Ongoing Analysis and Interpretation of Coastal Monitoring Data

Initial Review of Full Suite Monitoring

Geotechnical Interpretative Report

October 2009

Document Ref. No. 721229/002/GIR/002/Final

Prepared by

mouchel

York House
Thornfield Business Park
Standard Way
Northallerton
North Yorkshire
DL6 2XQ
UK

T 01609 777019
F 01609 779728

Produced for

Scarborough Borough Council
Town Hall
St. Nicholas Street
Scarborough
North Yorkshire
YO11 2HG

A great place to live, work & play

Document Control Sheet

Project Title	Ongoing Analysis and Interpretation of Coastal Monitoring Data
Report Title	Initial Review of Full Suite Monitoring. Geotechnical Interpretative Report
Report Reference	721229/002/GIR/002/Final
Version	B
Issue Date	October 2009

Record of Issue

Version	Status	Author + Date	Check + Date	Authorised + Date
A	Draft	P. Robinson	Dr. J Maund	Dr. J Maund
B	Final	P. Robinson	Dr. J Maund	Dr. J Maund
		19/10/09	19/10/09	

Distribution

Organisation	Contact	Format	Copies
Scarborough Borough Council	Mr R Siddle	Hard + CD	1
Mouchel Ltd	Dr. J Maund	Electronic	1
Mouchel Ltd	Northallerton Library	Hard	1

DISCLAIMER

This report is presented to Scarborough Borough Council in respect of the Ongoing Analysis and Interpretation of Coastal Monitoring Data and may not be used or relied on by any other person or by the client in relation to any other matters not covered specifically by the scope of this Report.

Notwithstanding anything to the contrary contained in the report, Mouchel Limited is obliged to exercise reasonable skill, care and diligence in the performance of the services required by Scarborough Borough Council and Mouchel Limited shall not be liable except to the extent that it has failed to exercise reasonable skill, care and diligence, and this report shall be read and construed accordingly.

This report has been prepared by Mouchel Limited. No individual is personally liable in connection with the preparation of this report. By receiving this report and acting on it, the client or any other person accepts that no individual is personally liable whether in contract, tort, for breach of statutory duty or otherwise.

Mouchel has used reasonable skill, care and diligence in any interpretation of the records made available by Scarborough Borough Council (i.e. ground investigation, rainfall information and other data) however, the inherent variability of ground conditions allows only definition of the actual conditions at the location and depths of exploratory holes and samples/tests there from, while at intermediate locations conditions can only be inferred.

New information, changed practices or new legislation may necessitate revised interpretation of the report after the date of its submission.

Contents

Tables

Figures

Appendices

EXECUTIVE SUMMARY

In October 2008, Mouchel were instructed by Scarborough Borough Council (SBC) to provide services relating to an Analysis and Interpretation of Coastal Monitoring Data from sites (Runswick Bay, Whitby, Scalby Ness, Scarborough North and South Bay, Knipe Point, Killerby, Filey Town & Brigg and Filey Flat Cliffs) along the North Yorkshire coastline. Mouchel were required to review, analyse and interpret existing data, provided in electronic and hardcopy format, held by SBC for all the sites mentioned above. This data covered previous plans, monitoring records, strategies, ground investigations, borehole records, groundwater information, laboratory test data and geomorphological mapping.

The findings of this analysis and interpretation were presented in Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL"*, March 2009. This report detailed a definition and understanding of the problems at each site based upon the existing data, identified current and potential risks associated with ground movements at each site, a series of early warning signs and trigger levels which needed to be related to the findings of an Ongoing Monitoring regime, a series of appropriate response actions in relation to the findings of the above monitoring and recommended frequencies for the Ongoing Monitoring at each site related to the findings of the above monitoring.

Mouchel were appointed by SBC (in June 2009) under a three year term commission, to begin the subsequent Ongoing Analysis and Interpretation of Coastal Monitoring Data to assess the existing monitoring equipment installed at the sites previously mentioned above. Mouchel carried out a thorough re-appraisal of the whole coastal monitoring system to assess the true capability of the existing system to provide adequate warning of any potentially damaging ground movements. This is reported in the Condition Survey Report (Mouchel Report No. *721229/001/CSR/02/FINAL*, July 2009) which was commissioned by SBC in order to provide a factual account of the current condition of all monitoring equipment under SBC's responsibility. A walkover survey of the sites was carried out during June 2009, whereby existing monitoring installations were examined and photographed. The inspections recorded the depth of instruments, depth of blockages within instrument tubing, functioning and non-functioning slip indicator mandrels, broken stopcock covers, missing instrument caps and damaged installations and, also noted where installations were not located; normally due to dense vegetation cover. The Condition Survey has effectively determined which instruments are capable of providing meaningful data during the Ongoing Analysis Full Suite and Restricted Suite Monitoring regime.

This report describes and details the findings of the **Initial Full Suite** monitoring event undertaken, in July 2009, as recommended in the preceding report of March 2009.

1 Introduction

1.1 Terms of Reference

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 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 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.

1.2 Definition of Prolonged Periods of Rainfall

Rainfall data records have been made available to Mouchel by SBC and the Environment Agency. Data supplied is referenced to stations throughout the region in particular at Loftus, Fylingdales, Whitby School, Scarborough, Mulgrave Castle, Ruswarp and Knipe Point. Within Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL,* reference was made to 'periods of heavy and / or prolonged rainfall' in terms of considering such an event with respect to their effects upon slope stability.

This subject has been refined through analysis of rainfall data records made available by the Environment Agency and SBC and the definition of such an event has been quantified within the context of the effects of such an event on the present monitoring regime frequency. The analysis and definition of this subject is to be presented in a separate report entitled '*Definition of Heavy and / or Prolonged Rainfall* – 721229/004/GIR/001'.

1.3 Description of the Project

1.3.1 Monitoring

The extent of the monitoring area (Figure 1) considered for the Ongoing Monitoring analysis is along the full length of Scarborough Borough Council's coastline from Staithes to Speeton. 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 ongoing analyses are to be undertaken in accordance with the recommendations of monitoring frequency detailed in Mouchel Report No.

721228/001/GR/01/02/FINAL. Site specific monitoring regimes have been planned to take place at intervals of one, two, three and six months beginning in July 2009. As some of the monitoring events for particular sites coincide throughout the three years period, they have been grouped together to be undertaken as 'Full' and 'Restricted' Suites. Table 1 details the frequency of Full and Restricted Suite monitoring to be undertaken over this period.

Table 1 Frequency of Ongoing Monitoring

YEAR	MONTH	SCOPE of MONITORING
ONE, 2009	July (1)	Full Suite
	Aug, Sept, Oct, Nov (2,3,4,5)	Restricted Suite
	Dec (6)	Full Suite
	Feb, Apr (8,10)	Restricted Suite
	June (12)	Full Suite
TWO, 2010	Dec (6)	Full Suite
	June (12)	Full Suite
THREE, 2011	Dec (6)	Full Suite
	June (12)	Full Suite

The sites and frequency of monitoring covered by the Full Suite of ongoing analysis are:

Runswick Bay - Six monthly (Bi-annual) for three years.

Whitby West Cliff - 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. Install a single line of survey pins down slope at 5 metre intervals in line with BH2 and monitor these at monthly intervals for six months then reverting to bi-annual intervals for remaining two and a half years if no significant movement detected.

Scalby Ness - Three monthly intervals for three years. Install 4No. recession points along north west and north east facing crests and monitor every month following installation for six months and then bi-annually for remaining two and a half years.

Scarborough North Bay - Monthly intervals for six months then every two months until month twelve. Revert to bi-annual intervals for the remaining two years if no significant movement detected.

Scarborough South Cliff - Monthly intervals for six months then every two months until month twelve. Revert to bi-annual intervals for the remaining two years if no significant movement detected. Install a line of survey pins down slope at 5 metre intervals in line with E3, BH2 and H4 and monitor in line with instrumentation.

Filey Town and Brigg - Monthly intervals for six months then every two months until month twelve. Revert to bi-annual intervals for the remaining two years if no significant movement detected

Filey Flat Cliffs - Monthly intervals for six months and then every two months until month twelve. Revert to bi-annual intervals for the remaining two years if no significant movement detected.

The Restricted Suite of ongoing analysis includes sites at:

Whitby West Cliff - 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. Install a single line of survey pins down slope at 5 metre intervals in line with BH2 and monitor these at monthly intervals for six months then reverting to bi-annual intervals for remaining two and a half years if no significant movement detected.

Scarborough North Bay - Monthly intervals for six months then every two months until month twelve. Revert to bi-annual intervals for the remaining two years if no significant movement detected.

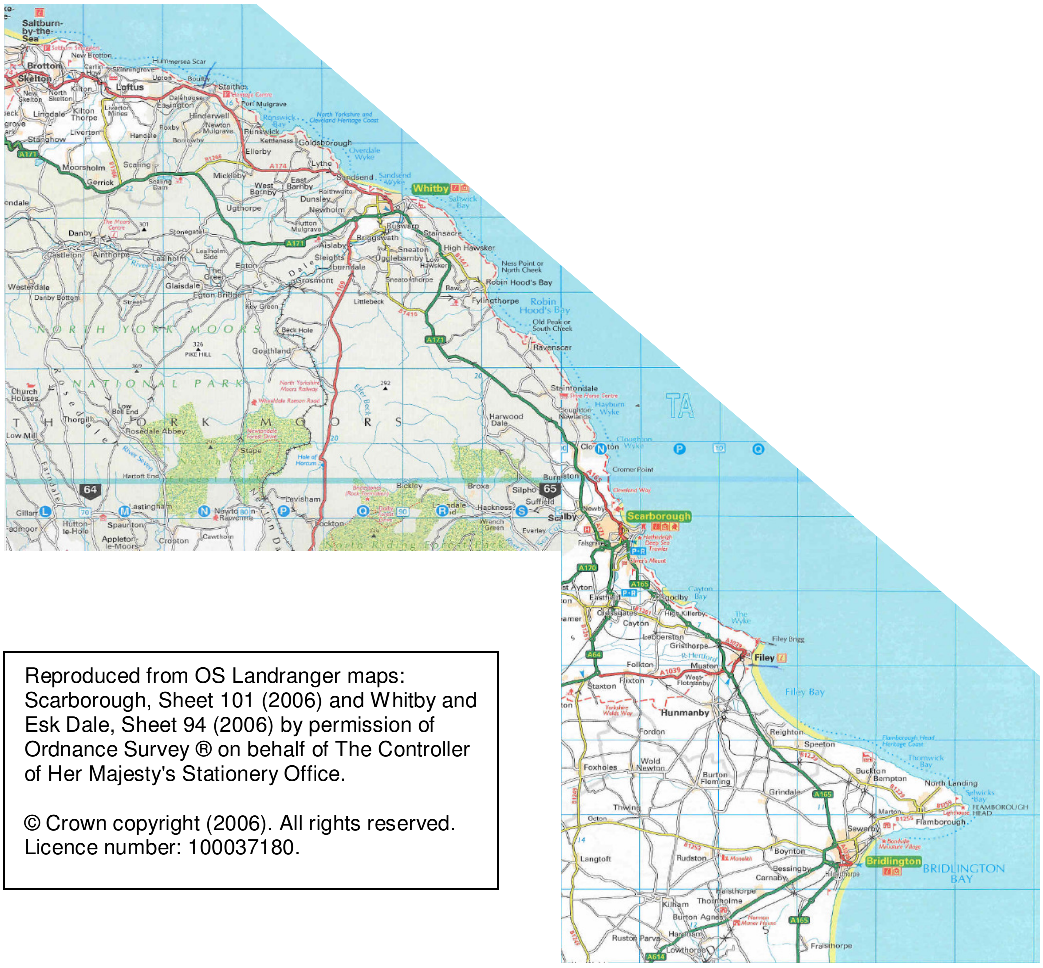
Scarborough South Cliff - Monthly intervals for six months then every two months until month twelve. Revert to bi-annual intervals for the remaining two years if no significant movement detected. Install a line of survey pins down slope at 5 metre intervals in line with H4, E3 and BH2 and monitor in line with instrumentation.

Filey Flat Cliffs - Monthly intervals for six months and then every two months until month twelve. Revert to bi-annual intervals for the remaining two years if no significant movement detected.

In addition to the sites detailed above, SBC have instructed Mouchel that Robin Hood's Bay site and additional borehole installations at Scarborough North Bay are to be included within successive analyses at some point in the future, while the site at Knipe Point has been removed from our remit until further notice. The recession point sites along with that at Killerby are similarly not under consideration for this analysis at the time of writing this report. The monitoring of instrumentation installed at Knipe Point is currently being undertaken by a third party on behalf of The National Trust.

Site location plans are presented as Figures 2 to 8 within the relevant chapters. Exploratory holes location plans illustrating the locations of instrumentation (automated piezometers, piezometers / slip indicators and inclinometer installations) are presented in Appendix A.

Figure 1 Scheme Location



Reproduced from OS Landranger maps: Scarborough, Sheet 101 (2006) and Whitby and Esk Dale, Sheet 94 (2006) by permission of Ordnance Survey ® on behalf of The Controller of Her Majesty's Stationery Office.

1.4 Previous Studies

Mouchel were required to review, analyse and interpret existing data, provided in electronic and hardcopy forms, held by SBC for all the sites mentioned in Section 1.1. This data covered previous plans, monitoring records, strategies, ground investigations, borehole records, groundwater information, laboratory test data and geomorphological mapping. A geotechnical interpretation and appraisal of these reports has been presented in Mouchel Report No. *721228/001/GR/01/02/FINAL*. An Arcview GIS layer has been produced with all the data and reports made available by SBC as well as reports produced by Mouchel. At each interval of monitoring, this layer is subsequently up-dated with the results of recorded monitoring data.

1.5 Instrumentation Monitoring Procedures

1.5.1 Inclinometers

The initial monitoring event for the Ongoing Monitoring Regime was initiated in July 2009 by a suitably qualified geotechnical engineer. Inclinometer instruments were initially investigated using a test probe (dummy) inclinometer on a 100 metre length cord. The test probe was lowered to the base of the tubing to prove its integrity. Where the instrument did not reach the base, due to a blockage or loss of tubing integrity, this depth was recorded and no further inclinometer data was recorded. Groundwater within the instrument tubing was measured and recorded using a dip meter. The measurement of groundwater in inclinometers is to continue throughout the term of the contract.

Although some inclinometer instruments are not monitored due to various failures / blockages within the installed tubing, these instruments are still being read with a dip meter to provide an indication of groundwater levels.

Where the instrument tubing was proved to be intact, a Vertical Digital Inclinometer probe (using a Bluetooth system (MkII) with a TDS Recon 200 PDA) was lowered to the base of the tubing, allow the probe to temperature stabilise and measurements were recorded at half metre intervals as the probe is raised. (The probe must be left at the base of the tube to allow for temperature stabilise prior to beginning data acquisition.) Readings of inclination were recorded in two directions (A0 and A180) within the inclinometer tube; A0 being the principal direction of interest in ground movements and A180 is in the opposite direction to this. B0 and B180 readings are also recorded automatically, B0 represents +90 degrees to the A0 direction and B180 is +90 degrees to A180 direction. The ‘B’ directions are not read manually as biaxial accelerometers read both the B axis during the survey.

This process was repeated in order to give two sets of ‘Baseline’ readings, which are averaged to give a more accurate ‘Baseline’ reading and create repeatable base data. Successive sets of readings are compared to the initial ‘Baseline’ readings to provide an indication of ground movements. The follow-up readings consist of recording a single set of readings in the A0 and A180 direction for each individual inclinometer instrument.

As further readings are recorded and processed, a graph of individual plots is built up over the monitoring period which will either display the effects of ground movement as successive plots deviate further from the baseline reading or, if no movements occur then the graphs will plot within millimetres of the baseline reading.

1.5.2 Piezometers and Slip Indicators

Groundwater levels within piezometer tubes have been recorded using a 50 metre length dip meter. A piezo tip emits an audible signal when it comes into contact with water, the depth to water is read off the tape and this is recorded. A comparison of the known installed instrument depth with the dipped depth gives an indication as to whether the tubing is clear to its base or is blocked / impeded at that depth.

Where slip indicators are present, they consist of one metre length mandrels resting at the base of piezometer tubes attached to a chord at ground level. The mandrels are lifted from base to top of the tube to indicate if any distortion or blockages have occurred within the tubing. Where mandrels were found to be jammed within the tubes, a reading was taken from ground level to the top of the mandrel to give an indication of the depth at which possible failure of the ground had taken place. Where this had occurred, the installation ceases to be of use since it has served its purpose in demonstrating failure or movement of the ground. Other installations continue to be read as the inserted mandrels function free of any obstacles. Hence, these instruments continue to demonstrate that no discernible ground movements are occurring.

Groundwater level readings recorded from inclinometer instruments should be viewed and interpreted with care. This type of installation is used for the monitoring of sub-surface ground movements and not groundwater monitoring. However, in conjunction with the correct instrumentation (piezometers), readings extracted from inclinometers can provide extra information on the nature of the prevailing groundwater regime at a site under observation.

1.6 Interpretation Views

1.6.1 Cumulative displacement

The most commonly used plot type is the Cumulative Displacement plot, which shows a displacement profile of a borehole. The plot shows the change in the position of the casing since the initial set of readings. If a user error has occurred during reading, the error will be accumulated through successive readings. If this is suspected, or anomalies occur, the data can be examined using the Incremental Displacement function.

1.6.2 Incremental Displacement

Another form of data presentation is the Incremental Displacement plot. This shows displacement over each probe length during the period since the initial reading sets. Unlike the Cumulative Displacement plot, operator error or instrument malfunction do not accumulate, as the data are plotted from reading to reading (i.e. delta previous not delta datum).

1.6.3 Absolute Position

This type of plot shows the absolute position of the casing and will determine the verticality of the installation. It does not pick up movement, but can be used for assessing installation error.

The Cumulative displacement plot is used to display results of inclinometer readings in-line with historic inclinometer data.

Previously recorded inclinometer data has not been amalgamated with that currently being collated as the various formats of the data would not produce a true, coherent interpretation of possible ground movements occurring at each of the sites being monitored. In some cases historic inclinometer monitoring data is not available (i.e. Filey and Filey Flat Cliffs) and hence comparisons with current data have not been possible. Where an interpretation of historic inclinometer data has been formulated, this will permit a continuum of interpretation to be developed. At this early stage of monitoring, there are no clear patterns of slope movements indicated by the ‘baseline’ readings. As more readings are taken, consecutive graphs may illustrate the nature and rate of any ground movements present at a site.

2 Runswick Bay

2.1 Site Location and Description

Runswick Bay is situated on the north east coast of England some 16 km north west of Whitby town at NGR NZ 800 160. 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 2 km 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 - Runswick Bay

2.1.1 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:

- 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.

- 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.

- Ings End – this area extends from south of Nettledale Beck to Limekiln Beck a distance of approximately 500 metres 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.

2.1.2 Site Walk-over

An initial site walkover was undertaken by a geotechnical engineer from Mouchel on 28th November 2008 and in early June 2009 as part of the Condition Survey. The Condition Survey (Mouchel Report No. 721229/001/CSR/02/FINAL, July 2009) was conducted in order to provide factual information on the existence, condition and functionality of the existing installations. The instruments were recorded as being in good working order and as such, they were deemed to be of use in providing useful ongoing data for recording ground movements where this phenomenon is occurring.

2.1.3 Topography and Geomorphology

The village of Runswick is situated at the foot of a steep, 80 metre 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.

2.1.4 *Existing Information*

A number of reports were provided by SBC for consultation, these are detailed in Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL, pp9-10.* Additional reports were provided by SBC for further consultation by Mouchel for the Ongoing Analysis. All of this data has been placed on an Arcview GIS layer for ease of use and availability.

2.2 Stratigraphy

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 2 Geological Stratigraphy of Runswick Bay

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

2.3 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.

2.4 Instrumentation

2.4.1 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 land-slipping is evidence that the permanent works which 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.

2.4.2 History of Monitoring

Data provided by SBC indicated, from reports, that there had 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 were derived from numerous records held by SBC.

Coastal 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 20 metres within bored pile portal frame shear keys. These instruments had been periodically monitored from this date onwards although monitoring records were only available from March 2000 to July 2002 and for 20th November 2008. The instruments may have been monitored through the intervening periods although data was not made available to confirm this.

2.5 Monitoring Regime

2.5.1 Recommended Monitoring Regime

As a consequence of the analysis and interpretation of monitoring data and reports made available by SBC, a regime of future monitoring was formulated. These recommendations have been reported in Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL.*

The recommendations for Runswick Bay were that a regime of regular monitoring and inspection be undertaken at six monthly intervals (bi-annually). This should be carried out over a period of three years to retrieve long term data for analysis in order to determine any seasonal patterns of rainfall, ground water levels and ground movements. The monitoring encompasses recording readings of inclination in two directions (A0 and A180) within the inclinometer tubes and also monitoring groundwater levels.

2.5.2 Ongoing Monitoring Regime

The ongoing monitoring regime was initialised in July 2009 and follows that detailed in Section 2.5.1, above. Taking into consideration the findings of the *Condition Survey Report,* the monitoring regime consists of the existing inclinometers (A001, A002, A003 and A004) located along the edge of the main access road leading down into Runswick village. The instruments were monitored using a Vertical Digital Bluetooth Inclinometer system (MkII) and a TDS Recon 200 PDA. Groundwater was measured using a dip meter.

2.5.3 Ongoing Monitoring Results

Inclinometer Readings

Inclinometer readings have been undertaken in accordance with the procedures detailed in Section 1.4 of this report. The initial monitoring event recorded two 'Baseline' readings which are averaged to give an accurate starting point for successive readings to be built upon.

The read-out produces a straight line of points relating the depth, from bottom to top of the borehole, to the inclination of the tube at that depth. Successive readings may produce a line which deviates from this which would illustrate the resulting cumulative amount of movement that has taken place since the initial reading.

The 'Baseline' readings are presented in Appendix B of this report.

Groundwater Readings

Groundwater levels were recorded during the Condition Survey (16th June 2009) and the initial set of Ongoing monitoring readings (9th July 2009). A comparison of the two sets of readings show very little change in groundwater levels, the largest difference being a rise of 70mm recorded in A004 (BH3). The fluctuating levels are probably due to a response in changing groundwater levels. Groundwater readings are presented in Appendix C, *Groundwater Monitoring Data*.

2.6 Conclusions

Inclinometer instrumentation was installed within the piles of a portal frame shear key system which was constructed as part of remedial works to restrict ground movements within the Runswick Bay area. Inclinometers were installed in piles in order to measure shear stresses within the piles caused by ground movements. Within Report 136 (from SBC) reference has been made to the determination of the piles response to loading from successive inclinometer readings. It has not been stated how this was to be done or how it was to be achieved. To date, Mouchel Ltd have been made aware by the Client that this information is not available and therefore no further comment can be made relating to this. Hence, initial and successive inclinometer readings are related to any general ground movements indicated by instrument readings.

