Reid's Canal Floodway Widening
(1050m to 2900m)

Geotechnical Assessment

Prepared for

Bay of Plenty Regional Council

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ICE GEO & CIVIL

Contents

1 Introduction

The Bay of Plenty Regional Council has progressively been upgrading Reids Canal to improve the security of its stopbanks and its flood carrying capacity. This project is part of on-going work to improve the Rangitaiki River flood protection system. Ice Geo and Civil Ltd has been engaged to assess the geotechnical aspects of the canal improvements from 1050m to 2900m on the left bank and 1050m to 2550m on the right bank. This section is Stage 2 of the canal upgrading project and it stretches from Thornton Road to the Stage 1 upgrading work carried out in the 2011 / 2012 construction season (Reference 1). Upgrading work has also been carried out on 1300m of canal near Edgecumbe (Reference 2).

Reids Canal lies to the east of the Rangitaiki River and is designed to take some of the river flow in floods with a return period above 40 years. The canal starts just upstream of Edgecumbe and re-joins the river between Matata Road and the river mouth. The canal has its own catchment of drains with a mixture of pumped feeds and flap-gated culverts. The normal canal flows are contained in an incised channel between berms and stopbanks on one or both sides. Much of the improvement work involves moving one or both of the stopbanks further away from the permanent waterway to increase the flood carrying capacity. The crest level of some existing sections of stopbank will be lifted to improve freeboard. The design flood level in the canal has not been increased.

There is a history of stopbank failure within the Rangitaiki Plains. No obvious problems were observed along Reids Canal in the flood of July 2004 but the collapse of the Rangitaiki River stopbank further upstream and consequent flooding of the land along the canal may have caused problems to go unnoticed. This report details the geotechnical investigations and analyses carried out to enable the design of new and upgraded sections of stopbank in Stage 2 of the project.

This report presents the following;

- information on the sub surface soil profile gained from in situ investigations,
- laboratory test results,
- the results of seepage analyses for the estimated 100 year return period flood,
- the results of seepage analyses for tide cycles,
- recommendations for the design of the stopbanks,
- comment on the availability of suitable soil for stopbank fill and
- an assessment of the amount of stopbank settlement expected.

This report is the property of our client, the Bay of Plenty Regional Council Plenty and Ice Geo and Civil Ltd. The comments within relate only to the

length of stopbank along Reids Canal from 1050m to 2900m on the left bank of the canal and 1050m to 2550m on the right bank.

The conclusions of this report are based on the interpretation of investigations carried out at isolated points only and limited laboratory testing. Therefore there could be ground or other conditions which have an effect on the integrity of the stopbanks that have not been identified.

2 Site and Upgrade Description

Figures 1a and 1b show the extent of the canal covered by this report and the LIDAR plot in Figure 2 shows the ground contours. The stopbank meterages referred to throughout the report are shown on Figure 1. The water level in this section of canal is tidal with an average high tide reading of about RL 0.9.

It can be seen from the LIDAR plot that the downstream part of this section of canal stage lies in very low land that was a peat swamp before being converted to dairy farming. To the left of the canal, from 1400 to 1700m, the land is as low as RL-1.0 (Moturiki datum) and from 1250m to 2300m, below RL0.0. The land to the right of the canal is marginally higher but is still below RL0.0 from 1250m to 2300m. Although the land is drained by pumps it remains too wet for stock in winter in many places.

Areas of seepage along the toe of the stopbank have been identified from approximately 1300m to 1500m and 1750m to 2300m on the left bank, and 1350m to 1450m and 2000m to 2050m on the right bank. Heave has also been observed by the farmers near 2300m on the left and right banks.

At the downstream end of this section of canal the land rises to around RL2.0 where the original peat swamp meets the old coastal fore-dunes. It can be seen in Figure 2 that there is an offset in ground level across the canal at this location. Figure 3 shows a larger LIDAR plot and aerial photograph of the canal. It can be seen from the offset in the dunes that there is a fault running along the alignment of the Rangitaiki River mouth. It is not clear whether the offset in the ground across the canal near Matata Road is due to a smaller fault or is the result of a stream break out at some time.

The higher ground at the upstream end of this section of canal is part of a complex levee system around the Orini Stream (Figure 3).

The Kope Canal joins the Reids Canal at a floodgate at 1800m. This has created in a triangular area of wetland between the stopbanks.

The proposed upgrading project consists of removing the existing left stopbank from 1050m to 1700m and rebuilding it about 30m further away from the permanent waterway. The new stopbank will be up to 4.3m high. The soil from the existing stopbank is to be reused as fill. The permanent water way will be widened to 40m and there will be minor raising of the stopbank level along the right bank. Berms 5.5m wide will be left between the permanent water way and the stopbanks.

Figure 1A: Site Layout

Figure 1B: Site Layout

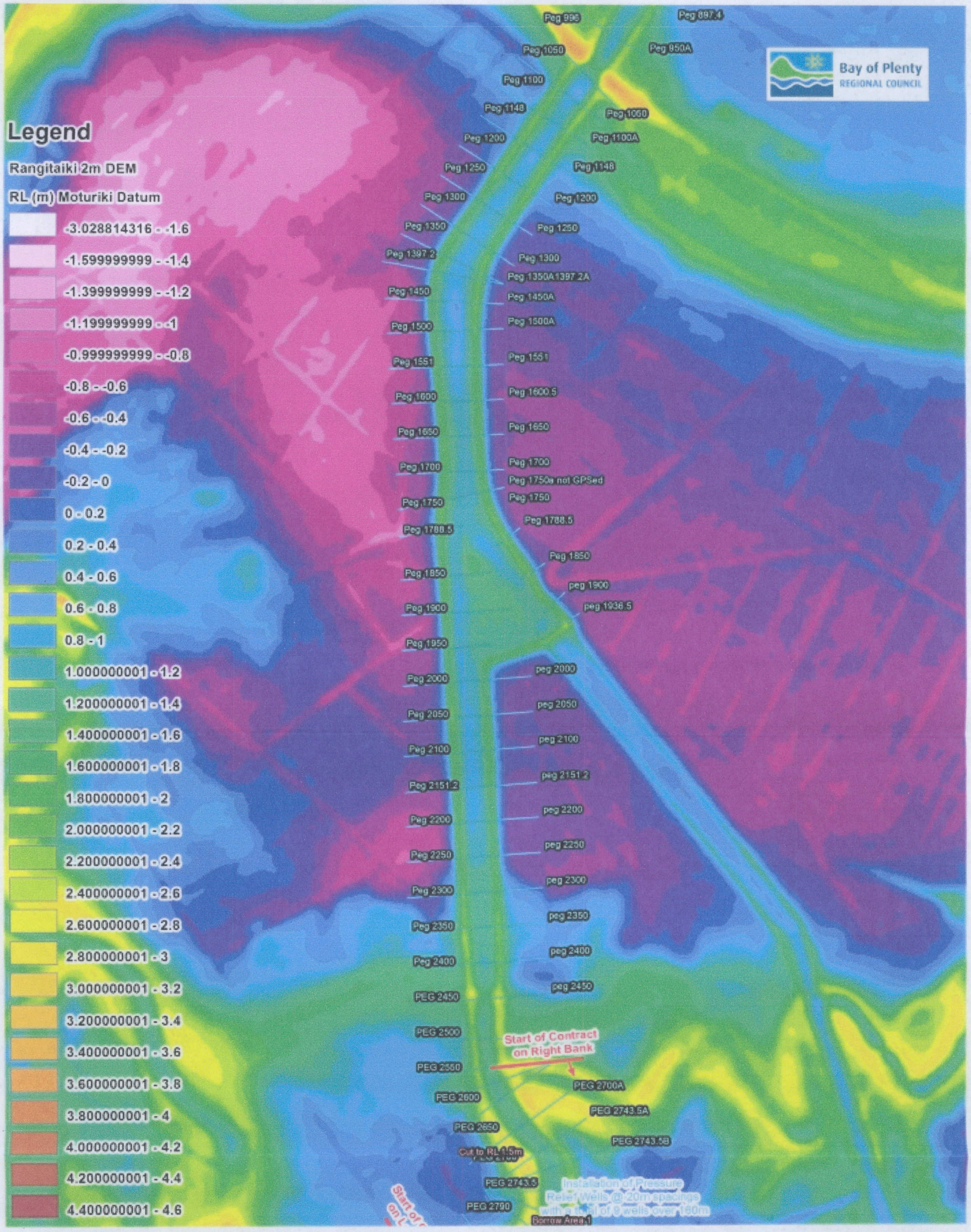
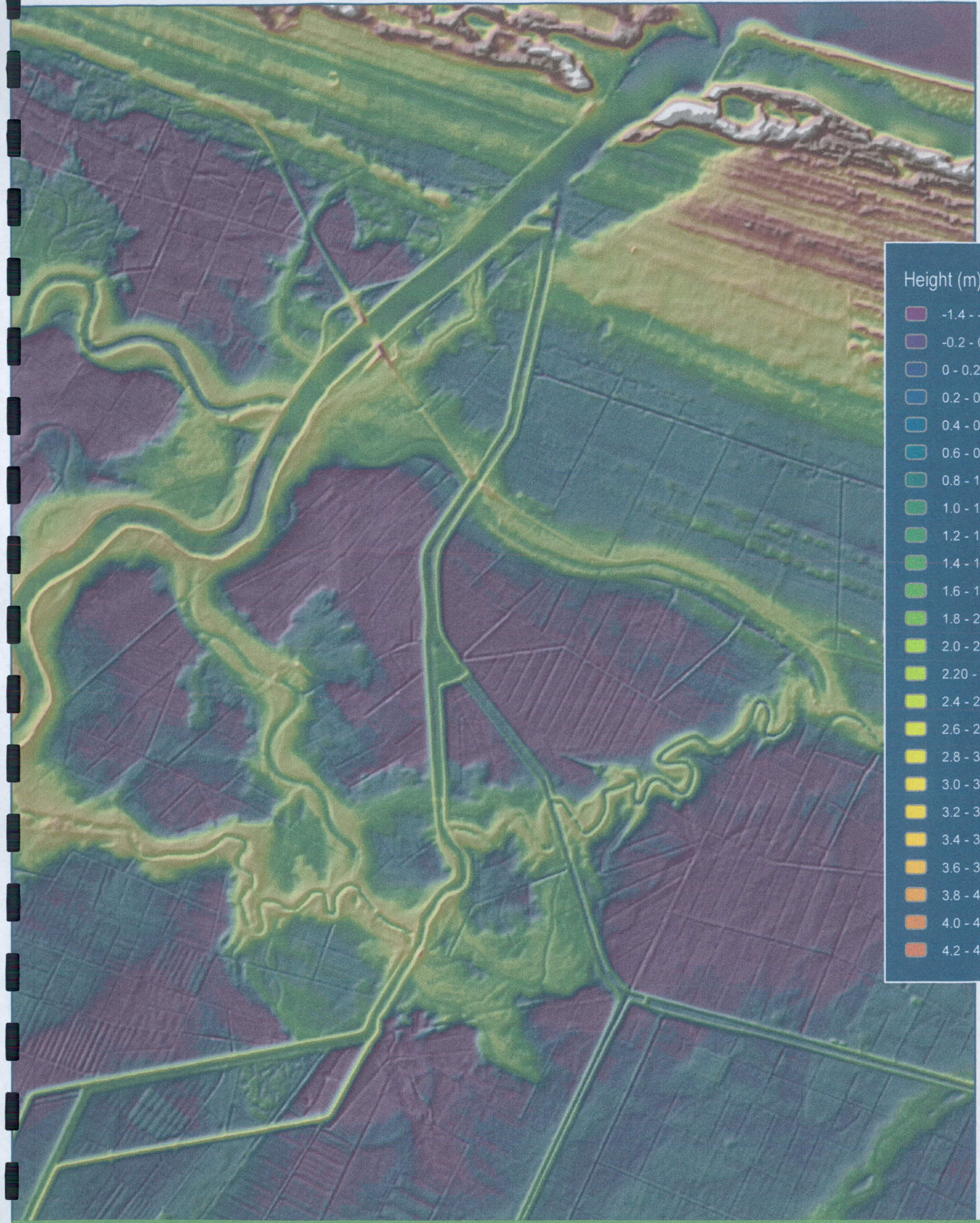
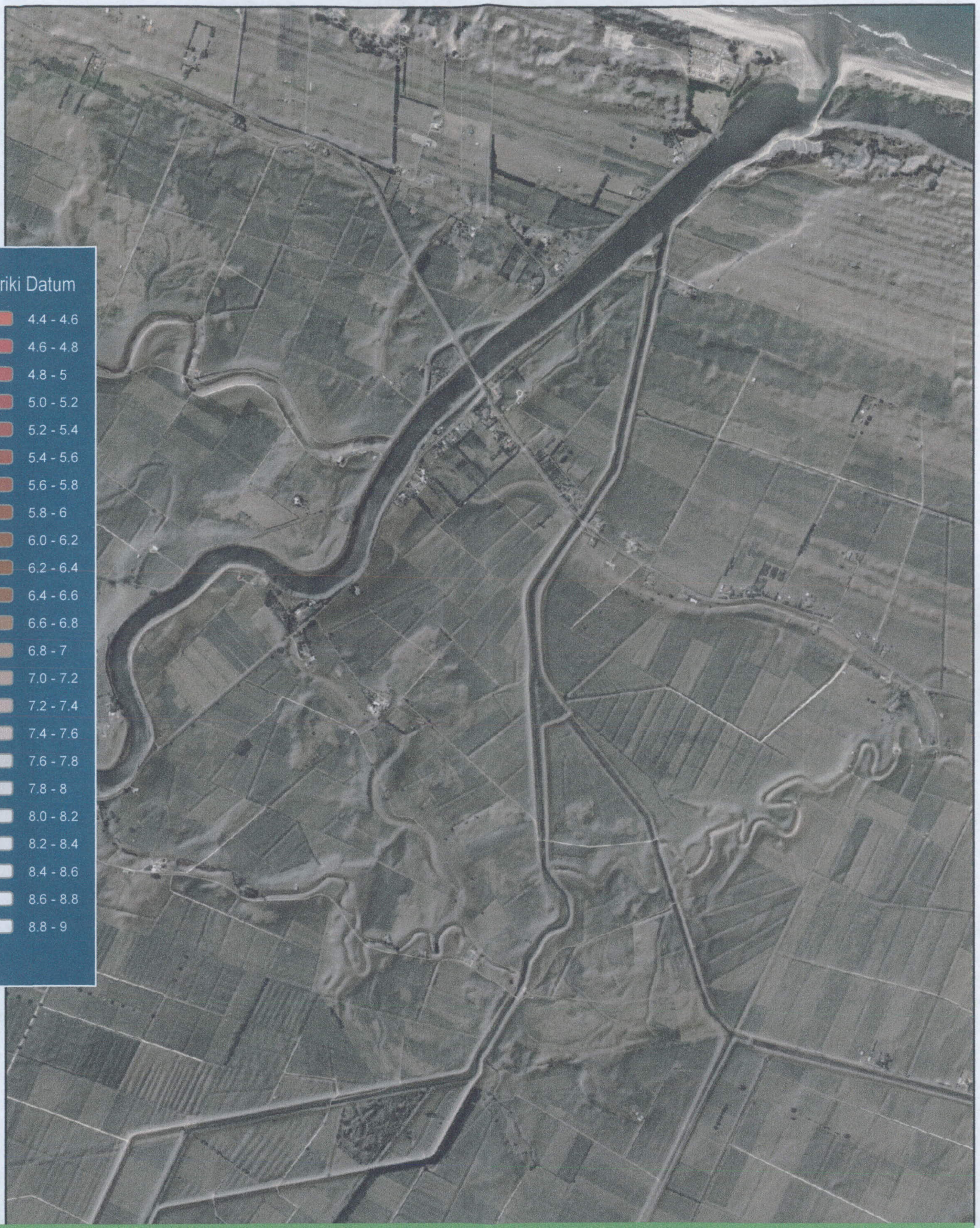


Figure 2: Ground contours





Height (m) Moturiki Datum

-1.4 - -0.2	4.4 - 4.6
-0.2 - 0	4.6 - 4.8
0 - 0.2	4.8 - 5
0.2 - 0.4	5.0 - 5.2
0.4 - 0.6	5.2 - 5.4
0.6 - 0.8	5.4 - 5.6
0.8 - 1	5.6 - 5.8
1.0 - 1.2	5.8 - 6
1.2 - 1.4	6.0 - 6.2
1.4 - 1.6	6.2 - 6.4
1.6 - 1.8	6.4 - 6.6
1.8 - 2	6.6 - 6.8
2.0 - 2.2	6.8 - 7
2.20 - 2.4	7.0 - 7.2
2.4 - 2.6	7.2 - 7.4
2.6 - 2.8	7.4 - 7.6
2.8 - 3	7.6 - 7.8
3.0 - 3.2	7.8 - 8
3.2 - 3.4	8.0 - 8.2
3.4 - 3.6	8.2 - 8.4
3.6 - 3.8	8.4 - 8.6
3.8 - 4	8.6 - 8.8
4.0 - 4.2	8.8 - 9
4.2 - 4.4	

Environment Bay of Plenty
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Reids Canal Surface Charateristics

250 125 0 250 500 750
Meters
Scale = 1:20.000

Note:
The DEM dataset is generated from LIDAR data captured in 2006.
The original LIDAR dataset has a vertical accuracy of 0.15m.
The DEM shown has a 2m cell size which as a consequence of some generalisation reduces the vertical accuracy to approximately 0.3m.

N

R750 Location F 08 May 2008

The widening work crosses to the right bank of the canal from 1700m to 1900m. The right stopbank will be moved back 30m and raised to up to 3.8m high.

Between 2400m and 2500m the major work crosses back to the left side of the canal. There is no existing formal stopbank along this side to the canal to the end of the section at 2900m as the natural ground level is relatively high. Widening of the canal will require a new stopbank up to 3.5m high on lower ground about 50m from the existing waterway.

3 Subsurface Investigations and Soil Profile

3.1 In Situ Test Programme

The initial subsurface investigations consisted of the drilling of 10 fully cored boreholes up to 14m deep along the proposed alignment of the stopbanks; therefore some were drilled at paddock level and others through the existing stopbanks. The boreholes were located to investigate the different sub surface soil profiles evident from the LIDAR plot, the problem areas identified by the farmers and the areas where there will be the highest head difference across the stopbank (Figure 1). The depth of the boreholes was determined by the soil profile found with drilling stopped when it was considered that the soil type would no longer have a significant influence on the seepage characteristics which affect stopbank security. The bore logs are included in Appendix A with a summary table of the main layers found. The soils have been logged generally in accordance with the New Zealand Geotechnical Society Guidelines (December 2005).

Borehole 1b was drilled due to no dune sands being found in BH1a. Dune sands were expected near the ground surface downstream of 1200m. The nature of the sand and its extent could have significant influence on the design of the stopbank. Three boreholes were drilled at the BH2 location as the first two encountered timber before the desired borehole depth.

Twelve falling head permeability tests were carried out in sand layers in various boreholes. The results are presented in Appendix G and are included in the bore logs. Five laboratory particle grading tests were also carried out to aid the estimation of permeability.

Nine test pits were excavated in the paddocks along the canal to confirm the soil type where there was lost core in the boreholes and to provide more information where there was a significant change in soil layers between adjacent boreholes. Most of the test pits were not excavated below 3m depth due to the low level of the paddocks relative to the permanent water level in the canal.

Seven hand augers were carried out on a cross section through the right stopbank at 1300m as part of a previous investigation into seepage at in this area (Reference 3). The logs of the augers and the subsurface soil profile are included in Appendix E.

As sand was found in the existing stopbank in some of the boreholes, the topsoil was scraped off the face of the stopbank in seven locations along the left bank and nine locations along the right bank to determine the extent of the sand layers and the suitability of the stopbank material for construction of the new stopbanks. The logs of these face scrapes are included in Appendix C.

Eleven cone penetrometer tests (CPT) were previously carried out in the basin between the canal and the Rangitaiki River as part of the investigations into the security of the river stopbank near Thornton School. The location of those CPT tests nearest the canal are shown marked up on Figure 1 and the CPT results are included in Appendix D. These CPT results were correlated with the nearby boreholes to develop soil models for the seepage analyses.

Organic content tests were carried out on four soil samples from the boreholes to provide information for the assessment of long term stopbank settlements. The results are included in Appendix E.

3.2 Left Bank

BH1b was drilled at 1020m in the remnant sand dune along which Matata Road runs. The simplified soil profile found is:

- 0 - 2.0m silty fine dune sand
- 2.0 – 2.4m soft estuarine clay. This clay was not found in any of the other boreholes.
- 2.4 – 3.0m silty fine sand with some organics
-
- 3.0 – 3.6m(RL0.7) medium to coarse sand. This level is consistent with the same sand found in BH1A, 30m upstream of BH1B but 1m lower in elevation.
- 3.6 – 3.8m silts found in most the basin
- 3.8 – 6.0m coarse sand and fine lapilli.
- 6.0m – medium to coarse sand. The sands were found to extend to over 12m depth.

No silty sand was found in BH1a where the coarse sand is overlain by a thick layer of firm to stiff sensitive silts.

The soil profile in BH2c at 1300m is:

- 0 – 0.3m organic silt
- 0.3 – 0.4m pumiceous silt
- 0.4 – 0.43m fine to medium pumice sand. This sand layer is considered to be a Tarawera Ash layer and is

found across most of the Rangitaiki Plains.

- 0.43 – 1.9m peat
- 1.9 – 4.1m silts as found in BH1a. These silts are over 3m lower than in BH1a, RL-2.5 compared to RL0.7.
- 4.1 – 6.6m peat with a 30% organic content and some timber
- 6.6m (RL-7.2) - dense medium sand

CPT tests 2 and 3 show a similar soil profile and depth of peat to BH2 except that the silt layer found at 1.9m depth is interpreted in the CPT tests as a silty sand. The 4m thickness of peat found in this area will cause considerable settlement of the new stopbank.

BH3 at 1600m has a similar soil profile to BH2 except that the lower peat layer is thinner and is underlain by a pumiceous gravelly sand containing some organic material and then the dense medium grained sand at RL-8.3. Test Pit 1, excavated at 1750m, showed the same soil profile to RL-4.0. CPT tests 6 and 9 show a similar profile with the pumiceous silt layer being interpreted as sand. In CPT5, further towards the centre of the basin, this silt appears to be thinner and has been correctly interpreted. The level of the dense, medium to coarse grained basement sand seems to be reasonably constant across the basin.

BH4 was located in the stopbank at 1900m as this is where the canal widening will change from the left hand side to the right hand side. The upper 1.6m of the stopbank consists of well compacted silt and sandy silt suitable for stopbank construction; however the lower 2.2m consists of coarse sand with some bands of sandy silt forming a layer of high permeability. This layer is likely to be the reason for the seepage observed at the inland toe of the stopbank.

At 1900m the soils beneath the stopbank are the same as in BH3 and Test Pit 1 except the weight of the stopbank has compressed the upper soil layers. In BH3 and TP1 the layers above the upper pumice silt layer are 2.1 and 1.8m thick respectively. Under the stopbank these layers are only 1.2m thick. The majority of this compression has been in the peat layer, which is less than 60% of the thickness of the layer at the other two test locations. The amount of compression of the lower peat layer cannot be accurately assessed due to core loss but it appears to be about 40% as for the upper layer. Therefore in this location it appears that there has been about 1.0m of peat consolidation. This is a useful indication of the amount of settlement that could be expected with similar soil profiles under the new stopbank. CPT11 shows the same soil profile as BH4, when the compression of the peat layers under the stopbank is taken in to account.

BH5 was drilled through the stopbank at 2200m at the edge of a sand levee. Some coarse sandy layers were found within the stopbank but overall it consisted of well compacted sandy silt. Below the stopbank the soil profile is:

- 2.3 - 2.4m organic silt (old ground surface)
- 2.4 – 5.5m coarse sands from the sand levee. Water passing through these sands is considered to be the cause of the heave which occurs in the adjacent paddock even at normal flow conditions in the canal.
- 5.5 – 7.1m(RL-4.6) layers of silt, peat / organic clay, sand
- 7.1 – 12.8m medium to coarse sand similar to BHs 3 and 4
- 12.8m (Rl-10.3)- dense well graded sand

Test Pit 2 was excavated at 2150m, about 15m from the toe of the existing stopbank, to refine the change point from the BH3 and 4 soil profile to the BH5 sand levee profile. The soil layers found were the same as in BH4 although they are at higher reduced levels. The transition to the levee sands is therefore between 2150m and 2200m. Current bedded medium to coarse sand was found beneath 400mm of silt in TP3 at 2300m, upstream from BH5. This pit was also 15m from the stopbank toe.

The medium to coarse grained sand found in BH5 rises in level from RL-5 at 2200m to RL-0.1 in TP3 (2300m) and TP4 (2450m). The ground surface at TP4 is 1m higher than at TP3 due to an increase in the thickness of the silt layer overlying the sand.

BH6 was drilled at the new centreline position at 2650m where the stopbank will cross a low basin between stream levees. As there was some core loss close to the ground surface TP5 was excavated nearby to confirm that the lost soil was not a sand layer. It was found that the upper section of core loss was peat and the only near surface sand layer is the 150mm thick layer of Tarawera Ash at 1.1m depth. A 500mm thick highly permeable pumice gravel layer was found in the pit at RL-2.8. This layer was lost in the borehole. The rest of the soil profile at BH6 is similar to that in boreholes 2, 3 and 4 with a 2m thick peat layer. A fine to medium grained dense sand layer at RL-5.5 extends to below RL-10.2. This sand is at a similar level to that in BH5,.

Test pit 7 was excavated on the new centreline at 2750m. A similar soil profile to that at TP5 was found:

- 0 – 1.2m silt
- 1.2 – 1.4m peat
- 1.4 – 1.6m coarse pumice sand.
- 1.6 – 2.6m peat
- 2.6 – 3.3m stiff pumiceous silt

- 3.3 – 3.7m pumice gravel to 15mm
- 3.7m(RL-2.8)- hard pumiceous silt

This soil profile was also found in TP 8 at 2820m, although this pit did not reach the gravel layer.

3.3 Right Bank

The position of the existing stopbank will be unchanged from 1000m to 1700m therefore boreholes 9, 10 and 11 were drilled through the stopbank. At BH11 (1200m) the top 700mm of the stopbank consists of clayey rock fill. The rest of the stopbank is low permeability silt or sandy silt, apart from one thin fine sand layer.

BH11 was at the edge of the old coastal sand dunes and the only organic material found below the stopbank was in thin bands within other deposits. The sub surface soils consist of silts and sands over a 1.2m thick pumice gravel layer at RL-3.8. This gravel is underlain by 1.2m of sensitive silt then a complex layering of sands. This soil profile is considered to be due to a combination of dune formation and alluvial deposition processes. The dense, fine to medium grained sand layer found in most boreholes is at RL-9.1.

It was found in BH10 at 1500m that there is 1.5m of clayey rock fill in the top of the stopbank but this is underlain by about 1m of sand. This sand was also found in the hand augers at 1350m (Reference 3). The remainder of the stopbank is sandy silt. The natural soil profile is similar to that found on the opposite side of the canal in boreholes 2 and 3. Core was lost between RL-1.4 and -2.2 with pumiceous silt found above and below the lost core. The permeability measured in a falling head test suggested there may be some fine sand layers in the silt. Timber was found in the lower layer of peat, as on the opposite side of the canal. The total thickness of peat found was 1.4m which is probably the result of compression from something in excess of 2m thickness. The hand augers carried out in the paddock at 1350m showed a similar soil profile to BH10 and1.2m thickness of just the upper peat layer.

BH9 was drilled at 1900m near the confluence of the Kope and Reids canals. There is 500mm of rock fill in the top of the stopbank, 800mm of good sandy silt fill and then layers of sand and pumice lapilli, plus some organic material. The natural soil profile consists of about 800mm of sandy silt underlain by 1.2m of spongy organic silt and the typical peat, silt and sand layers. Hard grey gravel was found in addition to pumice gravel in the coarse sand layers below RL-7.0. The dense sand layer was found at RL-9.5.

BH8 was drilled in the paddock at 2100m. Less than 1.0m of peat was found and the coarse gravelly sands are at less than 3.0m depth (RL-3.2). This is 1.4m higher than in the sand levee at BH5 on the opposite side of the canal. It seems that there is a buried levee in this area that cannot be picked up by LIDAR.

BH7, in the paddock at 2300m showed 2m of peat and organic clay but this was overlain by 2m of fine to medium grained sand, which was not found overlying peat anywhere else. It is considered that this sand is the result of a relatively recent overtopping of the stream. Below RL-4.2 are various layers of fine to coarse sand which are probably the result of levee formation. The peat contains 60% organic matter and has a water content of 555%, making it highly compressible.

3.4 Fill Sources

The borehole investigations picked up sand layers within the left stopbank at BH 4 (1900m) but none in BH5 (2200m). The investigations carried out by scraping the topsoil of the face of the stopbank showed other variations in the stopbank soils. It is considered that as much of this stopbank is to be completely moved, the whole length should be removed so that the soils can be well mixed and reused in the construction of the relocated and raised stopbanks.

Although most of the right stopbank is not being relocated the boreholes and face scrapes show there are considerable sand layers within it upstream from 1200m; up to 50% sand in places. This stopbank should therefore be rebuilt. It is estimated that imported or borrowed silt or clay, equivalent to approximately 30% of the volume of the stopbank, should be used to mix with the existing stopbank soils to make a reasonable fill. If the sand layers are removed from the stopbank the sand can be used in overlays.

The formation of the new 40m wide waterway will provide some fill however the investigations have shown that downstream from about 2500m the excavations will be in peat or sand, apart from a thin layer of surface silt. Most of the fill for stopbank construction will therefore have to come from the bend upstream of 2500m.

A test pit was excavated in the low bund at the edge of the canal at 2743Cm (TP6) and sandy silt and silt suitable for fill was found to below 2.1m depth (RL0.9). Test pit 9 was excavated near the edge of the waterway at 2850m and apart from one thin sand layer there is silt to 2.1m depth. The test pits along the new centreline in this area also showed at least 1m of surface silt. Therefore it is expected that 1 to 2m of fill suitable for stopbank construction could be won from this elevated area.

