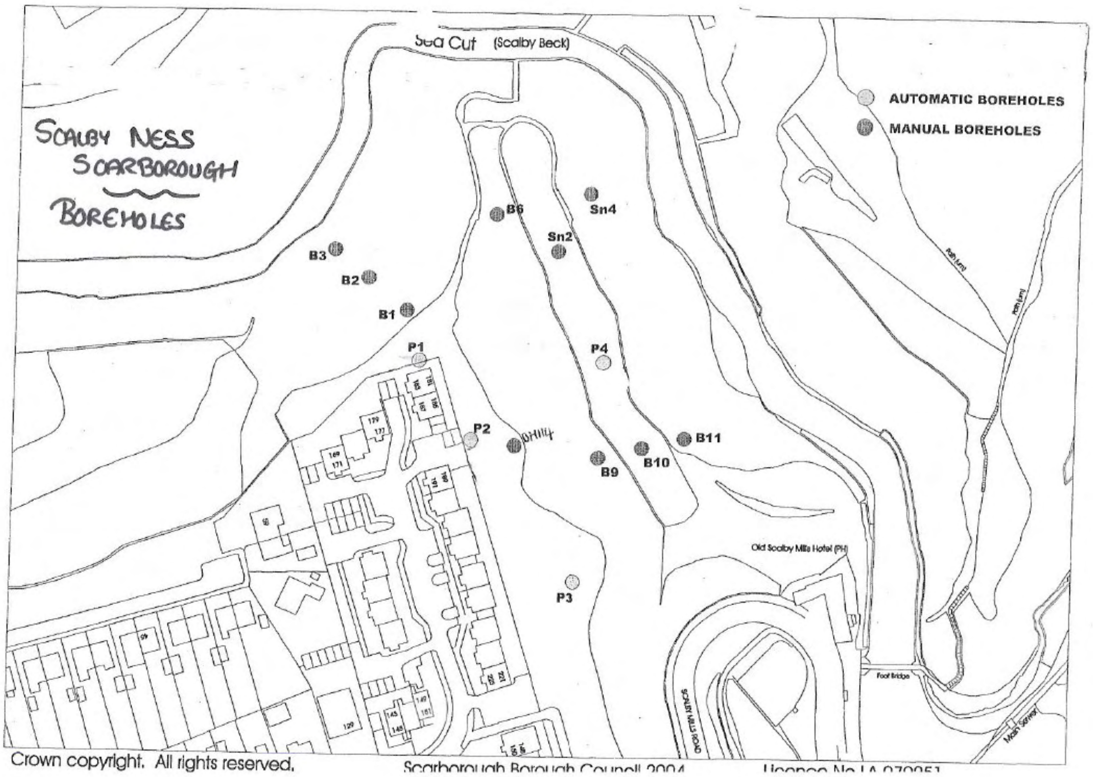
Drawing No. 12 – Site Plan of Flat Cliff (Inclinometers)



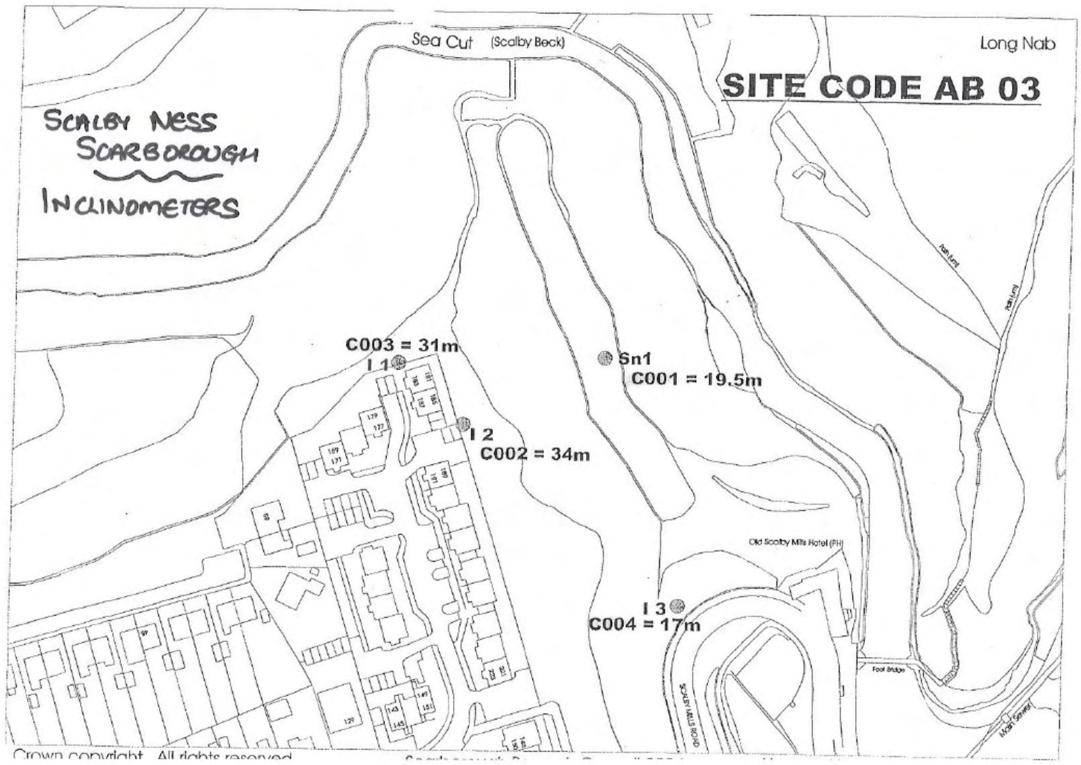
Drawing No. 1 – Site Plan of Runswick Bay (Inclinometers)