The results of monitoring the inclinometers have so far shown no movement. The initial monitoring event recorded two 'Baseline' readings which are averaged to give an accurate starting point for successive readings to be built upon.

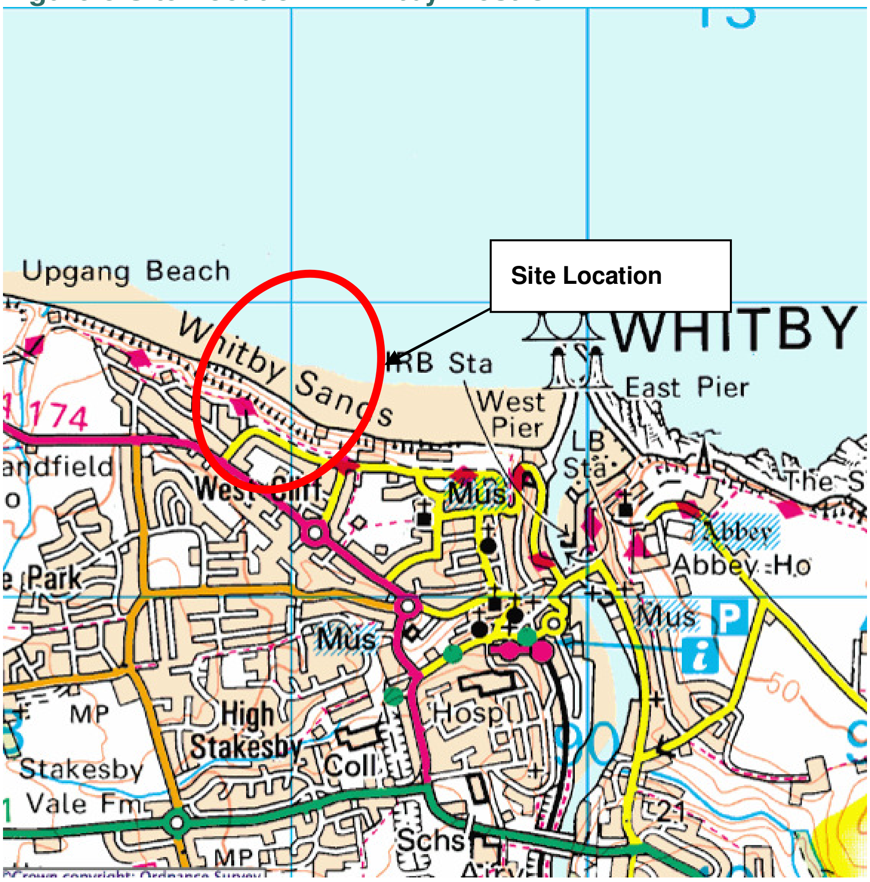
3 Whitby West Cliff

3.1 Site Location and Description

Whitby is located on the north east coast of England approximately 30 miles 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 40-45 metres at slope angles of 25 to 35 degrees. Set back approximately 10 metres 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 3 Site Location – Whitby West Cliff



3.1.1 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.

3.1.2 Site Walk-over

A site walkover was conducted by a geotechnical engineer from Mouchel on 28th November 2008 and in early June 2009 as part of a Condition Survey. The Condition Survey (Mouchel Report No. 721229/001/CSR/02/FINAL, July 2009) was conducted in order to provide factual information on the existence, condition and functionality of the inclinometer installation. The instrument was recorded as being in good working order and as such, was deemed to be of use in providing useful ongoing data for recording ground movements where this phenomenon is occurring.

3.1.3 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 40-45 metres 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.

3.1.4 Existing Information

A number of reports were provided by SBC for consultation, these are detailed in Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL, pp33-34.* Additional reports were presented by SBC for further consultation for the Ongoing Analysis. All of this data has been placed on an Arcview GIS layer for ease of use and availability.

3.2 Stratigraphy

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 5 metres in thickness. The underlying solid geology is indicated as the Middle Jurassic Scalby Formation, consisting of limestone, sandstone and mudstone.

Table 3 Geological Stratigraphy of Whitby

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

3.3 Groundwater Regime

Hydrology

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.

3.4 Instrumentation

3.4.1 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 known 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 2 metres in depth and up to 5 metres 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.

3.4.2 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.

BH2 monitoring data detailed in correspondence (dated 1st August 2006) for readings from 27th November 2000 to 24th July 2006.

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

‘Baseline’ readings provided for BH2 taken on 20th November 2008.

3.5 Monitoring Regime

3.5.1 Recommended Monitoring Regime

As a consequence of the analysis and interpretation of monitoring data and reports made available by SBC, a regime of future monitoring was formulated. These recommendations have been reported in Mouchel Report “*Analysis and Interpretation of Coastal Monitoring Data” 721228/001/GR/01/02/FINAL.*

The recommendations for Whitby West Cliff were that a regime of regular monitoring and inspection should be undertaken at monthly intervals for six months then reverting to bi-annual intervals for the remaining two and a half years if no significant movement is detected. 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. The monitoring encompasses recording readings of inclination in two directions (A0 and A180) within the inclinometer tube and also recording groundwater levels.

It was further recommended that a line of survey pins be set-out at regular 5 metre intervals down the line of the slope from beyond the crest and in line with the existing inclinometer (BH2). The survey stations are to be measured initially at a monthly frequency for six months to build up base data. If there is no significant movement (<5 mm) between each survey point, (between each monitoring event) then the frequency can be continued in line with the inclinometer monitoring i.e. on a bi-annual frequency.

3.5.2 Ongoing Monitoring Regime

The ongoing monitoring regime was initialised in July 2009 and follows that detailed in Section 3.5.1, above. Following on from the findings of the *Condition Survey Report*, monitoring is to consist of a single inclinometer (B001 / BH2) located within a path near the base of the coastal slope of West Cliff and the monitoring of surveying points. Groundwater was measured using a dip meter.

3.5.3 Monitoring Results

Inclinometer Readings

Inclinometer readings have been undertaken in accordance with the procedures detailed in Section 1.4 of this report. Two sets of readings were recorded in order to develop an accurate 'Baseline' reading from which all successive readings are referenced to. The read-out produces a straight line of points relating the depth, from bottom to top of the borehole, to the inclination of the tube at that depth. Successive readings may produce a line which deviates from this which would illustrate the resulting cumulative amount of movement that has taken place since the initial reading. The 'Baseline' readings are presented in Appendix B of this report.

Groundwater Readings

Groundwater levels were recorded during the Condition Survey (16th June 2009) and the initial set of Ongoing monitoring readings (9th July 2009). The two sets of readings show a fluctuation of 30mm occurring between the two dates, representing changes in tidal levels. Groundwater readings are presented in Appendix C, *Groundwater Monitoring Data*.

Survey Point Readings

A single line of 6 No. survey pins were set out from the crest extending down slope to borehole BH2 in order to supplement the monitoring of any slope movements at these locations. The initial readings from the survey points are presented in Appendix D.

3.6 Conclusions

The initial monitoring event recorded two ‘Baseline’ readings which are averaged to give an accurate starting point for successive readings to be built upon. The results of monitoring the inclinometers have so far shown no ground movement.

Initial readings of the recently installed survey stations have been recorded. At this point, they show no evidence of ground movements occurring. Further readings may provide data against which to make a comparison and provide evidence of ground movement or otherwise.

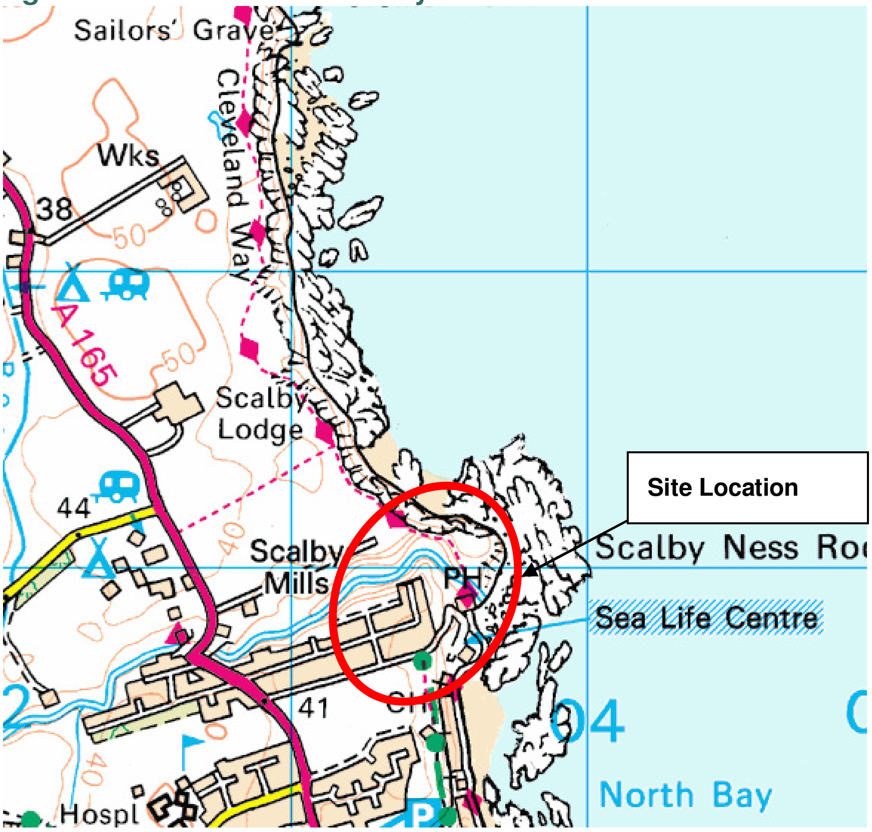
4 Scalby Ness

4.1 Site Location and Description

Scalby Ness forms a broad promontory to the north of Scarborough North Bay, approximately 3 km 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 25-30 m 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 4 Site Location – Scalby Ness



4.1.1 *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.

4.1.2 Site Walk-over

A site walkover was conducted by a geotechnical engineer from Mouchel on 28th November 2008 and in early June 2009 as part of the Condition Survey. The Condition Survey (Mouchel Report No. 721229/001/CSR/02/FINAL, July 2009) was conducted in order to provide factual information on the existence, condition and functionality of the existing installations.

4.1.3 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 30 metres 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 1 metre 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.

4.1.4 Existing Information

A number of reports were provided by SBC for consultation, these are detailed in Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL, p50.* Additional reports were presented by SBC for further consultation for the Ongoing Analysis. All of this data has been placed on an Arcview GIS layer for ease of use and availability.

4.2 Stratigraphy

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 4 Geological Stratigraphy of Scalby

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

4.3 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.

4.4 Instrumentation

4.4.1 Definition of Existing Problems

It has been known that 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.

4.4.2 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. Monitoring data for inclinometers I1, I3 and 2I is available from Report No. 197 with further readings, in gINT format, available for June 2004 to 2006.

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

Report No. 82 details the piezometer installation in BH114 at 40.54m bgl. Only three piezometer readings are recorded from 11th October to 29th November 2006; water levels of 32.92m to 32.85m depth.

A photographic record of the sites covering Scalby Ness 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.

4.5 Monitoring Regime

4.5.1 Recommended Monitoring Regime

As a consequence of the analysis and interpretation of monitoring data and reports made available by SBC, a regime of future monitoring was formulated. These recommendations have been reported in Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL.*

The recommendations for Scalby Ness were that a regime of regular monitoring and inspection be undertaken at three monthly intervals. Monitoring is to be carried out over a period of three years to retrieve long term data for analysis in order to determine any seasonal patterns of rainfall, ground water levels and ground movements. The monitoring encompasses recording readings of inclination in two directions (A0 and A180) within the inclinometer tubes and also monitoring groundwater levels within inclinometers and piezometers.

4.5.2 Ongoing Monitoring Regime

The ongoing monitoring regime was initialised in July 2009 and follows that detailed in Section 4.5.1, above. Following on from the findings of the *Condition Survey Report*, monitoring at Scalby consists of 3no. inclinometers (I1, I2 and I3) and 2no. piezometers (B6 and B9) located within the inner headland of Scalby Ness. The monitoring of the automated piezometers (P1, P2, P3 and P4) is currently being undertaken by SBC. The inclinometers were monitored using a Vertical Digital Bluetooth Inclinometer system (MkII) with a TDS Recon 200 PDA and piezometers were monitored using a dip meter.

The reduced monitoring regime is based upon the findings of the *Condition Survey Report.* This detailed 6no. piezometers recommended for replacement due to differences in dipped and installed depths and, an inclinometer (Sn1) and a piezometer (BH114) as not being located due to dense vegetation and hence not available to monitor. Following vegetation clearance and location, these instruments are to be brought into the monitoring regime.

4.5.3 Ongoing Monitoring Results

Inclinometer Readings

Inclinometer readings have been undertaken in accordance with the procedures detailed in Section 1.4 of this report. Two sets of readings were recorded in order to develop an accurate 'Baseline' reading from which all successive readings are referenced to. The 'Baseline' readings are presented in Appendix B of this report.

Groundwater Readings

Groundwater levels were recorded during the Condition Survey (16th June 2009) and the initial set of Ongoing monitoring readings (16th July 2009). Readings for I2 show a maximum decrease in ground water level of -370mm over this period and no change was indicated in B9. Groundwater readings are presented in Appendix C, *Groundwater Monitoring Data*.

Survey Point Readings

Survey pins were set out at four locations on the upper plateau area around the existing houses, some distance from the slope crest. Measurements are taken, in the same direction at each event, from these points to the slope edge in order to monitor cliff recession rates and slope movements at these locations. Initial readings are presented in Appendix D.

4.6 Conclusions

The initial monitoring event recorded two 'Baseline' readings which are averaged to give an accurate starting point for successive readings to be built upon. The results of monitoring the inclinometers have so far shown no ground movement. The inclinometer read-out produces a straight line of points relating the depth, from bottom to top of the borehole, to the inclination of the tube at that depth. Successive readings may produce a line which deviates from this which would illustrate the resulting cumulative amount of movement that has taken place since the initial readings.

Initial readings of the positions of the installed survey stations have been recorded. So far there is no evidence of ground movements occurring.

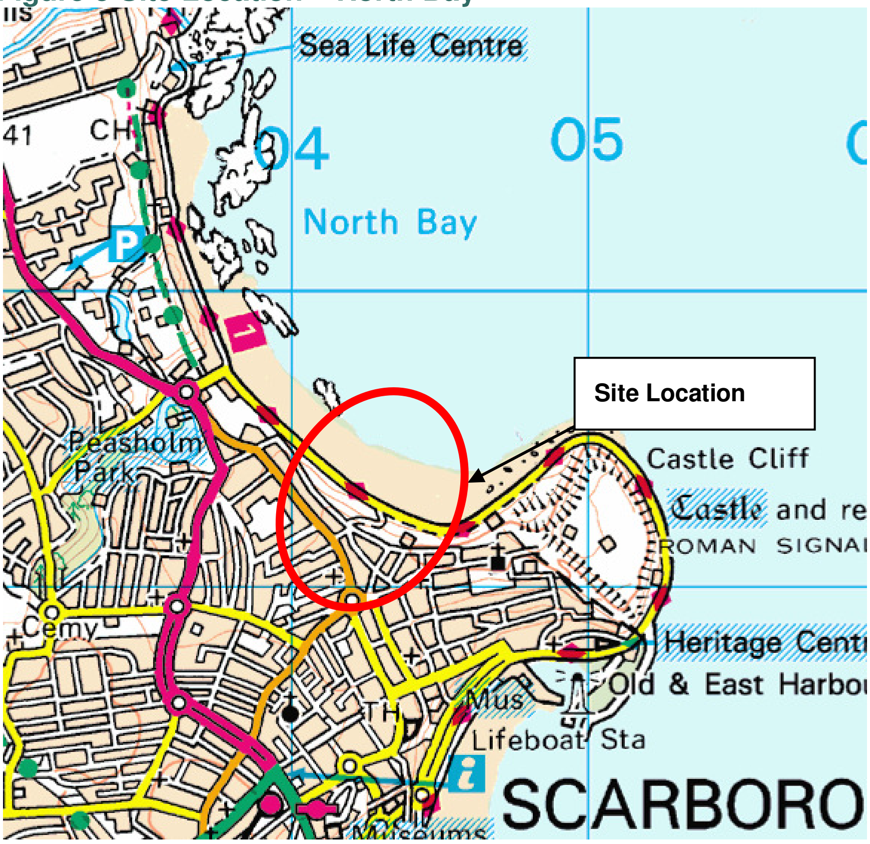
Groundwater level readings would seem to reflect the prevailing groundwater regime active over the site during the monitoring period.

5 Scarborough North Bay

5.1 Site Location and Description

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 5 Site Location – North Bay



5.1.1 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.

5.1.2 Site Walk-over

A site walkover was conducted by a geotechnical engineer from Mouchel on 28th November 2008 and in early June 2009 as part of the Condition Survey. The Condition Survey (Mouchel Report No. 721229/001/CSR/02/FINAL, July 2009) was conducted in order to provide factual information on the existence, condition and functionality of the four inclinometer installations. The instruments were recorded as being in good working order and as such, they were deemed to be of use in providing useful ongoing data for recording ground movements where this phenomenon is occurring.

5.1.3 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.

5.1.4 Existing Information

A number of reports were provided by SBC for consultation, these are detailed in Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL, pp67-68.* Additional reports were presented by SBC for further consultation for the Ongoing Analysis. All of this data has been placed on an Arcview GIS layer for ease of use and availability.

5.2 Stratigraphy

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 strata generally dip at an angle of 7 degrees in a south easterly direction.

Table 5 Geological Stratigraphy of Scarborough North Bay

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

5.3 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.

5.4 Instrumentation

5.4.1 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.

5.4.2 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 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 available at this time were not located.

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 North Bay 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.

5.5 Monitoring Regime

5.5.1 Recommended Monitoring Regime

As a consequence of the analysis and interpretation of monitoring data and reports made available by SBC, a regime of future monitoring was formulated. These recommendations have been reported in Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL.*

Due to the lack of valid continuous data from the installed piezometers, it has been recommended that piezometer monitoring is reinstated. Inclinometer and piezometer monitoring is to 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) for the remaining two years. Monitoring is to be carried out over a period of three years to retrieve long term data for analysis in order to determine any seasonal patterns of rainfall, ground water levels and ground movements. The monitoring encompasses recording readings of inclination in two directions (A0 and A180) within the inclinometer tubes and also monitoring groundwater levels within the inclinometer and piezometers.

5.5.2 Ongoing Monitoring Regime

The ongoing monitoring regime was initialised in July 2009 and follows that detailed in Section 5.5.1, above. Taking the findings of the *Condition Survey Report* into account, monitoring consists of groundwater readings from 3no. piezometers (located within the grounds of The Holms and 2no. inclinometers located atop the cliffs above The Holms.

The reduced monitoring regime is based upon the findings of the *Condition Survey Report.* This detailed two inclinometers and a piezometer (L11, L12 and N2) blocked at varying depths and two inclinometers (L4 and L6) not located due to dense vegetation and hence not available to monitor. Following vegetation clearance these instruments (L4 and L6) are to be brought into the monitoring regime.

5.5.3 *Ongoing Monitoring Results*

Inclinometer Readings

Inclinometers L11 and L12 were proved to be blocked at 8.30m and 12.50m, respectively hence, readings have not been recorded from the inclinometers at this site.

Groundwater Readings

Groundwater levels were recorded during the Condition Survey (16th June 2009) and the initial set of Ongoing monitoring readings (9th July 2009). The two sets of readings show a great reduction in piezometer L1 illustrating the effects of tidal influence upon this instrument. The remaining instruments show very little change in groundwater levels, the largest difference being -510mm recorded in L11, reflecting the overall groundwater regime at this site. Groundwater readings are presented in Appendix C, *Groundwater Monitoring Data*.

5.6 Conclusions

The initial monitoring event recorded two 'Baseline' readings which are averaged to give an accurate starting point for successive readings to be built upon. This produces a straight line of points relating the depth, from bottom to top of the borehole, to the inclination of the tube at that depth. The results of monitoring the inclinometers have so far shown no ground movement. Successive readings may produce a line which deviates from this that would illustrate the resulting cumulative amount of movement that has taken place since the initial readings.

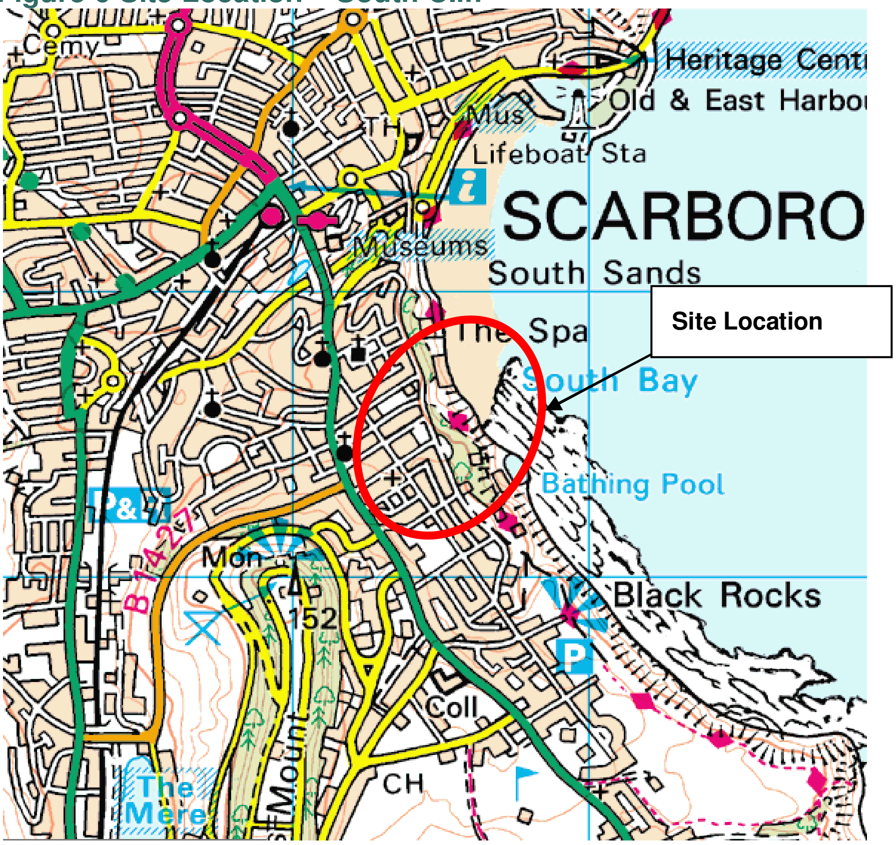
Groundwater results have so far shown the reactive nature of L1 to tidal fluctuations and readings in the remaining instruments would seem to reflect the prevailing groundwater regime at this site.