The soil which is excavated from the waterway which is not suitable for fill can be used for overlays and landscaping; however **if peat is used for overlays the thickness of the overlay will have to be doubled.**

4 Analysis Method

4.1 Discussion

The in situ investigations carried out provide subsoil profiles at isolated locations only. Although an effort has been made to build a degree of conservatism into the analysis of the stopbank cross sections discussed in following sections, the subsurface investigations show considerable variation in the soil layers above the basement sands and it is possible that in terms of the seepage response to a flood in the canal there are worse combinations of soil layers than those assumed.

The computer programme used to analyse the seepage through and under the stopbanks, Geo-Slope Seep/W (2004), is a two dimensional programme. Therefore three dimensional effects such as seepage parallel to the canal or across bends, cannot be accurately modelled. The seepage analyses carried out must therefore be considered indicative only.

Five possible problems could arise due to a flood in the canal;

- excessive flows under the stopbank,
- the removal of soil particles due to high hydraulic gradients, resulting in piping and collapse of the stopbank,
- heave of upper soil layers due to high water pressures, resulting in the exposure of high permeability soils, rapid piping and stopbank collapse,
- failure of either face of the stopbank due to high water level or draw down conditions and
- over-topping of the stopbank causing rapid erosion of the stopbank.

Heave and high seepage are already being experienced under normal flow conditions. The most common remedial measures for heave problems are the addition of an overlay on the ground surface or the construction of a pressure relief trench (or wells). The aim of the remedial measures for this canal is to achieve a minimum factor of safety against heave of 1.1 to 1.2.

The risk of piping can be reduced by increasing the length of the seepage path by the addition of overlays, or by installing a drain in the area susceptible to piping to allow seepage without the removal of soil particles. These drains also reduce the uplift pressures and risk of heave. The maximum hydraulic exit gradient considered acceptable with the light soils in this area is 0.4. Once piping is initiated by the lifting and cracking of surface low permeability layers, average hydraulic gradients as low as 0.1 can cause pipe formation to continue.

Seepage of only small volumes of water from the ground surface can significantly reduce the uplift pressures acting on a low permeability surface layer with a higher permeability layer beneath it. Seepage from the ground

surface behind the stopbank has therefore been allowed for in the computer models.

It is proposed to build the stopbanks with 4H:1V side batters, 3m wide crests and 5m wide berms to provide stability for the faces of the stopbanks.

Seepage analyses have been carried out on 7 cross sections along the left stopbank and 6 cross sections along the right stopbank. The soil models used at each cross section were based on all the nearest sub-surface investigations and the highest sand levels found in those investigations. Table 2 at the end of Section 5 summarises the measures recommended to achieve an acceptable level of protection against stopbank failure due to seepage.

4.2 Flood Hydrograph

Opus International Consultants Ltd (14 July 2011) has provided a hydrograph for the canal based on the following;

- a 100 year return period flood in the Rangitaiki River,
- a 20 year return period storm surge at the river mouth,
- high tide at the river mouth and
- an estimated 500mm sea level rise to 2090.

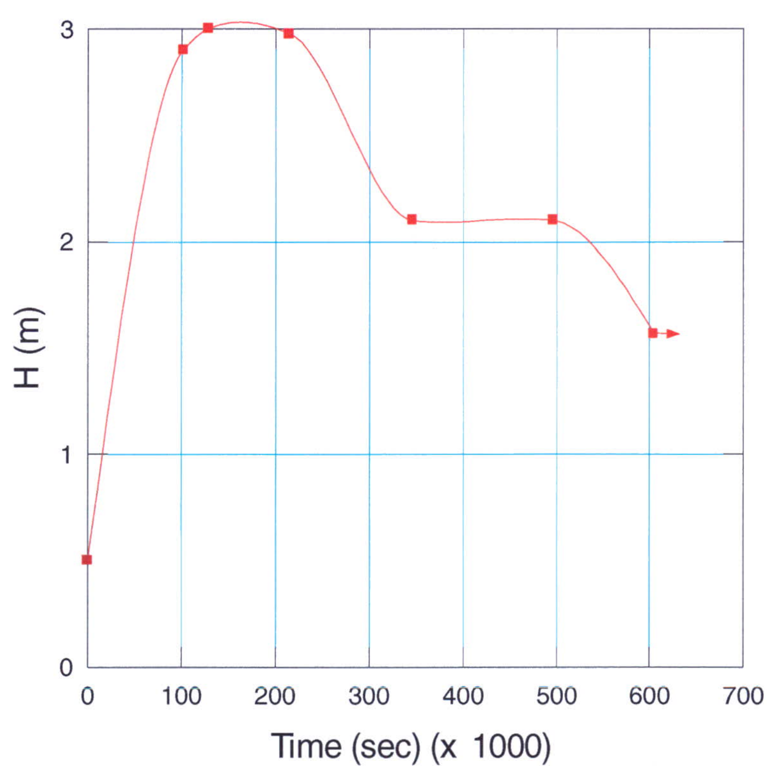


Figure 4: 100 year return period flood flow hydrograph

Figure 4 shows the eight day long hydrograph developed. In the analyses the hydrograph was adjusted to give 300mm freeboard at each cross section along the canal. The initial water level in the canal was assumed to be RL0.5 (approximately half tide) and that inland RL-1.0, due to the water level being kept down by pumping. The design depth of the waterway invert is RL-2.0.

Transient analyses were also carried out to check how much flow there would be from a drainage system due to normal tidal fluctuations in water level. Figure 5 shows the average tide cycle assumed.

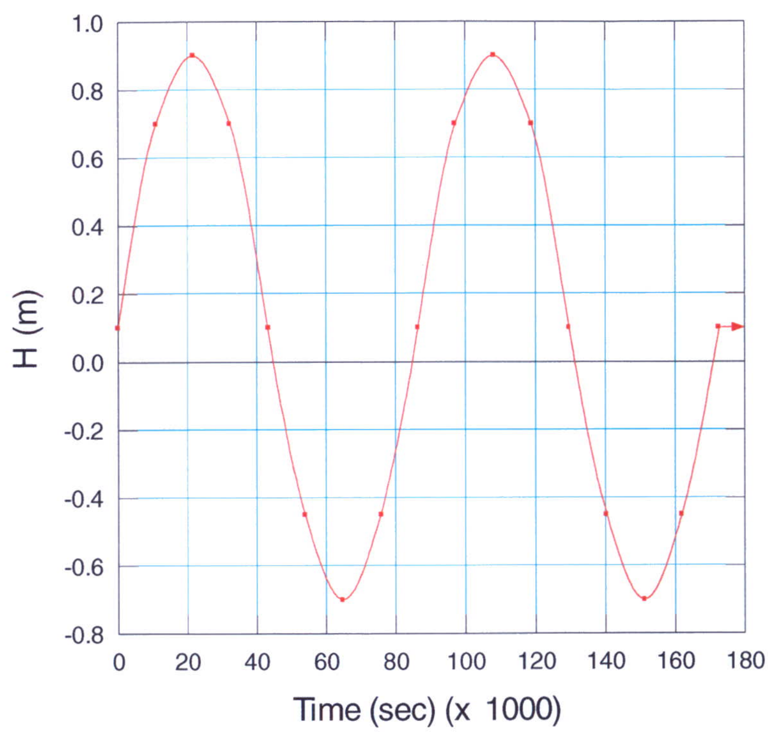


Figure 5: Average tide cycle

4.3 Soil Model

The soil layers found in the in situ investigations were simplified to form seepage analysis models for each of the stopbank cross sections. These are discussed in the following sections and are shown in Appendix H.

Below the surface layer of silt the soil layers were divided into layers on the basis of their seepage characteristics rather than their descriptions. Table 1 summarises the soils used and the permeabilities assumed. The permeabilities were based on the falling head tests and particle grading tests carried out for this investigation and results for similar soils elsewhere on the Rangitaiki Plains. The test results from the investigations for the Thornton

School section of the Rangitaiki River are particular relevant. The results are presented in Appendix G.

Particle grading tests have been used to estimate the soil permeabilities using the Hazen formula:

$$k=0.01d_{10}^{2}$$

The permeabilities derived using this formula for the Stage 2 length of stopbank are within 50% of those measured in falling head tests in the relevant layers. The falling head test result for 9.5m depth in BH4 is the same as the Hazen's estimation.

In terms of the assessment of the heave potential of the upper silt layer, it is conservative to assume a permeability on the low side of that found from the tests on the upper silts, and on the high side for the more permeable sand layers acting as aquifers. The relationship between horizontal permeability and vertical permeability was based on observation of the core from the boreholes.

It was assumed that the stopbanks would be made from sandy silt and the compaction process would cause a greater horizontal permeability than vertical.

Table 1: Assumed Soil Permeabilities

soil	**k_h** (m/s)	**k_v** (m/s)
stopbank fill	4×10^{-6}	2×10^{-6}
surface silt	2×10^{-7}	2×10^{-7}
medium to coarse sand	5×10^{-5}	5×10^{-5}
coarse sand	1×10^{-4}	3.33×10^{-5}
pumice gravel	3×10^{-4}	3×10^{-4}
pumice silt with some fine sand layers	2×10^{-5}	2×10^{-7}
silty fine sand (dune)	5×10^{-6}	5×10^{-6}
varved silt	1×10^{-6}	5×10^{-7}
peat / clay	5×10^{-8}	5×10^{-8}

The Geo-Slope Seep/W (2004) computer package used for the seepage analyses contains a library of soil grading curves, with corresponding hydraulic conductivity and water content versus water pressure relationships. The particle gradings observed on site were compared to those in the Seep library and the closest fit chosen as the soil model to be used in the seepage analyses.

The stopbank cross sections were generally modelled to at least 80m beyond the inland toe of the stopbank to prevent any boundary effects on seepage characteristics. Infinite elements were also used to increase the effective boundary distance. An initial steady state analysis was carried out with the canal at an average height. The water pressures generated from this model

were then used as the starting pressures for the transient flood flow analysis. It was conservatively assumed that there was no silt lying over sand layers day-lighting in the canal. It is likely that there will be silt covering sand layers at the start of a flood but these may be eroded away during the flood.

The weight of the upper silt layers was assumed to be 15 kN/m^3 when heave potential was being checked. 14kN/m^3 has been assumed for pumiceous silt and sand, 13kN/m^3 for organic silt and clay and 10.5kN/m^3 for peat.

4.4 Drainage Wick Model

Pressure relief is needed in some areas along the stopbanks as the surface soils across the basin are light and there are high permeability sand layers close to the surface. There is a positive pressure gradient from the canal into the basin under normal conditions (apart from in the levee areas). The installation of conventional pressure relief trenches or wells would therefore be very difficult.

Drainage wicks can be installed without any excavation and consequent hole collapse or piping problems. These wicks are usually used to accelerate consolidation of soft layers by shortening the horizontal drainage path and allowing excess water to flow relatively unimpeded to the ground surface. The design of the wick system usually allows the consolidation to take place over months, instead of the years required without them. Similar vertical drains can be used to relieve pressures in an earthquake and prevent liquefaction. These drains are usually closely spaced and have a very high vertical flow capacity. The pressure relief system required during a flood needs permeability characteristics between that for consolidation acceleration and that for liquefaction prevention.

Kilometres of vertical drains have been installed for the Tauranga Eastern Link highway construction project. Local contractors are consequently geared up for their installation on a large scale by cranes or excavators. The length of wick required at the canal can be installed with a 30 tonne excavator, making access along the stopbank and in the paddocks relatively easy.

The type of vertical wick drain that has been used on the Eastern Link is that made by Ceteau. It is has an inner ribbed plastic core wrapped in geotextile, producing outside dimensions of 100mm by 3mm. Details are given in Appendix I. As the wick is underground and away from UV light it has an indefinite life. The flow capacity of this wick is 60 x 10^{-6} m^3/s at a hydraulic gradient of 0.1, allowing for some kinks in the wick as the ground settles in a consolidation situation. If flow from the wick is unimpeded at the ground surface the vertical hydraulic gradient from a sand layer at depth would be 1 or more in a pressure relief situation.

Trials of seepage models were carried out varying the spacing of the wick drains to achieve an upwards flow capacity similar to a gravel filled trench. The result was two rows of wicks 650mm apart with the wicks offset in each row, 750mm apart. This produces a triangular grid of wicks at 750mm centres. Calculations showing how the drainage system is modelled as a

seepage element are shown in Appendix I. If the wicks intercept a layer of fine sand with a permeability of 5 x 10^{-5}m/s the equivalent vertical permeability of a 1m wide soil element is 1.6 x 10^{-3}m/s, similar to a gravel filled trench. The horizontal permeability of the element is determined by the width of the element (how far water has to travel to get to a wick drain). An allowance was made for 3mm of smeared clay or peat on the surface of the wick after it is pushed through the overlying soil layers. In reality this smeared soil will probably be scraped off as the tip of the wick is pushed into the sand. For a 1m wide element in fine sand the resulting horizontal permeability is 7 x 10^{-6} m/s. The Seep/W programme requires the definition of vertical to horizontal permeability, which for this case is 224. These values were changed in the analyses to reflect the width of the soil elements generated by the Seep/W programme.

The same soil parameters were assumed up the wick to the ground surface even though the wick passes through different soils, usually with lower permeabilities. This is considered acceptable as the calculation of the vertical element permeability makes no allowance for the permeability of the soil containing the wick. The horizontal permeability of the wick elements will be higher than that of most of the soils through which the wick passes, but this is considered acceptable as there is minimal horizontal flow in these soil layers compared to that in the sand layer being targeted. Different wick parameters could be set in each soil layer but this seems unduly complex.

The water from the wick drains will flow into a 1.5m wide, geotextile wrapped trench filled with clean gravel containing two novaflo pipes with outlets into the paddocks at approximate 30m intervals.

5 Seepage Analysis Results

5.1 Left Bank 1050m

The stopbank at this cross section is only 1.5m high, as shown in Appendix H. It is underlain by fine dune sand, containing one thin clay layer, overlying medium to coarse sand, a thin varved silt layer and further coarse sands. The initial seepage transient analysis was carried out assuming a permeability of 5 x 10^{-6}m/s for the dune sand. A second analysis was carried out assuming 1 x 10^{-5}m/s. No seepage problems were identified in either analysis.

The estimated seepage under the stopbank at peak flood conditions in the canal is 40 litres / m length / day.

5.2 Left Bank 1100m

BH1a was used to develop a soil model at 1100m where the stopbank will be 2.7m high. The model consists of silt to RL-0.6 underlain by coarse sand. The transient analysis showed that there could be heave problems due to high pressures under the silt. Due to the high permeability of the coarse sand any overlay to counteract heave would have to be very wide. Therefore analyses were carried out modelling drainage wicks. An effort was made to change the

level of the drainage wick outlets so that heave would be prevented in floods but there would be minimal flow due to normal tidal changes in the canal; however it was found that it is necessary to place the drainage wicks at the toe of the stopbank to prevent heave of the surface silt layer. The wicks would extend from RL0.7 to RL-3.0. (Figure 6 shows a wick drain and overlay layout for a cross section at 2200m.)

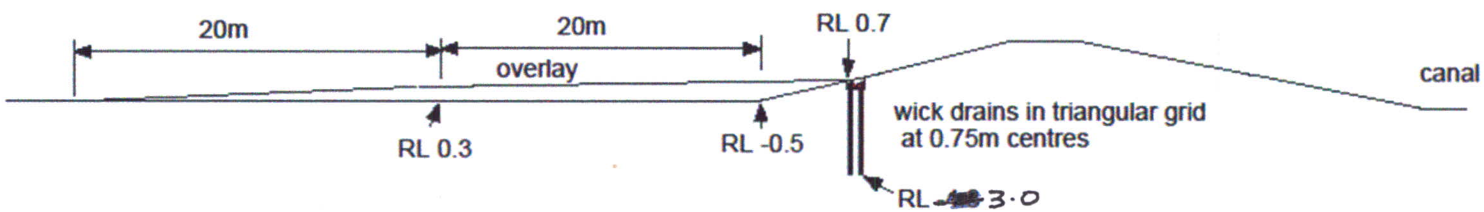
In the peak flood conditions flow of up to 4,000 litres / m length /day is expected. As the top of the wicks will be below the peak tide level in the canal, there may be flows up to 220 litres /m of drain over a 12 hour tide cycle.

5.3 Left Bank 1500m

The stopbank at 1500m will be 4.3m high as the ground level is RL-1.0. This is the highest part of the stopbank in Stage 2. As discussed in Section 3.2 above and shown in Appendix H, there is a complex system of coarse sand layers, peat and silt at this location. The coarse sand layer below only 500mm of surface silt and clay means that heave is a problem. Heave of the surface silt has been observed without the canal being in flood. A transient analysis of the flood in the canal showed that heave of the upper peat layer could also occur and the stability of the silt layer below this is also marginal.

Wick drains could be installed at the toe of the stopbank to prevent heave of the surface layer; however wick drains at this level would allow an excessive amount of water into the paddocks under normal tidal conditions in the canal. If the wick drains are lifted an overlay is required to hold the upper soil layers down. Analyses were carried out to see if a cut off trench would be a better option in this situation. It was found that any cut off would have to be to in excess of RL-5.0, which is beyond the depth of mixing by excavator and would have to be formed by very expensive deep soil mixing techniques. The required lateral extent of a cut off is also difficult to determine within an area of complex ground water flow.

Various analyses were carried out with combinations of drainage wicks and overlays. It was found that to prevent excess flow in normal conditions the drainage wicks should be lifted to RL0.7 or higher. This is 1.7m above the ground level and therefore leaves 1.7m of uplift pressure under the soil layers. An overlay without any drainage is therefore considered to be the most practical solution. An analysis of a 30m wide overlay at RL -0.2 (800mm thick) showed that the factor of safety against heave of the upper silt and peat layers would be adequate but that of the underlying silt would still be marginal at the edge of the overlay. The overlay has therefore been tapered from RL-0.2, 20m from the stopbank toe, to ground level at 40m.



Reid's Canal Left Bank Cross Section 2200m

Figure 6: Overlay and wick drain layout at 2200m Left Bank

5.4 Left Bank 2100m

An analysis was carried out for a cross section at approximately 2100m using the results of boreholes 3 and 5 and test pits 1 and 2. A ground level of RL-0.5 was assumed. The soil layers are similar to those at 1500m but the ground level is higher. This analysis was used to determine a suitable transition from the pure overlay at 1500m to the overlay plus wick drains at 2200m (Section 5.5). The analyses showed that a 40m wide overlay is required to prevent heave. This tapers from RL0.3 at the stopbank toe, to RL0.0 20m from the toe and ground level at 40m.

Wick drains are not required at 2100m but as can be seen in Table 2, they have been extended from 2200m to ensure there is good pressure relief coverage.

5.5 Left Bank 2200m

The analysis of the stopbank at 2200m was based on the soil found in BH5. As discussed earlier this cross section is at the edge of a stream levee. A thick coarse sand deposit was found under a thin surface silt covering; resulting in heave problems under normal conditions. Relatively thin layers of silt and peat were found at RL-3.2 and RL-3.7 respectively. The ground level is at RL-0.5. Transient analyses were carried out for this cross section as for that at 1500m. It was found that adequate factors of safety against uplift would be achieved with a 20m wide overlay rising from RL0, 20m from the stopbank toe to RL0.3 at the stopbank and drainage wicks at RL0.7.

Another analysis of this cross section was carried out assuming that there are dis-continuous or no silt and peat layers at depth. This is considered a possibility due to the stream changing course during the formation of the levee. This analysis showed that the overlay needed to be increased to RL 0.7 at the stopbank toe and should be tapered down to ground level at 40m. The peak flow from the wicks during a flood is expected to be 3,600 litres / m length / day. The transient analysis of a 12 hour tide cycle produced a flow of 190 litres / m of stopbank.

5.6 Left Bank 2400m

It was found that as the ground level rises to RL1.2 at 2400m, the thickness of silt covering the medium to coarse sand in the stream levee increases to 1.3m (TP4). The installation of drainage wicks at the stopbank toes was found to be sufficient to prevent heave of the surface silt layer. The overlay required at 2200m should be continued to tie into the rising ground towards 2350m.

5.7 Left Bank 2650m

The ground level at the toe of the stopbank at 2650m is RL0.2. The subsurface profile derived from the BH6 and TP5 results shows layers of

coarse sand, pumice lapilli, peat, silt and fine sand. Any overlay would need to be quite wide at this section due to the proximity of the highly permeable pumice lapilli layer to the ground surface. A drainage wick system at the toe of the stopbank extending to RL-2.0 is therefore recommended. The flow from the system at the peak of the flood would be 190 litres / m length / day and there would be minimal flow due to tidal fluctuations in the canal.

As the subsurface profile in the test pits at 2750m and 2820m was found to be similar to that at 2650m it is recommended that the drainage wicks system be extended to the upstream end of the Stage 2 works.

5.8 Right Bank Start to 1070m

The stopbank will be less than 1.5m high from the start of Stage 2 to 1070m. As the subsoils are similar to those at 1050m on the left bank no seepage problems are expected.

5.9 Right Bank 1200m

The stopbank will be 2.9m above the inland ground level at 1200m. Beneath the stopbank 2.5m of silt and silty fine sand was found overlying highly permeable sands and a thick pumice gravel layer. A transient seepage analysis showed that there could be high hydraulic exit gradients and heave problems at this cross section.

Due to the permeability of the gravel layer and its proximity to the ground surface, an overlay would have to be over 40m wide. A wick drainage system from RL1.0 to RL-3.0 is required to reduce the exit gradients and the uplift pressures. The flow from the drainage system at the peak of the flood is estimated at 820 litres / m length / day. As the wicks are at RL1.0 there will be no flow under normal tidal conditions.

5.10 Right Bank 1500m

At 1500m the stopbank will be 3.4m high due to the ground level being below RL0.0. Several high permeability layers were found beneath the stopbank and a transient seepage analysis showed that the uplift pressures in the top two sand layers could be enough to cause heave. High hydraulic exit gradients were also found at the inland toe of the stopbank. Due to the low ground level an overlay is more appropriate in this area than drainage wicks at the stopbank toe. It was found that an overlay bringing the ground level up to RL0.4 from the toe of the stopbank to 20m distance and tapering to ground level at 30m distance would adequately improve the factors of safety against uplift and reduce the hydraulic exit gradients.

5.11 Right Bank 1700m

The ground level at 1700m is RL-0.3 and the soil profile is similar to that at 1500m. The drop in ground level creates further head across the stopbank therefore to keep the overlay and the inflow from wick drains to a reasonable size, a combination of overlay and drains has been designed to prevent uplift problems. At the toe of the stopbank the overlay needs to be at RL0.2 and to extend to 20m width at this level. It can then taper down to ground level over a further 10m. The peak flow from the wick drains during the 100 year flood is expected to be 580 litres / m length / day. In a typical 12 hour tide cycle the inflow is estimated at 20 litres / m length.

It is recommended that the overlay be extended 40m up the Kope Canal from the floodgate to counteract high water pressures at the floodgate.

5.12 Right Bank 2100m

At 2100m there is less than 3m of relatively low permeability soil overlying a thick layer of coarse sand and gravel which will enable large outflows from any drainage wicks used to relieve uplift pressures near the toe of the stopbank. The level of the wicks has therefore been lifted to RL0.7 and the same overlay as at 1700m used to counteract the remainder of the uplift pressures. The base of the wicks should remain at RL-3.0. No flow is expected from the wicks under normal tidal conditions but a peak flow of 610 litres / m / day has been estimated under the 100 year flood conditions.

As the ground level in this area remains low, it is recommended that the overlay be extended 40 up the left side of the Kope Canal as for the right side.

5.13 Right Bank 2300m

2300m is close to the edge of a sand levee and a thick layer of sand was found only 600mm below the ground surface in BH7. Therefore although the ground level is 0.5m higher than at 2100m, drainage wicks and an overlay are still required to reduce hydraulic gradients and uplift pressures. Adequate stability is achieved with the wicks remaining at RL0.7 and the overlay lifted to RL0.5 for 20m width then tapering to ground level gradually at 40m from the stopbank toe. The peak flow from the wicks in the 100 year flood is expected to be 480 litres / m / day.

As the ground level rises up the sand levee the overlay should be tapered in to meet the ground level and the wicks continued along the stopbank toe, as for the left bank.

5.14 Side Drains and Pump Stations

There is a drain and pump station feeding into the canal on the left bank at 1770m (Shaw's pump station) and two drains feeding a single pump at 1870m on the right bank (Hammond's). There is a risk of uplift of the drain inverts

and piping developing in the inverts or sides of the drains near the stopbank when the canal water level is high.

Analyses of the seepage characteristics around the drains showed that if the Shaw's drain invert is lower than RL-2.0 within 20m of the stopbank, it needs to be brought up to this level by lining it with rock to prevent heave. There will also be high hydraulic exit gradients around the end of the drain so rock lining should be placed over geotextile across the invert and up the sides of the drain within 5m of the stopbank. Shaw's pump outlet will have to be relocated. It is important that a filter is placed around the pipe in accordance with the Regional Council guidelines to prevent the loss of fines due to flow along the outside of the pipe.

The Hammond's drains need to be lined with rock and geotextile to 60m from the canal waterway to prevent uplift and piping problems. The rock should be 300mm thick.

The water level in the Kope Canal may be significantly lower than in the Reids Canal during a flood. If it is assumed that the invert of the Kope Canal is the same as that of the Reids and there is a 1.5m head difference across the floodgate, rock lining is also required in the Kope Canal invert to 60m from the Reids Canal side of the floodgate.

Table 2 : Stopbank remediation measures summary

Location (m)	Remedial Options	Approximate peak flow from wick drains in 100 year design flood (litres / m drain / day)	Approximate flow from wick drains in average 12 hour tide cycle (litres / m drain)
	Left Bank		
start to 1070	nil		
1070 to 1250	wicks at RL0.7 to RL-3.0	4,100	220
1150 to 1950	overlay at RL-0.2 from S/B toe to 20m width, taper to ground level at 40m		
1950 to 2100	overlay at RL0.3 at S/B toe, RL0.0 at 20m width and ground level at 40m		
2100 to 2200	wicks at RL0.7 to RL-3.0 overlay at RL0.7 at S/B toe, RL0.0 at 20m width, ground level at 40m	3,600	190
2200 to 2400	place wicks to RL-3.0 at S/B toe as ground rises taper overlay into rising ground		
2400 to 2850	wicks to RL-3.0 at S/B toe		50

Location (m)	Remedial Options	Approximate peak flow from wick drains in 100 year design flood (litres / m drain / day)	Approximate flow from wick drains in average 12 hour tide cycle (litres/ m drain)
	Right Bank		
start to 1070	nil		
1070 to 1250	wicks at RL1.0 to RL-3.0	820	nil
1250 to 1500	overlay at RL0.4 from S/B toe to 20m width, to ground level at 30m		
1500 to 2000	wicks at RL0.2 to RL-3.0 overlay at RL0.2 at S/B toe to 20m width, to ground level at 30m extend overlay 40m upstream from Kope Canal floodgate	580	20
2000 to 2150	wicks at RL0.7 to RL-3.0 overlay to RL0.2 at S/B toe to 20m width, to ground level at 30m extend overlay 40m upstream from Kope Canal floodgate	610	nil
2150 to 2400	wicks at RL0.7 to RL-3.0 taper overlay up to RL0.5 at S/B toe to 20m width, ground level at 40m taper overlay into rising ground	480	nil
2400 to 2500	wicks to RL-3.0 at S/B toe		

6.0 Stopbank Settlements

The new and upgraded stopbanks will undergo settlement due to the addition of load onto the soils below. The amount of settlement is dependent on the applied load and the nature of the soils. The thickness of stopbank fill to be placed varies from less than 1m to about 4.0m. Across the site there is a wide change in foundation properties from relatively incompressible sands to very compressible peat.

It is considered that the majority of the settlement which occurs will be due to the consolidation of the organic layers. An attempt has been made to estimate this settlement by comparing the thickness of these layers under the existing stopbanks to the same layers without the stopbank load. The estimated settlements are given in Table 3. These values can only be considered rough estimates.

The organic layers are very soft to soft and a major proportion of the settlement is likely to occur while the stopbanks are being constructed, however the consolidation of organic layers can continue at a decreasing rate almost indefinitely due to the breakdown of the organic components. It is therefore suggested that that the settlement values given in the second column of Table 3 be used when estimating the total volume of earthworks required and the value in the third column be used to design the level of the stopbank crest at the end of construction, to allow for on-going settlement.

Table 3: Estimated settlements

meterage	estimated total settlement	estimated post construction settlement (mm)
Left bank		
start - 1200m	small	small
1200 - 1600m	2.0m	1.0m
1600 - 1850m	1.2m	0.6m
1850 - 2450m	0.25m	0.15m
2450 – 2890m	0.6m	0.3m
Right bank		
start - 1940m	0.25m	0.15m
2000 – 2400m	1.0m	0.5m
2400 - finish	small	small

7 Conclusions

1. The geology along this section of Reids Canal changes from dune sand to peat swamp to stream levee.

2. It is considered that due to the presence of sand layers within the existing stopbanks they should be rebuilt.

3. Most of the natural soil excavated on site downstream of 2500m will be unsuitable for stopbank fill. Upstream of 2500m there is 1 to 2m of suitable soil for fill.

4. A system of overlays and / or drainage wicks will be required along much of both stopbanks to reduce the risk of piping and heave in flood conditions.

5. Flows of up to 220 litres / m length may occur along 300m of drainage wicks during a normal tide cycle; however no significant flow is expected along the remainder of the drainage wicks.

6. Flows of up to 4,100 litres / m length per day are expected along 300m length of drainage wicks at the peak of the 100 year return period flood; however peak flows of less than 900 litres / m length per day are expected along the remainder of the drainage wicks.

7. The rebuilding of the stopbanks and placement of overlays will reduce the existing amount of seepage and wet areas along the stopbanks.

8. Some areas of the new stopbanks could settle significantly following construction and this should be allowed for in designing the crest levels.

9. Rock lining will be required along the adjoining drains and the Kope Canal to reduce the risk of piping and heave in flood conditions.

M. O'Halloran

M. O'Halloran 11 October 2012
BE, PhD, Dip BA, MIPENZ (Geotechnical), CPEng IntPE

References

1. Ice Geo and Civil (Oct. 2009) Reids Canal left bank upgrading, Geotechnical Assessment.

2. Ice Geo and Civil Ltd (Aug. 2011) Geotechnical assessment of Reids Canal Floodway widening, left bank 2950m to 3650m, right bank 2550m to 3390m.