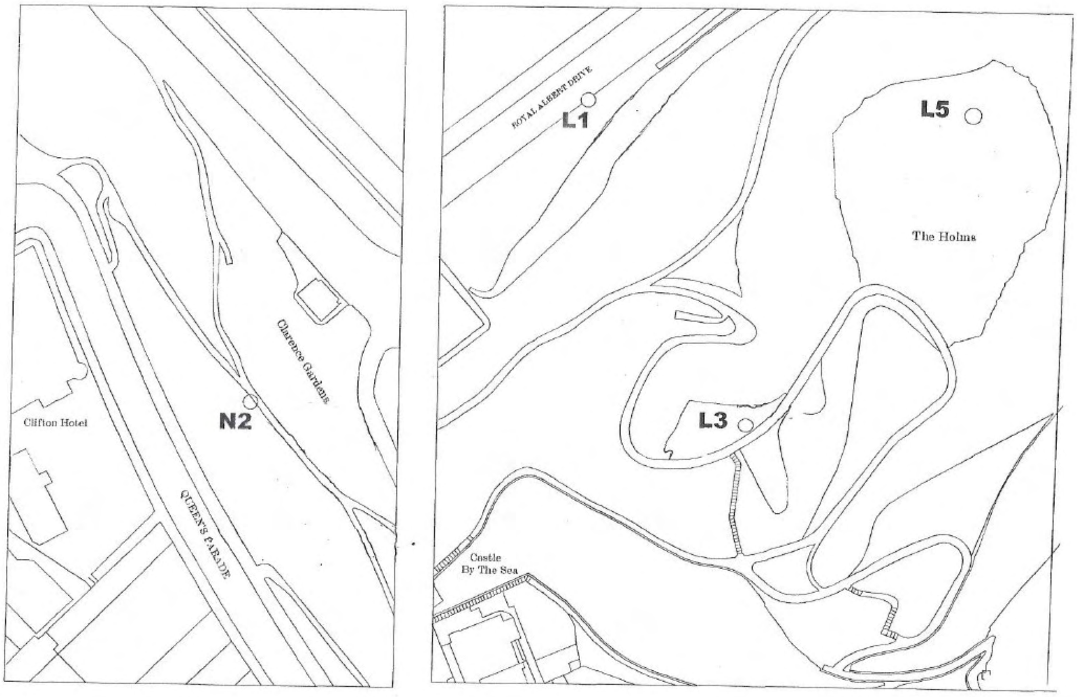
Drawing No. 2 – Site Plan of Whitby West Cliff (Inclinometer)