6 Scarborough South Cliff

6.1 Site Location and Description

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 6 Site Location – South Cliff



6.1.1 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.

6.1.2 Site Walk-over

A site walkover was conducted by a geotechnical engineer from Mouchel on 27th November 2008 and in early June 2009 as part of the Condition Survey. The Condition Survey (Mouchel Report No. 721229/001/CSR/02/FINAL, July 2009) was conducted in order to provide factual information on the existence, condition and functionality of the four inclinometer installations. The instruments were recorded as being in good working order and as such, they were deemed to be of use in providing useful ongoing data for recording ground movements where this phenomenon is occurring.

6.1.3 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.

6.1.4 Existing Information

A number of reports were provided by SBC for consultation, these are detailed in Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL, pp80-81.* Additional reports were presented by SBC for further consultation for the Ongoing Analysis. All of this data has been placed on an Arcview GIS layer for ease of use and availability.

6.2 Stratigraphy

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 36-76 metres 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 6 Geological Stratigraphy of Scarborough South Cliff

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

6.3 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.

6.4 Instrumentation

6.4.1 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.

6.4.2 History of Monitoring

Within the various garden areas of South Cliffs, 12 no. inclinometers and 22 no. 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 from the instrument installation date until late September 2006. A single set of readings (‘baseline’) are available for 24-25 July 2006 and November 2008.

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 5 no. 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 installed survey pins (C21A, B and C) covering the period 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.

6.5 Monitoring Regime

6.5.1 Recommended Monitoring Regime

As a consequence of the analysis and interpretation of monitoring data and reports made available by SBC, a regime of future monitoring was formulated. These recommendations have been reported in Mouchel Report “*Analysis and Interpretation of Coastal Monitoring Data” 721228/001/GR/01/02/FINAL.*

The recommendations for South Cliff were that a regular monitoring and inspection regime should be undertaken at monthly intervals for a period of six months and then every two months until month twelve. If no significant movement was revealed during this twelve month period then monitoring should revert to six monthly intervals (bi-annually) for a further two years.

Monitoring is to be carried out over a period of three years to retrieve long term data for analysis in order to determine any seasonal patterns of rainfall, ground water levels and ground movements. The monitoring encompasses recording readings of inclination in two directions (A0 and A180) within the inclinometer tubes and also monitoring groundwater levels.

6.5.2 Ongoing Monitoring Regime

The ongoing monitoring regime was initialised in July 2009 and follows that detailed in Section 6.5.1, above. Following on from the findings of the *Condition Survey Report*, monitoring consists of five inclinometers, fourteen piezometers and three lines of survey pins (associated with boreholes H4, E3 and BH2) located within the gardens of South Cliff. The inclinometers were monitored using a Vertical Digital Bluetooth Inclinometer system (MkII) with a TDS Recon 200 PDA and piezometers were monitored using a dip meter.

The reduced monitoring regime is based upon the findings of the *Condition Survey Report.* This detailed 6 no. inclinometers (I1, H4, H6, E3, E5, D1) and 8 no. piezometers / slip indicators (H1, G1, F5, F3, F1, E1, E4, BH1) blocked at varying depths. Also, inclinometer A1 was reported as not being located due to dense vegetation and hence not available to monitor. Following vegetation clearance this instrument is to be introduced into the monitoring regime.

6.5.3 Ongoing Monitoring Results

The monitoring regime, based upon the findings of the *Condition Survey Report,* detailed five inclinometers and fourteen piezometers to be in a serviceable condition and have been included in the monitoring regime.

Inclinometer Readings

Inclinometer readings have been undertaken in accordance with the procedures detailed in Section 1.4 of this report. Two sets of readings were recorded in the A0 and A180 directions in order to develop an accurate 'Baseline' reading from which all successive readings are referenced to. The read-out produces a straight line of points relating the depth, from bottom to top of the borehole, to the inclination of the tube at that depth. Successive readings may produce a line which deviates from this which would illustrate the resulting cumulative amount of movement that has taken place since the initial reading. The 'Baseline' readings are presented in Appendix B of this report.

Groundwater Readings

Groundwater levels were recorded during the Condition Survey (16th June 2009) and the initial set of Ongoing monitoring readings (15th July 2009). A comparison of the two sets of readings generally shows very little change in the groundwater levels over this period, the largest difference being -900mm recorded in H5. Exceptions to these readings are those recorded from AA10 (F2) and AA05 (E5) where groundwater level changes were -4570mm and +9660mm, respectively. These readings are possibly affected by the prevailing tidal regime at this site. Groundwater readings are presented in Appendix C, *Groundwater Monitoring Data*.

Survey Point Readings

Three lines of survey pins were set out from the crest extending down slope to boreholes H4 and E3 and, from BH2 extending down slope in order to supplement the monitoring of slope movements at these locations. Initial readings are presented in Appendix D.

6.6 Conclusions

The initial monitoring event recorded two 'Baseline' readings which are averaged to give an accurate starting point for successive readings to be built upon. The inclinometer read-out produces a straight line of points relating the depth, from bottom to top of the borehole, to the inclination of the tube at that depth. The results of monitoring the inclinometers have so far shown no ground movement. Successive readings may produce a line which deviates from this which would illustrate the resulting cumulative amount of movement that has taken place since the initial readings.

The results of groundwater monitoring has so far showed very little variations over a months' period, although within two inclinometers there has been differences of between 5.0 and 9.66metres recorded over a similar period. Ignoring the two exceptional readings taken in inclinometers, in general the groundwater monitoring results to-date reflect fluctuations in the prevailing groundwater regime within the various horizons in which piezometers have been installed.

Survey data recorded from the three installed lines of survey pins have yet to reveal any ground movements.

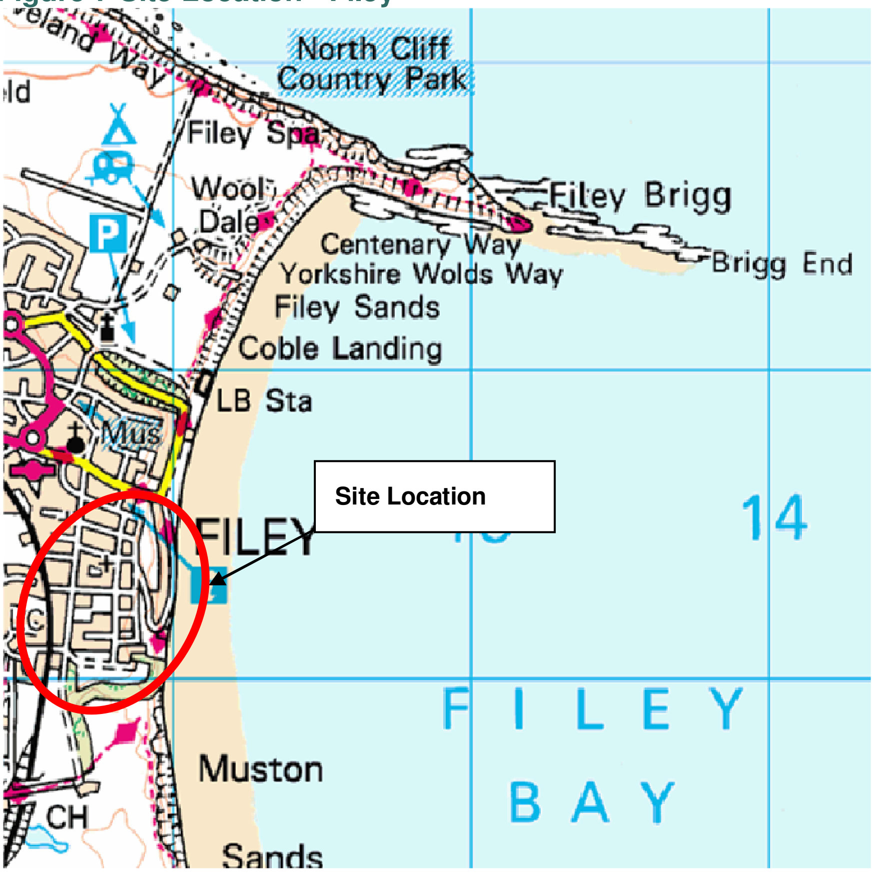
7 Filey Town

7.1 Site Location and Description

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 7 Site Location - Filey



7.1.1 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.

7.1.2 Site Walk-over

A site walkover was conducted by a geotechnical engineer from Mouchel on 27th November 2008 and in early June 2009 as part of the Condition Survey. The Condition Survey (Mouchel Report No. 721229/001/CSR/02/FINAL, July 2009) was conducted in order to provide factual information on the existence, condition and functionality of the four inclinometer installations. The instruments were recorded as being in good working order and as such, they were deemed to be of use in providing useful ongoing data for recording ground movements where this phenomenon is occurring.

7.1.3 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.

7.1.4 *Existing Information*

A number of reports were provided by SBC for consultation, these are detailed in Mouchel Report *"Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL, pp107-108.* Additional reports were presented by SBC for further consultation for the Ongoing Analysis. All of this data has been placed on an Arcview GIS layer for ease of use and availability.

7.2 Stratigraphy

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 7 Geological Stratigraphy of Filey

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

7.3 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.

7.4 Instrumentation

7.4.1 *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 down over the slopes from plateaux north and south of the ravine.

7.4.2 *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.

7.4.3 *Recommended Monitoring Regime*

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.

7.5 Monitoring Regime

7.5.1 *Recommended Monitoring Regime*

As a consequence of the analysis and interpretation of monitoring data and reports made available by SBC, a regime of future monitoring was formulated.

These recommendations have been reported in Mouchel Report "Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL.

The recommendations for Filey were that a regular monitoring and inspection regime should be undertaken at six monthly intervals (bi-annually) for a period of three years to retrieve long term data for analysis to determine any seasonal patterns of rainfall, ground water levels and ground movements. The monitoring encompasses recording readings of inclination in two directions (A0 and A180) within the inclinometer tubes and also monitoring groundwater levels.

7.5.2 Ongoing Monitoring Regime

The ongoing monitoring regime was initialised in July 2009 and follows that detailed in Section 7.5.1, above. Following on from the findings of the *Condition Survey Report*, monitoring consists of a single inclinometer and a piezometer located within Glen Gardens above the coastal slopes of Royal Parade. Piezometer instruments were located south of and also at the base of Martin's Ravine and on Royal Parade below Glen Gardens. The inclinometer was monitored using a Vertical Digital Bluetooth Inclinometer system (MkII) with a TDS Recon 200 PDA and piezometers were monitored using a dip meter.

The reduced monitoring regime is based upon the findings of the *Condition Survey Report.* This detailed an inclinometer (BH6) and a piezometer (BH4) as not being located due to dense vegetation and hence not available for monitoring. Following vegetation clearance these instruments are to be introduced into the monitoring regime.

7.5.3 Ongoing Monitoring Results

Inclinometer Readings

Inclinometer readings for BH3 have been undertaken in accordance with the procedures detailed in Section 1.4 of this report. Two sets of readings were recorded in the A0 and A180 directions in order to develop an accurate 'Baseline' reading from which all successive readings are referenced to. The read-out produces a straight line of points relating the depth, from bottom to top of the borehole, to the inclination of the tube at that depth. Successive readings may produce a line which deviates from this which would illustrate the resulting cumulative amount of movement that has taken place since the initial reading. The 'Baseline' readings are presented in Appendix B of this report.

Groundwater Readings

Groundwater levels were recorded during the Condition Survey (16th June 2009) and the initial set of Ongoing monitoring readings (8th July 2009). The two sets of readings show very little change over this period. The greatest difference of -60mm, recorded in BH1, is indicative of a decrease in the groundwater level over this period. However, within BH5B a difference of +10mm was recorded and indicates the tidal influence upon the water level in this instrument. Groundwater readings are presented in Appendix C, *Groundwater Monitoring Data*.

7.6 Conclusions

The initial monitoring event recorded two 'Baseline' readings which are averaged to give an accurate starting point for successive readings to be built upon. The results of monitoring the inclinometers have so far shown no ground movement. The inclinometer read-out produces a straight line of points relating the depth, from bottom to top of the borehole, to the inclination of the tube at that depth. Successive readings may produce a line which deviates from this which would illustrate the resulting cumulative amount of movement that has taken place since the initial readings.

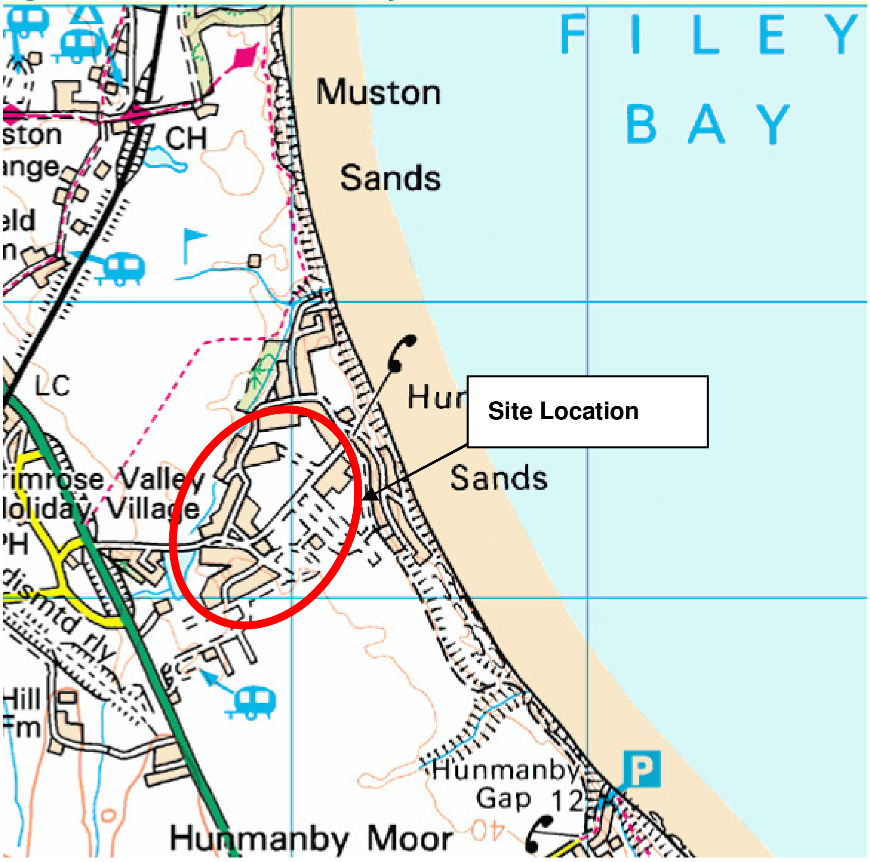
Groundwater levels at this site illustrate the variations prevalent in the groundwater regime at Filey. However, BH5B is probably influenced by tidal fluctuations.

8 Filey Flat Cliffs

8.1 Site Location and Description

Filey Flat Cliffs is situated near Primrose Valley Holiday Park, 2 km 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 8 Site Location – Filey Flat Cliffs



8.1.1 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.

8.1.2 Site Walk-over

A site walkover was conducted by a geotechnical engineer from Mouchel on 27th November 2008 and in early June 2009 as part of the Condition Survey. The Condition Survey (Mouchel Report No. 721229/001/CSR/02/FINAL, July 2009) was conducted in order to provide factual information on the existence, condition and functionality of the four inclinometer installations. The instruments were recorded as being in good working order and as such, they were deemed to be of use in providing useful ongoing data for recording ground movements where this phenomenon is occurring.

8.1.3 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.

8.1.4 Existing Information

A number of reports were provided by SBC for consultation, these are detailed in Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL, p117.* Additional reports were presented by SBC for further consultation for the Ongoing Analysis. All of this data has been placed on an Arcview GIS layer for ease of use and availability.

8.2 Stratigraphy

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 8 Geological Stratigraphy of Filey Flat Cliffs

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

8.3 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.

8.4 Instrumentation

8.4.1 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.

8.4.2 History of Monitoring

During a 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 Figure No. 8. Following a review of data provided 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.

8.5 Monitoring Regime

8.5.1 Recommended Monitoring Regime

As a consequence of the analysis and interpretation of monitoring data and reports made available by SBC, a regime of future monitoring was formulated. These recommendations have been reported in Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL.* The recommendations for Flat Cliffs were that a regular monitoring and inspection regime should be undertaken at monthly intervals for a period of six months and then every two months until month twelve. If no significant movement was revealed during this twelve month period then monitoring should revert to six monthly intervals (bi-annually) for a further two years.

Monitoring is to be carried out over a period of three years in order to retrieve long term data for analysis determine any seasonal patterns of rainfall, ground water levels and ground movements. The monitoring encompasses recording readings of inclination in two directions (A0 and A180) within the inclinometer tubes and also monitoring groundwater levels.

8.5.2 Ongoing Monitoring Regime

The ongoing monitoring regime was initialised in July 2009 and follows that detailed in Section 8.5.1, above. Following on from the findings of the *Condition Survey Report*, monitoring is to consist of a single inclinometer (BB02/A2) located on the landside of the main access road down through Flat Cliffs and 3 no. piezometers (A3, B1 and D1), one located within Flat Cliffs and the remainder located above the village beyond the cliff crest. The inclinometer was monitored using a Vertical Digital Bluetooth Inclinometer system (MkII) with a TDS Recon 200 PDA and piezometers were monitored using a dip meter.

The reduced monitoring regime is based upon the findings of the *Condition Survey Report* which detailed inclinometer BB01 (D2) as being blocked at 14.20m, 8 metres short of the installed depth. Hence, due to the discrepancy between the two depths this instrument was not monitored and has been recommended for replacement.

8.5.3 Ongoing Monitoring Results

Inclinometer Readings

Inclinometer readings for BB02 (A2) have been undertaken in accordance with the procedures detailed in Section 1.4 of this report. Two sets of readings were recorded in the A0 and A180 directions in order to develop an accurate 'Baseline' reading from which all successive readings are referenced to. The read-out produces a straight line of points relating the depth, from bottom to top of the borehole, to the inclination of the tube at that depth. Successive readings may produce a line which deviates from this which would illustrate the resulting cumulative amount of movement that has taken place since the initial reading. The 'Baseline' readings are presented in Appendix B of this report.

Groundwater Readings

Groundwater levels were recorded during the Condition Survey (16th June 2009) and the initial set of Ongoing monitoring readings (8th July 2009). The two sets of readings showed variations in groundwater levels within boreholes of between -520mm BB02 (A2), -390mm (D1), -40mm (A3) and +80mm (B1). Borehole BB01 (D2) was recorded as dry on each occasion. Groundwater readings are presented in Appendix C, *Groundwater Monitoring Data*.

8.6 Conclusions

The initial monitoring event recorded two 'Baseline' readings which are averaged to give an accurate starting point for successive readings to be built upon. The results of monitoring the inclinometers have so far shown no ground movement. The inclinometer read-out produces a straight line of points relating the depth, from bottom to top of the borehole, to the inclination of the tube at that depth. Successive readings may produce a line which deviates from this which would illustrate the resulting cumulative amount of movement that has taken place since the initial readings.

Historical inclinometer data has not been available for the inclinometers at this site from the installation dates of A2 and D2 up to the present. Therefore a comparison of past data with that currently being recorded has not been possible in order to build up a model of ground behaviour.

Groundwater levels at this site illustrate the variations in the groundwater regime prevailing at Flat Cliffs, although readings from BB02 (A2) are probably influenced by tidal fluctuations.

9 References

Anderton R, et al (1979) A Dynamic Stratigraphy of the British Isles, Chapter 17. George Allen & Unwin.

British Geological Survey (BGS) 1:50,000 Scale, Solid and Drift (Sheet 34 Guisborough)

British Geological Survey (BGS) 1:50,000 Scale, Solid and Drift (Sheet 35 Whitby).

British Geological Survey (BGS) 1:50,000 Scale, Solid and Drift (Sheet 44 Scalby)

British Geological Survey (BGS) 1:50,000 Scale, Solid and Drift (Sheet 54, Scarborough)

BS 1377: (1990) Soils for Civil Engineering Purposes. British Standards Institution.

BS 5930: (1999) Code of Practice for Site Investigations. British Standards Institution.

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

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

CIRIA Special Publication 149 (1998): A Guide to British Stratigraphic Nomenclature.

Environment Agency, 2006: Underground, Under Threat, Groundwater Protection: Policy and Practice.

Environmental Agency website, “What’s in my Backyard”? http:www://216.31.193.171/asp/1_introduction.asp

Lee, E.M. & Jones, D.K.C. (2004) Landslide Risk Assessment – Thomas Telford Ltd.

Mills. (1981) Site investigation report Knipe Point, Cayton Bay, North East Yorkshire, MSc Thesis.