3. Ice Geo and Civil (Aug. 2008) Reids Canal: Right bank Cross Section 4, Geotechnical assessment.

Appendix A

Bore Logs

Lower Reids Canal Borehole Summary (in terms of permeability)

Test	BH1B	BH1A	BH11	BH2A	BH2B	BH2b	BH10	BH3	BH9	BH4	BH8	BH5	BH7	BH6
Soil \ meterage	1020LB	1050LB	1200RB	1300LB	1300LB	1300LB	1500RB	1600LB	1750RB	1900LB	2100RB	2200LB	2300RB	2650LB
stopbank soils														
rock fill			2.9				2.65		2.6					
sandy silt			2.2						2.1	2.5		2.5		
coarse sand							**1.15**		**1.1**	**0.85**				
bands course sand and silt			**1.7**							**-0.5**				
sandy silt			1.1				0.05		0.2					
organic silt/silt	2.3	1.3		-0.6	-0.6	-0.6	-0.4		-1.6	-1.4	-0.25	0.5		0.25
silty fine sand	2.1													
green grey clay	0.2													
silty fine sand	-0.05													
organic clay/clayey silt								-0.9					0.3	
fine to medium sand							-1.35?	-1.6			-0.7?		-0.3	
medium to coarse sand	-0.7											-0.5		
silt	-1.25		-0.25											
silty fine sand	-1.5													
coarse sand and lapilli	-1.6	-0.75	-2.25											
organic clay / peat				-2.1 (-0.8?)	-2.1 (-1.1?)	-1.0	-2.2	-1.65	-2.6	-2.4 (-1.5?)	-1.0		-1.9	-0.35
medium to coarse sand	-3.7		-3.4											
pumice gravel			-3.75											
silt (some pumice lapilli bands)			-5.0	-2.8	-2.6	-2.5	-2.7	-3.0	-2.8	-2.6	-1.4	-3.15	-4.1	-2.2
peat										-2.8		-3.7		
silt										-3.2				
organic clay / peat				-5.1	-4.5	-4.9	-5.0	-6.15	-5.3	-4.3				
medium to coarse sand												-5.0		-4.8
fine to medium sand										-6.4			-4.5	-5.5
coarse sand													-5.2	
pumice gravelly sand								-6.9	-6.2		-3.25			
medium sand /banded fine and coarse			-6.5	-7.8		-7.2	-5.7	-8.35	-8.6	-8.7	-6.1		-6.5	
coarse sand			-10.3									-10.3		
base RL(m)	**-9.7**	**-3.2**		**-8.1**	**-4.9**	**-8.1**	**-9.4**	**-9.9**	**-10.0**	**-10.0**	**-10.8**	**-11.6**	**-10.2**	**-11.3**

Bore Hole Log

Borehole: BH1a

ICE GEO & CIVIL

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
Elevation: 1.3

North
Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
0.00	1.00			**organic clayey SILT**, brown, firm, moist					
	0.90			**pumiceous SILT**, some clay, brown, damp, firm					
0.50	0.75	100		**pumiceous SILT**, light creamy brown, firm to stiff, damp					
1.00	0.00			varved **SILT**, brown and grey, firm to stiff, sensitive, dilatant, moist	0.7	dis.			
1.50	-0.20								
	-0.60			varved **SILT**, brown and grey, firm to stiff, sensitive, dilatant					
2.00	-0.65			**coarse pumice SAND / fine LAPILLI**, grey					
	-0.75	100		varved **SILT**, brown and grey, firm to stiff, sensitive, dilatant					
2.50	-1.50			**coarse SAND and fine LAPILLI**, black and grey, pumice becoming coarser with depth to 4mm, some to 15mm	2.2	dis.	grad		
3.00	-1.70								
3.50–4.50	-3.20	100		**coarse SAND and fine LAPILLI**, black and grey, pumice becoming coarser with depth to 4mm, some to 15mm					
5.00–6.50				EOB					

Observations:
LB 1050m, moved hole to find dune sands, soakage test 3.5 - 4.5m, permeability 7 x 10-5 m/s

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling

Date started: 07/02/2012
Date finished: 07/02/2012
Logged by: M.O'H

Bore Hole Log

Borehole: BH1b

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East   North
Elevation: 2.3   Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
0.00					**organic SILT**, with some sand, brown, firm, damp					
	2.10				**silty fine SAND**, some bands sandy silt with some clay, brown grey with some orange staining, firm, dense, damp	0.3	dis.			
0.50		100								
	1.40									
1.00										
1.50										
2.00										
	0.20				estuarine **CLAY**, green grey, soft					
	-0.05				**silty fine SAND** with organic content, brown, spongy, soft, moist	2.5	dis.			
2.50		100								
3.00	-0.70									
	-0.90				medium to coarse **SAND**, grey and white speckled					
3.50	-1.25				varved **fine sandy SILT**, grey and brown, medium strength					
	-1.50				pumiceous **SILT**, light grey, dilatant, stiff					
	-1.52	100			**silty fine to medium SAND**, grey green, dense					
4.00	-1.60				**coarse SAND and fine LAPILLI**, black and white speckled, increasing pumice content with depth to 4mm					
4.50										
5.00										
		45								
5.50										
6.00	-3.70				**medium to coarse SAND**, some silty bands, grey					
						6.3	dis.			
6.50										

Observations:
LB 1020m

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

Date started: 07/02/2012
Date finished: 07/02/2012
Logged by: M.O'H

Bore Hole Log

Borehole: BH1b

ICE GEO & CIVIL

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
Elevation: 2.3

North
Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
6.50										
		100								
7.00										
7.50										
8.00										
		60								
8.50										
9.00										
9.50										
		40								
10.00										
					10.5m some silt content					
10.50										
11.00										
		5								
11.50										
12.00	-9.70				EOB					
12.50										
13.00										

Observations:
LB 1020m

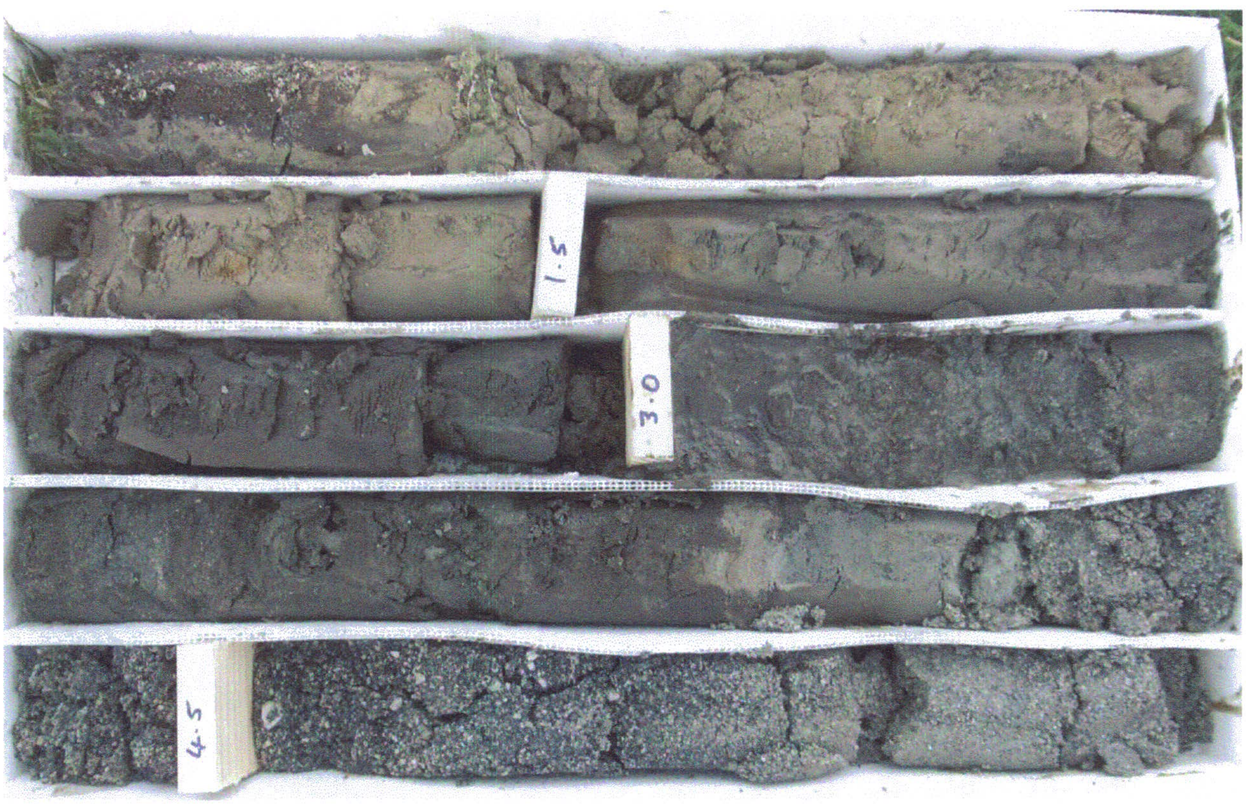
Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

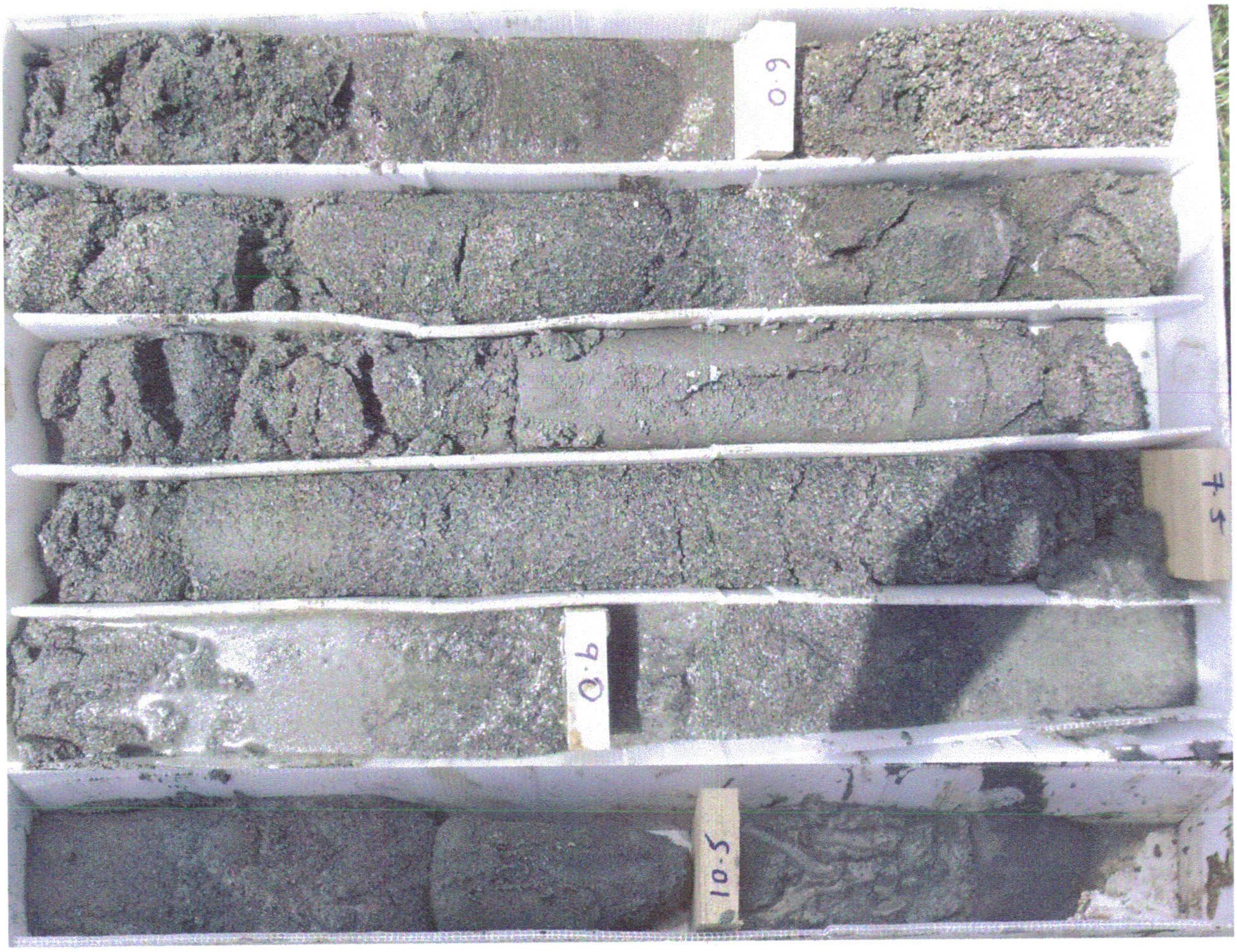
Date started: 07/02/2012
Date finished: 07/02/2012
Logged by: M.O'H

BH1a

BH1b



BH1b



Bore Hole Log

Borehole: BH2a

ICE GEO & CIVIL

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
North
Elevation: -0.6
Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
0.00	-0.70	100			**organic SILT**, black, moist					
	-0.80				**gritty organic SILT** (Tarawera Ash), black, firm, damp					
0.50					fine **SAND/SILT**, light brown at end of sample					
1.00										
1.50	-2.10				**organic CLAY/PEAT** , black, fibrous , homogeneous, very soft, H6	1.7	dis	att,org		
2.00	-2.80	100			varved pumiceous **SILT**, grey, stiff, sensitive possible thin fine pumice lapilli layers					
2.50										
3.00										
3.50		40								
4.00										
4.50	-5.10				**organic CLAY / PEAT**, some fibrous materials and roots, black, very soft, H6 wc 334% LL 222% PL 125% organic content 30%	5	dis	att,org		
5.00		40								
5.50										
6.00										
6.50										

Observations:
LB 1300m, hole moved due to timber/ very dense sand, soakage test 1.5 - 3.0m, permeability 2.5 x 10-5m/s

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

Date started: 07/02/2012
Date finished: 07/02/2012
Logged by: M.O'H

Bore Hole Log

Borehole: BH2a

ICE GEO & CIVIL

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
Elevation: -0.6

North
Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
6.50		40			6.8m tree?					
7.00	-7.80				**medium SAND**, some silt, grey, medium dense					
7.50	-8.10				EOB hard					
8.00										
8.50										
9.00										
9.50										
10.00										
10.50										
11.00										
11.50										
12.00										
12.50										
13.00										

Observations:
LB 1300m, hole moved due to timber/ very dense sand, soakage test 1.5 - 3.0m, permeability 2.5 x 10-5m/

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

Date started: 07/02/2012
Date finished: 07/02/2012
Logged by: M.O'H

Bore Hole Log

Borehole: BH2b

ICE GEO & CIVIL

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
Elevation: -0.6

North
Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
0.00		100			**organic SILT**, black, moist					
	-0.90				pumiceous **SILT,** light orangy grey with some orange staining, firm, damp					
0.50	-1.10									
1.00										
1.50	-2.10				**organic CLAY/PEAT** , black, fibrous , homogeneous, very soft, H6					
2.00	-2.60	100			varved pumiceous **SILT**, grey, stiff, sensitive possible thin fine pumice lapilli layers					
2.50										
	-3.30									
3.00	-3.60				**pumiceous SILT**, white, very senstive					
3.50		50			3.8 some fine pumice lapilli					
	-4.50				**TIMBER**					
4.00										
	-4.90				EOB					
4.50										
5.00										
5.50										
6.00										
6.50										

Observations:
LB 1300m, 2m upstream of BH2a,hole moved due to timber

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

Date started: 07/02/2012
Date finished: 07/02/2012
Logged by: M.O'H

ICE GEO & CIVIL

Bore Hole Log

Borehole: BH2c

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
Elevation: -0.6

North
Datum: Moturiki

Depth scale (m): 0.00, 0.50, 1.00, 1.50, 2.00, 2.50, 3.00, 3.50, 4.00, 4.50, 5.00, 5.50, 6.00, 6.50

elevation (m)	recovery (m)	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
			organic SILT, black, moist					
-0.90 (water level symbol) / -1.00			pumiceous **SILT,** light orangy grey with some orange staining, firm, damp					
-1.03	100		fine to medium pumice **SAND**, grey					
			organic CLAY/PEAT, black, fibrous , homogeneous, very soft, H5					
-2.50	100		varved pumiceous **SILT**, grey, stiff, sensitive possible thin fine pumice lapilli layers					
-3.60								
-4.40			pumiceous **SILT,** white, very sensitive					
-4.50			**silty fine SAND**, blue grey	4	dis.			
-4.70			**organic SILT**, brown, spongy, soft					
-4.90			timber, **organic CLAY / PEAT**, some fibres, grey brown, H6 5.7m increasing roots and timber					

Observations:
LB 1300m, 10m west BH2

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

Date started: 07/02/2012
Date finished: 07/02/2012
Logged by: M.O'H

ICE GEO & CIVIL
A division of ICE CONSTRUCTION LTD

Bore Hole Log

Borehole: BH2c

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
Elevation: -0.6

North
Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
6.50	-7.20				**medium SAND**, grey, dense	6.8	dis.	grad		
7.00										
7.50	-8.10				EOB, UTP					
8.00										
8.50										
9.00										
9.50										
10.00										
10.50										
11.00										
11.50										
12.00										
12.50										
13.00										

Observations:
LB 1300m, 10m west BH2

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

Date started: 07/02/2012
Date finished: 07/02/2012
Logged by: M.O'H

BH2a

BH2b

BH2c

Bore Hole Log

Borehole: BH3

ICE GEO & CIVIL — A division of ICE CONSTRUCTION LTD

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
North
Elevation: -0.9
Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
0.00					**organic CLAY**, black, very soft, wet					
	-1.15 ▼									
	-1.25				**organic CLAY**, dark brown, firm, moist					
0.50					**clayey SILT**, light grey, plastic, medium to firm, moist					
	-1.60	100			**fine to medium pumice SAND**					
	-1.65				**PEAT**, remnant fibres, homogeneous (almost clay), black, very soft, H7					
1.00										
1.50	-2.40									
	-2.60				**PEAT**, remnant fibres, homogeneous (almost clay), black, very soft, H7					
2.00	-3.00				**pumice SILT**, some angular pumice pieces to 20mm at surface, grey, stiff					
		100								
2.50										
3.00					3.0m sensitive layer					
3.50		100								
	-4.50				coarse pumice **SAND / fine LAPILLI**					
	-4.55				**pumice SILT**, grey, stiff					
	-4.70				varved **pumiceous SILT**, light grey, hard					
4.00	-4.90				pumice SILT, white, e. sensitive ??					
4.50										
5.00	-5.90				**pumice SILT**, white, e. sensitive					
	-5.91				**clayey SILT**, some organic fibres, grey, very soft, spongy					
	-6.15				**PEAT**, fibrous, homogeneous, black, soft to firm, H6					
5.50		100								
	-6.75				**clayey SILT**, some organic fibres, grey, very soft, spongy					
6.00	-6.80				**pumiceous sandy gravelly SILT**, pumice gravel to 2mm, grey, firm to stiff					
	-6.90									
	-7.10									
	-7.20				**pumiceous gravelly SAND**, pumice gravel to 3mm, some finer					
6.50										

Observations:
LB 1600m, soakage tests 0.7m, permeability 9 x 10-5m/s, 6 - 7.5m permeability 2.5 x 10-5m/s

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

Date started: 08/02/2012
Date finished: 08/02/2012
Logged by: M.O'H

Bore Hole Log

Borehole: BH3

ICE GEO & CIVIL

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
North
Elevation: -0.9
Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
6.50		75			sand bands, grey, dense	6.5	dis.	grad		
					PEAT, fibrous, homogeneous, black, soft to firm					
7.00					**pumiceous gravelly SAND**, pumice gravel to 3mm, some finer sand bands, grey, dense 6.9m 30mm fibrous layer					
7.50	-8.35				medium **SAND**, dark grey, dense 7.8m some pumice lapilli, dense					
8.00										
8.50										
9.00	-9.90				EOB					
9.50										
10.00										
10.50										
11.00										
11.50										
12.00										
12.50										
13.00										

Observations:
LB 1600m, soakage tests 0.7m, permeability 9 x 10-5m/s, 6 - 7.5m permeability 2.5 x 10-5m/s

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

Date started: 08/02/2012
Date finished: 08/02/2012
Logged by: M.O'H

BH3

Bore Hole Log

Borehole: BH4

ICE GEO & CIVIL — A division of ICE CONSTRUCTION LTD

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
Elevation: 2.5

North
Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
0.00					**organic sandy SILT**, topsoil, dark brown, dry					
	2.30				fine **sandy SILT**, brown / grey / orange, hard, dry, fill					
0.50										
		100								
1.00										
1.50										
	0.90				**SILT**, grey, firm					
	0.85				**coarse SAND**, some silt bands, grey, sand angular					
	0.60				**SILT,** grey, hard					
2.00										
	0.45				**coarse SAND**, some silt bands, grey, sand angular					
	0.40	75			**SILT,** grey, hard					
	0.20				**coarse SAND**, some silt bands, grey, sand angular permeability 5x10-6 m/s					
2.50										
3.00	-0.50				bands **coarse SAND** and **coarse sandy SILT**, moderately dense	3.2	dis.			
3.50		60								
	-1.38				**organic SILT**, brown					
4.00	-1.40				**SILT**, grey, stiff					
	-1.50									
4.50										
	-2.40				**organic CLAY / compressed PEAT**, spongy					
5.00	-2.60				pumiceous **SILT**, light grey brown, stiff					
	-2.75				fine pumice **LAPILLI** to 1mm / **medium SAND**, light grey	5.25 5.3	dis. dis.	org		
	-2.80				**PEAT**, homogeneous, fibrous, black, H5					
5.50		100								
	-3.20				varved **SILT**, some angular pumice to 20mm at surface, grey, stiff					
6.00	-3.50				**SILT**, grey, e. sensitive					
	-3.90	100								
6.50										

Observations:
LB 1900m S/B, soakage tests 1.5 - 3.0m, 9.0 - 10.5m, ground water level tidal

Vane no. Core Dia. 69mm	Rig: John Deere Contractor: Perry Drilling Ltd	Date started: 08/02/2012 Date finished: 08/02/2012 Logged by: M.O'H

Bore Hole Log

Borehole: BH4

ICE GEO & CIVIL

Project:	**Lower Reids Canal 2012**	Location:	**Reids Canal**
Client:	**EBoP**	Co-ordinates: East	North
		Elevation: 2.5	Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
6.50	-4.30		**PEAT**, black					
7.00	-4.65	100	medium pumice **SAND**					
	[illegible]		**PEAT**, black					
7.50	-4.70		**silty fine SAND**, grey					
	-4.80		medium pumice **SAND**, grey					
	-4.81		pumiceous **SILT**, grey					
	-4.83		rotten **timber**					
8.00	-5.00	50	rotten timber in **coarse gravelly SAND**, timber to 300mm, gravel black and pumice, rounded to 3mm					
8.50								
9.00	-6.40		**fine to medium SAND**, banded with some very fine lapilli rich bands, rare fine organic content, grey, dense					
9.50		40	permeability 2.5 x 10-5 m/s	9.5	dis.			
10.00								
10.50	-8.20		fine to medium **SAND**, grey	10.8	dis.			
11.00	-8.60	100	fine **sandy SILT,** some fine organic content, grey, stiff					
	-8.70		**coarse SAND** and fine pumice **LAPILLI**, dark grey					
11.50	-8.90							
12.00								
12.50	10.00		EOB dense dilatant sand, drill grabbibg					
13.00								

Observations:
LB 1900m S/B, soakage tests 1.5 - 3.0m, 9.0 - 10.5m, ground water level tidal

Vane no.		Rig:	John Deere	Date started:	08/02/2012
Core Dia.	69mm	Contractor:	Perry Drilling Ltd	Date finished:	08/02/2012
				Logged by:	M.O'H

BH4

BH4

Bore Hole Log

Borehole: BH5

ICE GEO & CIVIL

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
Elevation: 2.5

North
Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
0.00	2.40				**organic SILT**, topsoil					
0.50		100			**fine sandy SILT**, some lapilli near surface, brown/grey, stiff, dry, fill some coarse sandy layers					
1.00										
1.50										
2.00	0.50	100			**SILT**, grey, stiff					
	0.20				**organic SILT**, brown, firm, old ground surface?					
2.50	0.10				**coarse SAND**, speckled dark grey, some clayey silt bands 10 to 20mm thick	2.5	dis.			
	-0.20 (GWL)									
3.00	-0.50				**coarse SAND**, speckled dark grey, some clayey silt bands 10 to 20mm thick					
3.50		75								
4.00										
4.50	-2.00									
5.00										
5.50	-2.90				**coarse SAND**, speckled dark grey, some clayey silt bands 10 to 20mm thick					
	-3.00	100								
	-3.15				**pumiceous SILT**, some clay, some organic material, light grey, firm					
	-3.18									
	-3.21									
6.00	-3.50				medium pumice **SAND**, grey					
	-3.70				organic clay / **PEAT**, black, soft					
6.50		100			**pumiceous SILT**, some clay, grey, firm to stiff					

Observations:
LB 2200m S/B, adjacent paddock very wet, wheel tracks in toe of stopbank, GWL approx. 0.2m

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

Date started: 08/02/2012
Date finished: 08/02/2012
Logged by: M.O'H

Bore Hole Log

Borehole: BH5

ICE GEO & CIVIL
A division of ICE CONSTRUCTION LTD

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
Elevation: 2.5

North
Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
6.50					fine pumice **LAPILLI** banded with organic material and grey **SILT**	6.5	dis.			
	-4.40				**organic CLAY**, brown, spongy, soft (wc 131%, LL 138%, PL 87%, org 10%)					
7.00	-4.60				**silty fine SAND**, grey					
7.50	-5.00				**medium to coarse SAND**, some pumice gravel to 30mm and fine rounded black gravel, some bands fine sand, grey	7.8	dis.	grad		
8.00		100			falling head test 7.5 to 9.0m permeability 7 x 10-5 m/s					
8.50										
9.00										
9.50		100								
10.00						10.3	dis.			
10.50										
11.00		100								
11.50										
12.00										
12.50	-10.30	100			**coarse SAND**, dark grey / black	12.9	dis.			
13.00	-10.50									

Observations:
LB 2200m S/B, adjacent paddock very wet, wheel tracks in toe of stopbank, GWL approx. 0.2m

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

Date started: 08/02/2012
Date finished: 08/02/2012
Logged by: M.O'H

Bore Hole Log

Borehole: BH5

ICE GEO & CIVIL

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
Elevation: 2.5

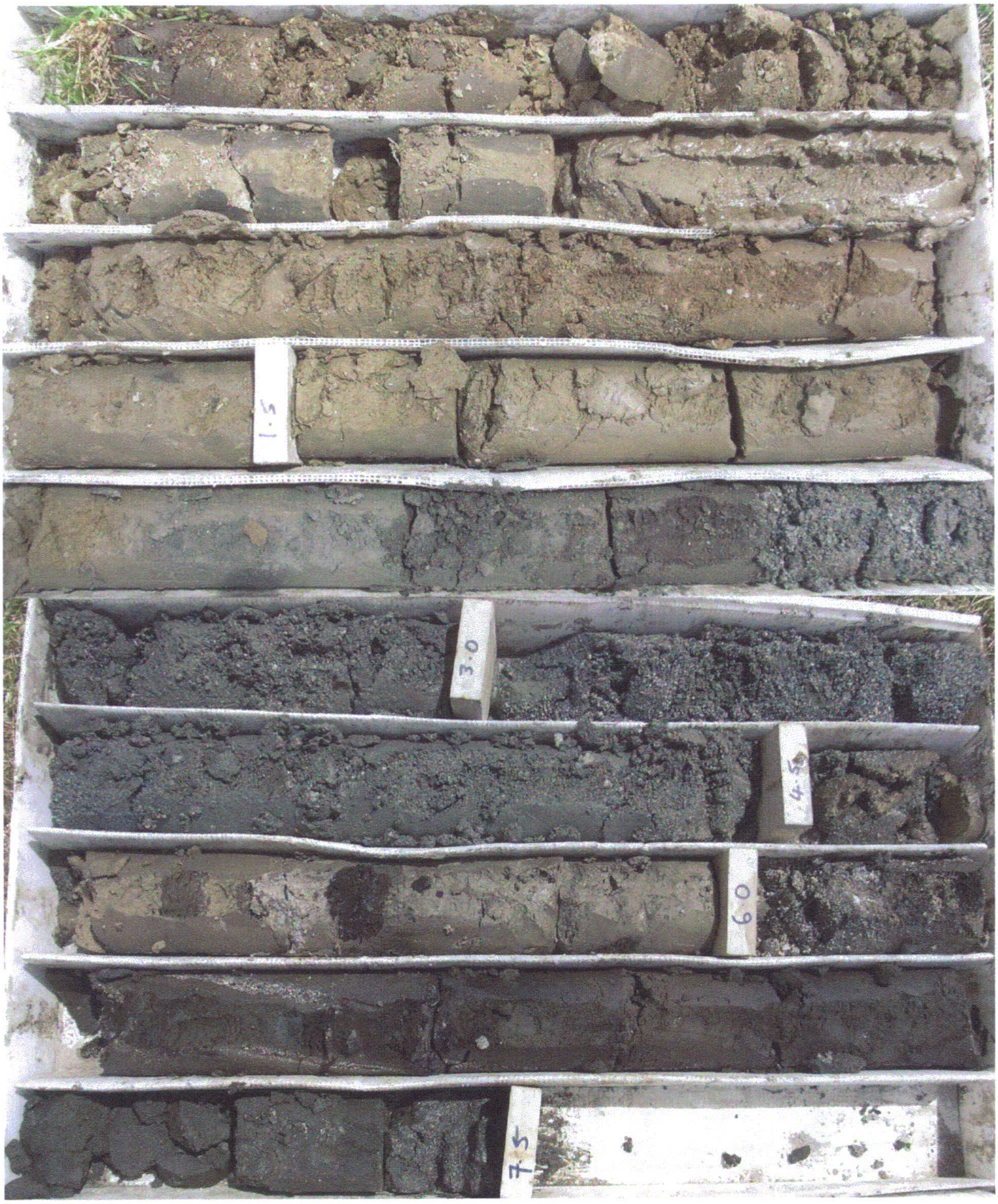
North
Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
13.00					**well graded SAND**, grey					
13.50						13.5	dis.			
		100								
14.00	11.60				EOB core bound					
14.50										
15.00										
15.50										
16.00										
16.50										
17.00										
17.50										
18.00										
18.50										
19.00										
19.50										