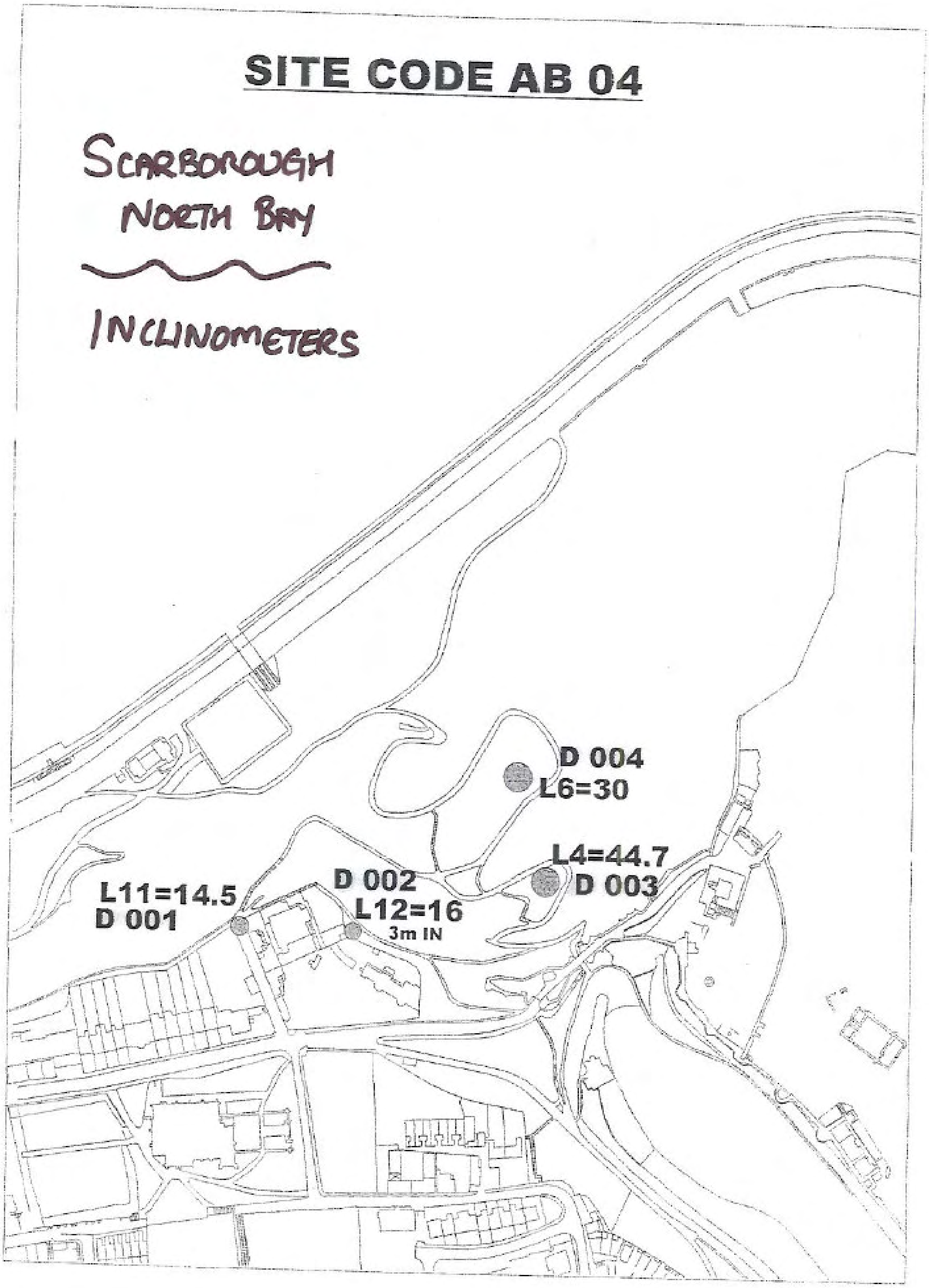
Drawing No. 3 – Site Plan of Scalby Ness (Piezometers)