Mouchel Report “*Analysis and Interpretation of Coastal Monitoring Data” 721228/001/GR/01/02/FINAL, March 2009.*

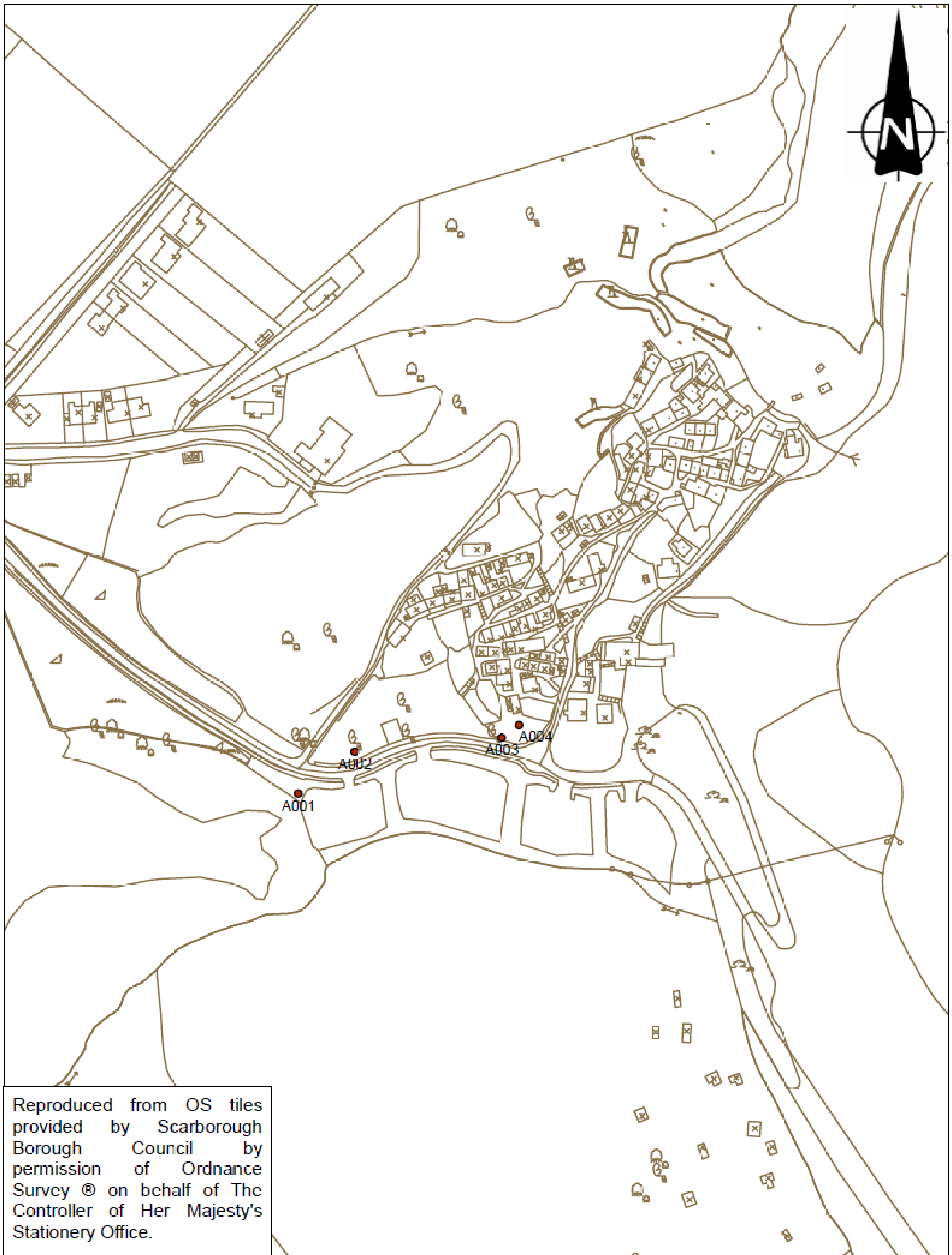
Mouchel Report “Ongoing *Analysis and Interpretation of Coastal Monitoring Data. Condition Survey Report” 721229/001/CSR/02/FINAL*, July 2009.

Scarborough Borough Council Records.

Spark, B W (1981) Geomorphology - 2nd Edition. Longman.

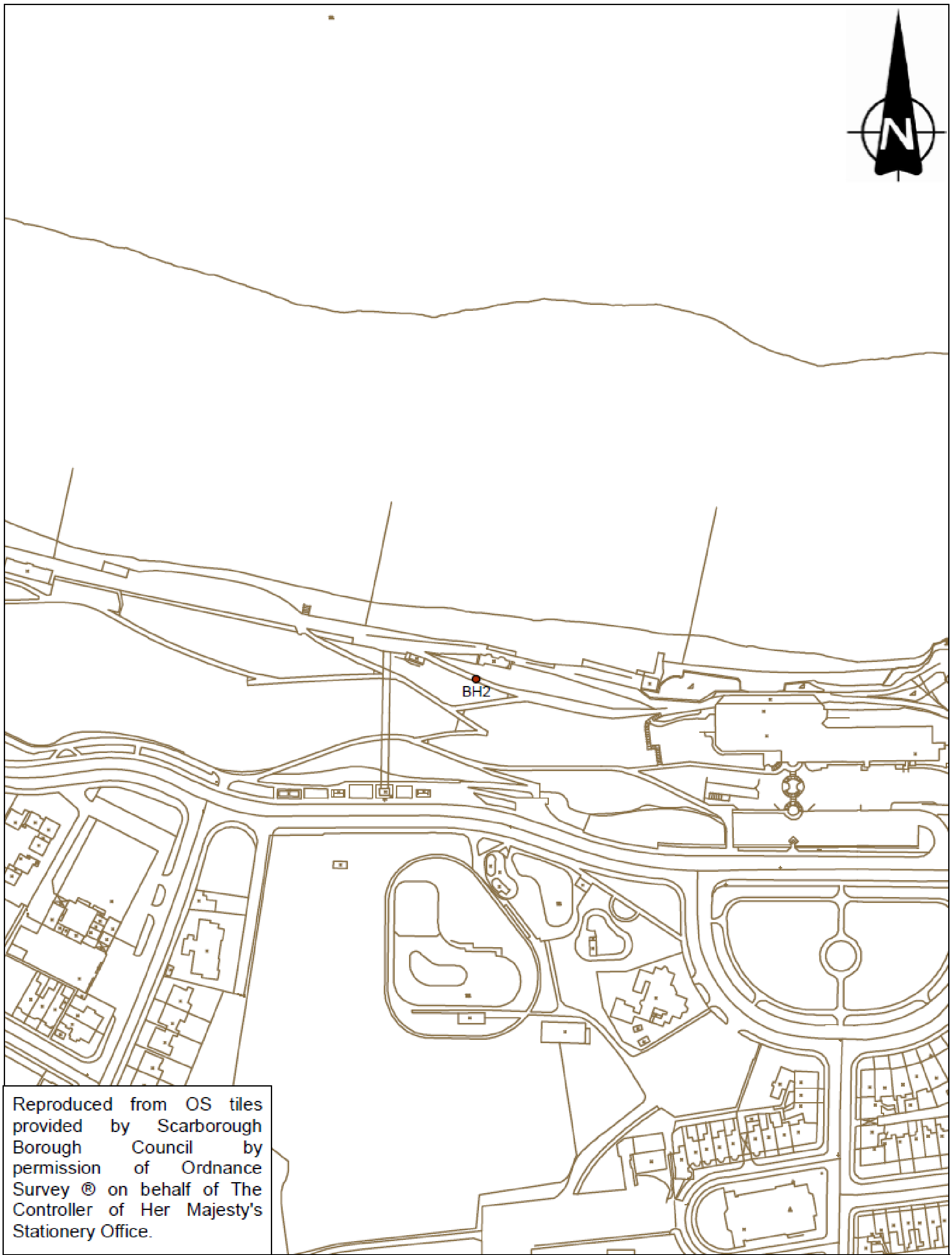
Tomlinson, M. J. (2001) Foundation Design and Construction - 7th Edition. Longman Ltd

Appendix A Exploratory Holes Location Plans



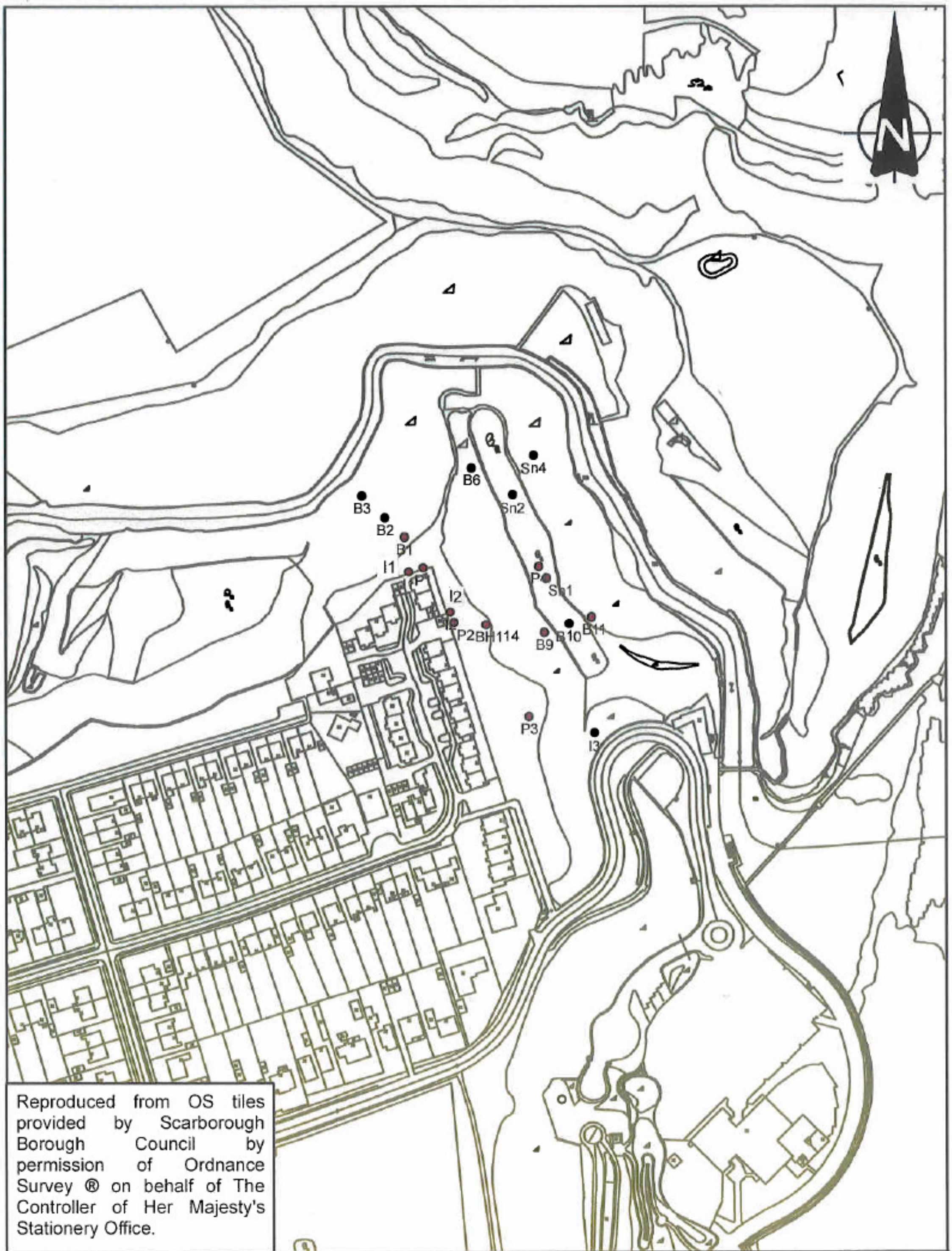
Runswick Bay Inclinometer Location Plan	Scale: 1:2,500	mouchel
Scarborough Borough Council Analysis and Interpretation of Coastal Monitoring Data		A great place to live, work & play

Drawing No. 1 Location Plan of Runswick Bay



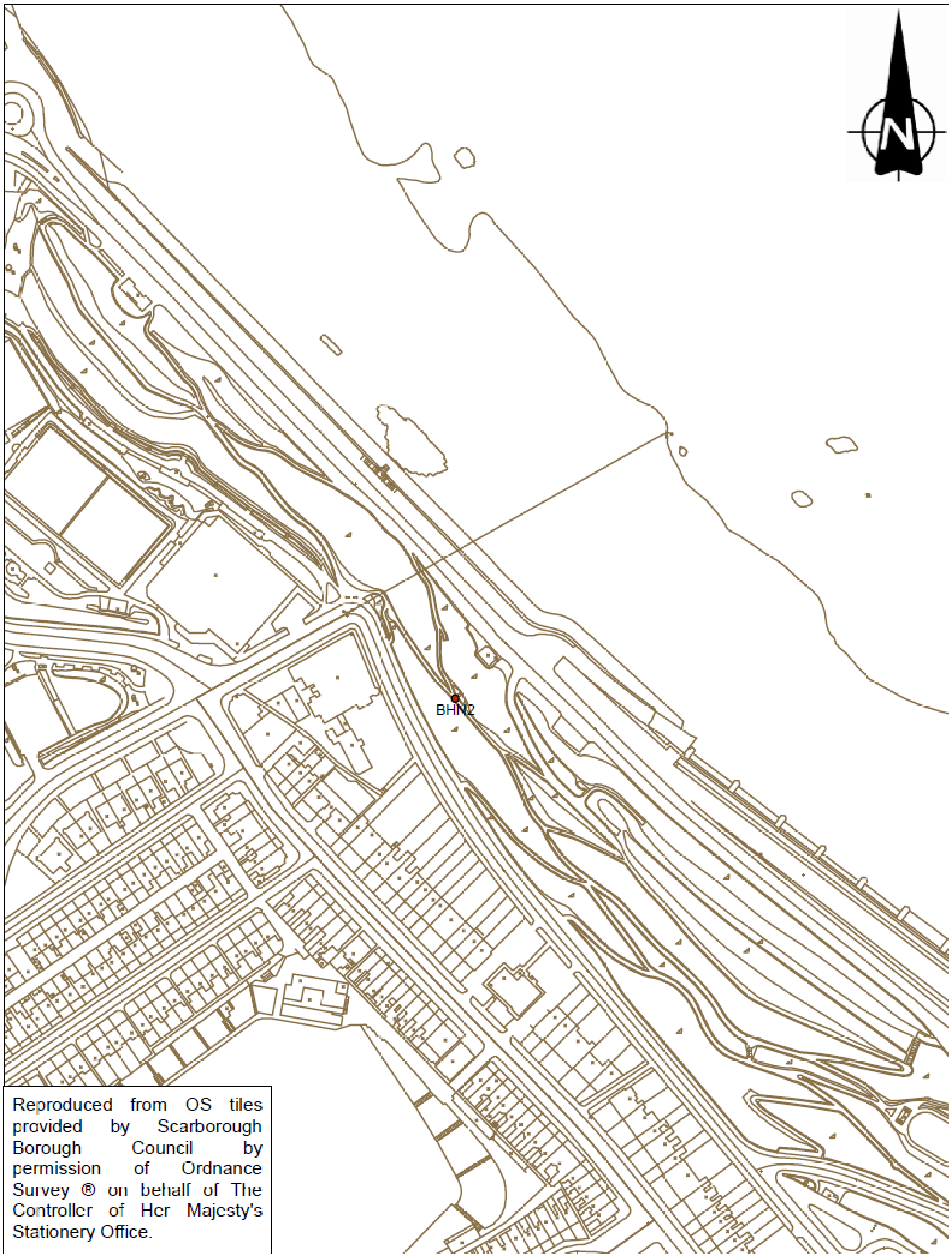
Whitby West Cliff Inclinometer Location Plan	Scale: 1:2,500	mouchel
Scarborough Borough Council Analysis and Interpretation of Coastal Monitoring Data		A great place to live, work & play

Drawing No. 2 Location Plan of Whitby West Cliff



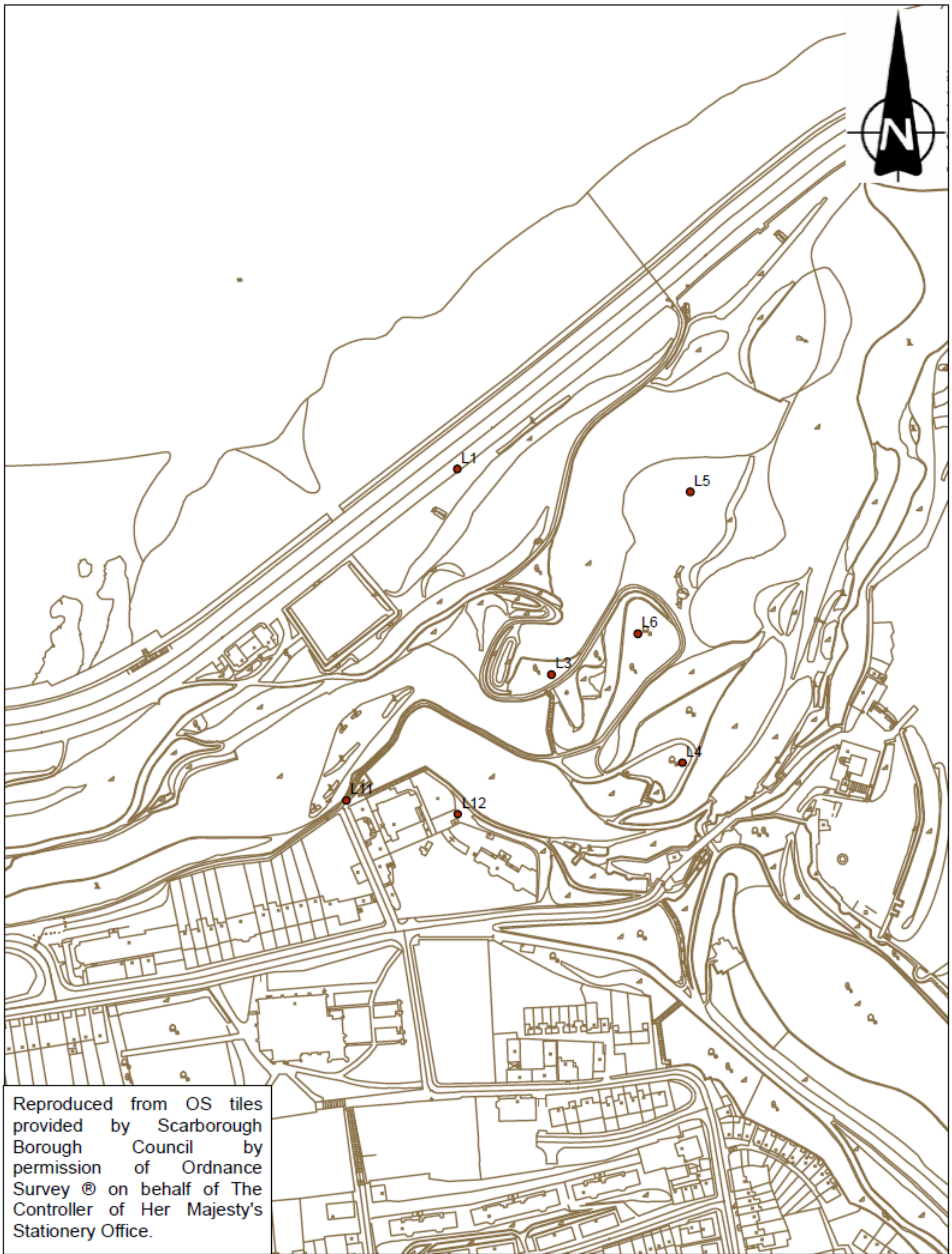
Scalby Ness Exploratory Holes Location Plan	Scale: 1:2,500	mouchel
Scarborough Borough Council Analysis and Interpretation of Coastal Monitoring Data		A great place to live, work & play

Drawing No. 3 Location Plan of Scalby Ness



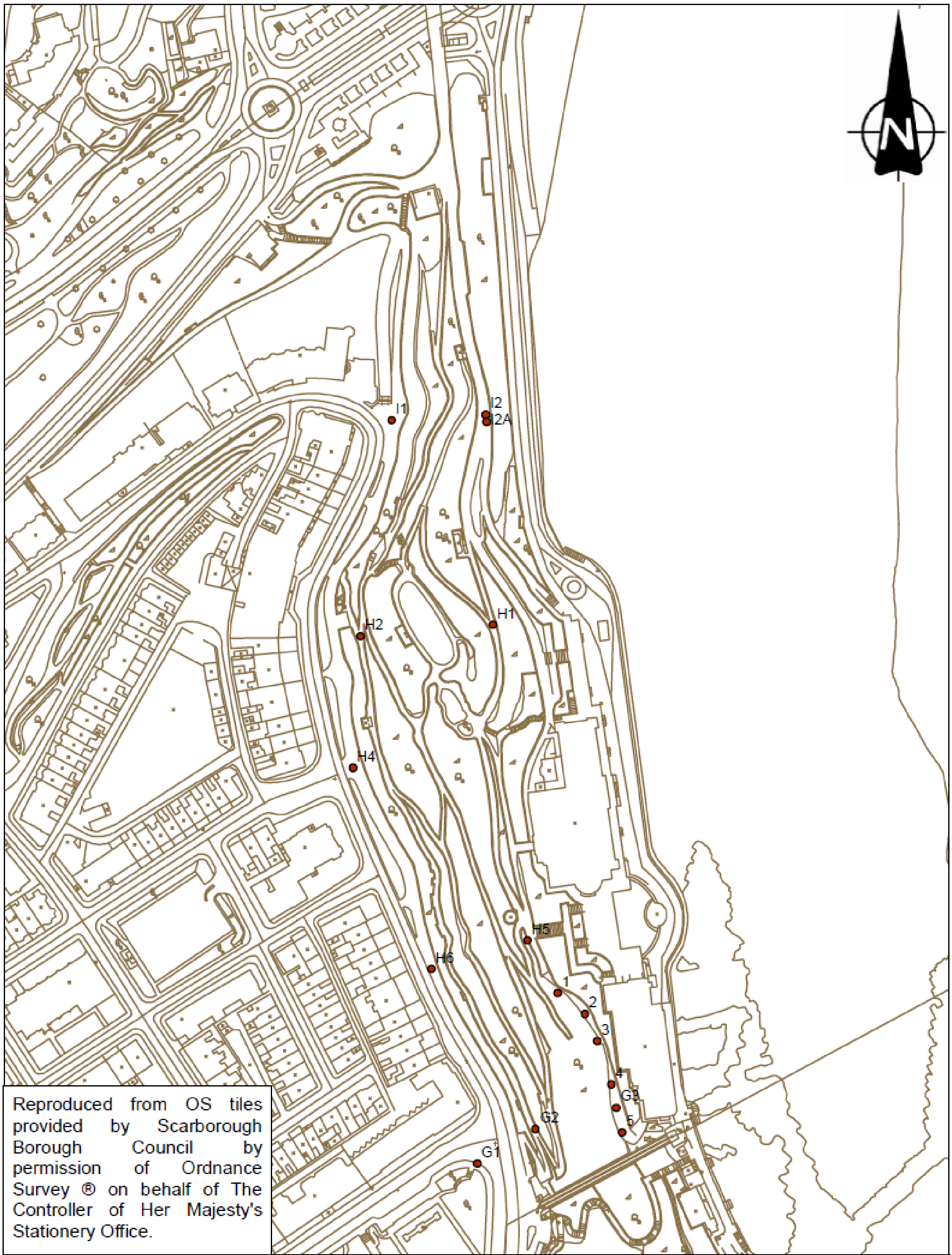
Scarborough North Bay (West Section) Piezometer Location Plan	Scale: 1:2,500	mouchel
Scarborough Borough Council Analysis and Interpretation of Coastal Monitoring Data		A great place to live, work & play

Drawing No. 4 Location Plan of Scarborough North Bay (West)



Scarborough North Bay (East Section) Exploratory Holes Location Plan	Scale: 1:2,500	mouchel
Scarborough Borough Council Analysis and Interpretation of Coastal Monitoring Data		A great place to live, work & play

Drawing No. 5 Location Plan of Scarborough North Bay (East)



Scarborough South Cliff (North Section) Exploratory Holes Location Plan	Scale: 1:2,500	mouchel
Scarborough Borough Council Analysis and Interpretation of Coastal Monitoring Data		A great place to live, work & play

Drawing No. 6 Location Plan of Scarborough South Cliff (North)