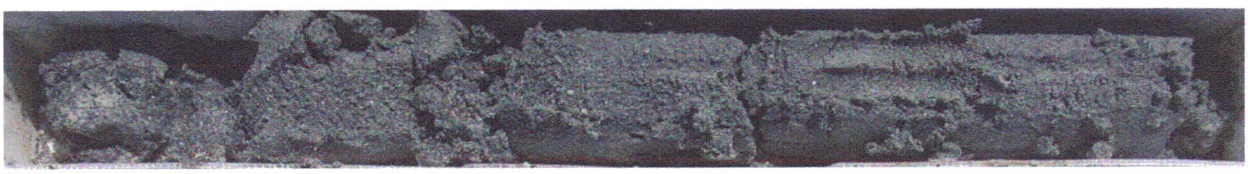
Observations:
LB 2200m S/B, adjacent paddock very wet, wheel tracks in toe of stopbank, GWL approx. 0.2m

Vane no. Core Dia. 69mm	Rig: John Deere Contractor: Perry Drilling Ltd	Date started: 08/02/2012 Date finished: 08/02/2012 Logged by: M.O'H

BH5



BH5



ICE GEO & CIVIL

Bore Hole Log

Borehole: BH6

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
Elevation: 0.25

North
Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
0.00	0.15				**organic fine sandy SILT**, brown, topsoil					
	0.00				**fine sandy SILT,** some clay, brown and grey with some Fe staining, stiff, damp					
0.50	-0.20	100			**clayey SILT**, light brown, soft, moist					
	-0.35				**fine sandy SILT**, grey brown, soft, moist					
	-0.65				fibrous **PEAT**, black, very soft , H5					
1.00										
1.50	-1.25				fibrous **PEAT**, black, very soft , H5					
2.00		100								
	-2.15				**clayey SILT,** grey, damp, firm					
2.50	-2.25				pumiceous **SILT,** some pumice pieces, grey, sensitive, dilatant, stiff					
3.00	-2.85	100			extremely sensitive pumice silt / sand? permeability 6 x 10-5 m/s					
3.50	-3.55				**pumiceous SILT,** white, e. sensitive, thin band pumice lapilli to 3mm					
	-3.65				pumiceous **SILT**, some fine lapilli, grey, very sensitive, stiff					
4.00		100								
4.50	-4.19				**fine SAND**, grey					
	-4.22				pumiceous **SILT**, some fine lapilli, grey, very sensitive, stiff					
	-4.25									
5.00	-4.75				pumiceous **SILT**, some fine lapilli, grey, very sensitive, stiff					
	-4.85				banded pumice **LAPILLI** to 2mm and **fine SAND**, pumice dominant					
5.50	-5.45	100			**fine to medium SAND**, grey					
6.00										
6.50										

Observations:
LB 2650m, soakage test 3.0 - 4.5m

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

Date started: 09/02/2012
Date finished: 09/02/2012
Logged by: M.O'H

Bore Hole Log

Borehole: BH6

ICE GEO & CIVIL — A division of ICE CONSTRUCTION LTD

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
Elevation: 0.25

North
Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
6.50						6.5	dis.			
		90								
7.00										
7.50										
8.00										
		80								
8.50										
9.00										
9.50										
		60								
10.00										
10.50	10.25				EOB					
11.00										
11.50										
12.00										
12.50										
13.00										

Observations:
LB 2650m, soakage test 3.0 - 4.5m

Vane no. Core Dia. 69mm	Rig: John Deere Contractor: Perry Drilling Ltd	Date started: 09/02/2012 Date finished: 09/02/2012 Logged by: M.O'H

BH6

Bore Hole Log

Borehole: BH7

ICE GEO & CIVIL — A division of ICE CONSTRUCTION LTD

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
Elevation: 0.3

North
Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
0.00					**organic SILT / PEAT**, dark brown					
	0.00	100			**clayey SILT**, grey, soft, moist					
0.50	-0.30									
	-0.35				fine to medium **SAND**, grey					
1.00										
1.50	-1.20				fine to medium **SAND**, grey					
2.00										
	-1.90	100			**PEAT**, black, fibrous, homogeneous, very soft, H5 wc 561% LL 425% PL 228%	2.5	dis.			
2.50										
	-2.55									
3.00	-2.70				organic content 60%					
	-3.00				**clayey SILT**, grey, firm					
	-3.01				pumice **LAPILLI** to 1.5mm					
3.50					**organic CLAY**, dark brown, spongy, very soft	3.5	dis.			
	-3.50				**PEAT**, fibrous, homogeneous, black, very soft, H6					
4.00										
	-4.10				**silty fine SAND**, grey					
4.50	-4.18									
	-4.20				pumiceous **SILT**, grey					
	-4.50				fine to medium **SAND,** grey					
5.00										
		100								
5.50	-5.20				coarse **SAND**, grey					
6.00										
6.50										

Observations:
RB 2300m, soakage test 4.5 - 6.0m permeability 5 x 10-5 m/s

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

Date started: 09/02/2012
Date finished: 09/02/2012
Logged by: M.O'H

Bore Hole Log

Borehole: BH7

ICE GEO & CIVIL — A division of ICE CONSTRUCTION LTD

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
Elevation: 0.3

North
Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
6.50										
	-6.50	100			well graded **SAND**, grey					
7.00	-6.80				bands **fine to medium SAND**, **coarse SAND** and **fine LAPILLI**, dense					
7.50										
8.00		75								
8.50										
9.00					9.3m 100mm silty band					
9.50		60								
10.00										
10.50	10.20				EOB					
11.00										
11.50										
12.00										
12.50										
13.00										

Observations:
RB 2300m, soakage test 4.5 - 6.0m permeability 5 x 10-5 m/s

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

Date started: 09/02/2012
Date finished: 09/02/2012
Logged by: M.O'H

BH7

BH7

Bore Hole Log

Borehole: BH8

ICE GEO & CIVIL — A division of ICE CONSTRUCTION LTD

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East North
Elevation: -0.25 Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
0.00		100			**organic sandy SILT**, topsoil, firm, damp					
	-0.50				**clayey SILT**, grey and brown, firm, damp					
	-0.55				pumiceous **clayey SILT**, light grey brown, soft to firm					
0.50	-0.65				sensitive pumice silt?					
	-0.95				medium pumice **SAND**, grey					
1.00	-0.96				**PEAT**, black, fibrous, homogeneous, soft , H5					
	-1.40	100			pumiceous **SILT**, some pumice pieces at surface, grey, stiff					
1.50	-1.75									
	-2.05				pumiceous **SILT**, rare organic fragments, grey, very sensitive, dilatant					
2.00	-2.40				varved pumiceous **SILT**, grey, stiff					
	-2.65	100			pumiceous **SILT**, rare organic fragments, grey, very sensitive, dilatant					
2.50	-2.85				varved pumiceous **SILT**, grey, stiff					
	-3.15				well graded pumice **SAND** and fine **LAPILLI** to 2mm					
3.00	-3.25				**gravelly coarse SAND**, grey, pumice gravel to 40mm, fine black and green gravel, rare silty bands permeability 5 x 10-5 m/s	3.3	dis.			
3.50										
4.00		100								
4.50										
5.00		40								
5.50										
	-6.05				banded **fine SAND** and **LAPILLI / coarse SAND**, bands approx. 10mm, rare charcoal					
6.00										
6.50										

Observations:
RB 2100m, soakage test 3.0 - 4.5m

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

Date started: 09/02/2012
Date finished: 09/02/2012
Logged by: M.O'H

Bore Hole Log

Borehole: BH8

ICE GEO & CIVIL

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
Elevation: -0.25

North
Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
6.50		80								
7.00										
7.50										
8.00	-8.25	75			**coarse gravelly SAND**, speckled black and white					
8.50	-8.75				banded **fine SAND** and **LAPILLI / coarse SAND**, bands approx. 10mm, rare charcoal					
9.00	-9.25				**coarse SAND** and **GRAVEL** to 12mm, grey					
9.50	-9.75	80			banded **fine SAND** and **LAPILLI / coarse SAND**, bands approx. 10mm, rare charcoal					
	10.00				**coarse SAND** and **GRAVEL** to 12mm, grey					
10.00						10	dis.			
	10.50				**coarse SAND**, dark grey					
10.50	10.75				EOB					
11.00										
11.50										
12.00										
12.50										
13.00										

Observations:
RB 2100m, soakage test 3.0 - 4.5m

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

Date started: 09/02/2012
Date finished: 09/02/2012
Logged by: M.O'H

BH8

BH8

Bore Hole Log

Borehole: BH9

ICE GEO & CIVIL

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
Elevation: 2.6

North
Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
0.00					rock fill					
0.50	2.10				**sandy SILT**, some clay, brown, grey, stiff, damp					
1.00		100								
	1.30				**SILT**, grey, stiff, damp					
	1.25				**silty sandy pumice LAPILLI** to 1.5mm, grey, hard					
1.50	1.10									
	0.80				mixed pumice **LAPILLI** and **PEAT**, soft					
2.00	0.60				fine to medium **SAND**, dark grey					
	0.20	100			**fine sandy SILT**, grey, stiff					
2.50										
3.00	-0.40									
	-0.70				**SILT**, grey, spongy, soft wc 39.4%					
3.50						3.5	dis.	wc		
		100								
4.00										
	-1.60				**organic CLAY / PEAT**, brown, soft, 4.3m 20mm grey pumiceous silt layer					
	-1.75				**coarse SAND / GRIT**, black, Tarawera Ash					
4.50	-1.77				**organic CLAY / PEAT**, brown, soft,					
	-1.84				pumiceous **CLAY**, grey, firm					
	-1.90									
5.00										
	-2.50				pumiceous **SILT**, light grey, e. sensitive, firm					
	-2.60				**PEAT and rotten timber**, black, fibrous, some pockets of fine pumice lapilli					
	-2.80				pumiceous **SILT**, some fine pumice pieces at surface, grey, sensitive, stiff					
5.50		100								
6.00	-3.40									
	-3.60				pumiceous **SILT**, grey, sensitive, stiff					
6.50										

Observations:
RB 1750m S/B

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

Date started: 09/02/2012
Date finished: 09/02/2012
Logged by: M.O'H

Bore Hole Log

Borehole: BH9

ICE GEO & CIVIL

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
North
Elevation: 2.6
Datum: Moturiki

elevation (m)	recovery (m)	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
	100						
-4.45 to -4.60		pumiceous **SILT**, light grey / white, e. sensitive, stiff	7.1	dis.			
-5.30		**PEAT and rotten timber**, dark brown, fibrous, some pockets of fine pumice lapilli, soft, H7					
	100						
-6.15 to -6.40		**fine gravelly silty SAND**, gravel fine lapilli to 1.5mm, medium dense					
-6.90 to -7.10		**fine gravelly silty SAND**, gravel fine lapilli to 1.5mm, medium dense					
-7.10 to -7.90	100	**gravelly coarse SAND**, pumice and grey gravel to 6mm, some fine to medium sand					
-8.40 to -8.60		**gravelly coarse SAND**, pumice and grey gravel to 6mm, some fine to medium sand					
-8.60 to -9.15	100	banded **fine to medium SAND** 5mm thick and clean pumice **LAPILLI** to 2mm 10 to 20mm thick					
-9.15 to -9.30		fine **SAND**, grey, some silt					
-9.30 to -9.50		banded **fine to medium SAND** 5mm thick and clean pumice **LAPILLI** to 2mm 10 to 20mm thick					
-9.50 to -10.00	100	fine to medium **SAND**, grey, dense					
-10.00		EOB, core binding					

Observations:
RB 1750m S/B

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

Date started: 09/02/2012
Date finished: 09/02/2012
Logged by: M.O'H

BH9

BH9

Bore Hole Log

Borehole: BH10

ICE GEO & CIVIL

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
Elevation: 2.65

North
Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
0.00					clayey rock fill					
0.50										
		100								
1.00										
1.50	1.15									
2.00	0.55				fine to medium **SAND**, grey brown, medium density					
	0.25				**silty fine to medium SAND**, grey brown, medium density					
2.50	0.05	100			**fine sandy SILT**, grey brown, stiff					
3.00	-0.35				**organic sandy SILT**, brown					
	-0.40				**SILT**, some fine sand, grey, stiff					
3.50		100								
	-1.25				pumiceous **SILT**, light grey brown, stiff					
4.00	-1.35				soakage test 4.5 to 6.0m permeability 2.5 x 10-5 m/s					
4.50										
	-2.15				pumiceous **SILT**, light grey brown , stiff					
	-2.20				**organic CLAY / PEAT**, black, soft					
5.00	-2.35				fine to medium **SAND**, grey, medium density	5.1	dis.			
	-2.50				**fibrous PEAT and rotten timber**, black, soft					
	-2.70	100			pumiceous **SILT**, grey, firm to stiff					
5.50										
6.00	-3.35									
	-3.60				**PEAT**, dark brown					
	-3.63									
6.50	-3.75									

Observations:
RB 1500m S/B, at 8.4m grind through 600mm of tree, move forward 5m then wash drill to 8m

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

Date started: 10/02/2012
Date finished: 10/02/2012
Logged by: M.O'H

Bore Hole Log

Borehole: BH10

ICE GEO & CIVIL — A division of ICE CONSTRUCTION LTD

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
Elevation: 2.65

North
Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
6.50		100			medium to coarse pumice **SAND**, grey					
7.00					pumiceous **SILT,** grey, stiff, sensitive, dilatant 7.0m 5mm layer medium to coarse pumice sand 7.08m 5mm layer medium to coarse pumice sand					
	-4.65				pumiceous **SILT**, white					
7.50	-4.85				**organic SILT**, dark brown, spongy 7.6m 5mm layer white silt					
8.00	-5.00	100			**PEAT**, homogeous, fibrous, brown, remnant flax and rotten timber, H5, dense timber at 8.4m hole shifted					
8.50	-5.75				timber in pumice **LAPILLI** to 2mm					
	-6.05				banded pumice **LAPILLI and fine to medium SAND** (50/50)					
9.00	-6.45	100			coarse **SAND**, grey speckled					
9.50	-7.15									
10.00										
10.50	-7.85	100			fine to medium **SAND**, some fine lapilli, grey					
11.00										
11.50										
12.00	-9.35				EOB					
12.50										
13.00										

Observations:
RB 1500m S/B, at 8.4m grind through 600mm of tree, move forward 5m then wash drill to 8m

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

Date started: 10/02/2012
Date finished: 10/02/2012
Logged by: M.O'H

BH10

BH10

Bore Hole Log

Borehole: BH11

ICE GEO & CIVIL

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
Elevation: 2.9

North
Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
0.00					clayey rock fill					
0.50										
	2.20	100			**sandy SILT**, some clay, brown / grey, stiff, fill					
1.00										
	1.65				fine **SAND**, some silt, brown / grey					
	1.55				fine **sandy SILT**, grey brown, stiff, fill					
1.50	1.40									
	1.10				fine **sandy SILT**, dark grey with orange staining, firm					
2.00	0.90				**SILT,** some pumice lapilli, dark grey, firm to stiff					
		100								
2.50										
					2.9m some fine black gravel					
3.00										
	-0.25	100			pumiceous **SILT**, light grey brown, e. sensitive, timber					
	-0.50									
3.50	▼									
	-1.00				**silty fine SAND**, brown grey					
4.00	-1.20	100			**fine sandy SILT**, grey with organic bands, soft, spongy, sensitive					
4.50										
5.00										
	-2.25	100			**coarse SAND / fine LAPILLI**					
	-2.30				well graded fine to coarse pumice **SAND**, rare pumice to 50mm, layered?					
5.50										
6.00										
	-3.40				fine to medium **SAND**, grey					
6.50										

Observations:
RB 1200m S/B, soakage test 6.5 - 7.5m

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

Date started: 10/02/2012
Date finished: 10/02/2012
Logged by: M.O'H

Bore Hole Log

Borehole: BH11

ICE GEO & CIVIL
A division of ICE CONSTRUCTION LTD

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East | North
Elevation: 2.9 | Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
6.50	-3.75	90			pumice **GRAVEL**, typically to 5mm, some to 80mm and charcoal					
7.00					permeability 1.5 x 10-4 m/s					
7.50										
8.00	-5.00	75			**SILT**, grey, very sensitive					
8.50					8.5m 30mm layer fine lapilli					
					becoming fine sand					
9.00										
9.50	-6.50	100			banded **fine SAND** and **LAPILLI** to 4mm, lapilli dominant					
10.00	-7.10				fine to medium **SAND**, dark grey					
	-7.27				pumiceous **SILT**, white, stiff					
	-7.30				fine to medium **SAND**, dark grey					
10.50	-7.50				medium **SAND**, light grey					
11.00	-7.90	50			fine to medium **SAND**, some thin layers with organic material					
11.50										
12.00	-9.10				fine to medium **SAND** with some fine lapilli, grey, dense					
12.50		80								
13.00										

Observations:
RB 1200m S/B, soakage test 6.5 - 7.5m

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

Date started: 10/02/2012
Date finished: 10/02/2012
Logged by: M.O'H

Bore Hole Log

Borehole: BH11

ICE GEO & CIVIL — A division of ICE CONSTRUCTION LTD

Project: **Lower Reids Canal 2012**
Client: **EBoP**

Location: **Reids Canal**
Co-ordinates: East
Elevation: 2.9

North
Datum: Moturiki

depth (m)	elevation (m)	recovery (m)	graphic log	Classification	description	samp depth (m)	sample type	SPT result	Vane result (kPa)	other
13.00										
	10.30									
					coarse **SAND**, speckled dark grey, some fine black gravel to 3mm					
13.50	10.60				EOB					
14.00										
14.50										
15.00										
15.50										
16.00										
16.50										
17.00										
17.50										
18.00										
18.50										
19.00										
19.50										

Observations:
RB 1200m S/B, soakage test 6.5 - 7.5m

Vane no.
Core Dia. 69mm

Rig: John Deere
Contractor: Perry Drilling Ltd

Date started: 10/02/2012
Date finished: 10/02/2012
Logged by: M.O'H

BH11

BH11

Appendix B

Test Pit Logs

Project:	Lower Reids Canal 2012	Test:	**TP1 (1750m LB) 20m from to**
Client:	EBoP	Elevation:	-1.0
Location:	Reids Canal	Date:	07/06/2012
Number:		Logged by:	M. O'Halloran

Depth (m)	Elev(m)	Graphic Log	Description	Sample
0.0			**SILT**, brown	
	-1.25		**SILT**, orange grey	
0.5	-1.6		**organic SILT**, brown	
	-1.7		medium to coarse pumice **SAND**	
	-1.85		**PEAT**, black, homogeneous	
1.0				
1.5				
	-2.8		pumiceous **SILT**, grey, stiff	
2.0				
2.5				
3.0				
	-4.1		EOB, water coming in from base	
3.5				
4.0				
4.5				

ICE GEO & CIVIL
A division of ICE CONSTRUCTION LTD

Project: **Lower Reids Canal 2012**
Client: EBoP
Location: Reids Canal
Number:

Test: **TP2 (2150m LB) 15m from to**
Elevation: 0.0
Date: 07/06/2012
Logged by: M. O'Halloran

Depth (m)	Elev(m)	Description	Sample
0.0		organic **SILT**, topsoil, brown	
	-0.25	**clayey SILT**, orange mottled grey	
0.5	-0.6	fine to medium **SAND**, grey	
	-0.75	**PEAT** and timber, dark brown	
1.0			
1.5	-1.6	pumiceous **SILT,** grey, stiff	
2.0			
	-2.25	pumice **LAPILLI** to 2mm	
	-2.3	organic **CLAY**, brown, soft	
2.5			
3.0	-3.3	EOP water coming up from base	
3.5			
4.0			
4.5			

ICE GEO & CIVIL
A division of ICE CONSTRUCTION LTD

Sheet 1 of 1

HAND AUGER TEST PIT LOGS.GPJ HAND AUGER BASIC.GDT 22/7/12

Project:	**Lower Reids Canal 2012**
Client:	EBoP
Location:	Reids Canal
Number:	

Test:	**TP3 (2300 LB) 15m from toe**
Elevation:	0.3
Date:	07/06/2012
Logged by:	M. O'Halloran

Depth (m)	Elev(m)	Graphic Log	Description	Sample
0.0			organic **SILT**, brown, topsoil	
	0.1		**SILT**, grey	
	-0.1		medium to coarse pumice **SAND**, grey, current bedded	
	-1.2		EOP hole collapsing	

Depth scale: 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5

ICE GEO & CIVIL
A division of ICE CONSTRUCTION LTD

Project:	**Lower Reids Canal 2012**	Test:	**TP4 (2450m LB) 20m from to**
Client:	EBoP	Elevation:	1.3
Location:	Reids Canal	Date:	07/06/2012
Number:		Logged by:	M. O'Halloran

Depth (m)	Elev(m)	Graphic Log	Description	Sample
0.0			organic **SILT**, dark brown, topsoil	
	1.15		**SILT**, orange stained grey, some fine to medium sand in narrow bands	
0.5				
1.0				
	-0.05		medium to coarse **SAND**, current bedded, sulphur smell, high inflow	
1.5				
2.0				
2.5	-1.2		EOP hole collapsing	
3.0				
3.5				
4.0				
4.5				

ICE GEO & CIVIL
A division of ICE CONSTRUCTION LTD

Project:	Lower Reids Canal 2012	Test:	TP5 (2650m LB) new centre li
Client:	EBoP	Elevation:	0.3
Location:	Reids Canal	Date:	07/06/2012
Number:		Logged by:	M. O'Halloran

Depth (m)	Elev(m)	Graphic Log	Description	Sample
0.0			organic **SILT**, brown	
	0.1		clayey **SILT**, orange stained grey	
0.5				
	-0.3		organic **CLAY**, some timber	
	-0.4		**CLAY**, grey, soft, plastic	
1.0				
	-0.8		medium to coarse pumice **SAND**, grey	
	-0.95		**PEAT**, black, fibrous	
1.5				
2.0				
2.5				
	-2.5		**SILT**, grey	
3.0				
	-2.8		pumice **GRAVEL** to 10mm, big inflows	
3.5				
	-3.3		pumiceous **SILT**, varved, hard	
	-3.6		EOP	
4.0				
4.5				

HAND AUGER TEST PIT LOGS.GPJ HAND AUGER BASIC.GDT 22/7/12

ICE GEO & CIVIL
A division of ICE CONSTRUCTION LTD

Project:	**Lower Reids Canal 2012**	Test:	**TP6 (2743mC LB) fill**
Client:	EBoP	Elevation:	3.0
Location:	Reids Canal	Date:	07/06/2012
Number:		Logged by:	M. O'Halloran

Depth (m)	Elev(m)	Graphic Log	Description	Sample
0.0			**sandy SILT**, brown, topsoil	
0.5	2.5		fine **sandy SILT**, orange stained grey	
1.0	2		**SILT**, grey	
1.5				
			2.1m pockets of fine to medium SAND	
2.0				
	0.9		EOB	
2.5				
3.0				
3.5				
4.0				
4.5				

ICE GEO & CIVIL
A division of ICE CONSTRUCTION LTD

Project:	Lower Reids Canal 2012	Test:	TP7 (2750m LB) centre line
Client:	EBoP	Elevation:	0.5
Location:	Reids Canal	Date:	07/06/2012
Number:		Logged by:	M. O'Halloran

Depth (m)	Elev(m)	Graphic Log	Description	Sample
0.0	0.4		**organic SILT**, brown, topsoil	
			SILT, some clay, orange stained grey, moist	
	-0.7		**PEAT**, fibrous	
	-0.9		pumice **SAND,** coarse, water inflow	
	-1.1		**PEAT**, homogeneous, dark brown	
	-2.1		pumiceous **SILT**, grey, stiff	
	-2.8		pumice **GRAVEL** to 15mm, some silt	
	-3.2		pumiceous **SILT**, varved, hard	
	-3.8		EOP	

Depth scale: 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5

ICE GEO & CIVIL
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Project: **Lower Reids Canal 2012**
Client: EBoP
Location: Reids Canal
Number:

Test: **TP8 (2820m LB) centre line**

Elevation: 1.0
Date: 07/06/2012
Logged by: M. O'Halloran

Depth (m)	Elev(m)	Graphic Log	Description	Sample
0.0			fine **sandy SILT**, brown, fine , topsoil	
	0.8		**SILT**, orange speckled grey	
0.5				
1.0				
	-0.3		pumiceous **SILT**, grey, some pockets fine sand and fine lapilli, firm	
1.5				
	-0.8		organic **SILT**, brown	
2.0	-1		**SILT**, white	
	-1.2		organic **SILT**, brown	
	-1.25		medium to coarse pumice **SAND**	
2.5	-1.5		**PEAT**, brown, homogeneous, fibrous	
3.0				
	-2.2		pumiceous **SILT**, grey	
3.5	-2.5		EOP	
4.0				
4.5				

ICE GEO & CIVIL
A division of ICE CONSTRUCTION LTD

Sheet 1 of 1

Project:	Lower Reids Canal 2012	Test:	TP9 (2850m LB) fill
Client:	EBoP	Elevation:	2.0
Location:	Reids Canal	Date:	07/06/2012
Number:		Logged by:	M. O'Halloran

Depth (m)	Elev(m)	Graphic Log	Description	Sample
0.0			fine **sandy SILT**, brown, topsoil	
	1.85		fine to medium **SAND**, orange brown	
	1.75		**silty fine SAND / sandy SILT**, orange stained grey	
	0.8		**SILT**, orange stained grey	
	-0.1		fine pumice **SAND**, light grey	
	-0.4		EOB	

Depth scale (m): 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5

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Sheet 1 of 1

Test Pit 2

Test Pit 3

Test Pit 4

Test Pit 5

Test Pit 6

Test Pit 7

Test Pit 9

Appendix C

Stopbank Face Logs

Lower Reids Canal
(1050m to 2850m)

Stopbank Investigations – June 2012

Soils within stopbank

Left Bank

meterage	approximate thickness from top of stopbank	soil
1100LB	0.0m	mixed SILT
	1.3m	mixed sandy SILT and some small pockets of sand, well compacted
1300LB	full height	mixed sandy clayey SILT, well compacted
1500LB	full height	well graded SAND, some silt, medium density
1750LB	0.0m	silty fine SAND, medium density
	1.5m	clayey, silty rotten ROCK, hard, dense (old access track/berm overlying stopbank material?)
	3.9m	sandy SILT, firm, brown
1900LB BH4	0.0m	sandy SILT
	2.5m	bands coarse SAND and SILT
2200LB BH5	full height	fine sandy SILT
2450LB	full height	silty fine to medium SAND, orange brown 100mm grey fine to medium sand layers at 1.0m and 1.5m depth

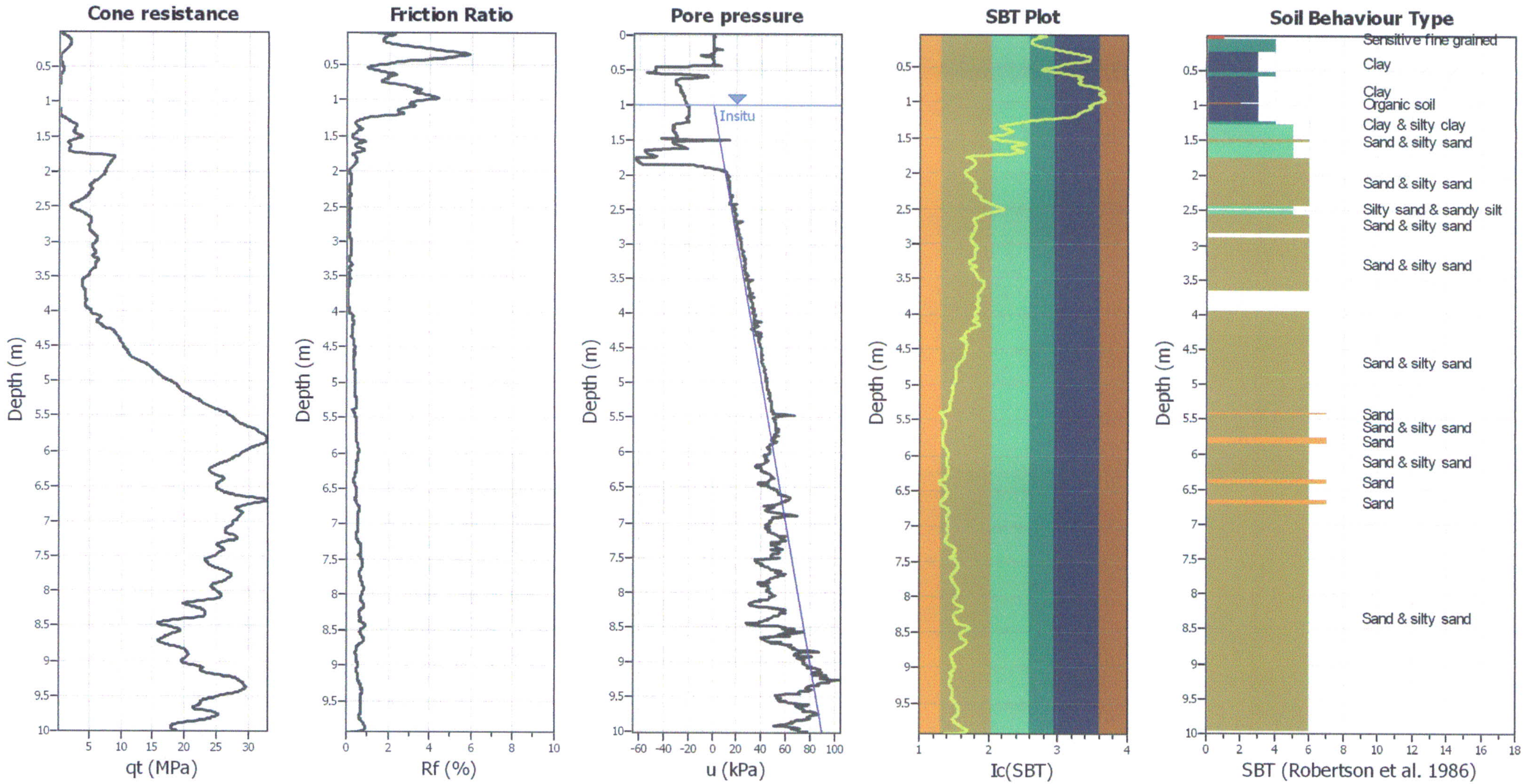
Right Bank

1100mRB BH11	0.0m	clayey rock fill
	0.7m	sandy SILT
1300mRB	full height	silty fine to medium SAND, dense
1500mRB BH10	0.0m	clayey rock fill
	1.5m	fine to medium SAND
1600mRB	0.0m	sandy SILT / fine to medium silty SAND, with lumps of silt to 100mm
	1.0m	fine to medium SAND
	1.5	silty fine to medium SAND, with pockets medium to coarse sand and lumps of silt to 100mm
	2.2	medium SAND
	2.5	silty fine to medium SAND, with pockets medium to coarse sand and lumps of silt to 100mm
1720m BH9	0.0m	rock fill
	0.5m	sandy SILT
	1.1m	sand and lapilli
1800mRB	0.0m	sandy SILT, less sand with depth
	2.5m	layers silty fine to medium SAND and coarse SAND
	3.2m	fine to medium SAND
	3.5m	SILT, some sand, well compacted
2000mRB	0.0m	silty fine to medium SAND, well compacted
	1.5m	sandy SILT
	2.8m	fine to medium SAND, some silt
	3.3m	silty SAND / sandy SILT, well compacted
2200mRB	0.0m	silty fine to medium SAND
	2.3m	medium to coarse SAND, some silt, loose, wet
	2.8m	fine sandy SILT
	3.2m	medium to coarse SAND, some silt, loose, wet
	3.5m	silty fine to medium SAND, compacted
2400mRB	0.0m	well graded SAND, some silt, moderately loose
	1.9m	sandy SILT
	2.2m	medium to coarse pumice SAND, some silt
		100mm below ground level 50mm of Tarawera Ash