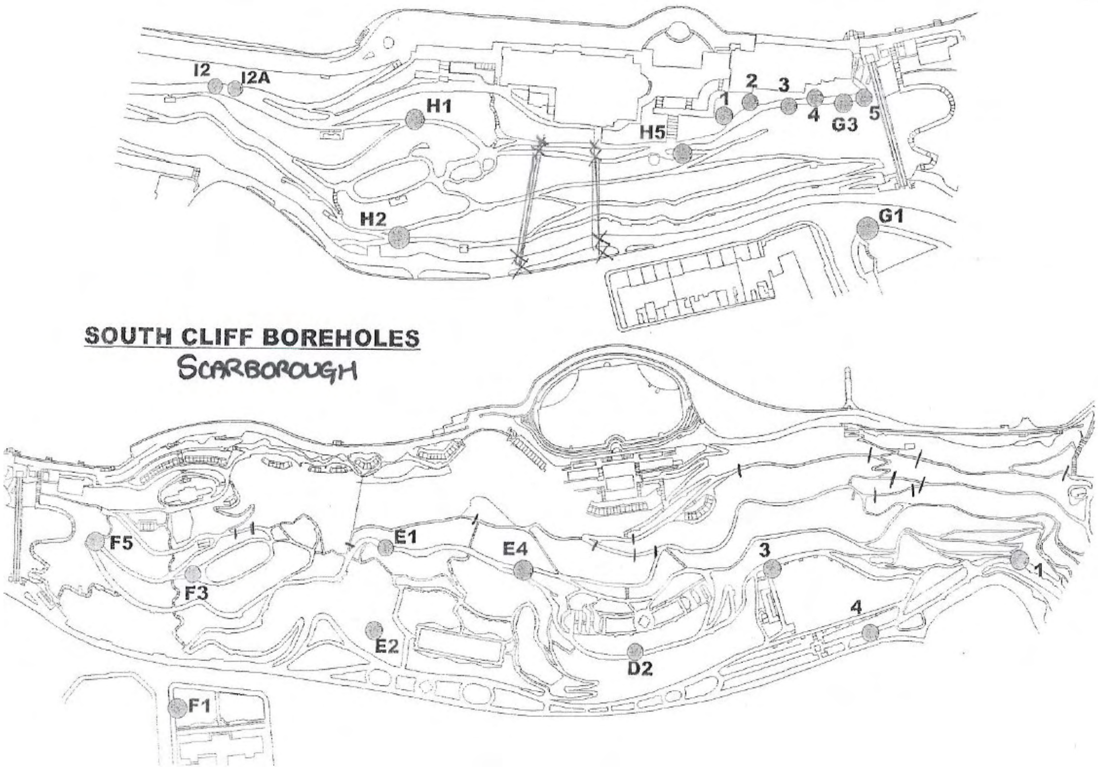
Drawing No. 4 – Site Plan of Scalby Ness (Inclinometers)



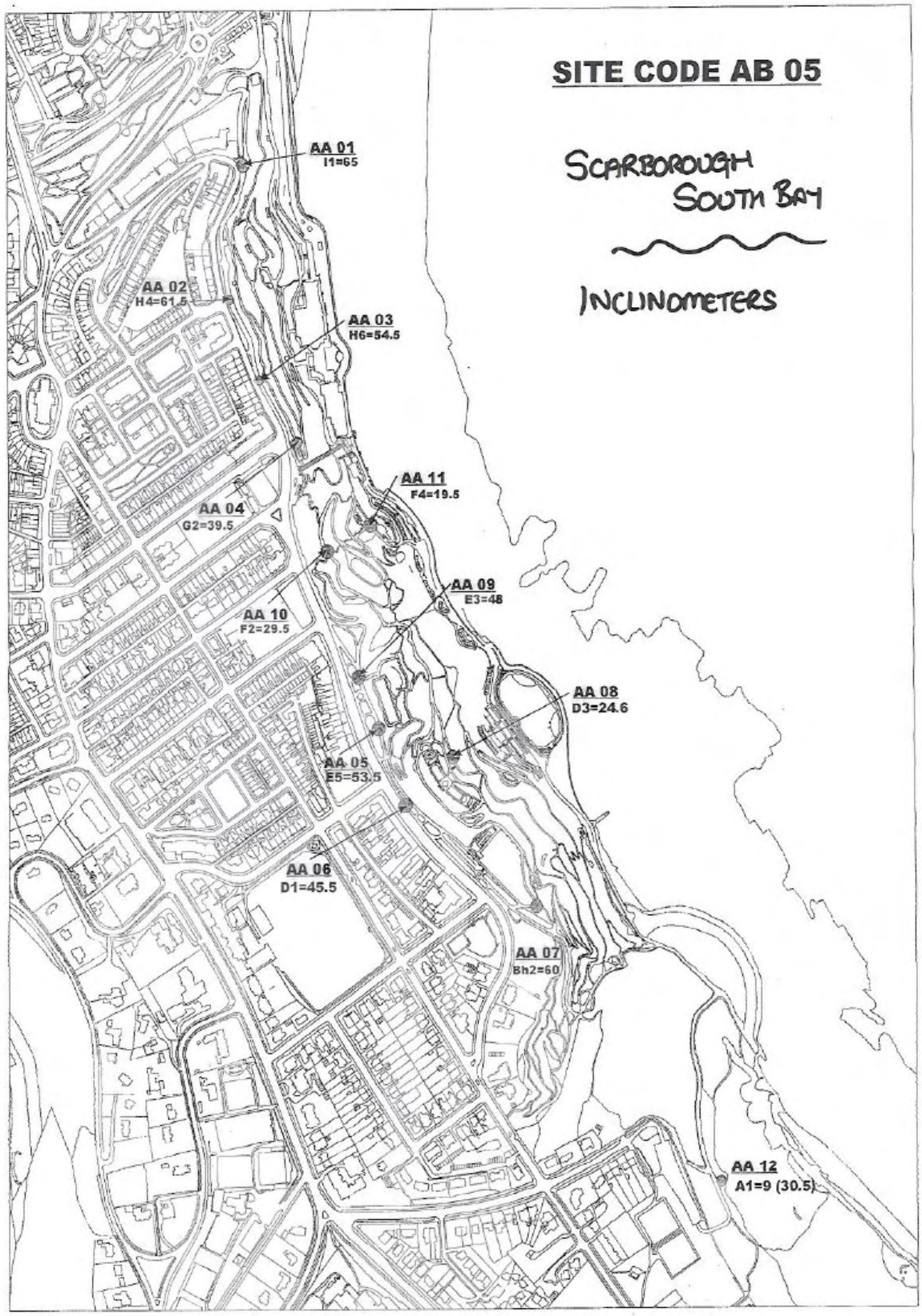
Drawing No. 5 – Site Plan of Scarborough North Bay (Piezometers)