Scarborough South Cliff (Central Section)
Exploratory Holes Location Plan

Scale:
1:2,500

mouchel

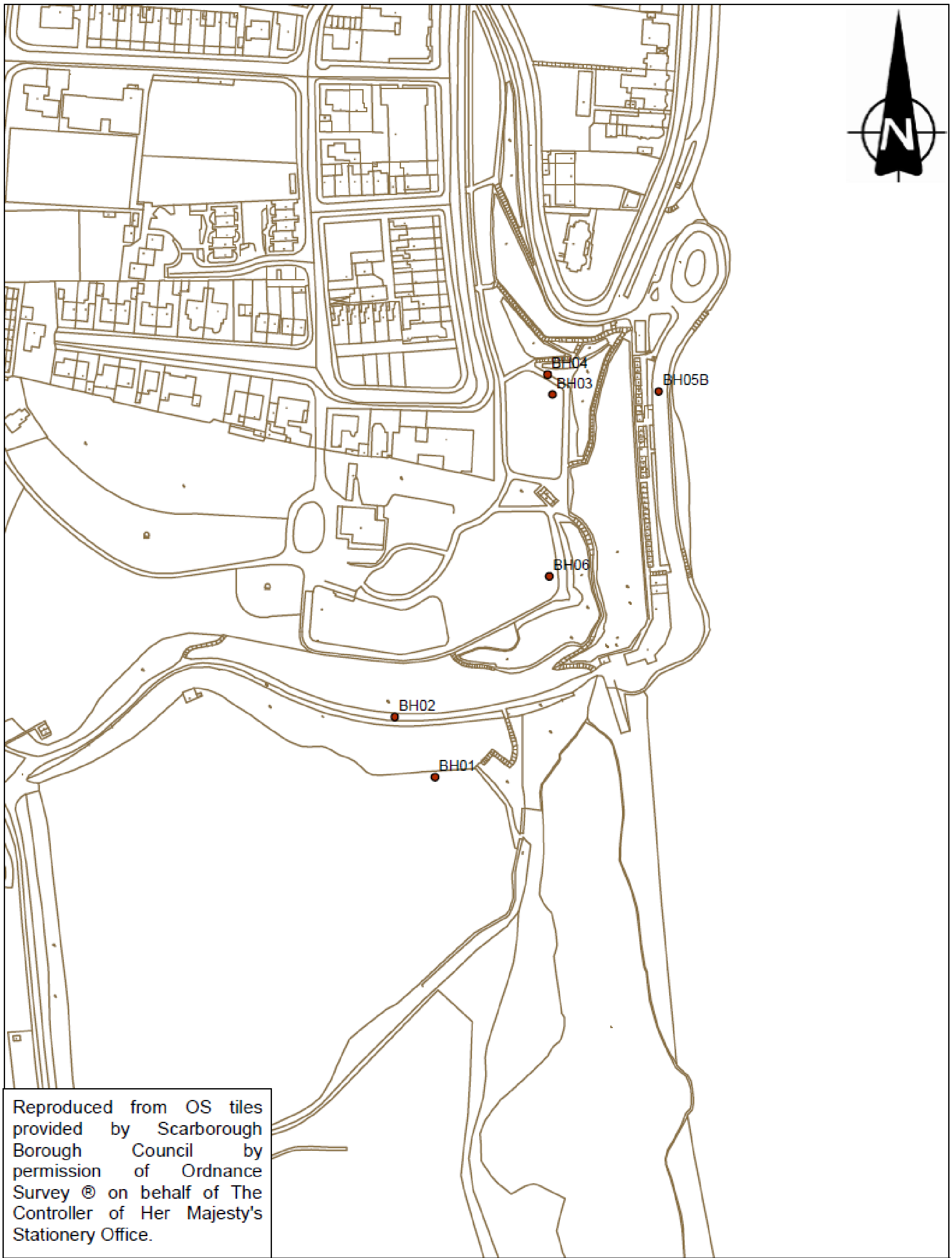
Scarborough Borough Council
Analysis and Interpretation of Coastal Monitoring Data

A great place to live, work & play

Drawing No. 7 Location Plan of Scarborough South Cliff (Central)

Scarborough South Cliff (South Section) Exploratory Holes Location Plan	Scale: 1:2,500	mouchel
Scarborough Borough Council Analysis and Interpretation of Coastal Monitoring Data		A great place to live, work & play

Drawing No. 8 Location Plan of Scarborough South Cliff (South)



Filey Exploratory Holes Location Plan	Scale: 1:2,500
Scarborough Borough Council Analysis and Interpretation of Coastal Monitoring Data	

Drawing No. 9 Location Plan of Filey Town

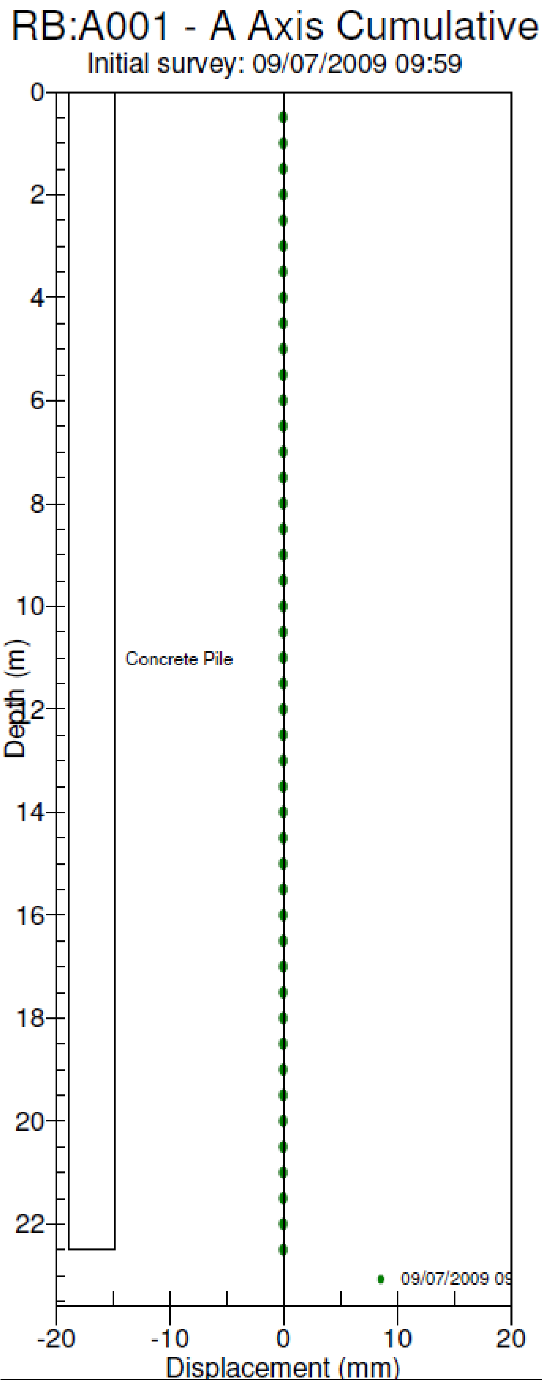
Filey Flat Cliffs Exploratory Holes Location Plan

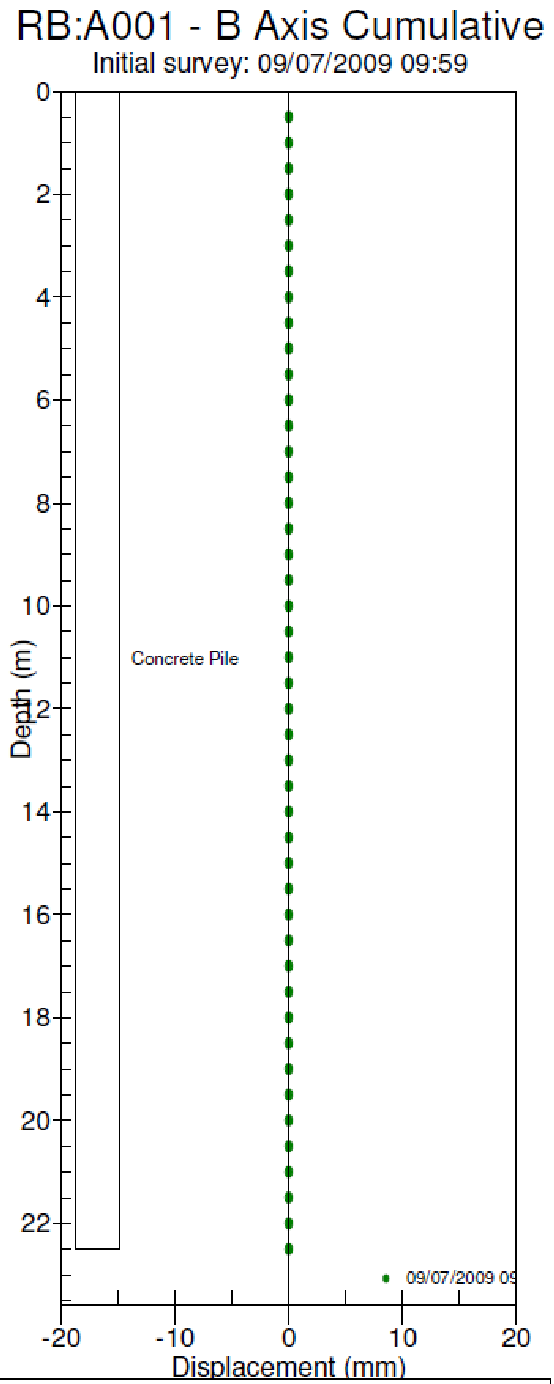
Scale: 1:2,500

Scarborough Borough Council
Analysis and Interpretation of Coastal Monitoring Data

Drawing No. 10 Location Plan of Filey Flat Cliffs

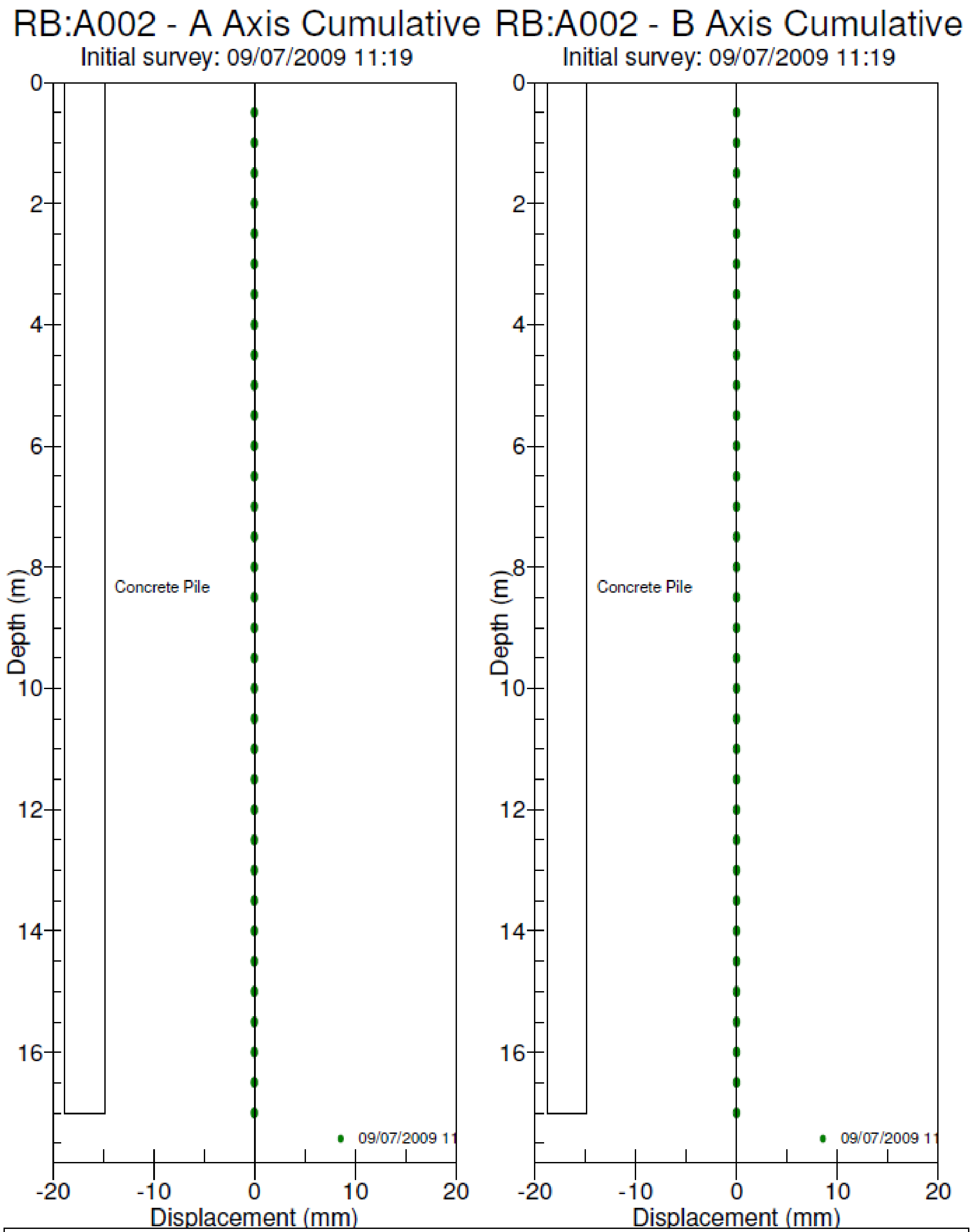
Appendix B Inclinometer Data Graphs





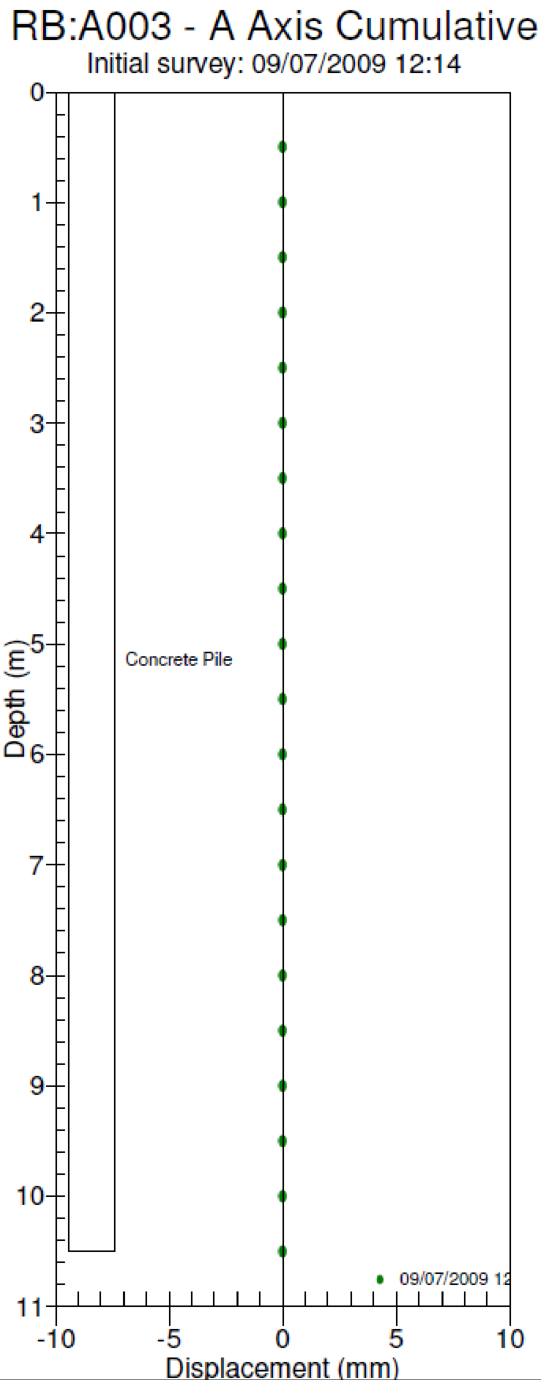
PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Runswick Bay
INSTALLATION: A001
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

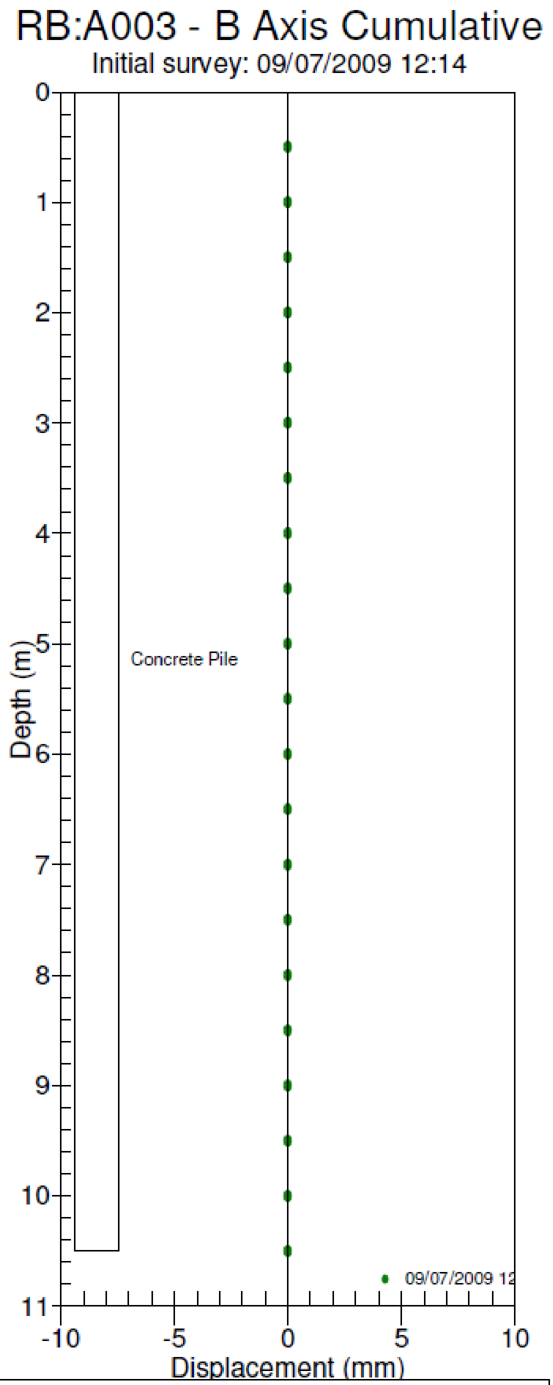
NOTE: A0 direction: East



PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Runswick Bay
INSTALLATION: A002
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

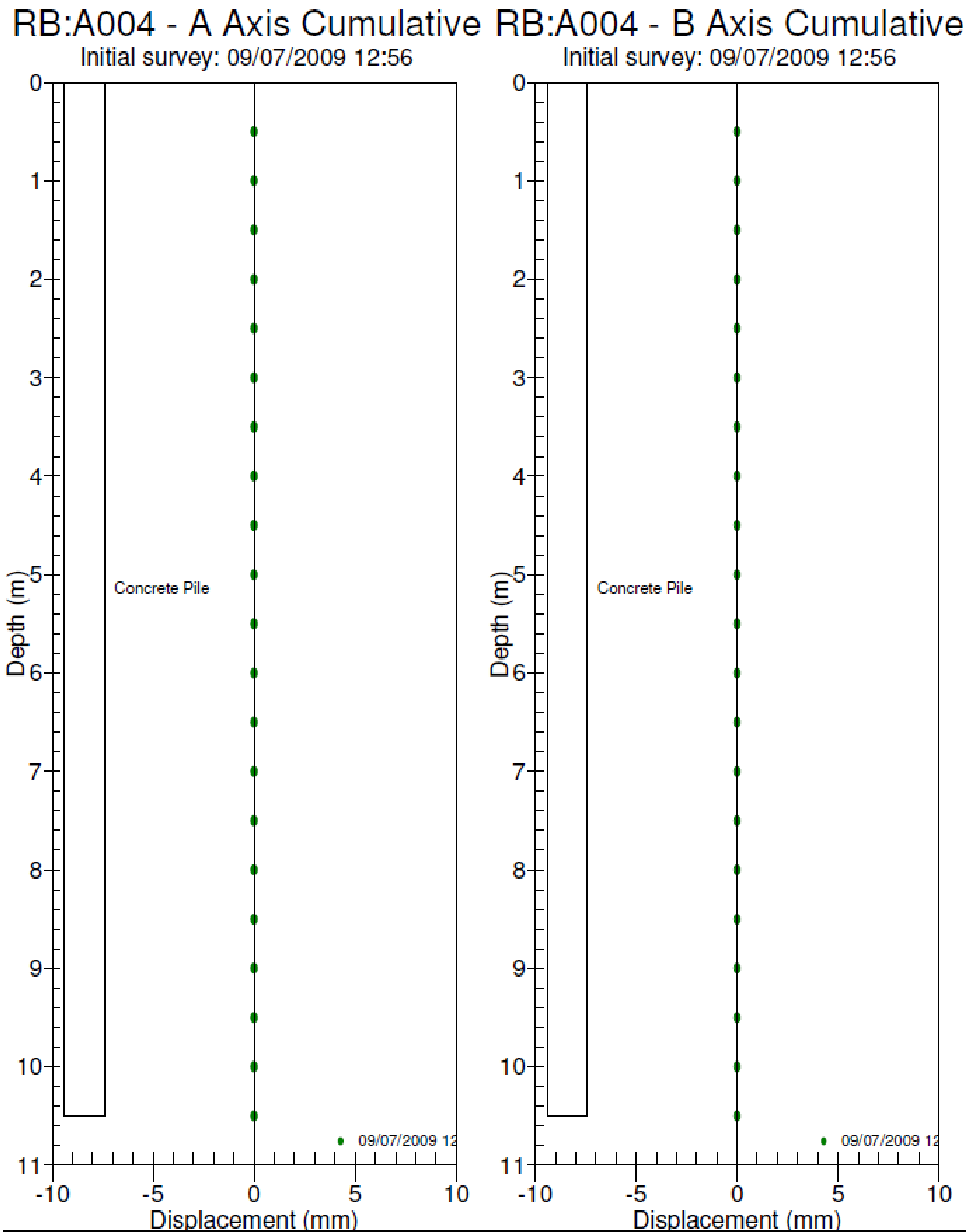
NOTE: A0 direction: East





PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Runswick Bay
INSTALLATION: A003
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