Appendix D

Cone Penetrometer Test Results

CPT basic interpretation plots



Input parameters and analysis data

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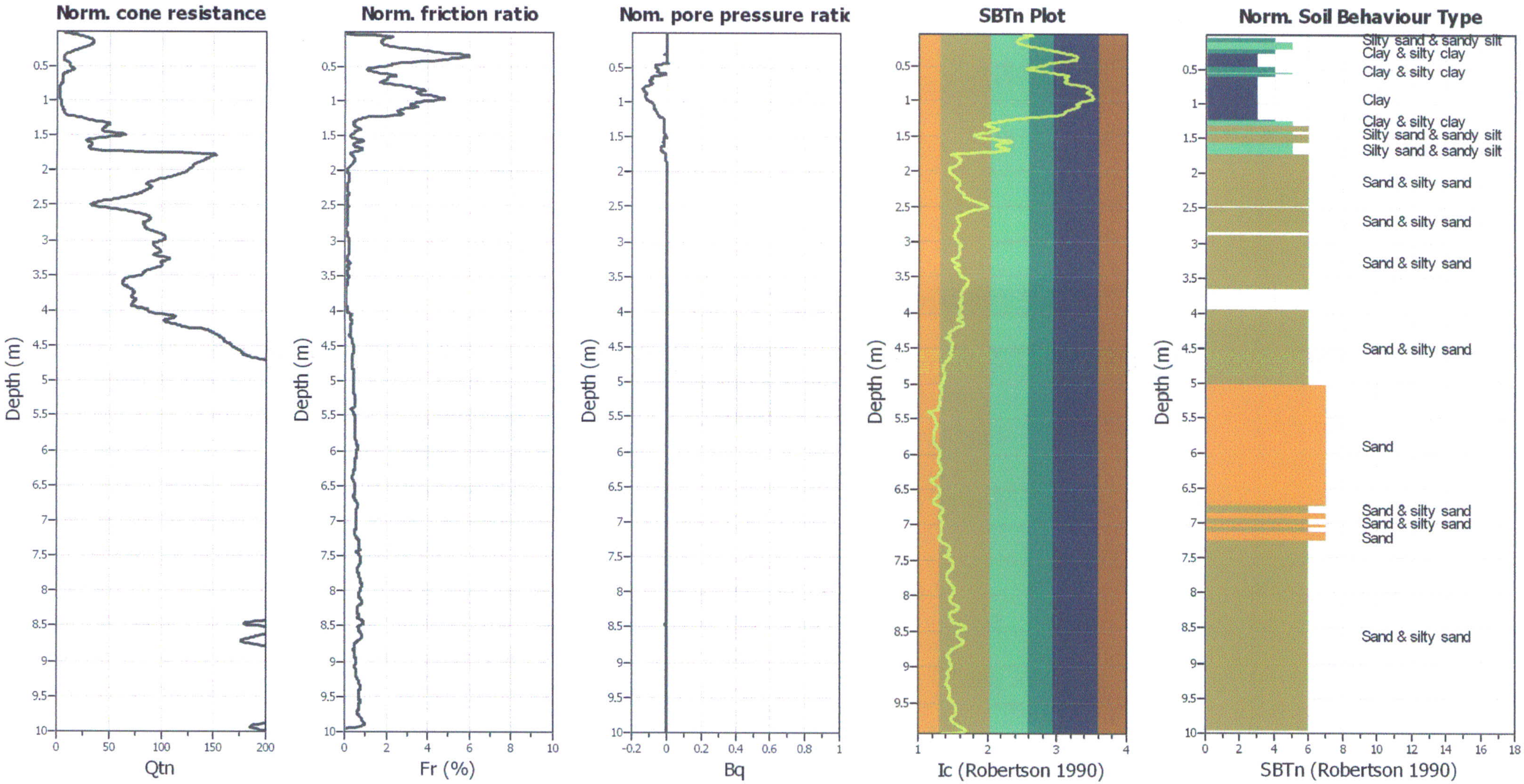
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No		
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes		
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only		
Peak ground acceleration:	0.24	Use fill:	No	Limit depth applied:	No		
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A		

SBT legend

1. Sensitive fine grained	4. Clayey silt to silty	7. Gravely sand to sand
2. Organic material	5. Silty sand to sandy silt	8. Very stiff sand to
3. Clay to silty clay	6. Clean sand to silty sand	9. Very stiff fine grained

CPT basic interpretation plots (normalized)



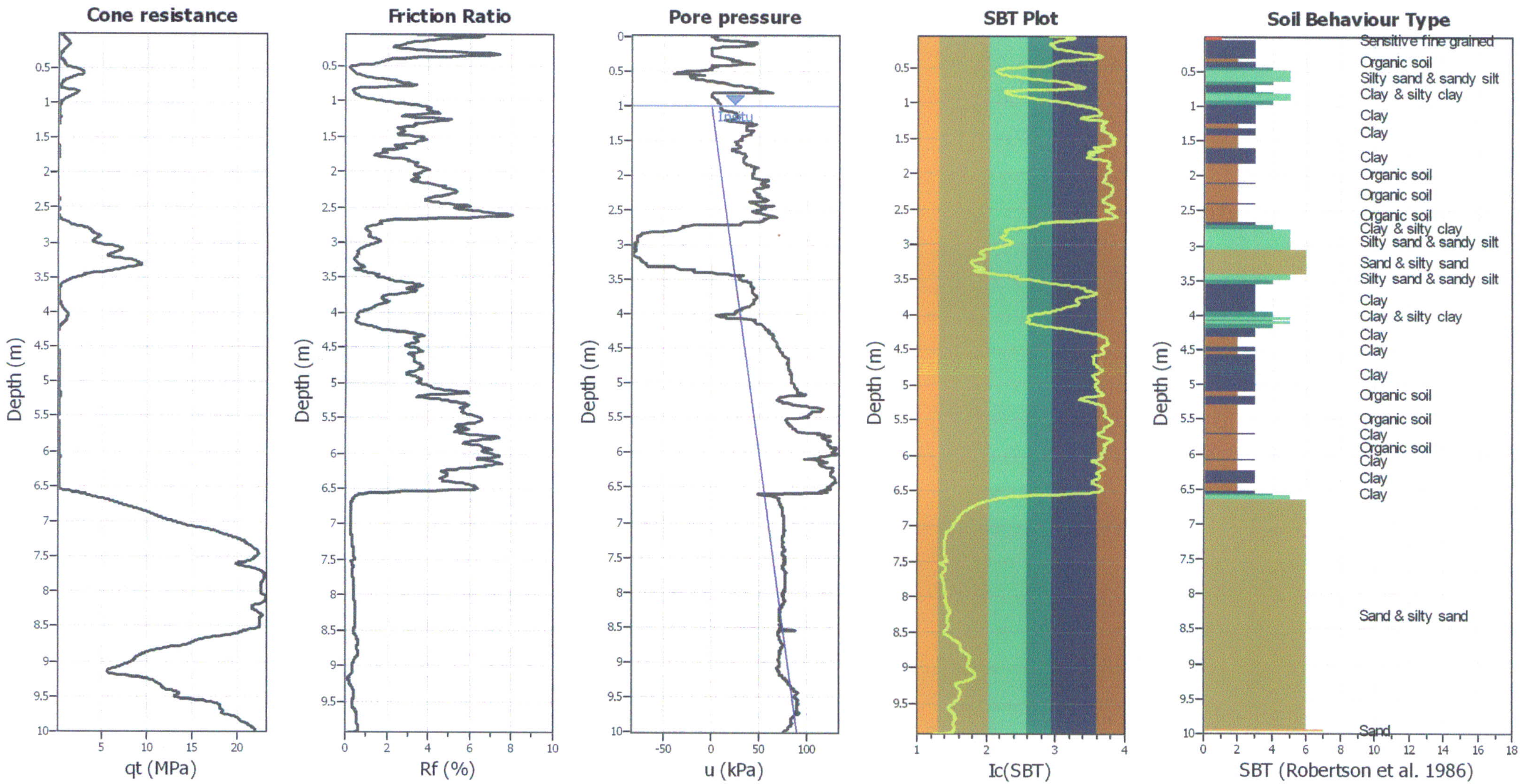
Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.00 m	Fill weight:	N/A		
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No		
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes		
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only		
Peak ground acceleration:	0.24	Use fill:	No	Limit depth applied:	No		
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A		

SBTn legend

1. Sensitive fine grained
2. Organic material
3. Clay to silty clay
4. Clayey silt to silty
5. Silty sand to sandy silt
6. Clean sand to silty sand
7. Gravely sand to sand
8. Very stiff sand to
9. Very stiff fine grained

CPT basic interpretation plots



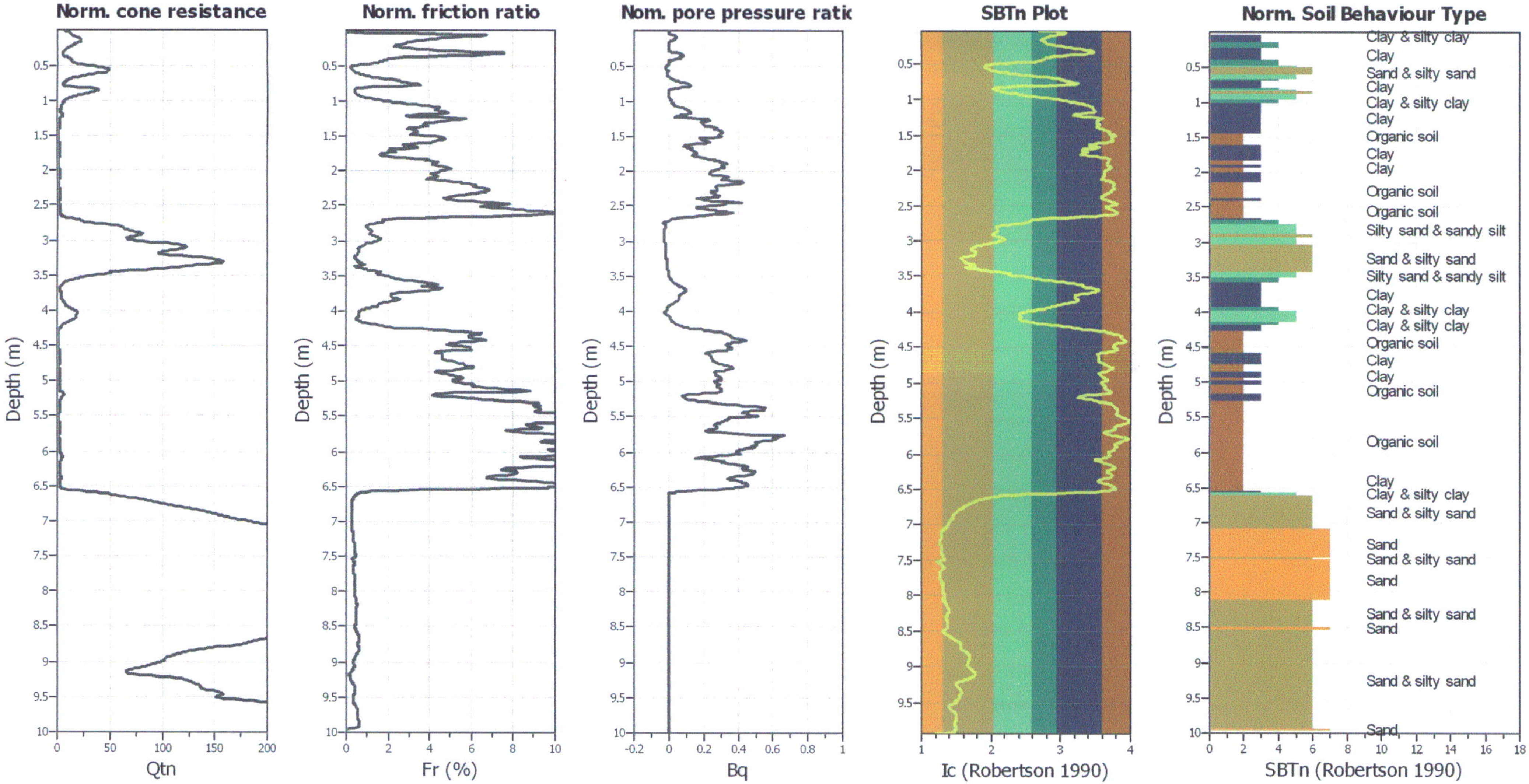
Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.24	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A

SBT legend

1. Sensitive fine grained	4. Clayey silt to silty	7. Gravely sand to sand
2. Organic material	5. Silty sand to sandy silt	8. Very stiff sand to
3. Clay to silty clay	6. Clean sand to silty sand	9. Very stiff fine grained

CPT basic interpretation plots (normalized)



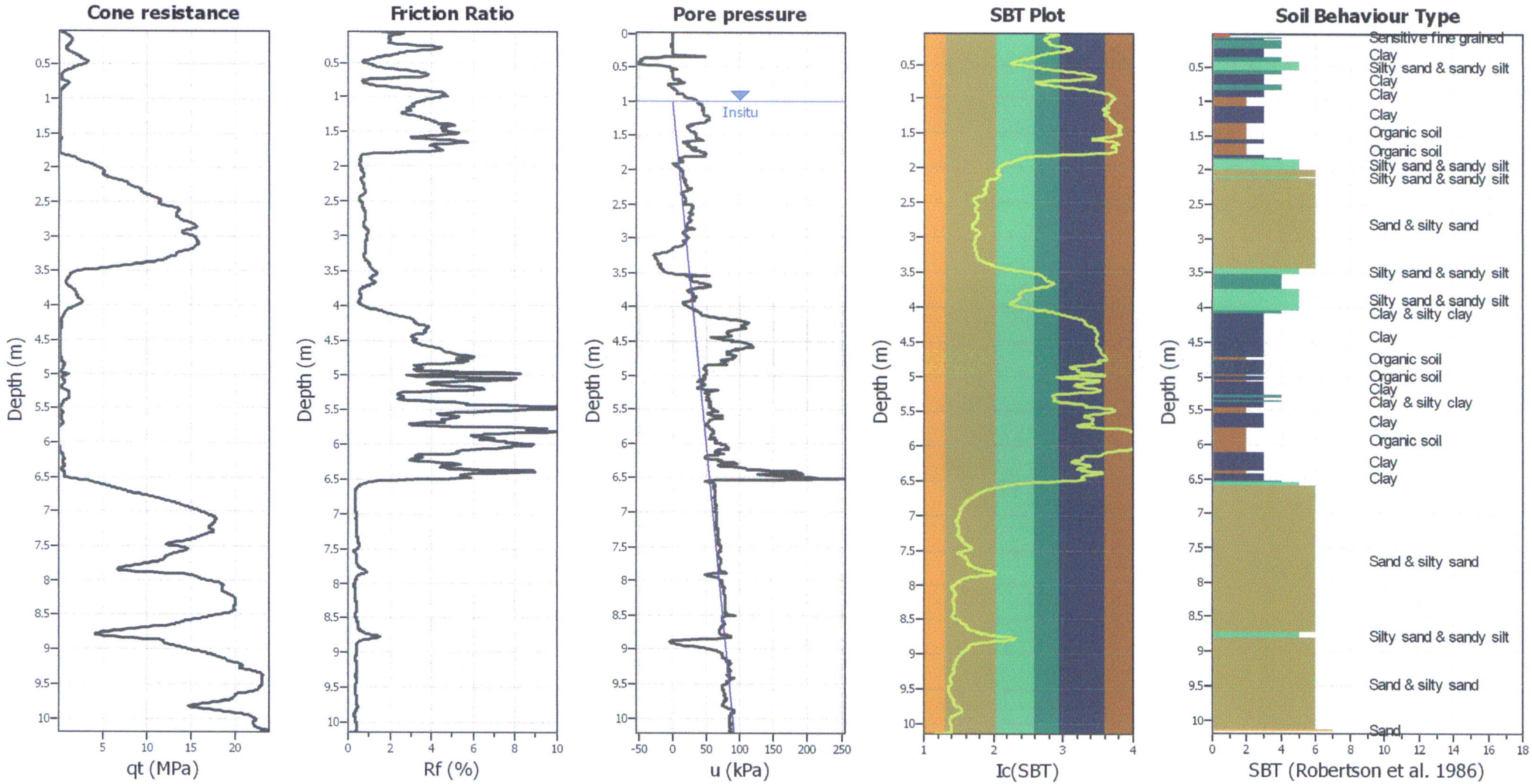
Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.24	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A

SBTn legend

1. Sensitive fine grained	4. Clayey silt to silty	7. Gravely sand to sand
2. Organic material	5. Silty sand to sandy silt	8. Very stiff sand to
3. Clay to silty clay	6. Clean sand to silty sand	9. Very stiff fine grained

CPT basic interpretation plots



Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
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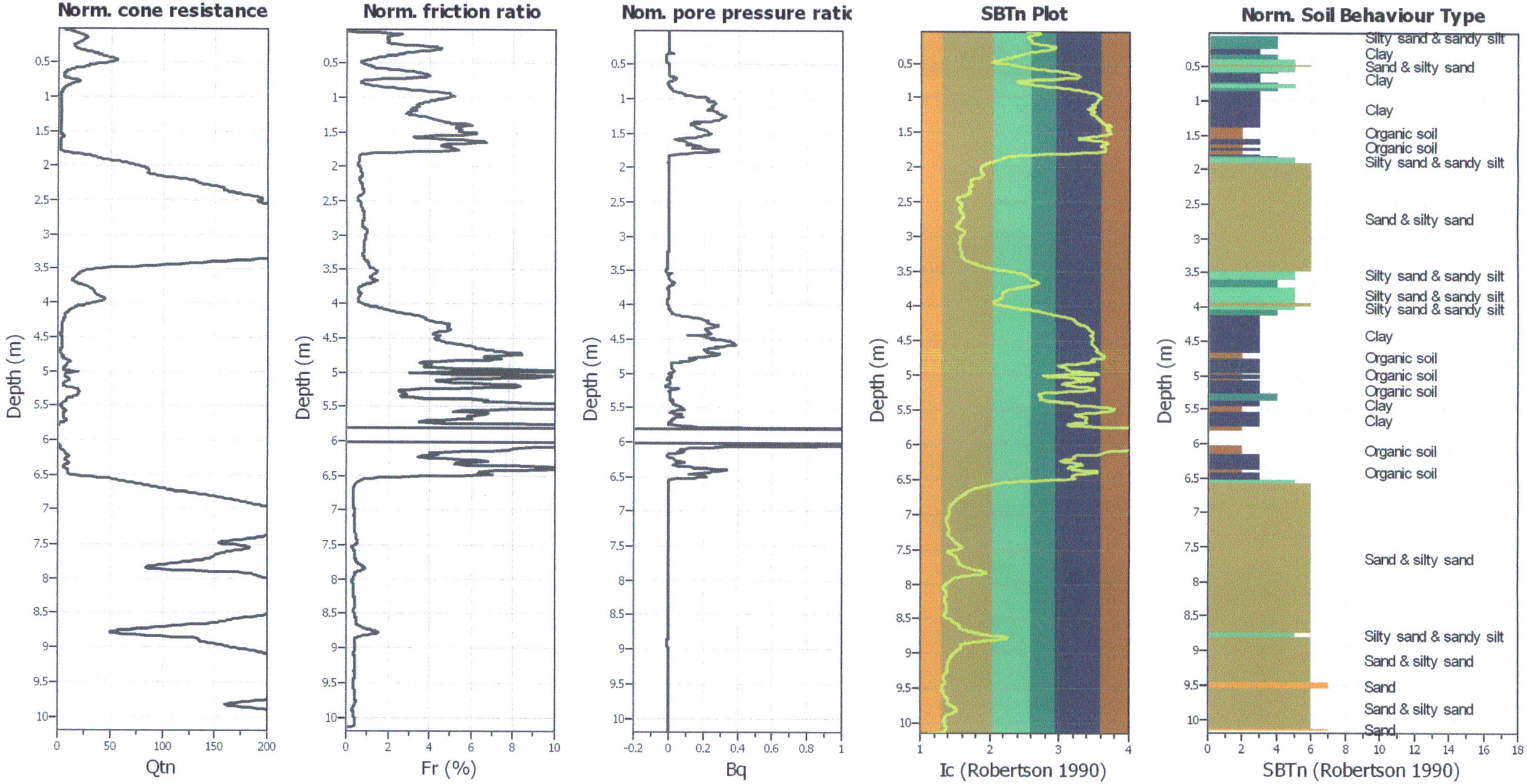
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.24	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A

SBT legend

1. Sensitive fine grained
2. Organic material
3. Clay to silty clay
4. Clayey silt to silty
5. Silty sand to sandy silt
6. Clean sand to silty sand
7. Gravely sand to sand
8. Very stiff sand to
9. Very stiff fine grained

CPT basic interpretation plots (normalized)



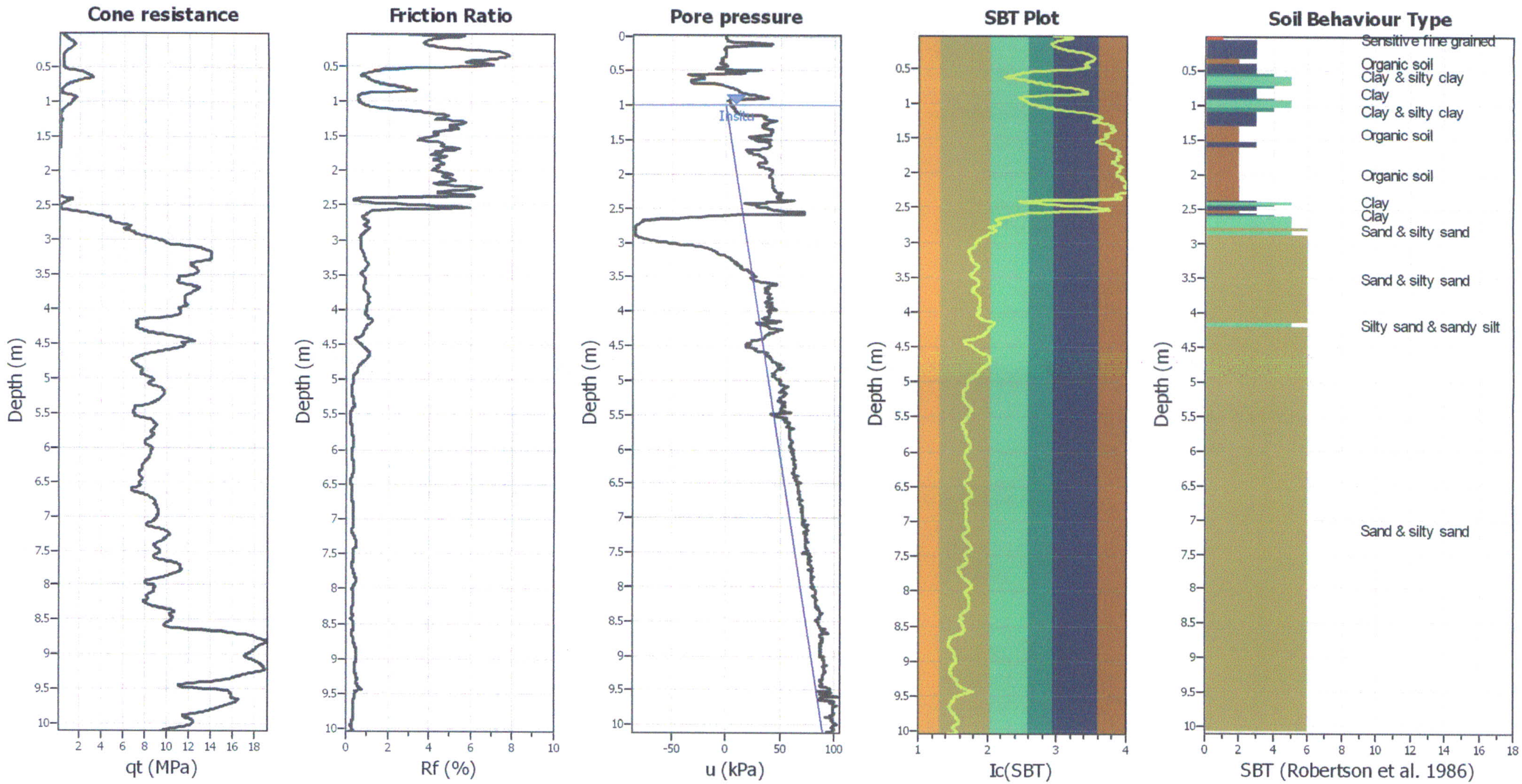
Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.24	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A

SBTn legend

1. Sensitive fine grained	4. Clayey silt to silty	7. Gravely sand to sand
2. Organic material	5. Silty sand to sandy silt	8. Very stiff sand to
3. Clay to silty clay	6. Clean sand to silty sand	9. Very stiff fine grained

CPT basic interpretation plots



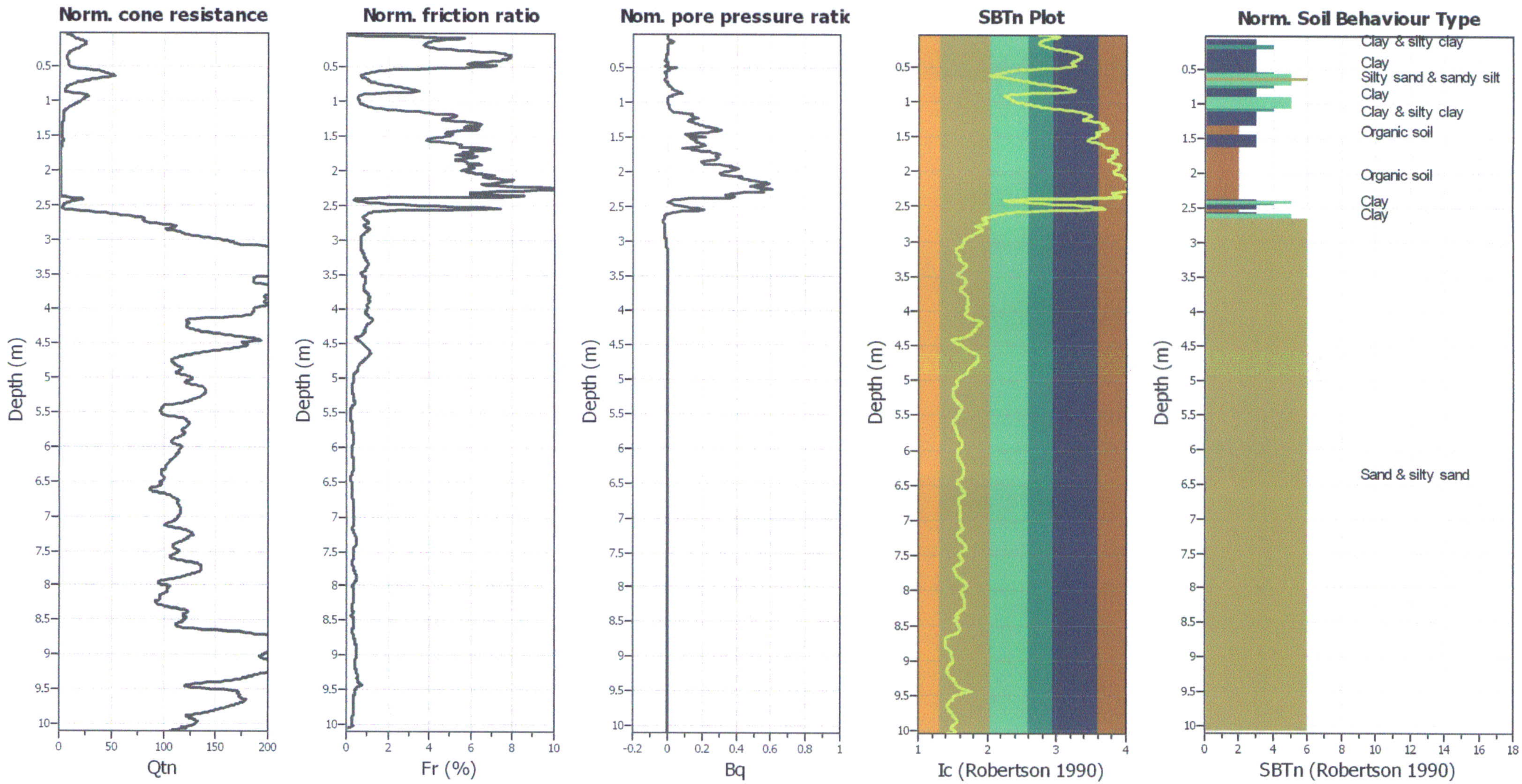
Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.24	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A

SBT legend

1. Sensitive fine grained
2. Organic material
3. Clay to silty clay
4. Clayey silt to silty
5. Silty sand to sandy silt
6. Clean sand to silty sand
7. Gravely sand to sand
8. Very stiff sand to
9. Very stiff fine grained

CPT basic interpretation plots (normalized)