Drawing No. 6 – Site Plan of Scarborough North Bay (Inclinometers)

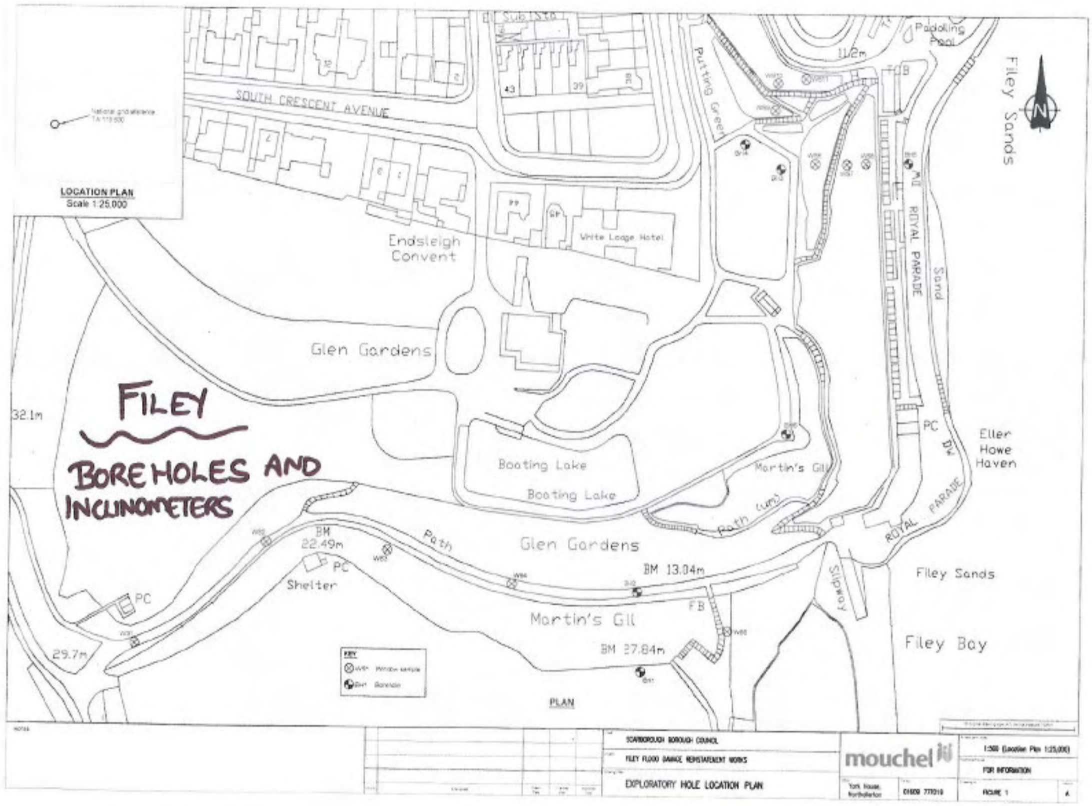


Drawing No. 7 – Site Plan of Scarborough South Bay (Piezometers)