NOTE: A0 direction: South East



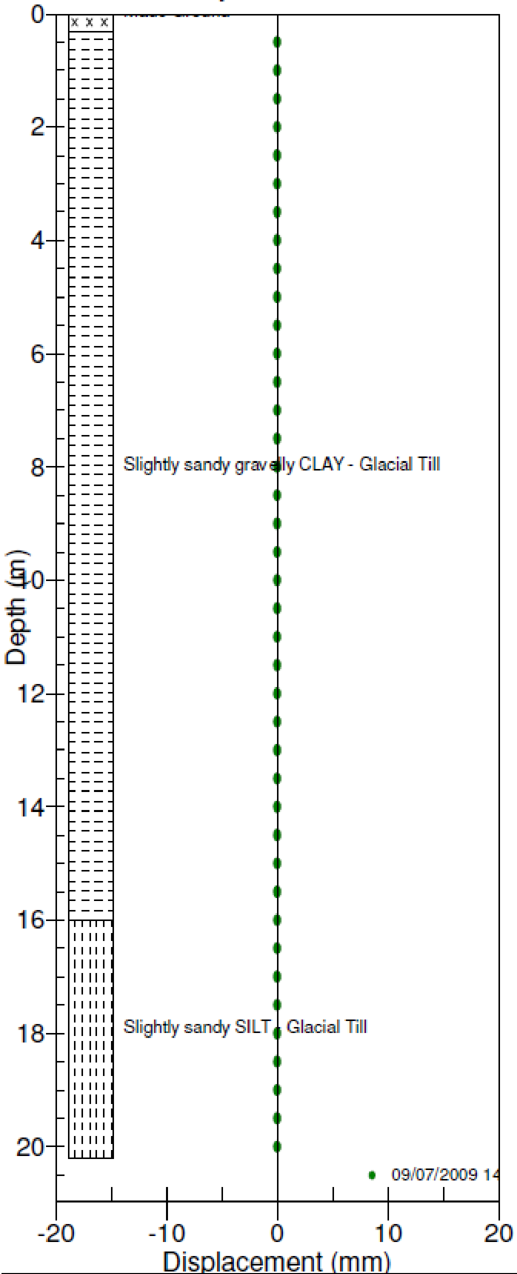
PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Runswick Bay
INSTALLATION: A004
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

mouchel

NOTE: A0 direction: South East

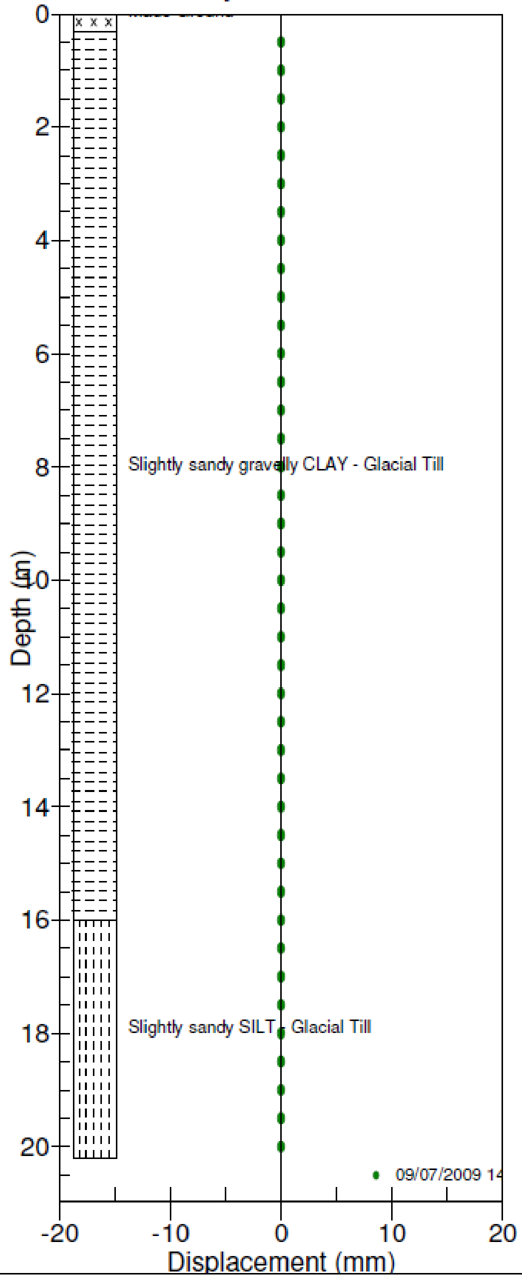
WWC:BH2 - A Axis Cumulative

Initial survey: 09/07/2009 14:40



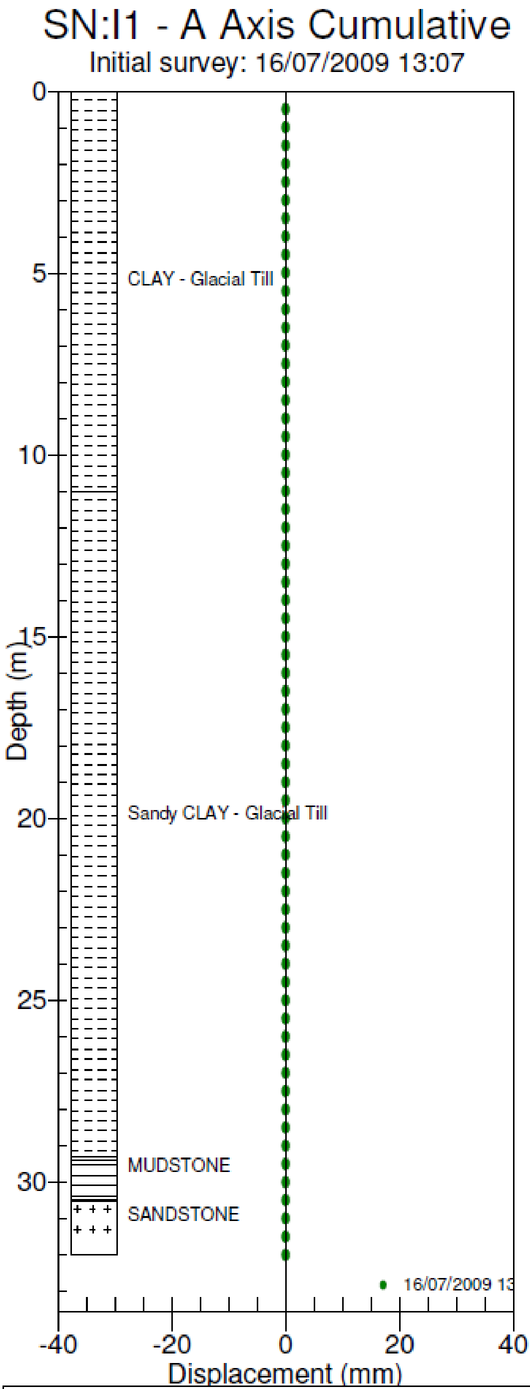
WWC:BH2 - B Axis Cumulative

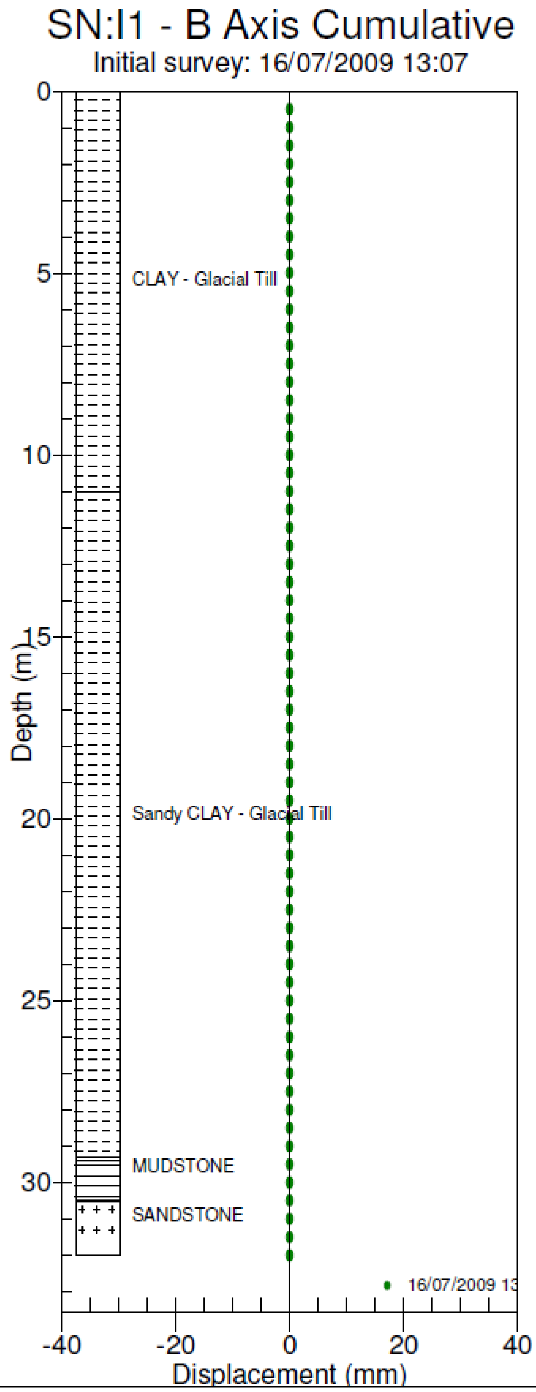
Initial survey: 09/07/2009 14:40



PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Whitby West Cliff
INSTALLATION: BH2
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

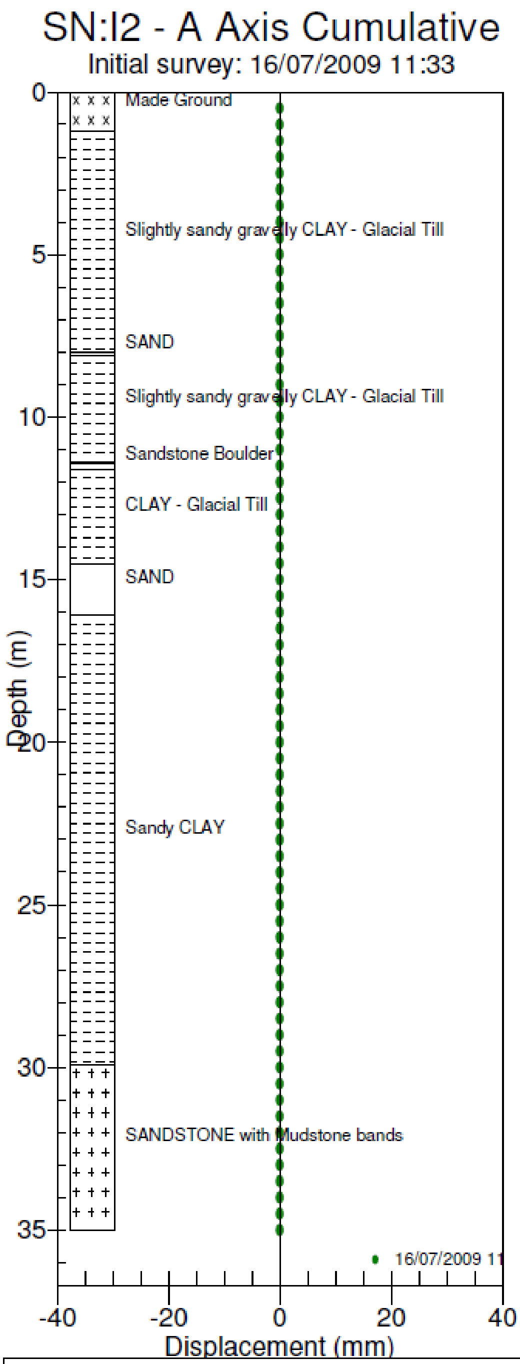
NOTE: A0 direction: North

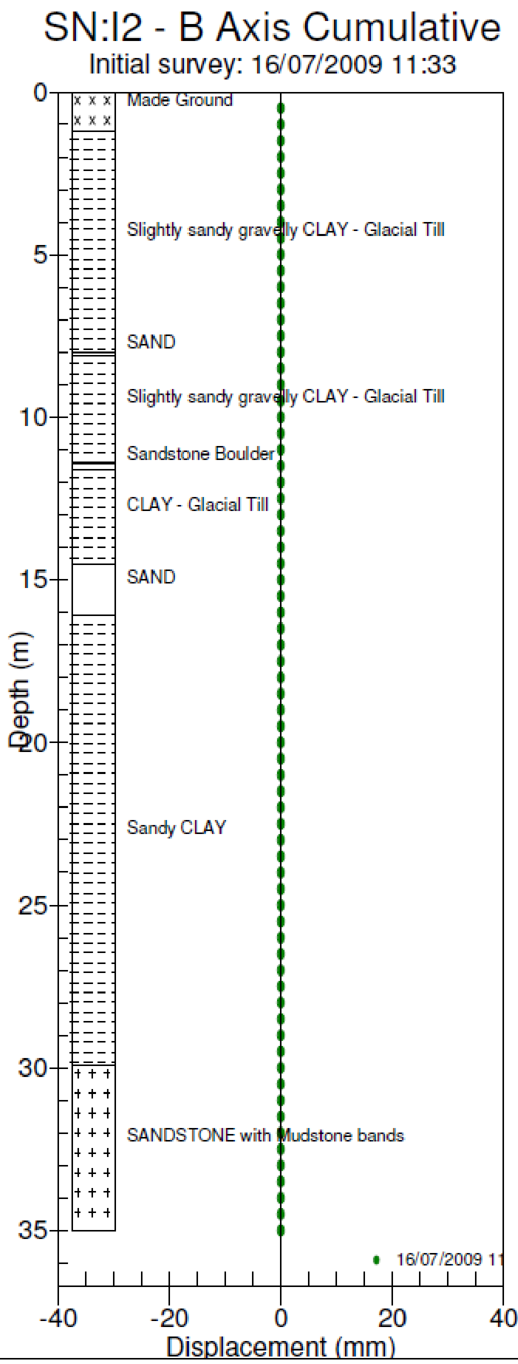




PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Scalby Ness
INSTALLATION: I1
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

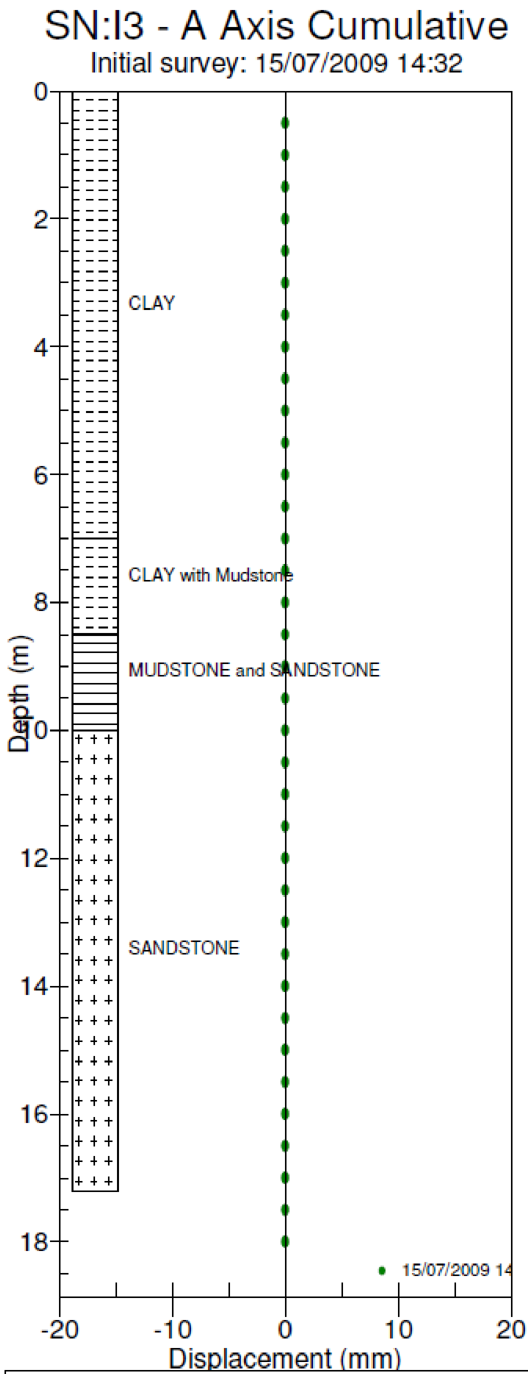
NOTE: A0 direction: North

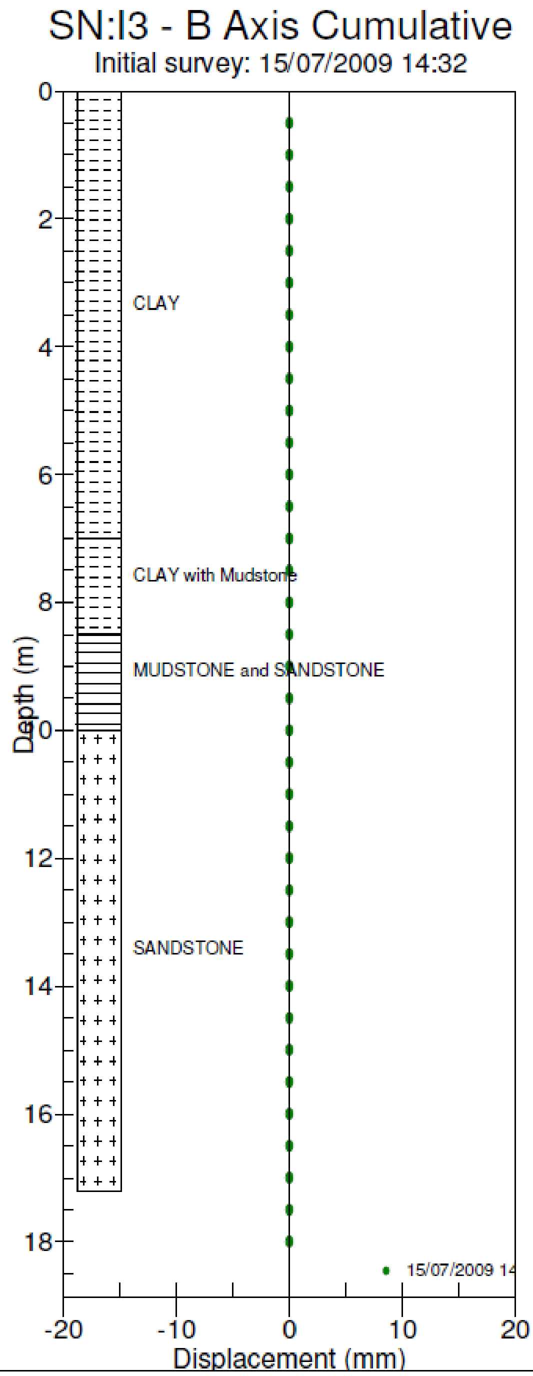




PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Scalby Ness
INSTALLATION: I2
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

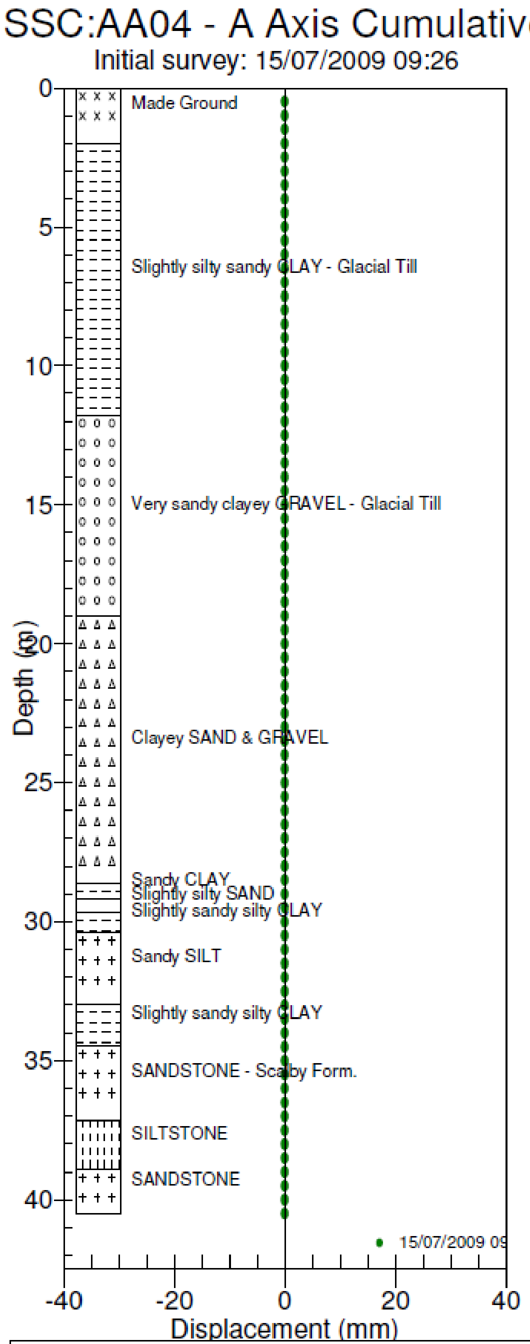
NOTE: A0 direction: North East

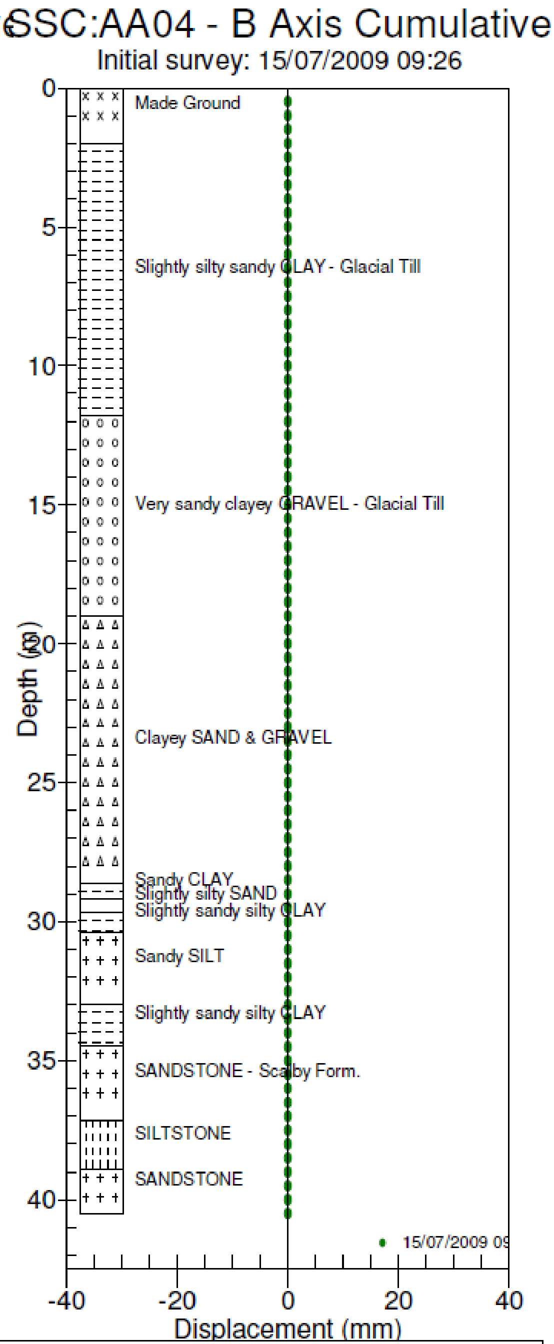




PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Scalby Ness
INSTALLATION: I3
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