Input parameters and analysis data

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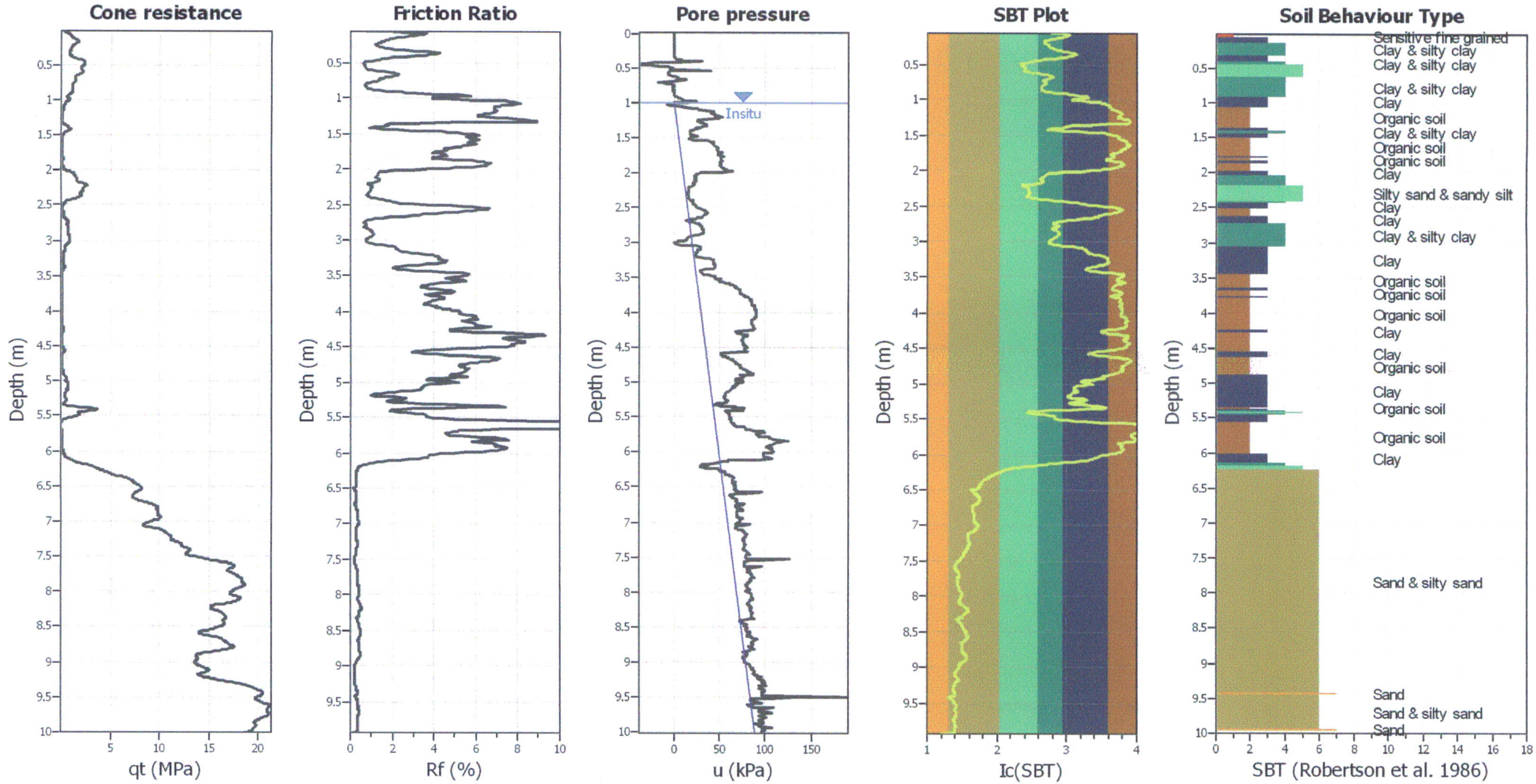
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.24	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A

SBTn legend

- 1. Sensitive fine grained
- 2. Organic material
- 3. Clay to silty clay
- 4. Clayey silt to silty
- 5. Silty sand to sandy silt
- 6. Clean sand to silty sand
- 7. Gravely sand to sand
- 8. Very stiff sand to
- 9. Very stiff fine grained

CPT basic interpretation plots



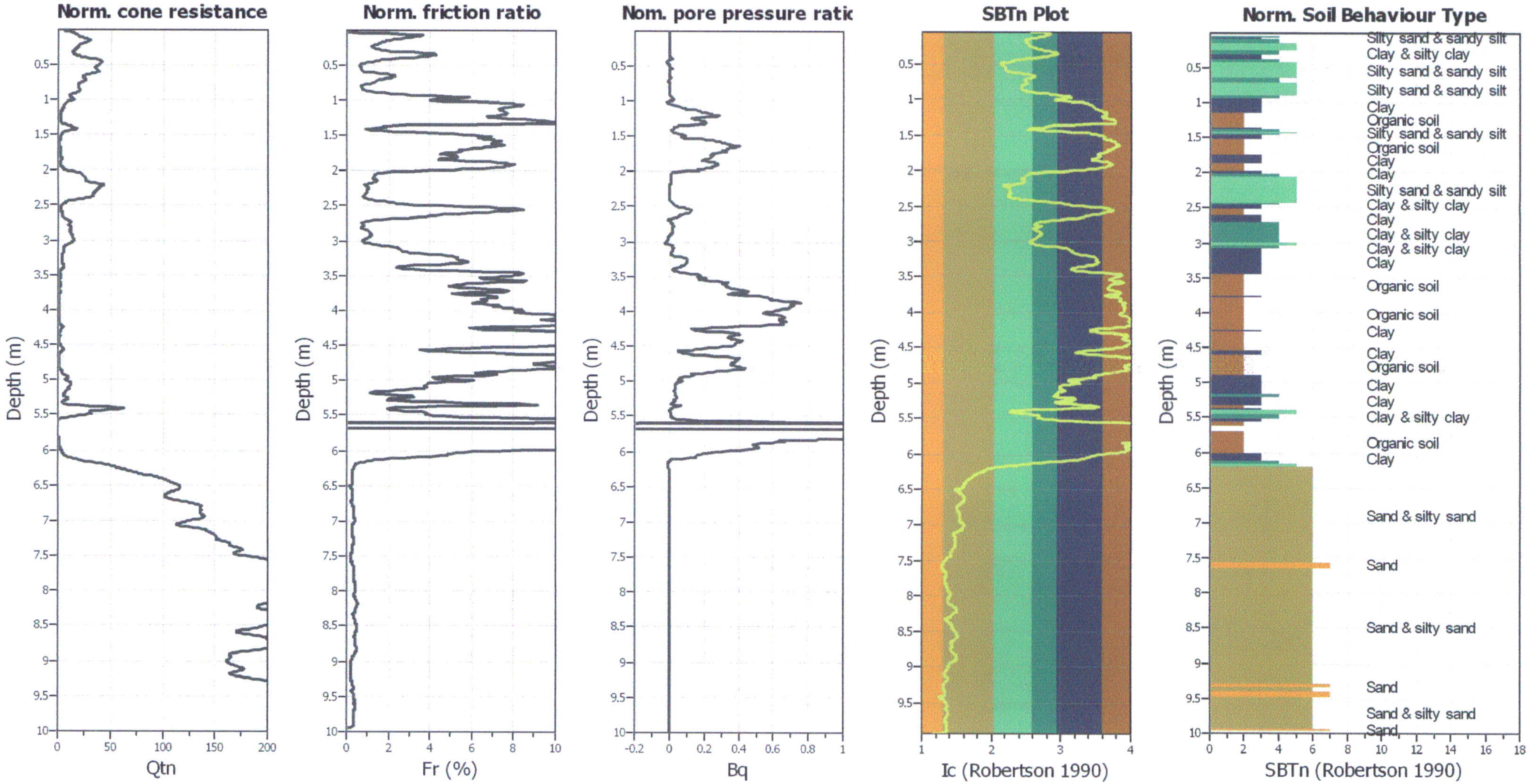
Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.24	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A

SBT legend

1. Sensitive fine grained	4. Clayey silt to silty	7. Gravely sand to sand
2. Organic material	5. Silty sand to sandy silt	8. Very stiff sand to
3. Clay to silty clay	6. Clean sand to silty sand	9. Very stiff fine grained

CPT basic interpretation plots (normalized)



Input parameters and analysis data

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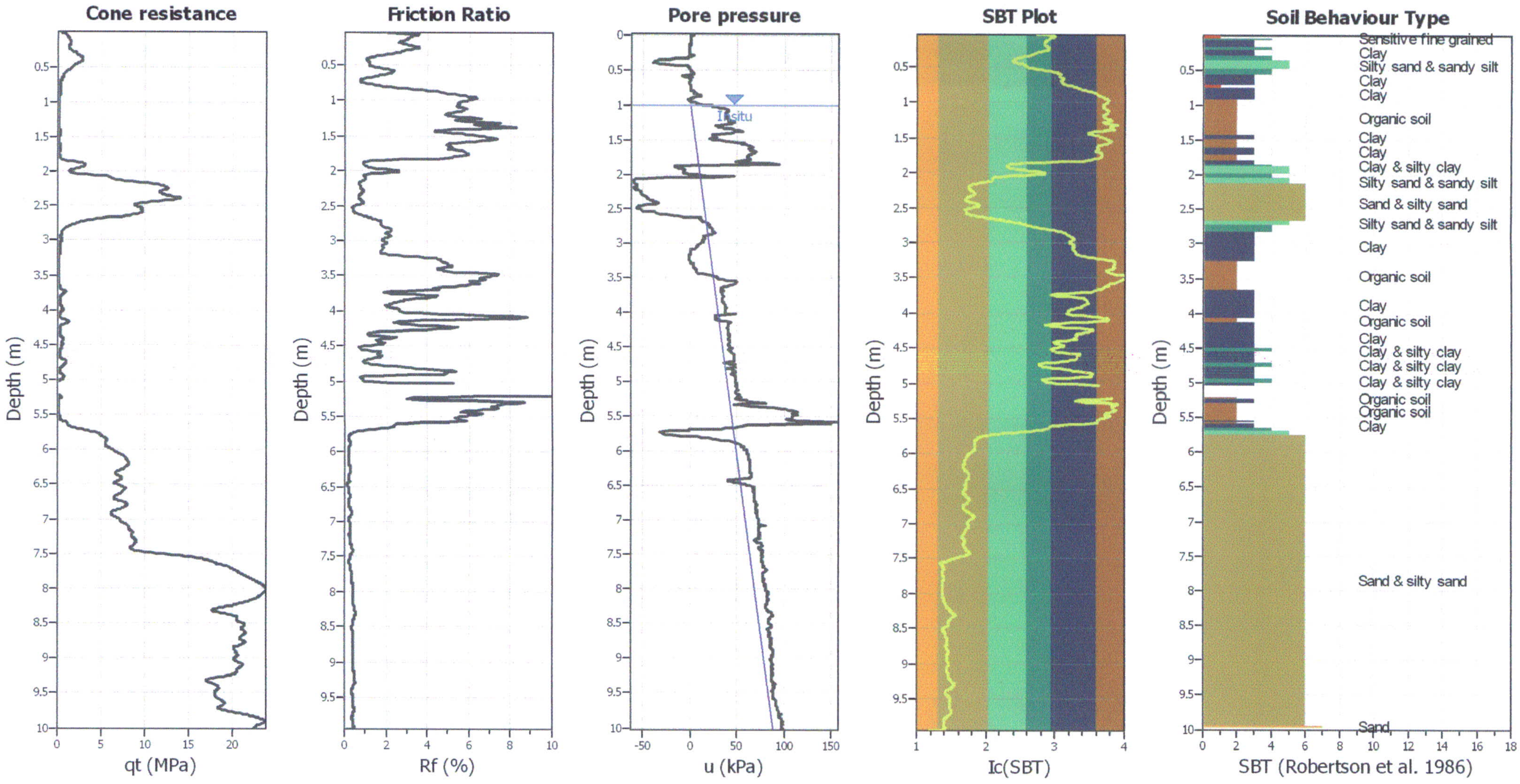
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.24	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A

SBTn legend

1. Sensitive fine grained	4. Clayey silt to silty	7. Gravely sand to sand
2. Organic material	5. Silty sand to sandy silt	8. Very stiff sand to
3. Clay to silty clay	6. Clean sand to silty sand	9. Very stiff fine grained

CPT basic interpretation plots



Input parameters and analysis data

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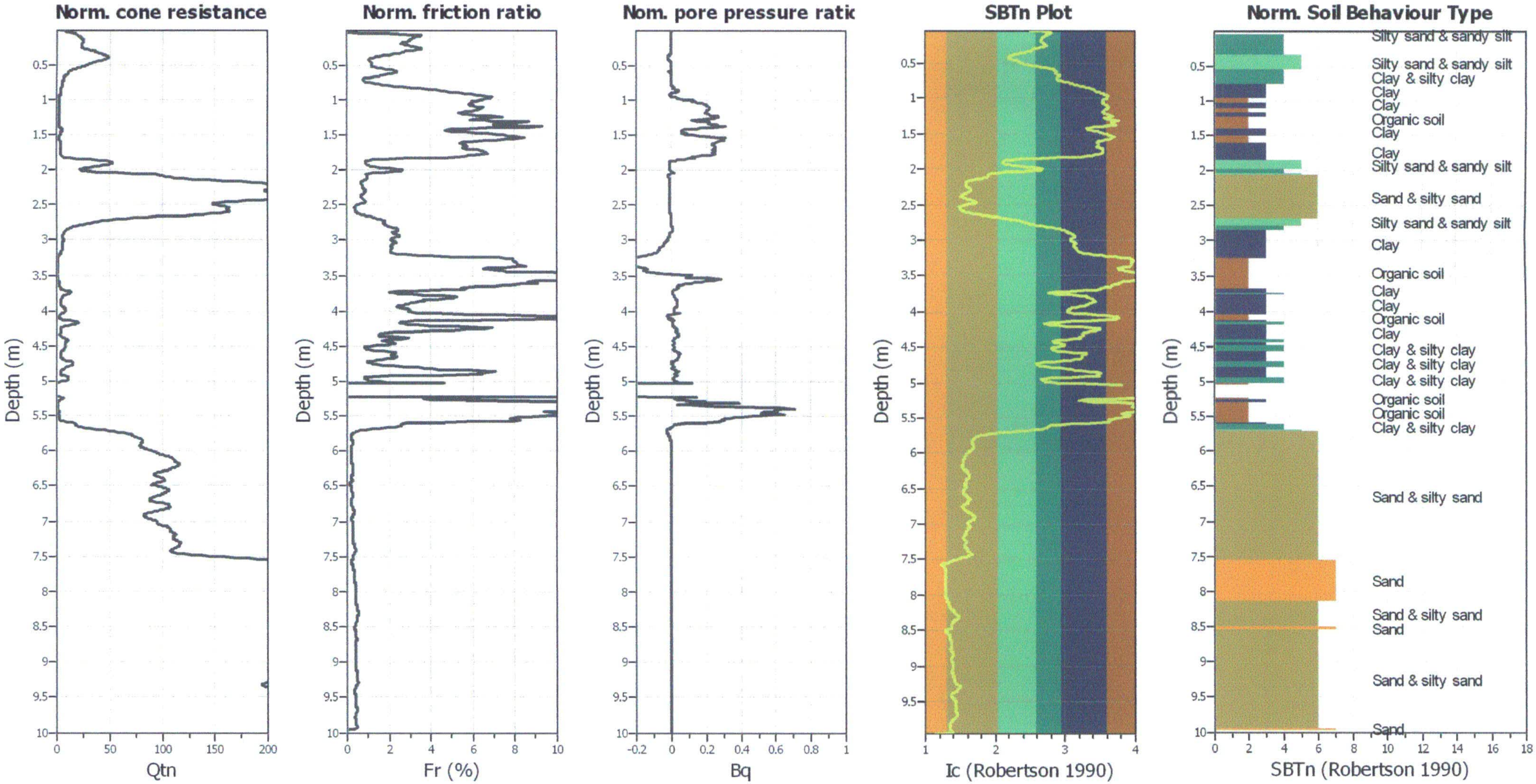
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.24	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A

SBT legend

1. Sensitive fine grained	4. Clayey silt to silty	7. Gravely sand to sand
2. Organic material	5. Silty sand to sandy silt	8. Very stiff sand to
3. Clay to silty clay	6. Clean sand to silty sand	9. Very stiff fine grained

CPT basic interpretation plots (normalized)



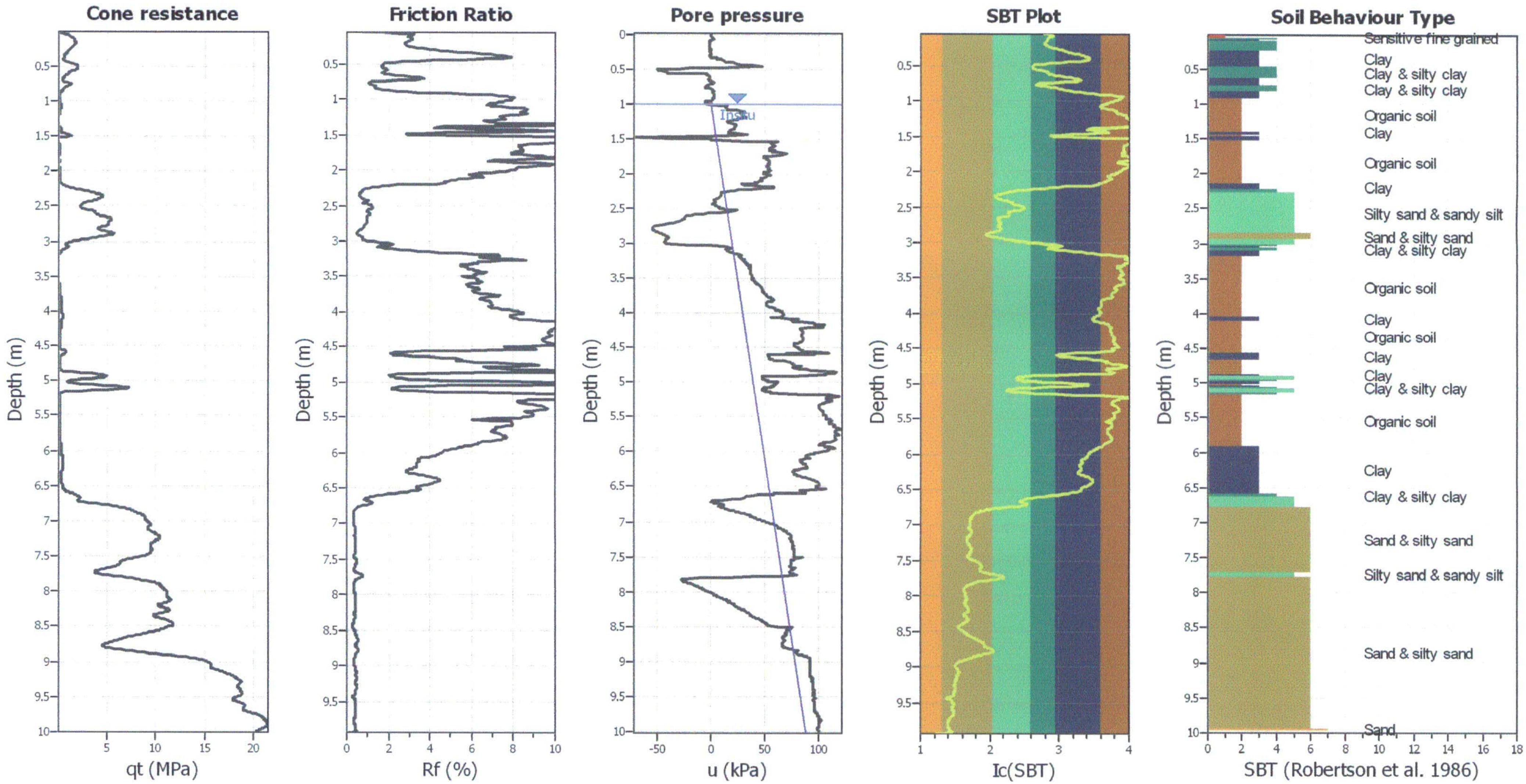
Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.00 m	Fill weight:	N/A		
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No		
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes		
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only		
Peak ground acceleration:	0.24	Use fill:	No	Limit depth applied:	No		
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A		

SBTn legend

- 1. Sensitive fine grained
- 2. Organic material
- 3. Clay to silty clay
- 4. Clayey silt to silty
- 5. Silty sand to sandy silt
- 6. Clean sand to silty sand
- 7. Gravely sand to sand
- 8. Very stiff sand to
- 9. Very stiff fine grained

CPT basic interpretation plots



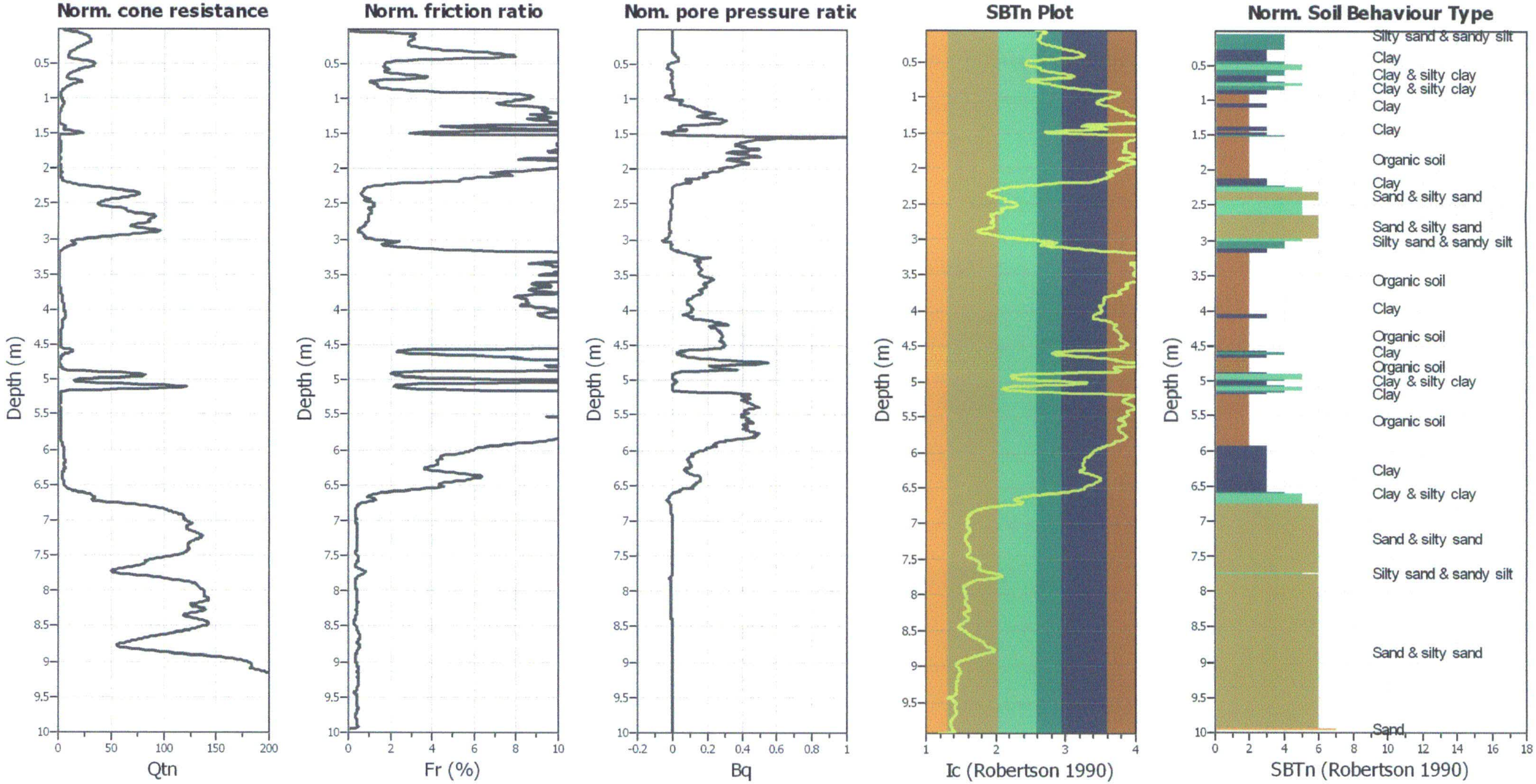
Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.00 m	Fill weight:	N/A		
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No		
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes		
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only		
Peak ground acceleration:	0.24	Use fill:	No	Limit depth applied:	No		
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A		

SBT legend

1. Sensitive fine grained
2. Organic material
3. Clay to silty clay
4. Clayey silt to silty
5. Silty sand to sandy silt
6. Clean sand to silty sand
7. Gravely sand to sand
8. Very stiff sand to
9. Very stiff fine grained

CPT basic interpretation plots (normalized)



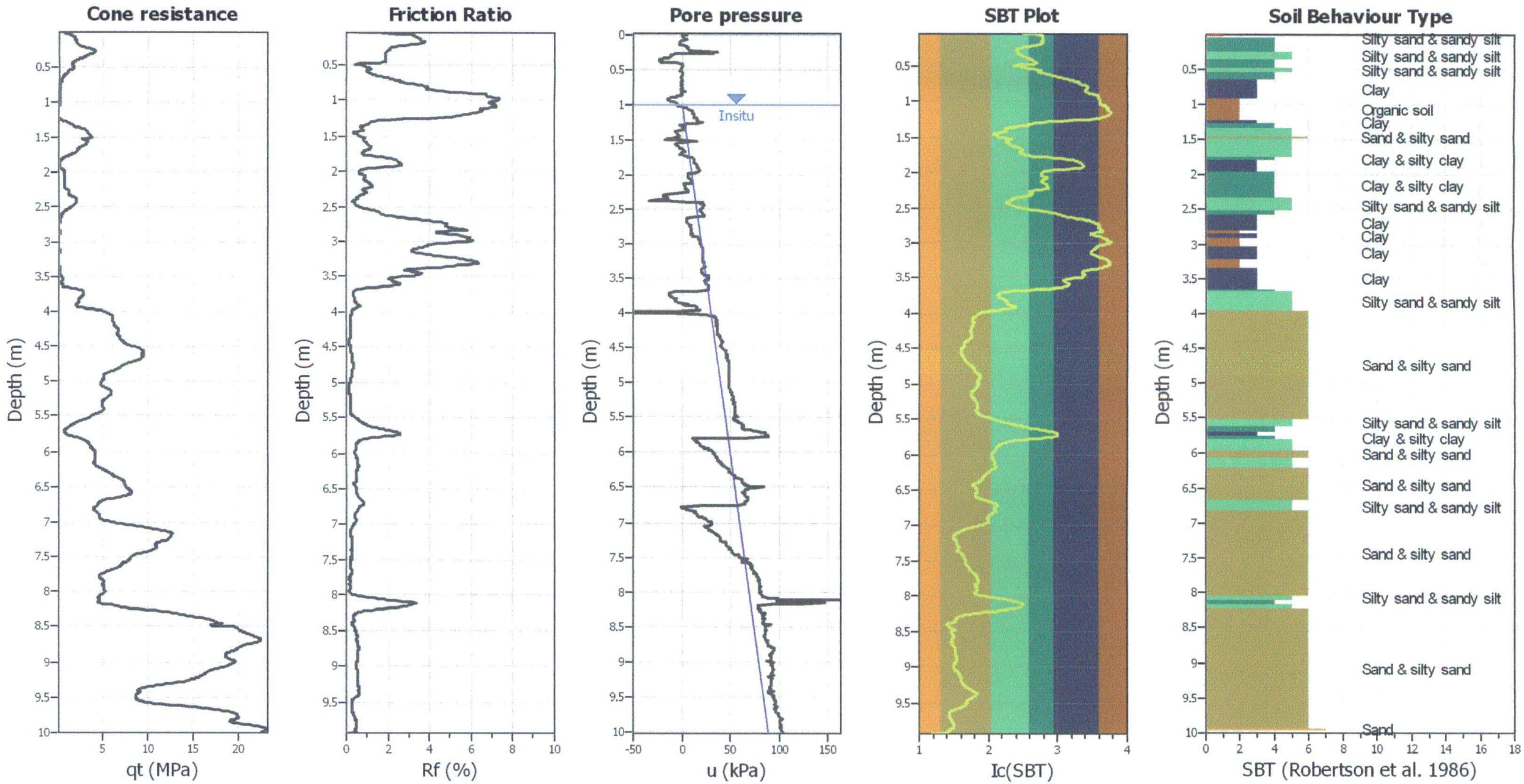
Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.00 m	Fill weight:	N/A		
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No		
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes		
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only		
Peak ground acceleration:	0.24	Use fill:	No	Limit depth applied:	No		
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A		

SBTn legend

1. Sensitive fine grained	4. Clayey silt to silty	7. Gravely sand to sand
2. Organic material	5. Silty sand to sandy silt	8. Very stiff sand to
3. Clay to silty clay	6. Clean sand to silty sand	9. Very stiff fine grained