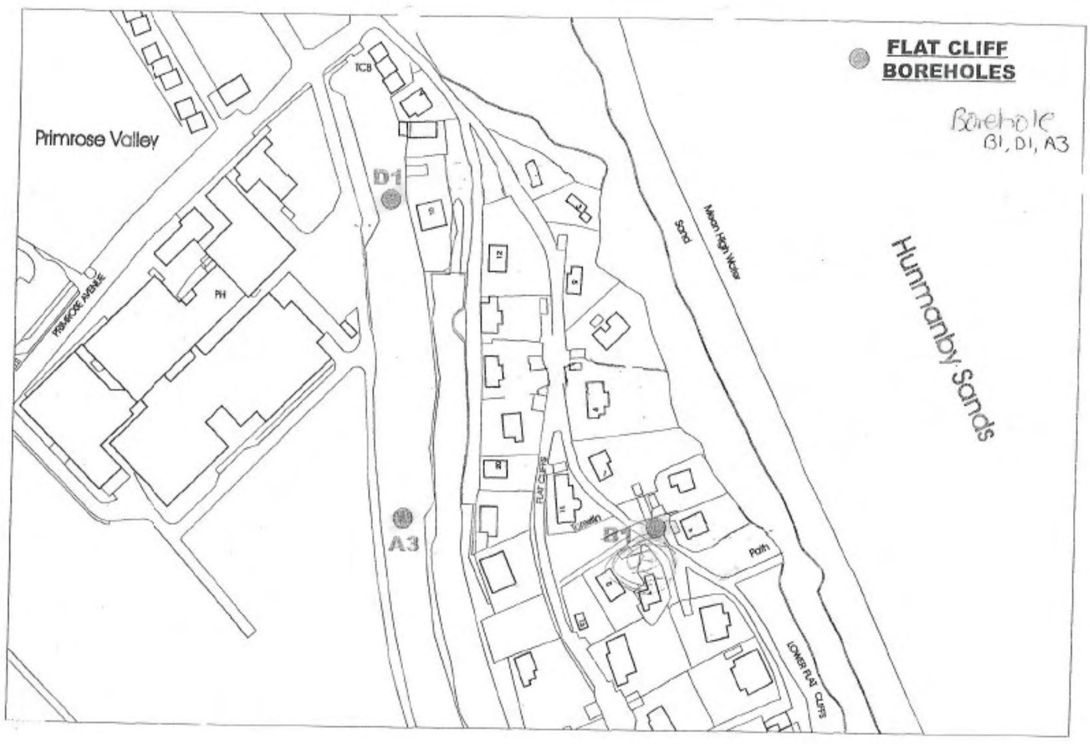


Drawing No. 8 – Site Plan of Scarborough South Bay (Inclinometers)

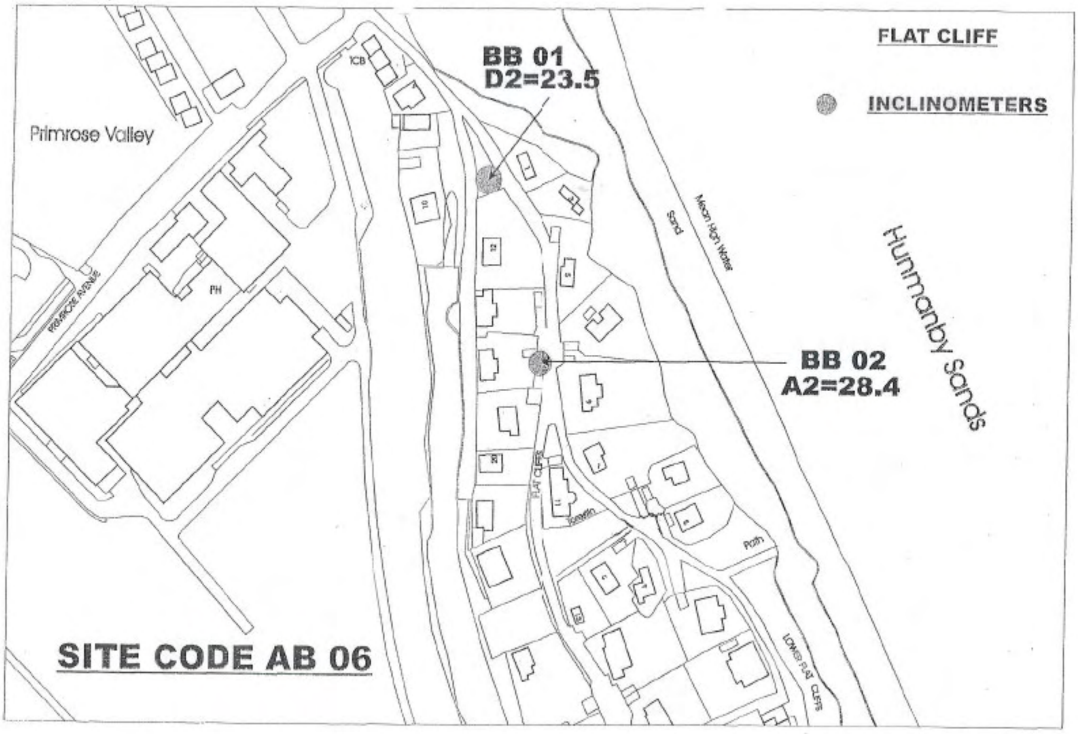
Drawing No. 9 – Site Plan of Proposed G.I. Plan Cayton Cliff, North Yorkshire (Provisional)