NOTE: A0 direction: East

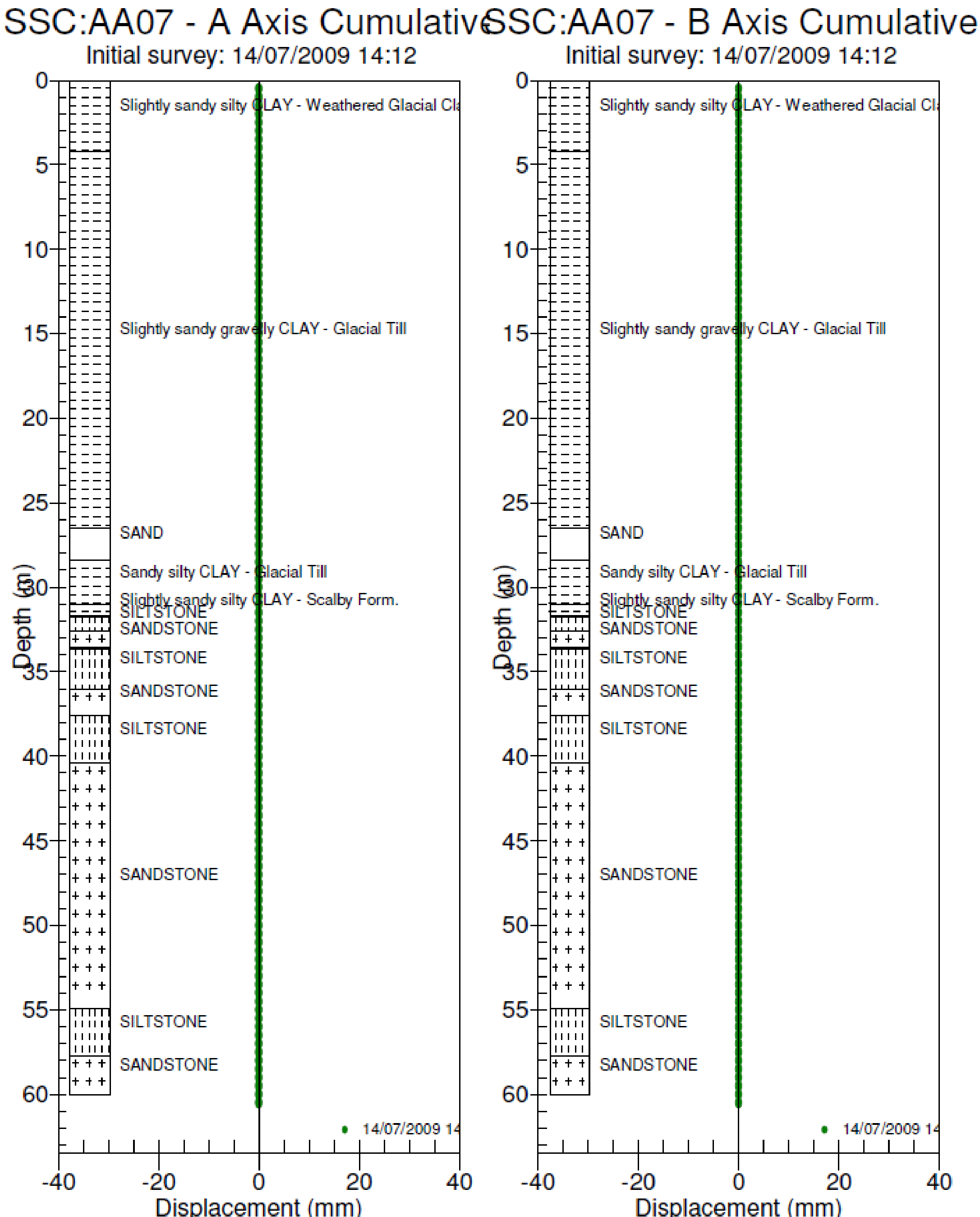




PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Scarborough South Cliff
INSTALLATION: AA04 (G2)
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

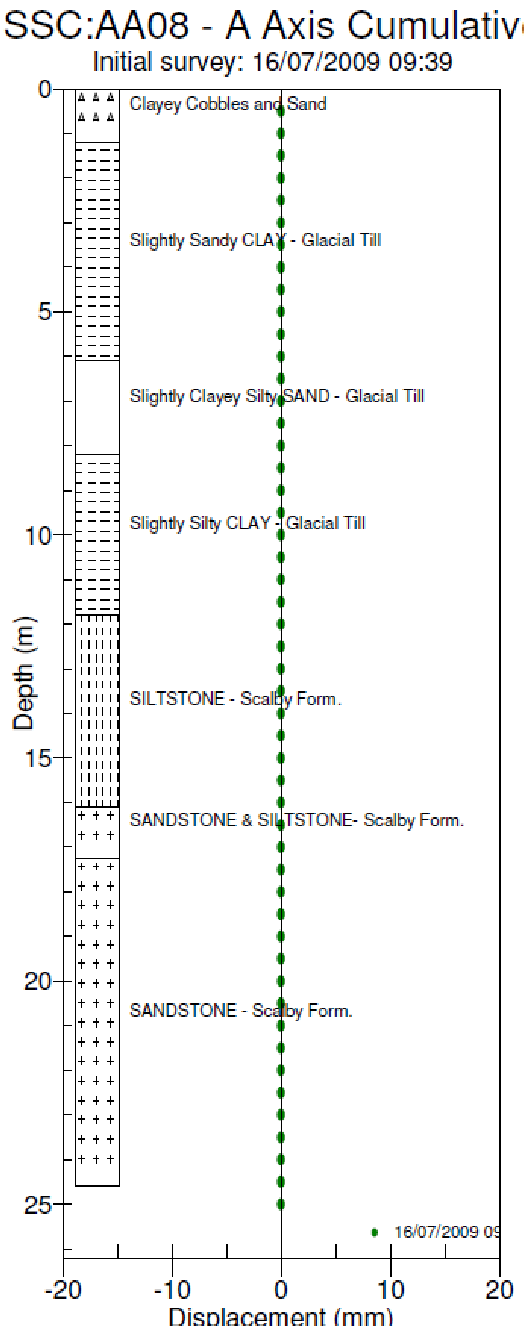
NOTE: A0 direction: North East

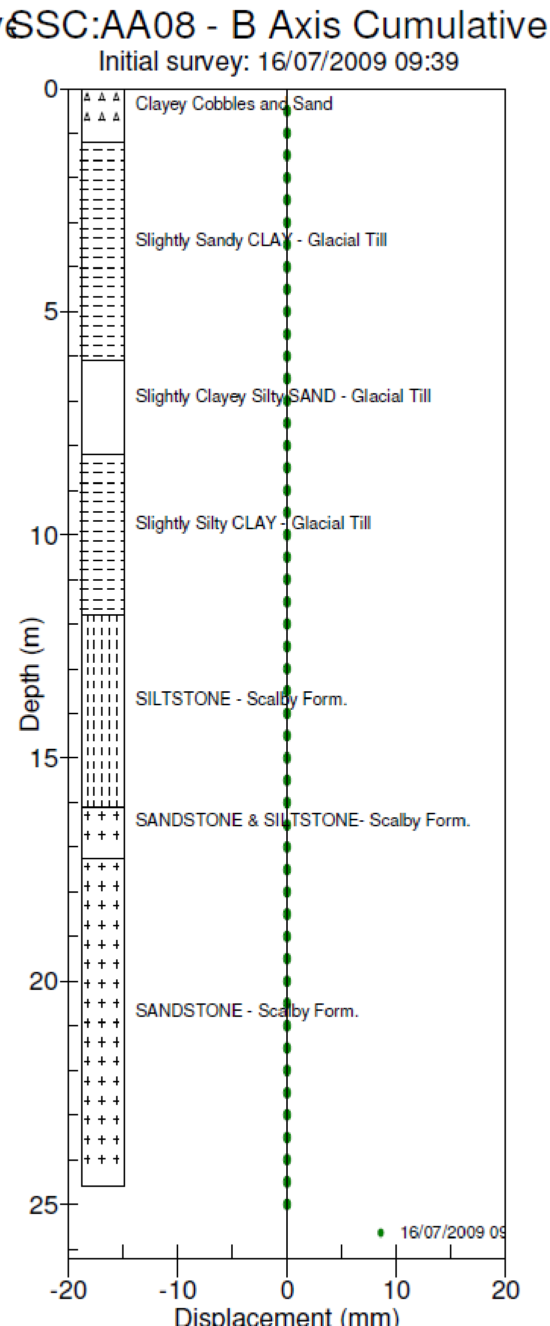
mouchel



PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Scarborough South Cliff
INSTALLATION: AA07 (BH2)
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

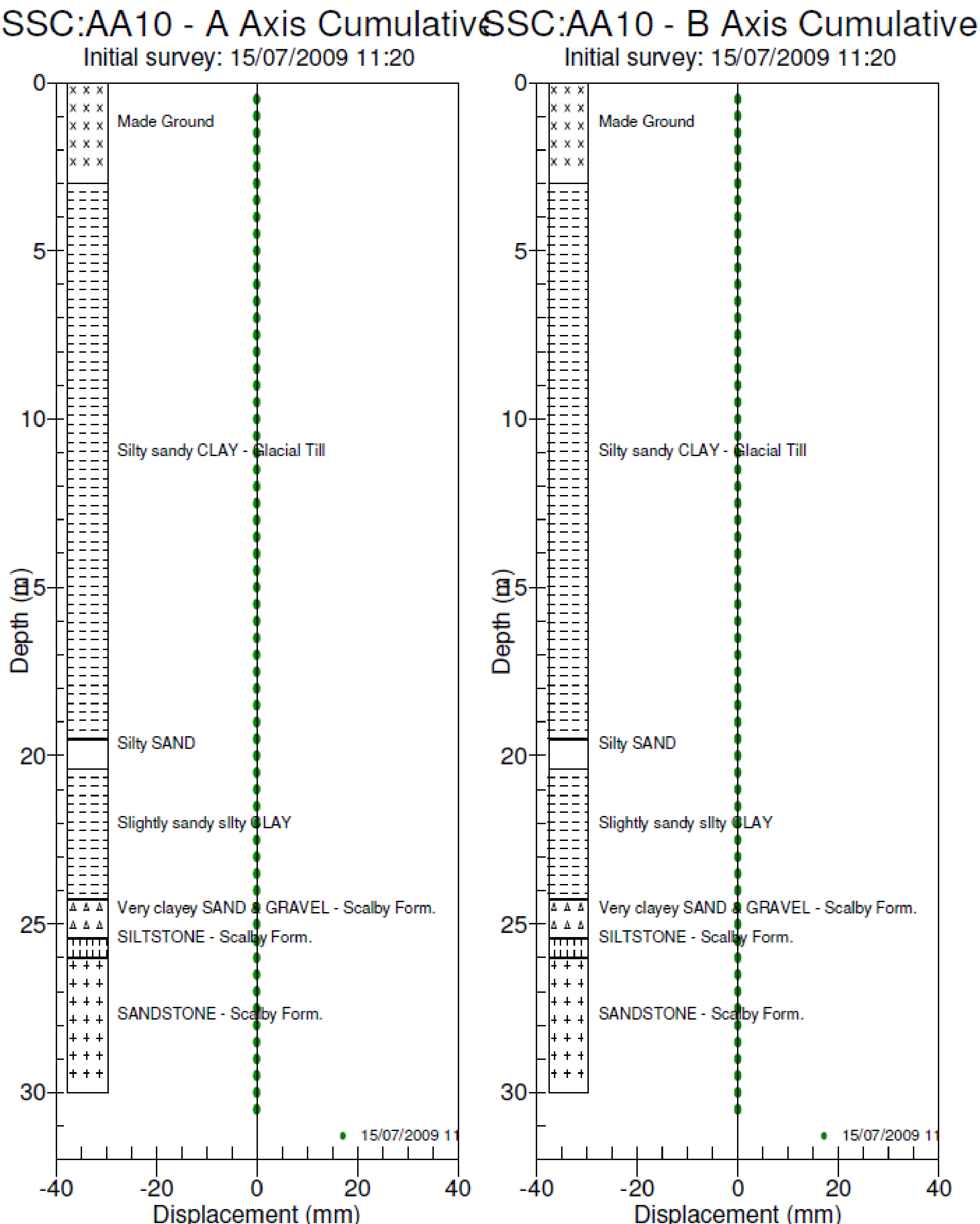
NOTE: A0 direction: North East





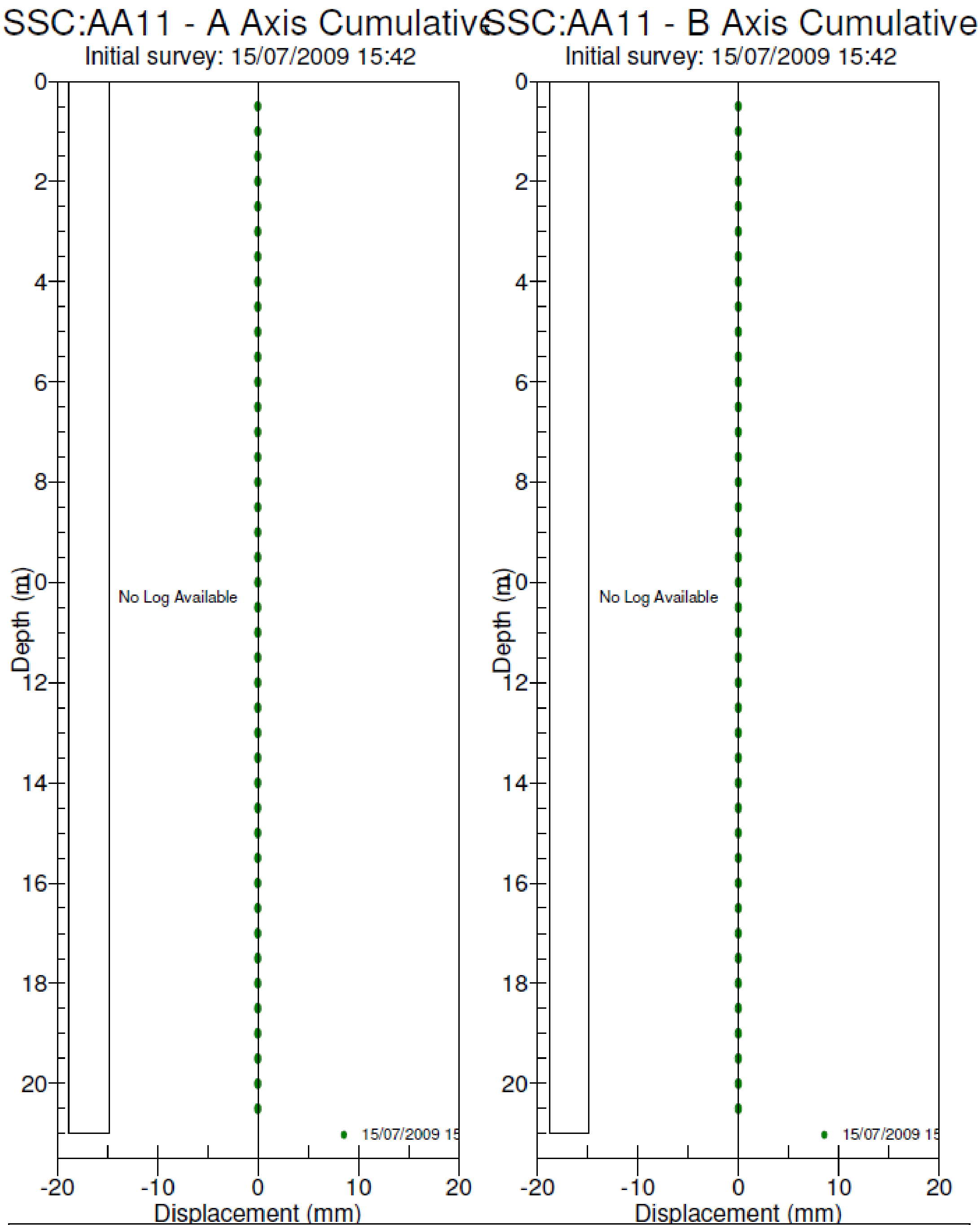
PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Scarborough South Cliff
INSTALLATION: AA08 (D3)
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

NOTE: A0 direction: East



PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Scarborough South Cliff
INSTALLATION: AA10 (F2)
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

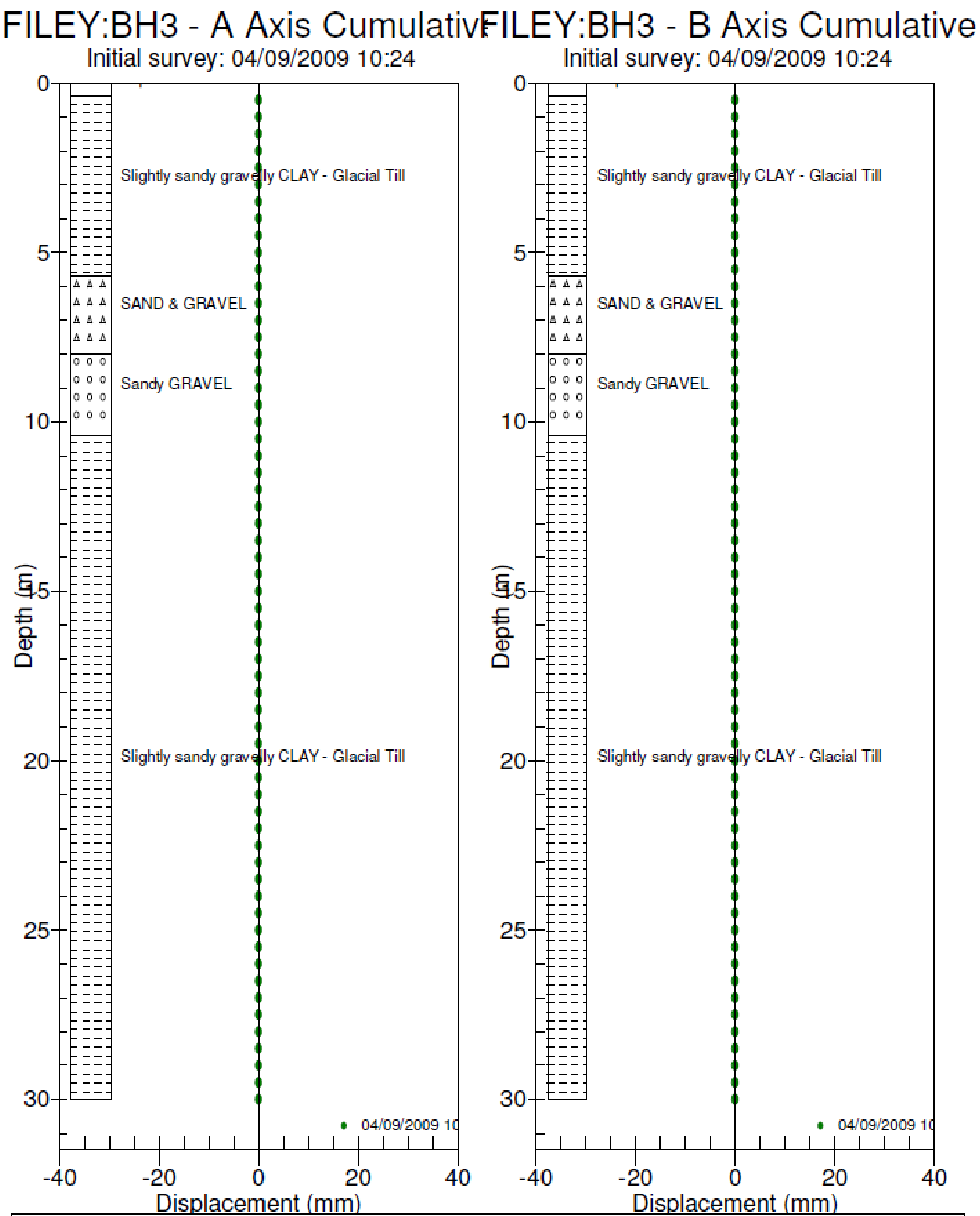
NOTE: A0 direction: North East



PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Scarborough South Cliff
INSTALLATION: AA11 (F4)
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