CPT basic interpretation plots



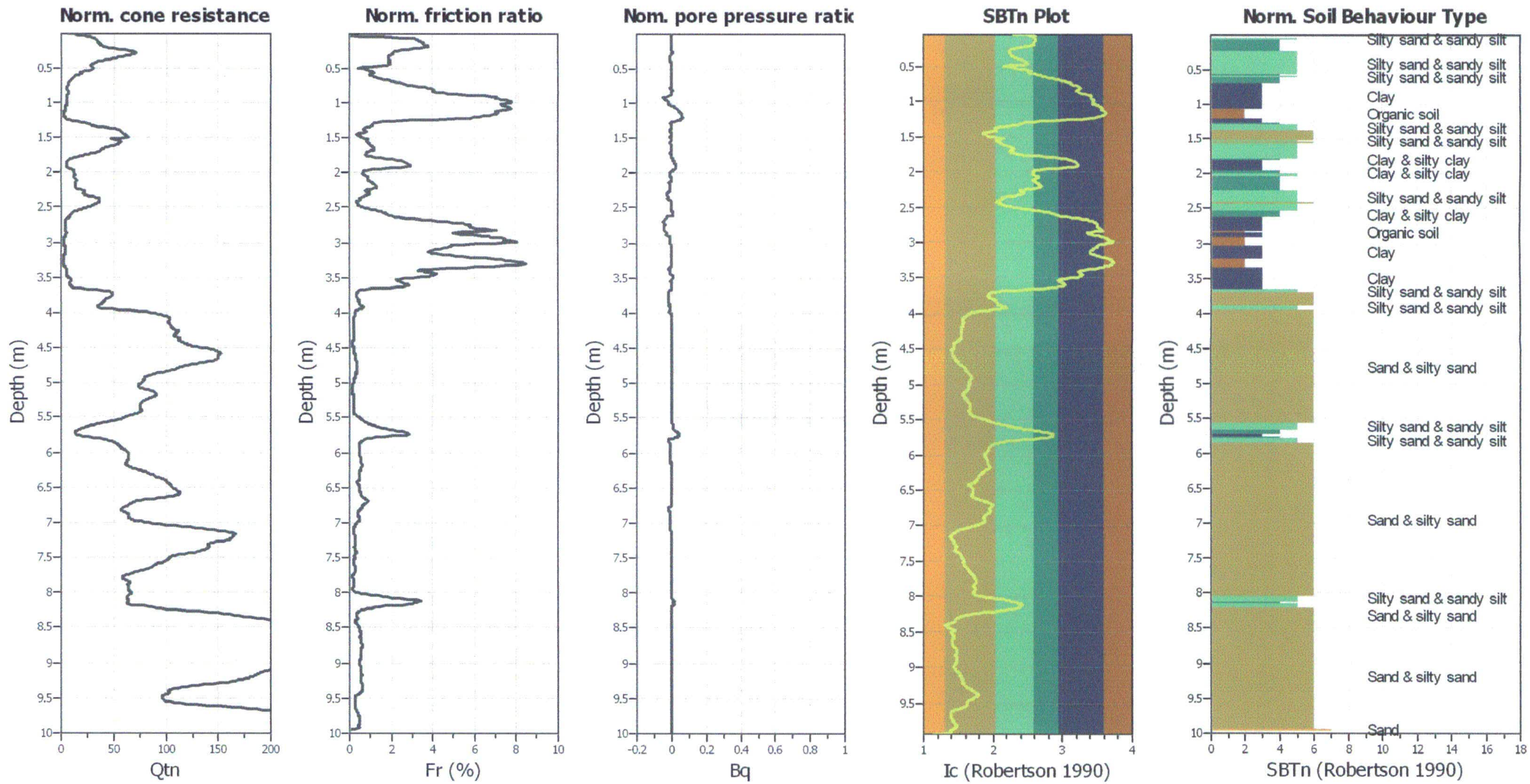
Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.24	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A

SBT legend

1. Sensitive fine grained	4. Clayey silt to silty	7. Gravely sand to sand
2. Organic material	5. Silty sand to sandy silt	8. Very stiff sand to
3. Clay to silty clay	6. Clean sand to silty sand	9. Very stiff fine grained

CPT basic interpretation plots (normalized)



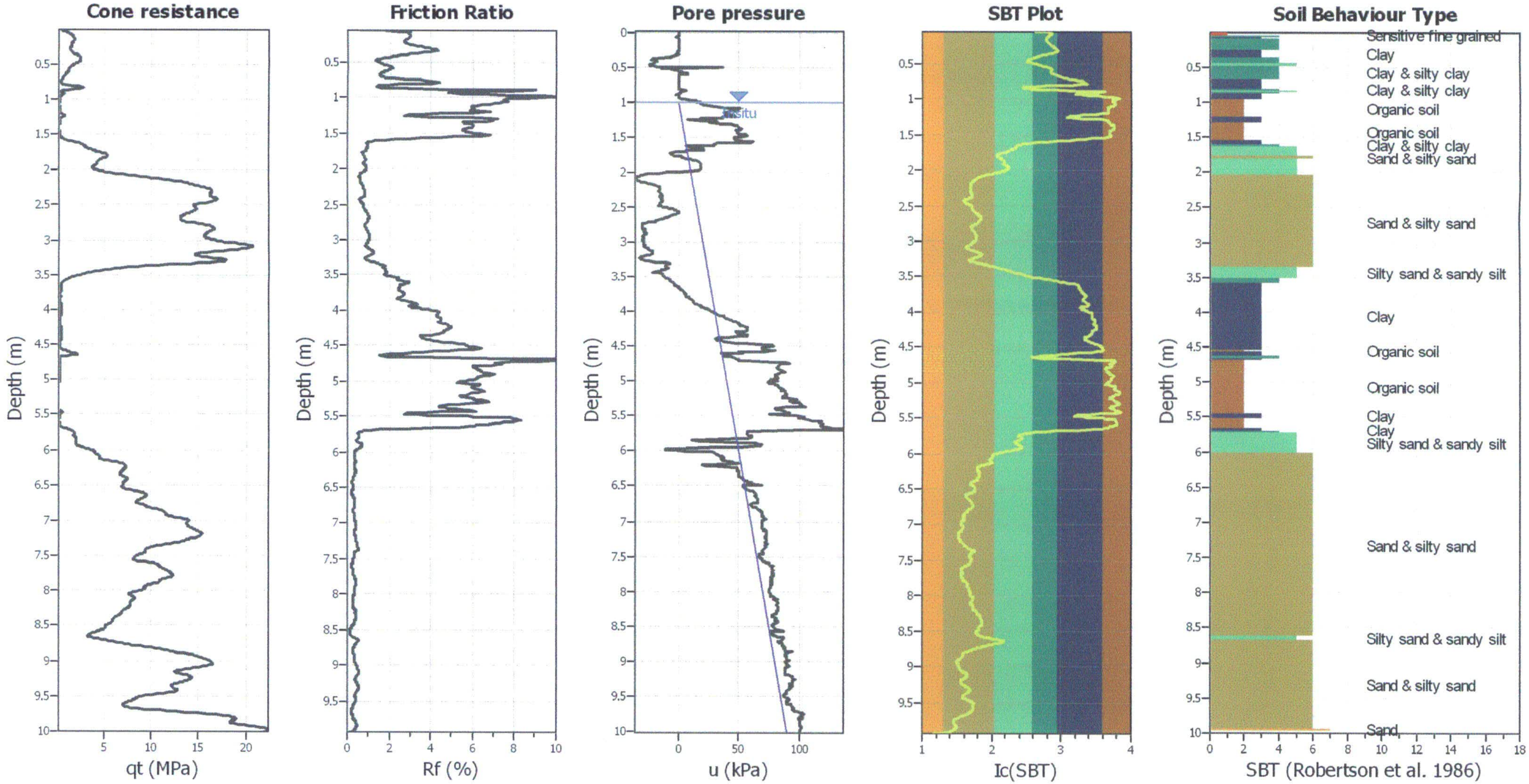
Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.24	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A

SBTn legend

1. Sensitive fine grained	4. Clayey silt to silty	7. Gravely sand to sand
2. Organic material	5. Silty sand to sandy silt	8. Very stiff sand to
3. Clay to silty clay	6. Clean sand to silty sand	9. Very stiff fine grained

CPT basic interpretation plots



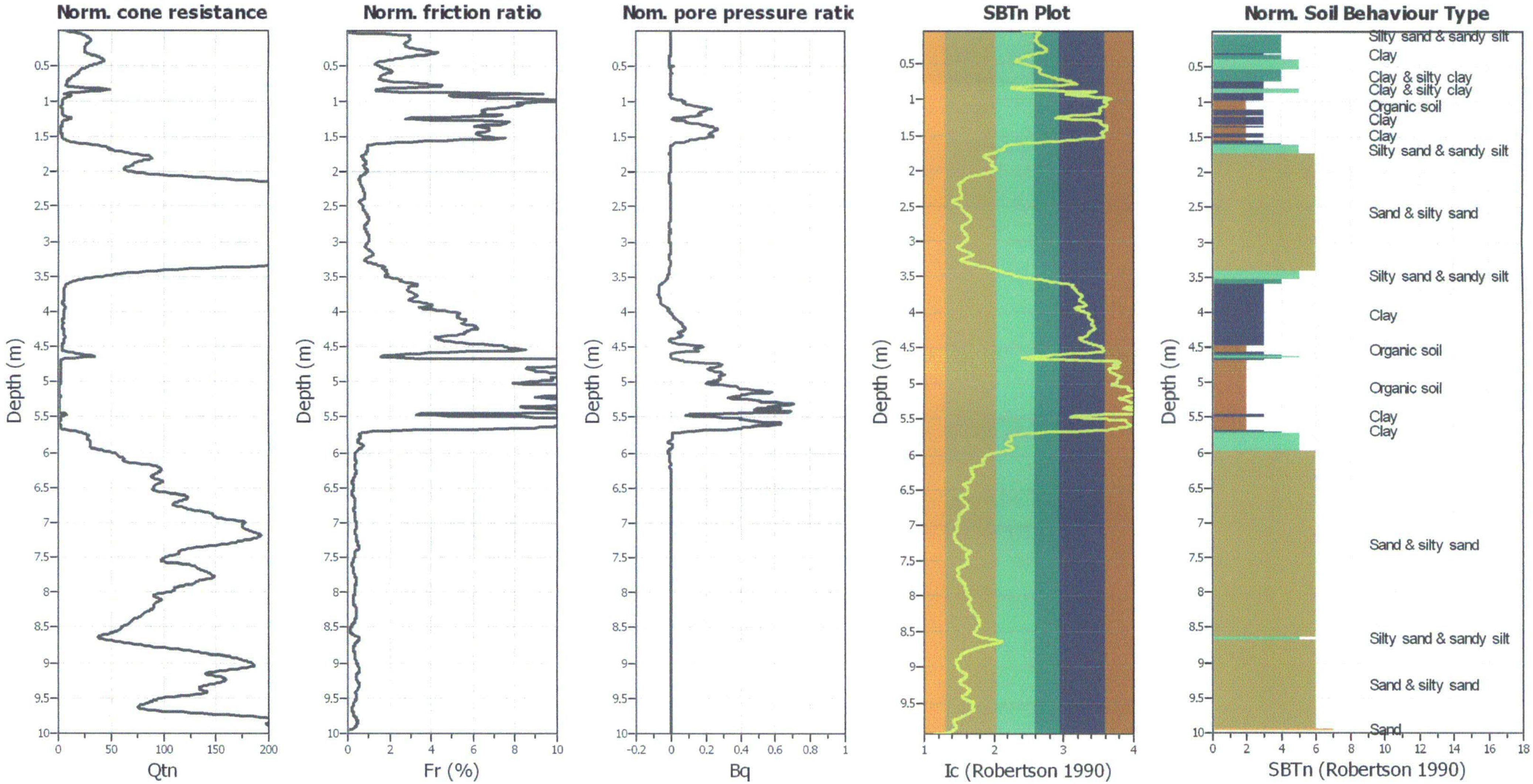
Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.24	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A

SBT legend

1. Sensitive fine grained
2. Organic material
3. Clay to silty clay
4. Clayey silt to silty
5. Silty sand to sandy silt
6. Clean sand to silty sand
7. Gravely sand to sand
8. Very stiff sand to
9. Very stiff fine grained

CPT basic interpretation plots (normalized)



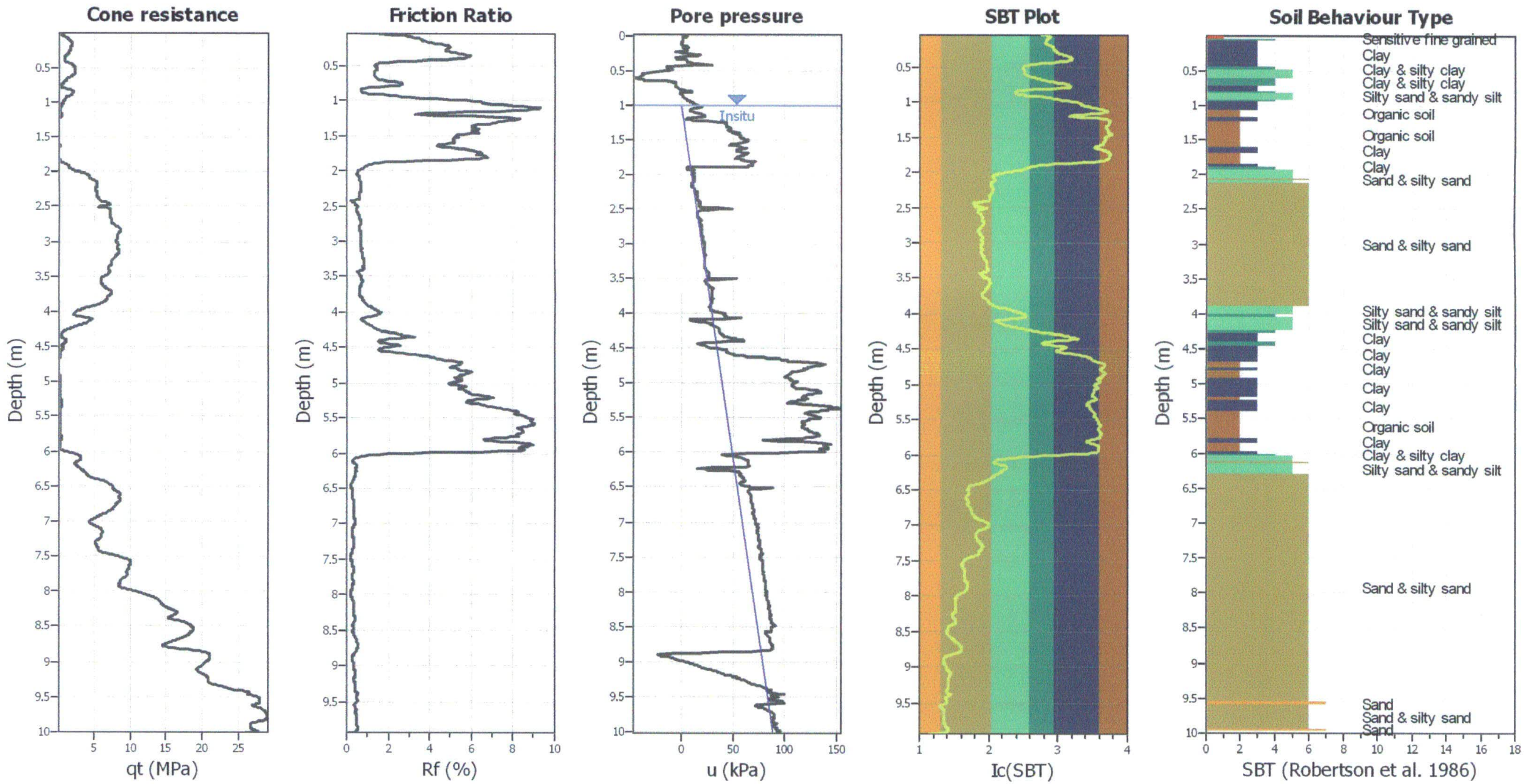
Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.24	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A

SBTn legend

1. Sensitive fine grained
2. Organic material
3. Clay to silty clay
4. Clayey silt to silty
5. Silty sand to sandy silt
6. Clean sand to silty sand
7. Gravely sand to sand
8. Very stiff sand to
9. Very stiff fine grained

CPT basic interpretation plots



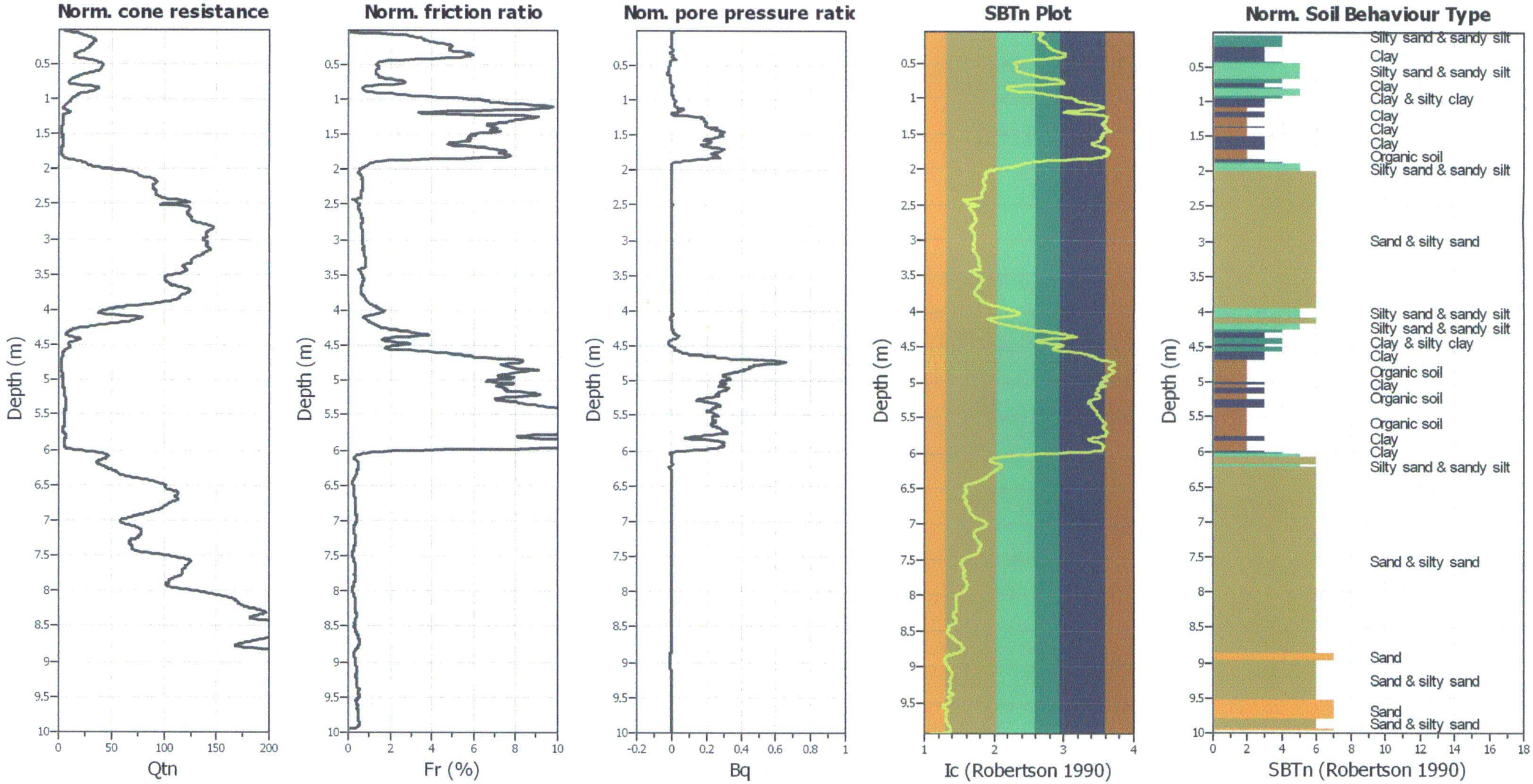
Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.24	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A

SBT legend

1. Sensitive fine grained	4. Clayey silt to silty	7. Gravely sand to sand
2. Organic material	5. Silty sand to sandy silt	8. Very stiff sand to
3. Clay to silty clay	6. Clean sand to silty sand	9. Very stiff fine grained

CPT basic interpretation plots (normalized)



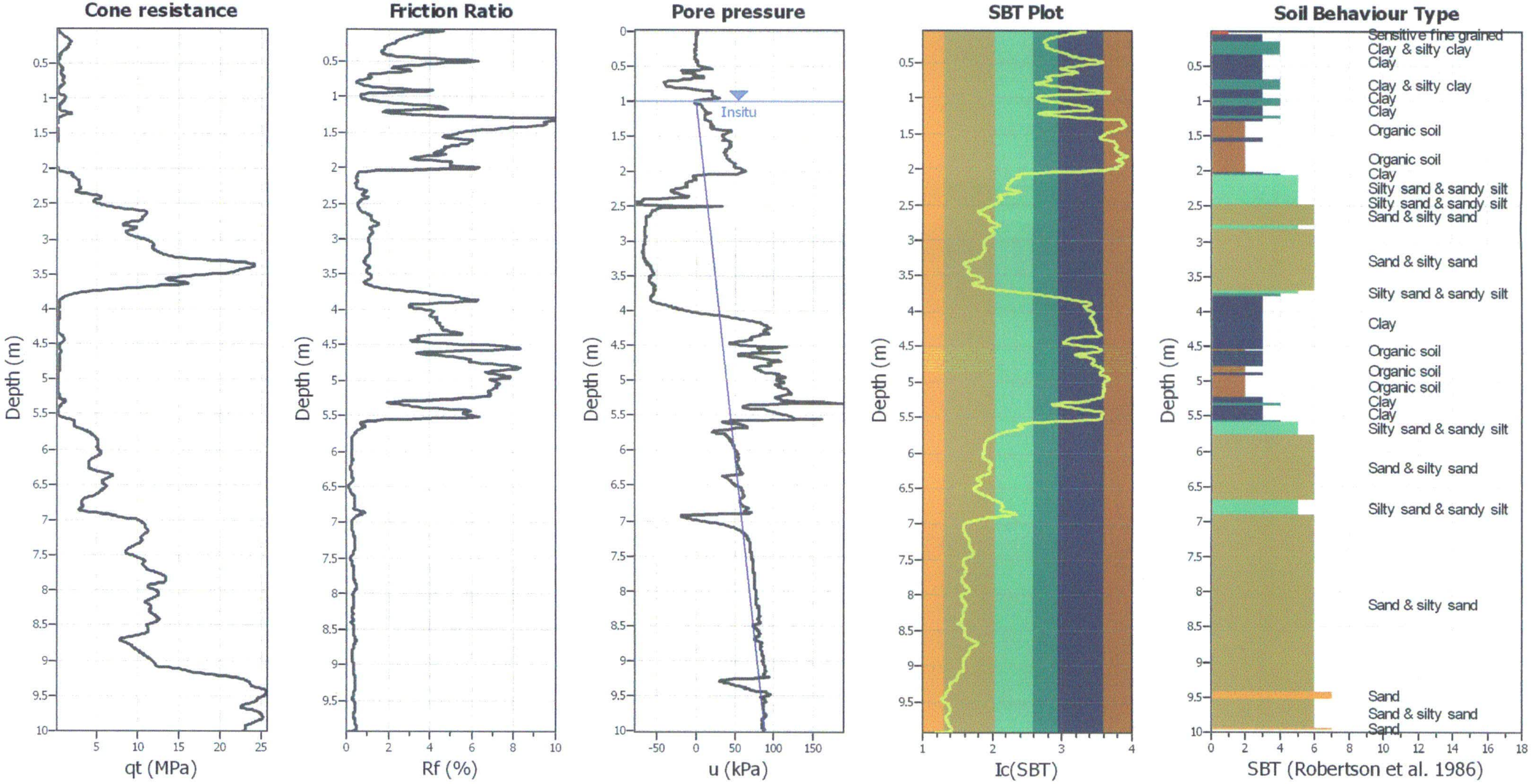
Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.24	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A

SBTn legend

1. Sensitive fine grained	4. Clayey silt to silty	7. Gravely sand to sand
2. Organic material	5. Silty sand to sandy silt	8. Very stiff sand to
3. Clay to silty clay	6. Clean sand to silty sand	9. Very stiff fine grained

CPT basic interpretation plots



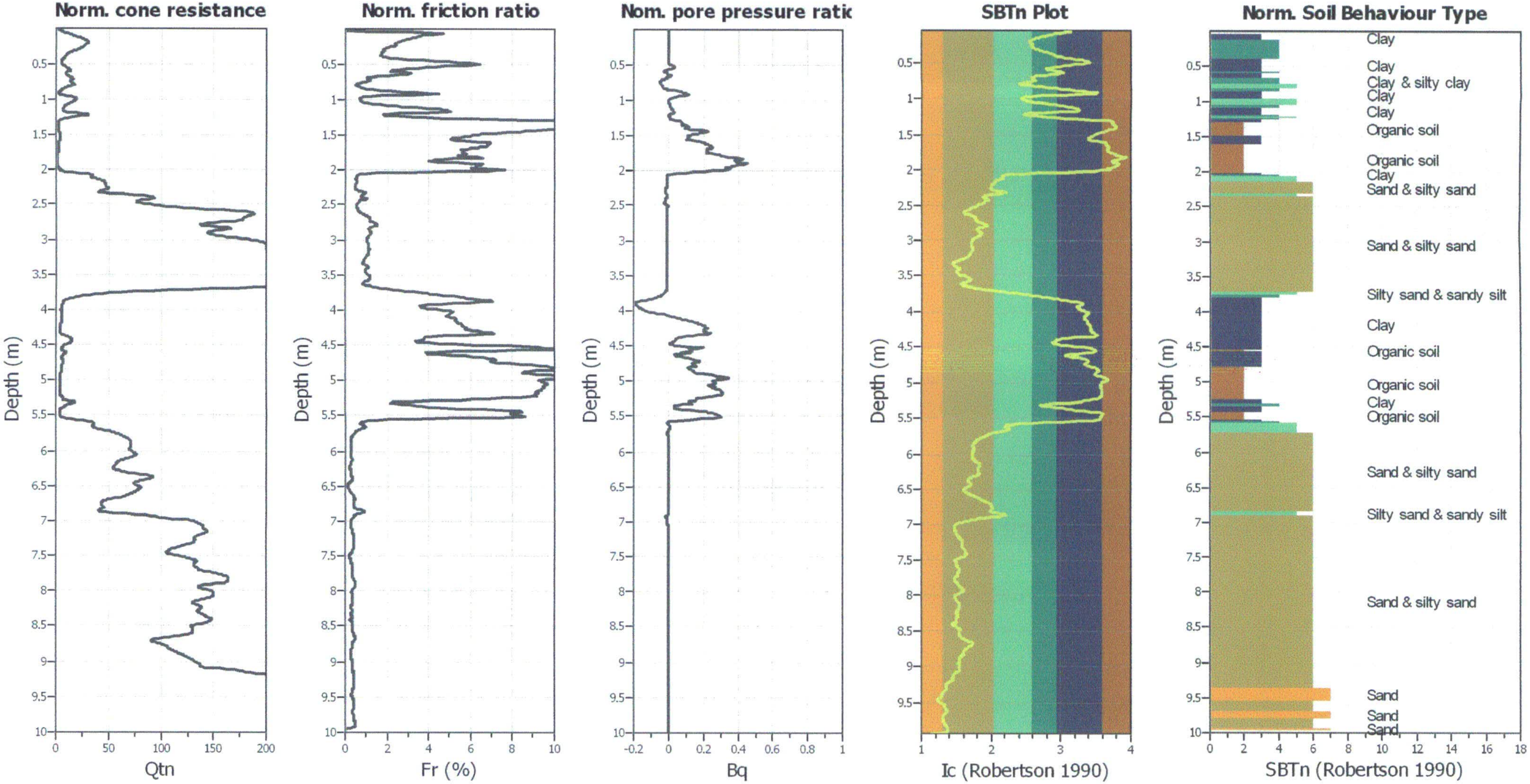
Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.24	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A

SBT legend

1. Sensitive fine grained	4. Clayey silt to silty	7. Gravely sand to sand
2. Organic material	5. Silty sand to sandy silt	8. Very stiff sand to
3. Clay to silty clay	6. Clean sand to silty sand	9. Very stiff fine grained

CPT basic interpretation plots (normalized)



Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.24	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A

SBTn legend

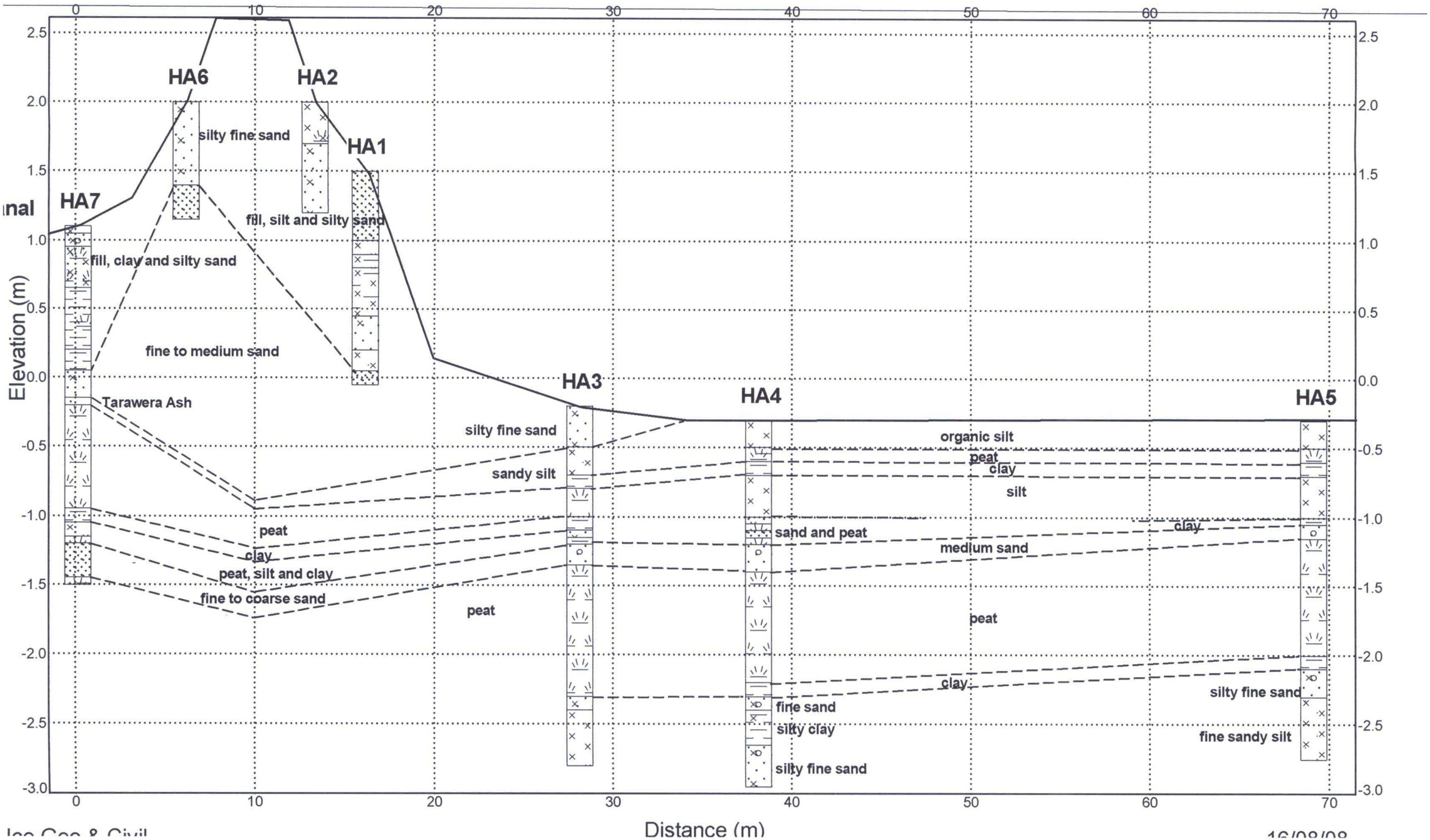
1. Sensitive fine grained	4. Clayey silt to silty	7. Gravely sand to sand
2. Organic material	5. Silty sand to sandy silt	8. Very stiff sand to
3. Clay to silty clay	6. Clean sand to silty sand	9. Very stiff fine grained