Drawing No. 10 – Site Plan of Filey (Piezometers and Inclinometers)



Drawing No. 11 – Site Plan of Flat Cliff (Piezometers)



Drawing No. 12 – Site Plan of Flat Cliff (Inclinometers)

Appendix A: Site Photographs of Runswick Bay

Plate 1. Site view showing slope morphology looking west towards Ings End.

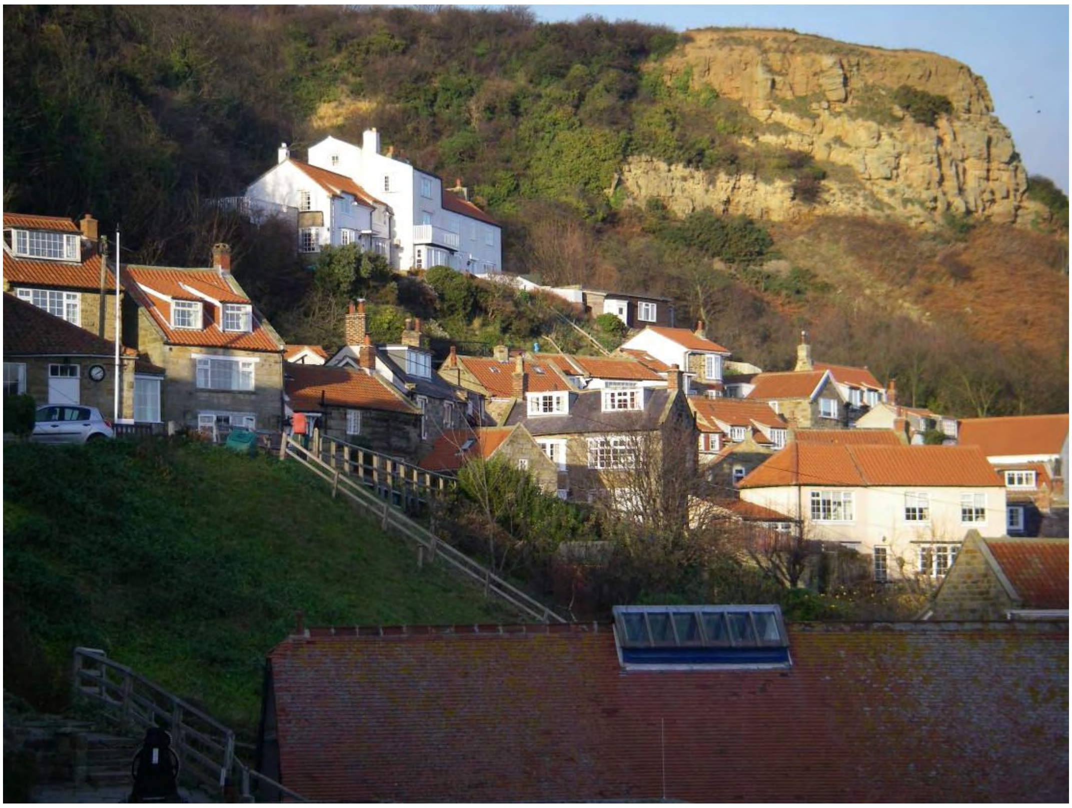


Plate 2. Site view looking north towards Cauldron Cliff.

Plate 3. Site view looking towards only access road.

Plate 4. Site view looking south-south east across rock armour revetment towards Dother Pits.

Appendix B: Site Photographs of Whitby West Cliff

Plate 5. Site view looking east along West Cliff towards The Spa.