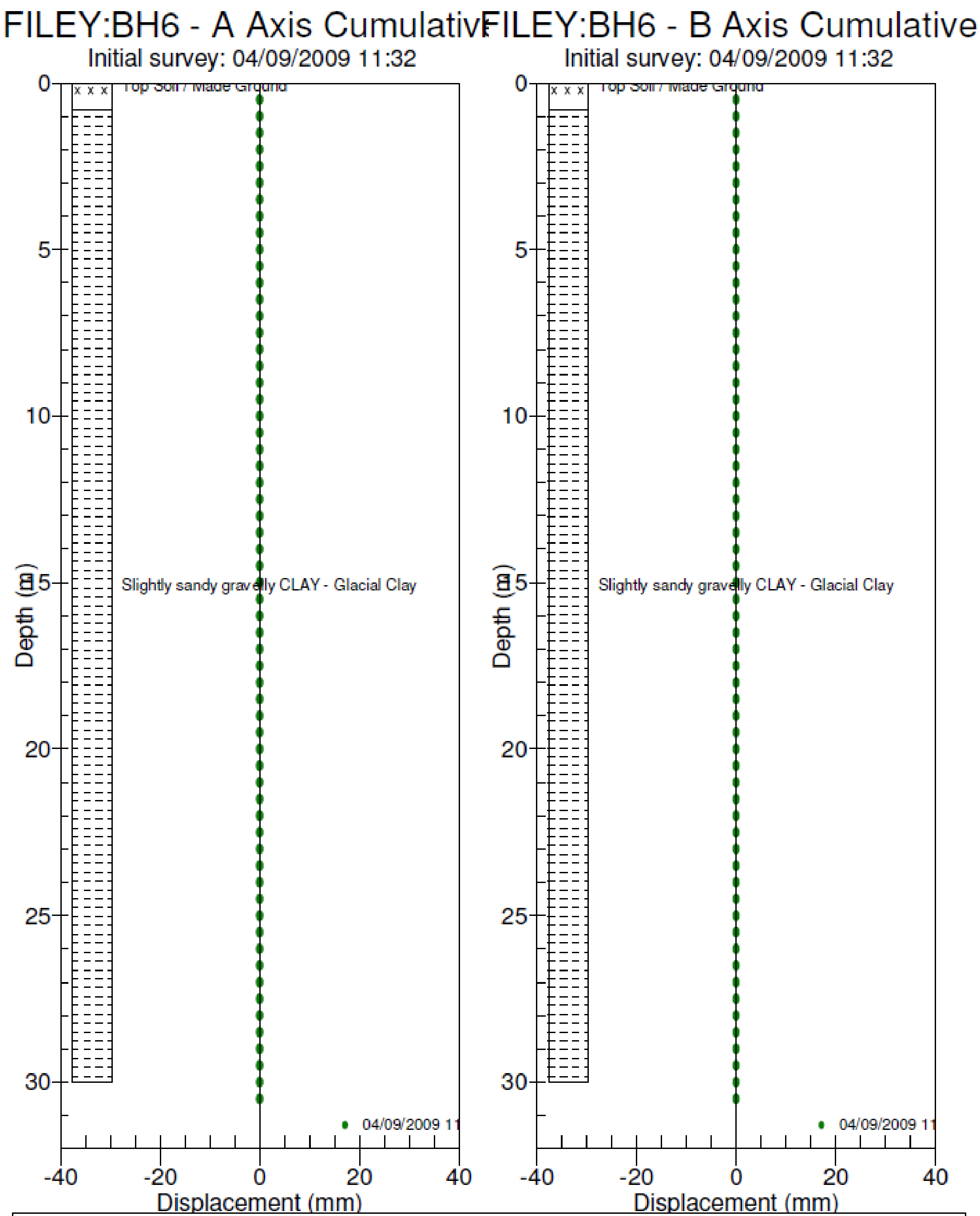
mouchel

NOTE: A0 direction: North East



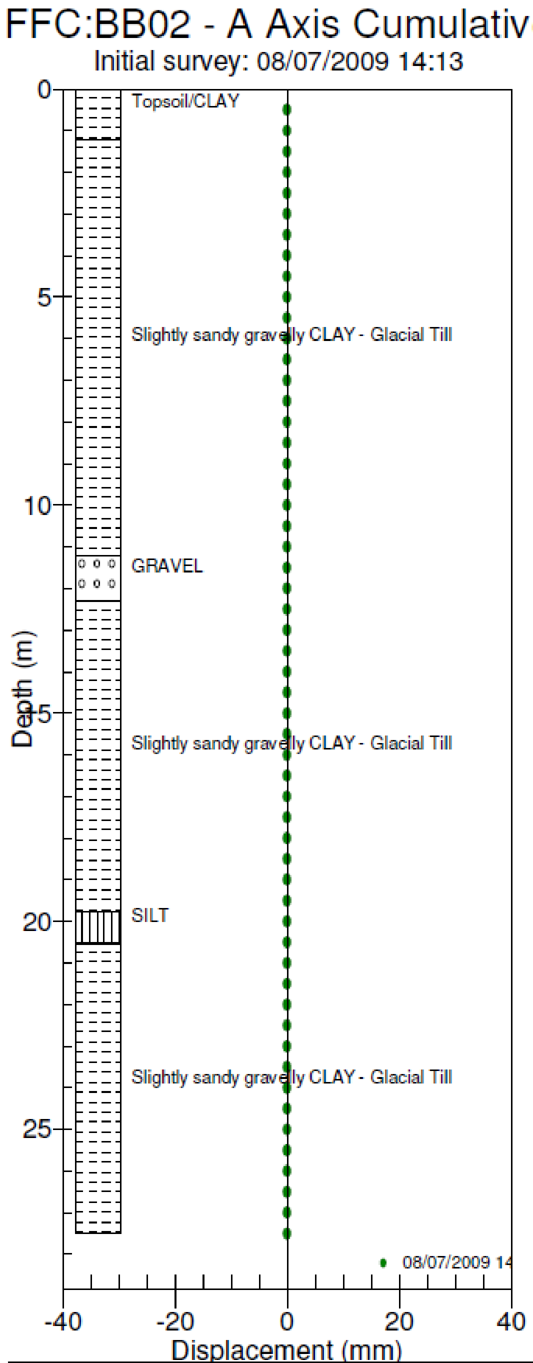
PROJECT: Ongoing Analysis of Coastal Monitoring Data
SITE: Filey Town
INSTALLATION: BH3
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

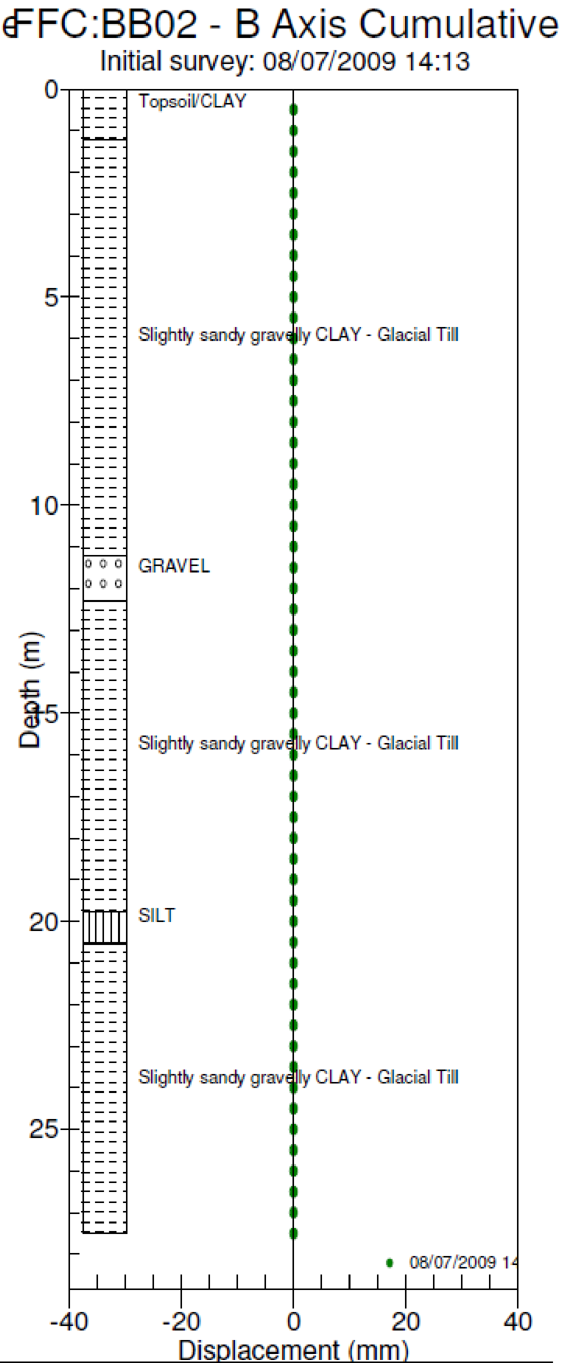
NOTE: Ao direction: North East



PROJECT: Ongoing Analysis of Coastal Monitoring Data
SITE: Filey Town
INSTALLATION: BH6
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

NOTE: Ao direction: North East





PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Filey Flat Cliffs
INSTALLATION: BB02 (A2)
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

mouchel

NOTE: A0 direction: East

Appendix C Groundwater Monitoring Data

Groundwater Monitoring Readings – July 2009

SITE Exploratory hole No.	Date (2009)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped Depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
RUNSWICK BAY							
A001	9th July	Inclino	N/A	0.69	21.31	20.00	Concrete Pile
A002	9th July	Inclino	N/A	13.01	17.00	16.00	Concrete Pile
A003	9th July	Inclino	N/A	0.82	10.10	10.00	Concrete Pile
A004	9th July	Inclino	N/A	2.33	10.47	10.00	Concrete Pile
WHITBY WEST CLIFF							
BH2	9th July	Inclino	13.78	7.73	19.90	20.00	Stiff, sandy silt
SCALBY NESS							
I1	16th July	Inclino	35.47	6.37	32.10	31.60	Brown sandstone
I2	16th July	Inclino	34.11	0.37	35.05	34.80	Sandstone with mudstone bands
I3	16th July	Inclino	13.37	11.51	17.80	17.20	Fine to medium grained sandstone
B6	16th July	Piezo	18.55	7.63	8.42	8.55	No details
B9	16th July	Piezo	17.80	2.44	7.90	8.05	No details

Groundwater Monitoring Readings – July 2009

SITE Exploratory hole No.	Date (2009)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
SCARBORO' NORTH BAY							
L1 (a)	15th July	Piezo	7.03	2.00	8.00	10.00	Slightly sandy siltstone
L1 (b)	15th July	Piezo	7.03	10.27	15.04	16.00	Slightly weathered siltstone
L3 (a)	15th July	Piezo	30.78	1.41	1.41	20.70	Highly weathered sandstone
L3 (b)	15th July	Piezo	30.78	Dry	20.19	27.40	Moderately weathered sandstone to highly weathered mudstone
L5 (a)	15th July	Piezo	33.33	Dry	13.77	24.00	Highly weathered sandstone to slightly weathered siltstone
L5 (b)	15th July	Piezo	33.33	Dry	13.77	33.00	Sandstone and siltstone
L11	15th July	Piezo	55.63	7.23	14.30	14.50	Fine to medium grained sandstone
L12	15th July	Piezo	56.24	Dry	15.30	15.90	Fine to medium grained sandy siltstone

Groundwater Monitoring Readings – July 2009

SITE Exploratory hole No.	Date (2009)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped Depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
SCARBORO' SOUTH CLIFF							
AA01 (I1)	15th July	Inclino	47.95	43.00	65.10	65.00	Sandstone
AA02 (H4)	15th July	Inclino	53.85	Dry	61.30	61.50	Sandstone
AA03 (H6)	15th July	Inclino	55.76	49.57	54.40	54.50	Sandstone
AA04 (G2)	15th July	Inclino	47.62	40.10	40.60	39.50	Sandstone and siltstone
AA10 (F2)	15th July	Inclino	34.98	23.40	30.50	29.50	Sandstone and siltstone
AA11 (F4)	15th July	Inclino	N/A	16.02	20.20	19.50	No details
AA09 (E3)	15th July	Inclino	58.06	33.81	48.50	48.00	Sandstone and siltstone
AA05 (E5)	15th July	Inclino	63.06	42.34	54.80	53.50	Sandstone and siltstone
AA08 (D3)	15th July	Inclino	38.43	21.35	25.02	24.60	Fine sandstone
AA06 (D1)	15th July	Inclino	64.1	32.20	46.50	46.40	Silty mudstone
AA07 (Bh2)	15th July	Inclino	56.33	46.20	60.00	60.00	Fine to coarse grained sandstone
I2	15th July	Piezo	22.69	21.55	31.00	31.10	Clayey fine sand

Groundwater Monitoring Readings – July 2009

SITE Exploratory hole No.	Date (2009)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped Depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
SCARBORO' SOUTH CLIFF							
I2A	15th July	Piezo	22.69	19.00	19.00	19.00	Clayey coarse sand
H2 (a)	15th July	Piezo	46.52	29.20	29.20	30.00	Silty fine and medium sand
H2 (b)	15th July	Piezo	46.52	34.30	37.50	38.50	Silty fine and medium sand
H1 (a)	15th July	Piezo	26.45	Dry	15.30	15.75	Gravel in a clayey silty sand
H1 (b)	15th July	Piezo	26.45	Dry	4.28	36.00	Fine to coarse sand and gravel
H5	15th July	Piezo	23.35	1.64	6.91	9.70	Firm to stiff sandy silty clay
1 Spa	15th July	Piezo	N/A	12.92	13.90	13.90	No details
2 Spa	15th July	Piezo	N/A	9.10	12.80	12.80	No details
3 Spa	15th July	Piezo	N/A	6.69	11.48	11.48	No details
4 Spa	15th July	Piezo	N/A	6.48	7.27	7.27	No details
G3	15th July	Piezo	18.15	4.88	6.17	6.17	Medium coarse gravel

Groundwater Monitoring Readings – July 2009

SITE Exploratory hole No.	Date (2009)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped Depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
SCARBORO' SOUTH CLIFF							
5 Spa	15th July	Piezo	N/A	Dry	8.80	8.80	No details
G1 (a)	15th July	Piezo	55.48	36.40	36.40	36.60	Clayey silty coarse sand
G1 (b)	15th July	Piezo	55.48	Dry	2.10	16.80	Clayey fine to coarse gravel
E2 (a)	15th July	Piezo	51.81	3.80	17.70	19.00	Slightly clayey slightly silty fine sand
E2 (b)	15th July	Piezo	51.81	1.29	8.20	8.85	Sandy silty clay
D2 (a)	15th July	Piezo	46.54	6.12	19.09	19.00	Firm silty sandy clay
D2 (b)	15th July	Piezo	46.54	1.10	5.04	5.00	Clayey fine to coarse sand
Bh3 (a)	15th July	Piezo	53.83	37.56	42.40	45.40	Slightly sandy mudstone
Bh3 (b)	15th July	Piezo	53.83	9.94	12.30	12.45	Stiff sandy, silty clay
Bh4 (a)	15th July	Piezo	59.00	8.40	30.85	30.85	Firm to stiff, sandy silty clay
Bh4 (b)	15th July	Piezo	59.00	8.56	33.90	33.90	Firm to stiff, sandy silty clay

Groundwater Monitoring Readings – July 2009

SITE Exploratory hole No.	Date (2009)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped Depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
SCARBORO' SOUTH CLIFF							
Bh1 (a)	15th July	Piezo	49.77	Dry	30.60	30.60	Silty sandstone
Bh1 (b)	15th July	Piezo	49.77	12.58	19.90	19.90	Stiff, sandy, silty clay
FILEY TOWN							
BH1	8th July	Piezo	28.768	13.06	13.65	14.00	Sandy gravely CLAY
BH2	8th July	Piezo	16.942	0.56	2.00	2.00	Clayey sandy gravel
BH5B	8th July	Piezo	7.541	6.04	6.18	6.45	Gravely fine to coarse sand – Made Ground
BH3	8th July	Inclino	27.098	16.25	30.00	29.70	Stiff, slightly sandy, slightly gravely CLAY
BH6		Inclino	27.33			30.00	Stiff, slightly sandy, gravely CLAY

Groundwater Monitoring Readings – July 2009

SITE Exploratory hole No.	Date (2009)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped Depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
FLAT CLIFFS							
BB01 (D2)	8th July	Inclino	25.54	Dry	14.20	22.50	Firm slightly sandy, slightly gravely CLAY
BB02 (A2)	8th July	Inclino	17.93	1.59	28.10	28.85	Firm slightly sandy, slightly gravely CLAY
B1	8th July	Piezo	15.64	2.06	23.38	24.50	Fine to medium SAND with clay bands
D1	8th July	Piezo	36.09	16.37	20.48	20.50	Stiff slightly sandy gravely CLAY
A3	8th July	Piezo	36.77	18.04	30.40	30.50	Firm slightly sandy gravely CLAY

N/A - Not Available
Piezo - Piezometer
Inclino – Inclinometer

Automated Piezometer Groundwater Monitoring Readings

(To Be Inserted)

Appendix D Survey Data

Initial Monitoring of Survey Points – July 2009

Whitby West Cliff					
BH2	Easting	Northing	Height (m)	Slope Distance	Remarks
MP1	489306.554	511468.120	40.864	8.319	Monitor point co-ordinates derived directly from GPS observations. Distances to edge measured with tape measure.
MP2	489308.296	511474.546	35.887	7.869	
MP3	489310.241	511481.188	32.126	8.655	
MP4	489313.968	511487.066	26.988	12.623	
MP5	489315.765	511498.358	21.652	11.657	
MP6	489314.795	511508.928	16.825		

Scalby Ness					
	Easting	Northing	Height (m)	Slope Distance	Remarks
MP1	503417.846	490962.702	35.853	3.15	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	503425.536	490962.701	36.059	4.30	
MP3	503429.459	490952.269	35.509	2.66	
MP4	503434.045	490941.940	34.969	4.18	

Scarborough South Cliff (North Section)					
H4	Easting	Northing	Height (m)	Slope Distance	Remarks
MP1	504353.903	487885.382	48.508	7.206	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	504359.701	487888.093	45.197	6.079	
MP3	504364.788	487888.922	41.974	9.117	
MP4	504372.839	487890.600	38.039	10.317	
MP5	504381.799	487893.850	34.090	9.246	
MP6	504389.334	487897.564	30.228		

Initial Monitoring of Survey Points – July 2009 (Continued)

Scarborough South Cliff (Central Section)					
E3	Easting	Northing	Height (m)	Slope Distance	Remarks
MP1	504549.325	487431.090	54.322	10.725	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	504559.474	487434.499	53.691	12.990	
MP3	504571.837	487437.291	50.847	10.256	
MP4	504579.847	487440.336	45.212	13.849	
MP5	504592.579	487444.628	41.856		

Scarborough South Cliff (South Section)					
BH2	Easting	Northing	Height (m)	Slope Distance	Remarks
MP1	504754.082	487134.614	55.305	12.035	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	504764.242	487137.096	49.350	6.004	
MP3	504769.607	487136.013	46.881	7.212	
MP4	504775.961	487137.850	44.007		

Appendix E Installation Photographs

Plate 1 Runswick Bay A001

Plate 2 Runswick Bay A002

Plate 3 Runswick Bay A003

Plate 4 Runswick Bay A004

Plate 5 Whitby West Cliff Bh2

Plate 6 Scalby Ness I1

Plate 7 Scalby Ness I2

Plate 8 Scalby Ness I3

Plate 9 Scalby Ness P1

Plate 10 Scalby Ness P2

Plate 11 Scalby Ness P3

Plate 12 Scalby Ness P4

Plate 15 Scalby Ness B6

Plate 16 Scalby Ness B9

Plate 17 Scarborough North Bay L11

Plate 18 Scarborough North Bay L12

Plate 19 Scarborough North Bay L1

Plate 20 Scarborough North Bay L5

Plate 21 Scarborough North Bay L3

Plate 22 Scarborough South Cliff I1

Plate 23 Scarborough South Cliff H4

Plate 24 Scarborough South Cliff H6

Plate 25 Scarborough South Cliff G2

Plate 26 Scarborough South Cliff F2

Plate 27 Scarborough South Cliff F4

Plate 28 Scarborough South Cliff E3

Plate 29 Scarborough South Cliff E5

Plate 30 Scarborough South Cliff D3

Plate 31 Scarborough South Cliff D1

Plate 32 Scarborough South Cliff Bh2

Plate 33 Scarborough South Cliff I2

Plate 34 Scarborough South Cliff I2A

Plate 35 Scarborough South Cliff H2

Plate 36 Scarborough South Cliff H1

Plate 37 Scarborough South Cliff H5

Plate 38 Scarborough South Cliff 1 Spa

Plate 39 Scarborough South Cliff 2 Spa

Plate 40 Scarborough South Cliff 3 Spa

Plate 41 Scarborough South Cliff 4 Spa

Plate 42 Scarborough South Cliff G3

Plate 43 Scarborough South Cliff 5 Spa

Plate 44 Scarborough South Cliff F5

Plate 45 Scarborough South Cliff F3

Plate 46 Scarborough South Cliff E2

Plate 47 Scarborough South Cliff E1

Plate 48 Scarborough South Cliff E4

Plate 49 Scarborough South Cliff D2

Plate 50 Scarborough South Cliff Bh3

Plate 51 Scarborough South Cliff Bh4

Plate 52 Scarborough South Cliff Bh1

Plate 53 Filey Flat Cliffs A2

Plate 54 Filey Flat Cliffs B1

Plate 55 Filey Flat Cliffs D1

Plate 56 Filey Flat Cliffs A3

Appendix F Site Photographs of Runswick Bay

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

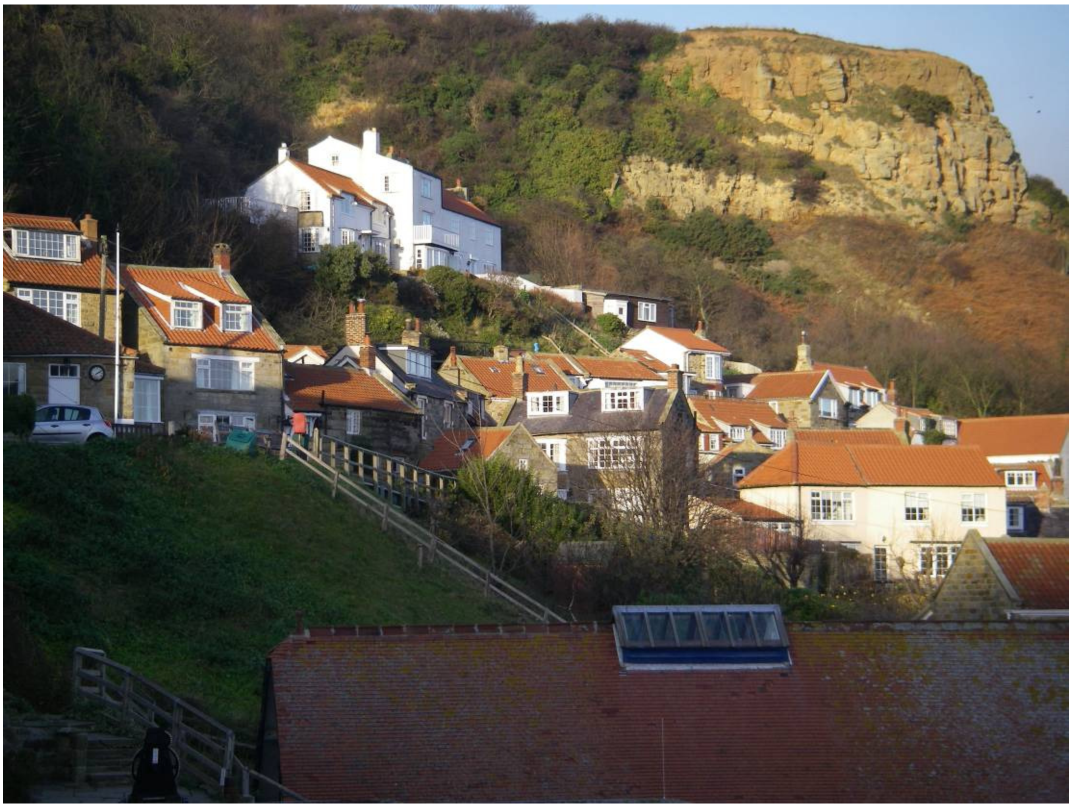


Plate 2 Site view looking north towards Cauldron Cliff.

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 G 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 H 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 I 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 J Site Photographs of Scarborough South Cliff

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

Plate 22 Site view showing 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 slope crest retaining walls at Prince of Wales 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 retaining wall and slope failure behind The Spa on Spa Cliff.

Appendix K 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 down Martin's Ravine. (Note stream on the right side).

Plate 46 Site view of slope failures towards the base of Martin's Ravine.

Plate 47 Site view of coastal slopes immediately south of Martin’s Ravine.

Plate 48 Site view of Filey Brigg looking west.

Plate 49 Site view of gullying and slumping of glacial tills at Filey Brigg.

Plate 50 Site view looking east at slumped glacial tills at Filey Brigg.

Appendix L 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.