Plate 6. Site view looking west along West Cliff towards Sandsend.

Plate 7. Site view of West Cliff slopes looking west.

Plate 8. Site view of West Cliff slopes looking east.

Appendix C: Site Photographs of Scalby Ness

Plate 9. Site view looking north across Scalby Beck from the Upper Plateau.

Plate 10. Site view looking north across Scalby Beck from the Upper Plateau.

Plate 11. Site view looking south across Upper Plateau showing slope crest and residential properties.

Plate 12. Site view of Behaviour Unit II showing over steepened back-scarp below Upper Plateau.

Plate 13. Site view looking north at Scalby Beck showing rock outcrops.

Plate 14. Site view of slopes showing mid-slope back rotated block and surface tension cracking.

Appendix D: Site Photographs of Scarborough North Bay

Plate 15. Site view of The Holms towards Castle Cliff.

Plate 16. Site view of The Holms looking up towards Scarborough Castle.

Plate 17. Site view of The Holms looking up towards Castle by The Sea.

Plate 18. Site view of the Castle from Castle by The Sea. (Note retaining walls in the mid-ground).

Plate 19. Site view of The Holms with Castle Cliff in the background.

Plate 20. Site view of The Holms.

Appendix E: Site Photographs of Scarborough South Bay

Plate 21. Site view looking south towards Holbeck Gardens and Holbeck Cliff.

Plate 22. Site view of steep slope angles above South Bay Pool Cliff.

Plate 23. Site view of Italian Gardens showing bench-cut paths and slope angles.

Plate 24. Site view looking north at arcuate embayment at South Cliff Gardens.

Plate 25. Site view looking south at arcuate embayment at South Cliff Gardens.

Plate 26. Site view looking south at the cliff railway and slopes of Prince of Wales Cliff.

Plate 27. Site view of retaining wall and slope failure behind The Spa on Spa Cliff.

Plate 28. Site view looking south across Spa Cliff showing steep slope angles and bench-cut paths.

Plate 29. Site view looking north across Spa Chalet Cliff showing steep slope angles and bench-cut paths.

Plate 30. Site view of slope crest retaining walls at Prince of Wales Cliff.

Appendix F: Site Photographs of Knipe Point

Plate 31. Site view looking south west along crest of Cayton Cliff.

Plate 32. Site view looking south west along regressing crest showing recent failure.

Plate 33. Site view looking south west at slope debris flow.

Plate 34. Site view looking south east at slope debris and ponding water near base.

Plate 35. Site view looking north east along regressing crest showing recent failure.

Plate 36. Site view looking north across north side of Knipe Point.

Plate 37. Site view of mid-slope ‘benching’ from retrogressive rotational slides.

Plate 38. Site view of ponding water and mudslide on mid-slope location.

Plate 39. Site view (taken below Plate 33) of backscarp showing groundwater issues.

Appendix G: Site Photographs of Killerby

Plate 40. Site view looking south across Killerby Cliffs.

Plate 41. Site view looking north across Cayton Bay towards Knipe Point.

Appendix H: Site Photographs of Filey Town and Brigg

Plate 42. Site view of Crescent Hill showing lower slope failure.

Plate 43. Site view from Glen Gardens looking down slope failure to Royal Parade.

Plate 44. Site view looking north across Glen Gardens.

Plate 45. Site view looking up Martin's Ravine at outfall.

Plate 46. Site view looking down Martin's Ravine. Note stream on the right side.

Plate 47. Site view of slope failures towards the base of Martin's Ravine.

Plate 48. Site view of coastal slopes immediately south of Martin's Ravine.

Plate 49. Site view of Filey Brigg looking west.

Plate 50. Site view of gullying and slumping of glacial tills at Filey Brigg.

Plate 51. Site view of tension cracks in slumped glacial tills at Filey Brigg.

Plate 52. Site view looking east at slumped glacial tills at Filey Brigg.

Appendix I: Site Photographs of Filey Flat Cliffs

Plate 53. Site view looking north across Filey Bay towards Filey Brigg.

Plate 54. Site view looking south across Filey Bay towards Flamborough Head.

Plate 55. Site view of tension cracks in access road into Flat Cliffs.

Plate 56. Site view of leaning timber garage at No. 5 Flat Cliffs, seaward of coastal slopes.

Plate 57. Site view of property on 'level' mid-slope bench with steep back slopes in background.

Plate 58. Site view looking down slope from 'level' mid-slope bench.