Appendix E

Previous Investigations – Cross Section 4

Project: Reid's Canal
Client: Environment Bay of Plenty
Location: Reid's Canal CS1
Number: 1

Figure 1: Subsurface Cross Section Reid's Canal
Cross Section 4



Project:	**Reid's Canal**	Test:	**HA1**
Client:	Environment Bay of Plenty	Elevation:	1.5
Location:	Reid's Canal CS1	Date:	08/08/2008
Number:	1	Logged by:	M. O'Halloran

Depth (m)	Elev(m)	Graphic Log	Description	Sample
0.0			brown **silty fine to medium SAND, some fine gravel**	
0.5	1		brown **fine sandy SILT**	
	0.9		brown **fine GRAVEL**, wet	
▼	0.8		mixed grey and brown **clayey SILT**, soft	
1.0	0.45		brown / grey **silty fine to medium SAND**	
	0.2		brown / grey **fine sandy SILT**, fill	
1.5	0.05		grey **fine to medium SAND**	
	-0.05		EOB - collapsing, grey SILT??	
2.0				
2.5				
3.0				
3.5				
4.0				
4.5				

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Project: **Reid's Canal**		Test: **HA2**
Client: Environment Bay of Plenty		Elevation: 2.0
Location: Reid's Canal CS1		Date: 08/08/2008
Number: 1		Logged by: M. O'Halloran

Depth (m)	Elev(m)	Graphic Log	Description	Sample
0.0			brown **organic SILT**, topsoil	
	1.7		brown silty fine to medium SAND, some gravel to 3mm	
0.5				
	1.2		**GRAVEL**	
1.0				
1.5				
2.0				
2.5				
3.0				
3.5				
4.0				
4.5				

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HAND AUGER REIDS CANAL.GPJ HAND AUGER BASIC.GDT 10/8/12

Project:	**Reid's Canal**	Test:	**HA3**
Client:	Environment Bay of Plenty	Elevation:	-0.2
Location:	Reid's Canal CS1	Date:	08/08/2008
Number:	1	Logged by:	M. O'Halloran

Depth (m)	Elev(m)	Graphic Log	Description	Sample
0.0			brown **silty fine SAND**, fill, firm	
	-0.5		brown **organic fine sandy SILT**, some grit (Tarawera Ash)	
0.5	-0.7		brown **organic CLAY**,soft	
	-0.8		brown / black fibrous **PEAT**	
	-1		light brown / grey **CLAY**, plastic, firm	
1.0	-1.1		grey **silty fine SAND**	
	-1.15		brown **organic CLAY**, soft	
	-1.2		grey **medium to coarse pumice SAND and fine LAPILLI**	
	-1.35		dark brown / black fibrous **PEAT**, very soft	
1.5				
2.0	-2.3		grey pumice **silty fine SAND**	
	-2.4		grey pumice SILT, dilatant	
2.5	-2.8		EOB	
3.0				
3.5				
4.0				
4.5				

HAND AUGER REIDS CANAL.GPJ HAND AUGER BASIC.GDT 10/8/12

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Project: **Reid's Canal**
Client: Environment Bay of Plenty
Location: Reid's Canal CS1
Number: 1

Test: **HA4**
Elevation: -0.3
Date: 08/08/2008
Logged by: M. O'Halloran

Depth (m)	Elev(m)	Graphic Log	Description	Sample
0.0			black **organic SILT**, some clay	
	-0.5		black fibrous **PEAT** and brown **CLAY**, plastic, soft	
	-0.6		light grey with Fe staining **CLAY**, soft	
	-0.7		light grey with Fe staining **SILT**, soft	
0.5				
	-1		grey silty **fine to medium SAND**	
	-1.05		brown fine fibrous **PEAT**	
	-1.1		grey **fine to medium pumice SAND**	
1.0	-1.15		brown fine fibrous **PEAT**	
	-1.2		grey **medium pumice SAND**, some fine lapilli	
	-1.4		brown fine fibrous **PEAT**	
1.5				
	-2.2		green grey **CLAY**, plastic, soft	
2.0	-2.3		grey pumice **silty fine SAND with some lapilli** to 3mm	
	-2.4		light greenish brown / grey **silty CLAY**, soft, some fibres	
	-2.65		grey **silty fine SAND with some lapilli** to 3mm	
2.5				
	-2.95		EOB squeezing	
3.0				
3.5				
4.0				
4.5				

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Project:	**Reid's Canal**	Test:	**HA5**
Client:	Environment Bay of Plenty	Elevation:	-0.3
Location:	Reid's Canal CS1	Date:	08/08/2008
Number:	1	Logged by:	M. O'Halloran

Depth (m)	Elev(m)	Graphic Log	Description	Sample
0.0			black **organic SILT, some clay**	
	-0.5		black fibrous **PEAT**	
	-0.6		grey with Fe staining **CLAY**, soft, plastic	
	-0.7		grey with Fe staining **SILT**	
	-1		light brown **organic CLAY**	
	-1.05		grey **medium pumice SAND, some fine lapilli**	
	-1.15		black fibrous **PEAT**	
	-2		green grey **CLAY**, plastic, soft	
	-2.1		light grey brown **pumice silty fine SAND, some rounded pumice** to 10mm	
	-2.3		grey pumice **fine sandy SILT**	
	-2.75		EOB - losing sample	

Depth scale: 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5

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Project: **Reid's Canal**
Client: Environment Bay of Plenty
Location: Reid's Canal CS1
Number: 1

Test: **HA6**

Elevation: 2.0
Date: 08/08/2008
Logged by: M. O'Halloran

Depth (m)	Elev(m)	Graphic Log	Description	Sample
0.0			brown **silty fine SAND**	
0.6	1.4		grey **fine to medium SAND**	
0.85	1.15		EOB - hole collapsing	

Depth scale: 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5

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Project:	**Reid's Canal**	Test:	**HA7**
Client:	Environment Bay of Plenty	Elevation:	1.1
Location:	Reid's Canal CS1	Date:	08/08/2008
Number:	1	Logged by:	M. O'Halloran

Depth (m)	Elev(m)	Graphic Log	Description	Sample
0.0	1.05		brown **organic SILT**, topsoil	
	0.95		grey with Fe staining **silty fine to medium SAND and fine GRAVEL** (placed berm?)	
	0.65		grey and black **ASH**, hard, gritty	
0.5			grey **organic CLAY** with fibres	
	0.2		light grey/brown **CLAY**, plastic, soft	
1.0	0.05		grey **fine to medium SAND**	
	-0.15		black **coarse SAND**, Tarawera Ash	
	-0.2		dark brown/black **fibrous PEAT**	
1.5				
2.0	-0.95		light grey / brown **CLAY**	
▼	-1.05		light grey **SILT**	
	-1.15		dark brown / black **fibrous PEAT**	
	-1.2		light grey fine to medium pumice **SAND**, running in	
2.5	-1.45		brown **clayey PEAT**	
	-1.5		EOB	
3.0				
3.5				
4.0				
4.5				

HAND AUGER REIDS CANAL.GPJ HAND AUGER BASIC.GDT 10/8/12

ICE GEO & CIVIL
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Appendix F

Organic Content Test Results

PLASTICITY INDEX / WATER CONTENT TEST REPORT

Project :	Lower Reid's Canal
Location :	Edgecumbe
Client :	Ice Geo & Civil Ltd
Contractor :	N/A
Sampled by :	M O'Halloran (Ice, Geo & Civil)
Date sampled :	Unknown
Sampling method :	Drilling
Sample description :	In-situ Materials
Sample condition :	Natural State (as received)

Project No :	255549.00/0TL
Lab Ref No :	12/116
Client Ref No :	--

Test Results

Bore hole number :	BH2a	BH5	BH7
Laboratory reference :	12/116B	12/116F	12/116H
Material description :	Peat	Organic Clay	Peat
Material depth :	5.0m	6.5m	2.5m
Material tested :	< 425µm	< 425µm	< 425µm
Liquid limit :	222	138	425
Plastic limit :	125	87	228
Plasticity index :	97	51	197
Material tested :	Whole Soil	Whole Soil	Whole Soil
Natural water content :	334%	131%	561%

Bore hole number :	BH9
Laboratory reference :	12/116I
Material description :	Organic Silt
Material depth :	3.5m
Material tested :	< 425µm
Liquid limit :	Not applicable
Plastic limit :	Non plastic
Plasticity index :	Not applicable
Material tested :	Whole Soil
Natural water content :	39.4%

Test Methods		Notes
Water Content	NZS 4402 : 1986, Test 2.1	This report may only be reproduced in full.
Liquid Limit	NZS 4402 : 1986, Test 2.2	
Plastic Limit	NZS 4402 : 1986, Test 2.3	
Plasticity Index	NZS 4402 : 1986, Test 2.4	

Date tested : 13 March 2012
Date reported : 23 March 2012

laboratory — All tests reported herein have been performed in accordance with the laboratory's scope of accreditation

IANZ Approved Signatory

Designation : *Laboratory Manager*
Date : 23 March 2012

PF-LAB-101 (18/12/2010)

Opus International Consultants Ltd
Tauranga Laboratory
Quality Management Systems Certified to ISO 9001

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PO Box 9057, Tauranga 3142, New Zealand

Telephone +64 7 578 5425
Facsimile +64 7 578 3382
Website www.opus.co.nz

Appendix G

Falling Head Test and Laboratory Permeability Test Results

Lower Reids Canal Stage 2

Falling Head Test Results

Borehole	**depth** (m)	**RL** (m)	**soil**	**k_h** (m/s)
BH1a	3.5 to 4.5	-2.2 to -3.2	coarse sand and lapilli	7×10^{-5}
BH2a	1.5 to 3.0	-2.1 to -3.6	pumice silt and lapilli layers kh=10kv	2.5×10^{-5}
BH3	0.7 to 0.75	-1.6 to -1.65	fine to medium pumice sand	9×10^{-5}
BH3	6.0 to 7.5	-7.4 to -8.9	gravelly medium sand, some finer sand bands, kh=3kv	2.5×10^{-5}
BH4	1.5 to 3.0	1.0 to -0.5	coarse sand	5×10^{-6}
BH4	9.0 to 10.5	-6.5 to -8.0	fine to medium sand with fine lapilli bands kh=10kv	2.5×10^{-5}
BH5	7.5 to 9.0	-5.0 to -6.5	coarse gravelly sand, some fine sand bands kh=10kv	7×10^{-5}
BH6	3.0 to 4.5	-2.75 to -4.25	silt, some fine sand bands	6×10^{-5}
BH7	4.5 to 6.0	-4.2 to -5.7	medium and coarse sands	5×10^{-5}
BH8	3.0 to 4.5	-3.25 to -4.75	banded coarse and fine sands kh=10kv	5×10^{-5}
BH10	4.5 to 6.0	-1.85 to -3.35	fine to medium sand	2.5×10^{-5}
BH11	6.5 to 7.5	-3.6 to -5.1	fine pumice gravel	1.5×10^{-4}

Particle Grading Results

Sample	**Description**	**D_{10}** (mm)	**D_{60}** (mm)	**permeability** (m/s)
BH1A 2.2m	coarse sand / fine lapilli	0.063	0.88	4.0×10^{-5}
BH2C 6.8m	medium sand	0.075	0.32	5.6×10^{-5}
BH3 6.5m	well graded sand, minor gravel	0.075	0.425	5.6×10^{-5}
BH4 9.5m	fine to medium sand	0.05	0.22	2.5×10^{-5}
BH5 10.3m	medium to coarse sand	0.11	0.52	1.2×10^{-4}

Rangitaiki River

Thornton School Section

Falling Head Test Results

Borehole	depth (m)	RL (m)	soil	k_h (m/s)
BH1	5.0 to- 6.0	-3.6 to -4.6	layered pumice lapilli 0.5 to 20mm and fine sand	3×10^{-4}
BH2	5.0 to 6.0	-6.0 to -7.0	layered pumice lapilli to 4mm and well graded sand	5×10^{-5}
BH3	13.0 to 14.0	-10.9 to - 11.9	layered pumice lapilli to 2mm and well graded sand	6×10^{-5}
BH4	9.5 to 10.5	-9.4 to -10.4	well graded gravely sand	1.5×10^{-5}
BH5	5.0 to 6.0	-3.5 to -4.5	layered coarse sand and fine gravel	2×10^{-5}
BH6	5.0 to 6.0	-5.4 to -6.4	gravely medium to coarse sand	8×10^{-5}
BH6	8.0 to 9.0	-8.4 to -9.4	banded pumice lapilli to 2mm and fine to medium sand	6×10^{-5}

Particle Grading Results

Sample	Description	D_{10} (mm)	D_{60} (mm)	permeability (m/s)
HA2 1.1m	grey fine sandy silt	0.0055	0.04	3.0×10^{-7}
HA2 1.3m	grey silt	0.0015	0.025	2.3×10^{-8}
HA2 2.5m	grey silty fine sand	0.016	0.11	2.6×10^{-6}
HA10 1.0m	grey sandy silt	0.0065	0.05	4.2×10^{-7}
HA10 2.5m	medium to coarse sand	0.09	0.8	8.1×10^{-5}
HA12 1.1m	medium to coarse sand	0.02	0.35	4.0×10^{-6}

Reids Stage 1
(LB 2950m to 3650m, RB 2550m to 3390m)

Particle Grading Results

Sample	Description	D_{10} (mm)	D_{60} (mm)	permeability (m/s)
TP3 1-3.0m	silty fine sand	0.031	0.12	9.6×10^{-6}
TP4 0.2m	fine sandy silt	0.009	0.063	8.1×10^{-7}
TP5 0.2m	silty sand	0.005	0.115	2.0×10^{-7}
TP7 0.5-1.7m	silty fine to medium sand	0.013	0.15	1.7×10^{-6}
TP9 1.5-3.0m	silty fine sand	0.008	0.09	6.4×10^{-7}
TP10 0.9-1.7m	fine to coarse sand	0.15	0.4	$2.3 \times 10^{-4*}$
TP12 0.2-3.0m	fine sandy silt	0.005	0.045	2.5×10^{-7}

Rangitaiki River Section 15 – Laboratory Permeability Results (left bank 9300 to 9900m)

CONSTANT HEAD PERMEABILITY TEST REPORT

Project: **Rangitaiki Stopbanks Section 15**
Location: **Unknown**
Client: **ICE Geo & Civil Ltd**
Source: -
Sampled by: **M. O'Halloran** Date: **28/08/07**
Sampling Method: **Pushtube Sample**

OPUS

Project No: **2-68229.82**
Lab Ref No: **07/229/006**
Client No:

SOIL PROPERTIES

Sample ID:	BH1		BH2		BH2			
Depth:	3.0m		4.5m		6.0m			
Sample description	Grey brown silty fine SAND		Brownish grey SILT.		Dk grey brown organic SILT and pumiceous sandy SILT.			
Specimen Status	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Specimen length (mm)	119.87		120.01	118.36	119.70	118.73		
Specimen diameter (mm)	60.10		59.47	59.09	59.85	59.82		
Specimen mass (g)	450.84	510.94	526.65	515.61	475.94	466.48		
As rec'd Water Content (%)	31.9	-	64.4	-	91.1	-		
Water content of test sample (%)	31.9	49.5	64.4	60.9	91.1	87.3		
Wet density (t/m^3)	1.33		1.58	1.59	1.41	1.40		
Dry density (t/m^3)	1.00		0.96	0.99	0.74	0.75		
Saturation by calculation (%)	52		98	97	99	96		
Saturation calculations uses the Assumed/Tested Solid Density= (t/m^3)=	2.60 (Assumed)		2.60 (Assumed)		2.30 (Assumed)			
	Head (kPa)	Permeability (m/s)	Head (kPa)	Permeability (m/s)	Head (kPa)	Permeability (m/s)	Head (kPa)	Permeability (m/s)
	3	**3.0E-05**	35	**4.2E-08**	35	**2.0E-07**		
	6	**3.1E-05**	50	**4.6E-08**	50	**2.1E-07**		
	13	**2.8E-05**						
Saturation by pore pressure response (B value) =	**0.76**		**0.96**		**0.96**			

Notes: 1. 1kPa Head = 0.10m H_2O
2. (m/s) = metres per second
3. X.YE-0Z = X.Y x 10^{-0Z}m/s

Sample Test Conditions

Sample ID:	**BH1: 3.0m**	**BH2: 4.5m**	**BH2: 6.0m**	
Cell Pressure (kPa) =	550	570	590	
Saturation Backpressure (kPa) =	500	500	500	
Effective Confining Pressure (kPa) =	**50**	**70**	**90**	
Temperature during Test (°C) =	20	20	20	

Permeant Liquid Used: **Deaired Tap Water**

Test Methods		Notes
Permeability Test :	ASTM D5084-03:Method A-Constant Head Method	1.The sample was tested using the ELE test apparatus to enable back pressure saturation.
Water Content :	NZS 4402 : 1986 Test 2.1	

Date tested : 5/09/07

Testing is covered by IANZ Accreditation

Date reported : 11/09/07

IANZ Approved Signatory

All tests reported herein have been performed in accordance with the laboratory's scope of accreditation

Designation: *Senior Civil Engineering Technician*

Date : 11/09/07

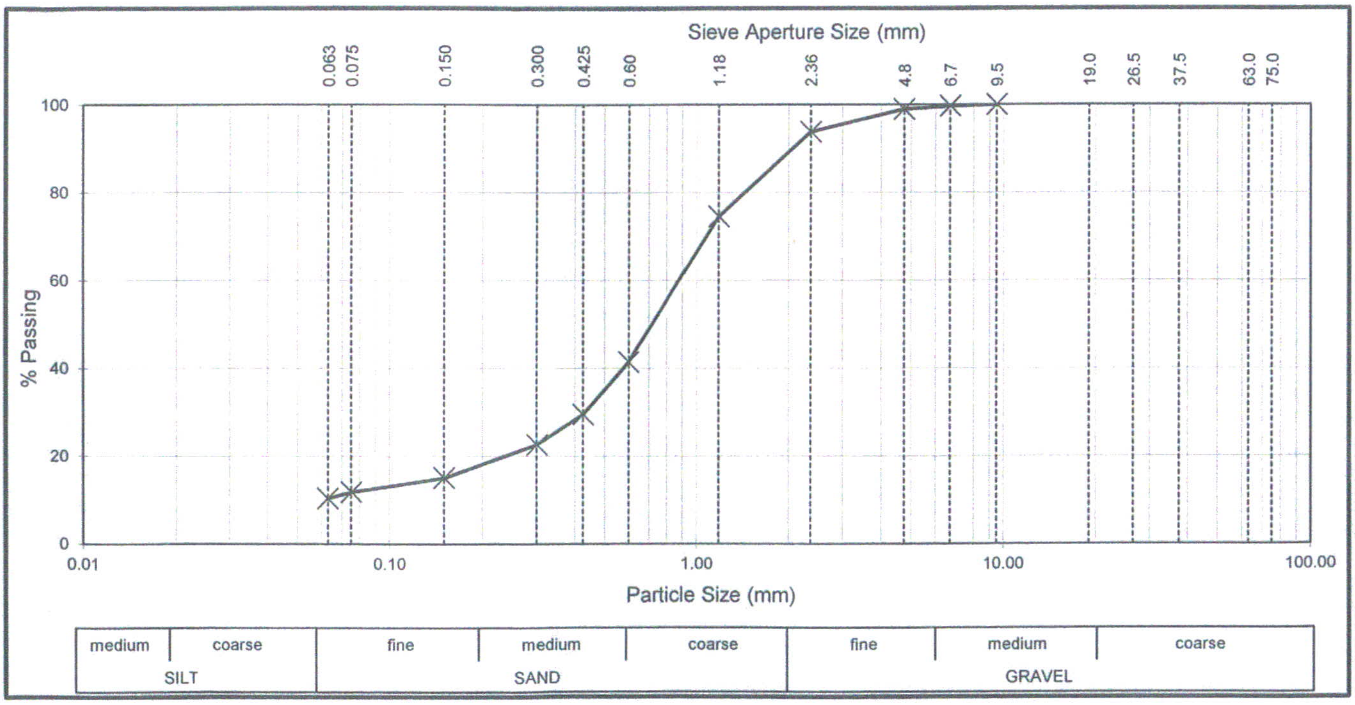
PARTICLE SIZE DISTRIBUTION TEST REPORT

Project :	Lower Reid's Canal
Location :	Edgecumbe
Client :	Ice Geo & Civil Ltd
Contractor :	N/A
Sampled by :	M O'Halloran (Ice, Geo & Civil)
Date sampled :	Unknown
Sampling method :	Drilling
Sample description :	Coarse SAND, Fine Lapilli with minor Gravel & Silt
Sample condition	Natural State (as received)
Bore hole no :	BH1a
Depth :	2.2 Metres

Project No :	**255549.00/0TL**
Lab Ref No :	**12/116A**
Client Ref No :	**--**

Sieve Analysis

Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing
75.00	-	19.00	-	2.36	**94**	0.300	**23**
63.00	-	9.50	**100**	1.18	**75**	0.150	**15**
37.50	-	6.70	**100**	0.60	**41**	0.075	**12**
26.50	-	4.75	**99**	0.425	**30**	0.063	**10**



Test Method	**Notes**
Particle Size Distribution - NZS 4402 : 1986 : Test 2.1	The fraction passing the finest seive was obtained by difference. This report may only be reproduced in full.

Date tested : 12 March 2012
Date reported : 23 March 2012

All tests reported herein have been performed in accordance with the laboratory's scope of accreditation

IANZ Approved Signatory

Designation : *Laboratory Manager*
Date : 23 March 2012

Opus International Consultants Ltd
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Telephone +64 7 578 5425
Facsimile +64 7 578 3382
Website www.opus.co.nz

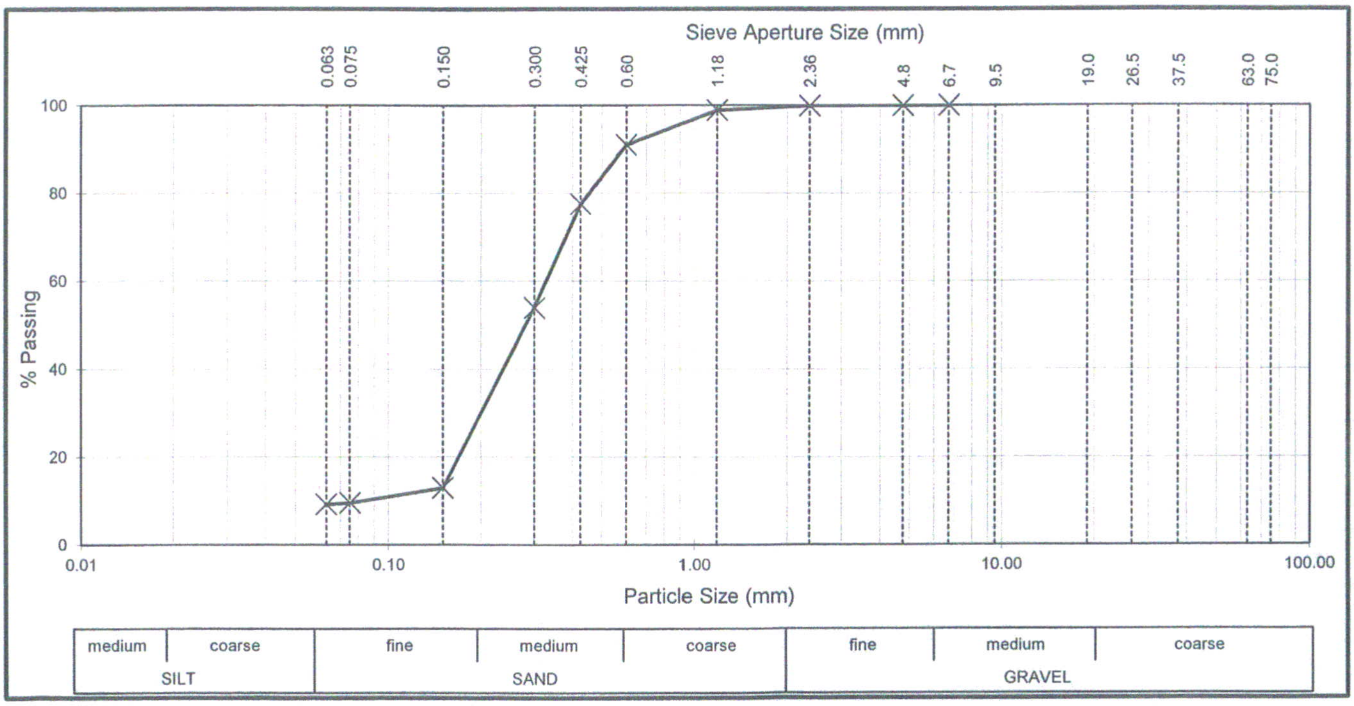
PARTICLE SIZE DISTRIBUTION
TEST REPORT

Project :	**Lower Reid's Canal**
Location :	**Edgecumbe**
Client :	**Ice Geo & Civil Ltd**
Contractor :	**N/A**
Sampled by :	**M O'Halloran (Ice, Geo & Civil)**
Date sampled :	**Unknown**
Sampling method :	**Drilling**
Sample description :	**Medium SAND with minor Silt**
Sample condition	**Natural State (as received)**
Bore hole no :	**BH2c**
Depth :	**6.8 Metres**

Project No :	**255549.00/0TL**
Lab Ref No :	**12/116C**
Client Ref No :	--

Sieve Analysis

Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing
75.00	-	19.00	-	2.36	**100**	0.300	**54**
63.00	-	9.50	-	1.18	**99**	0.150	**13**
37.50	-	6.70	**100**	0.60	**91**	0.075	**10**
26.50	-	4.75	**100**	0.425	**78**	0.063	**9**



Test Method	Notes
Particle Size Distribution - NZS 4402 : 1986 : Test 2.8.1	The fraction passing the finest seive was obtained by difference. This report may only be reproduced in full.

Date tested : 12 March 2012
Date reported : 23 March 2012

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PARTICLE SIZE DISTRIBUTION
TEST REPORT

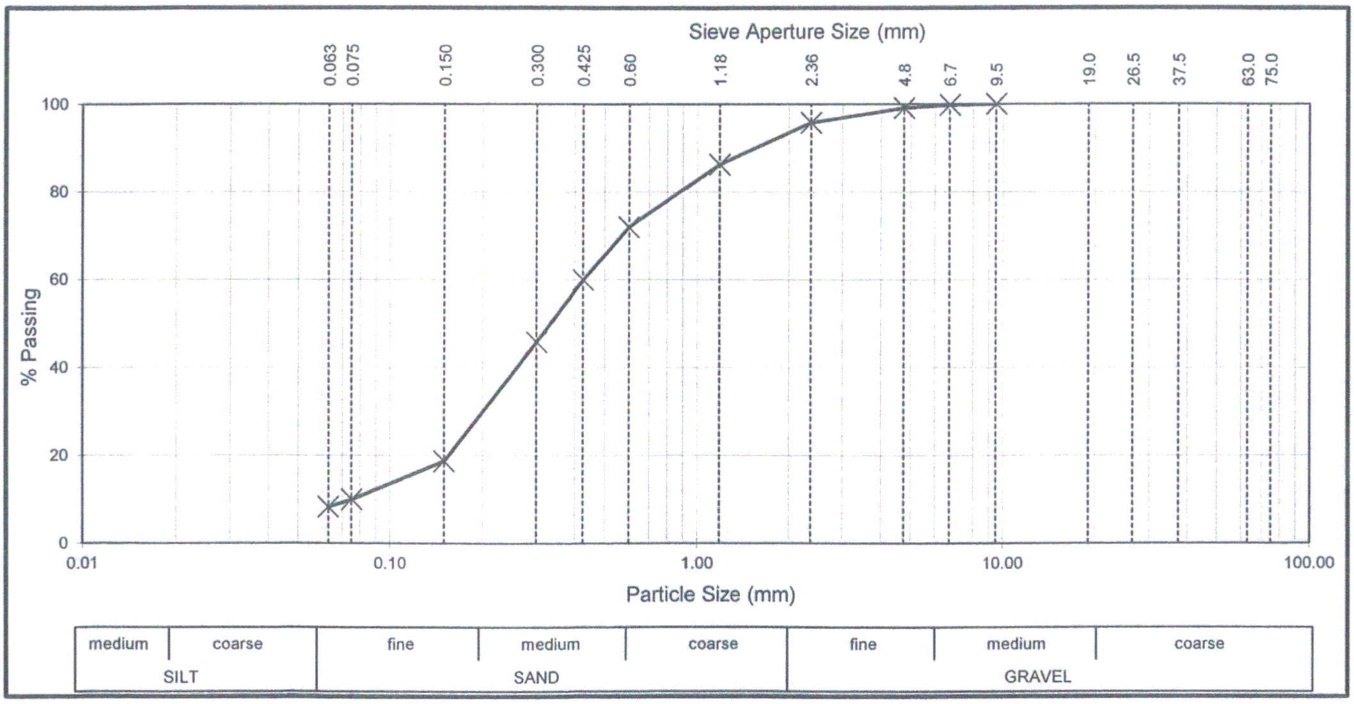
OPUS

Project :	**Lower Reid's Canal**
Location :	**Edgecumbe**
Client :	**Ice Geo & Civil Ltd**
Contractor :	**N/A**
Sampled by :	**M O'Halloran (Ice, Geo & Civil)**
Date sampled :	**Unknown**
Sampling method :	**Drilling**
Sample description :	**SAND with minor Gravel & Silt**
Sample condition	**Natural State (as received)**
Bore hole no :	**BH3**
Depth :	**6.5 Metres**

Project No :	**255549.00/0TL**
Lab Ref No :	**12/116D**
Client Ref No :	**--**

Sieve Analysis

Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing
75.00	-	19.00	**-**	2.36	**96**	0.300	**46**
63.00	-	9.50	**100**	1.18	**86**	0.150	**19**
37.50	-	6.70	**100**	0.60	**72**	0.075	**10**
26.50	-	4.75	**99**	0.425	**60**	0.063	**8**



Test Method	**Notes**
Particle Size Distribution - NZS 4402 : 1986 : Test 2.8.1	The fraction passing the finest seive was obtained by difference. This report may only be reproduced in full.

Date tested : 12 March 2012
Date reported : 23 March 2012

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Date : 23 March 2012

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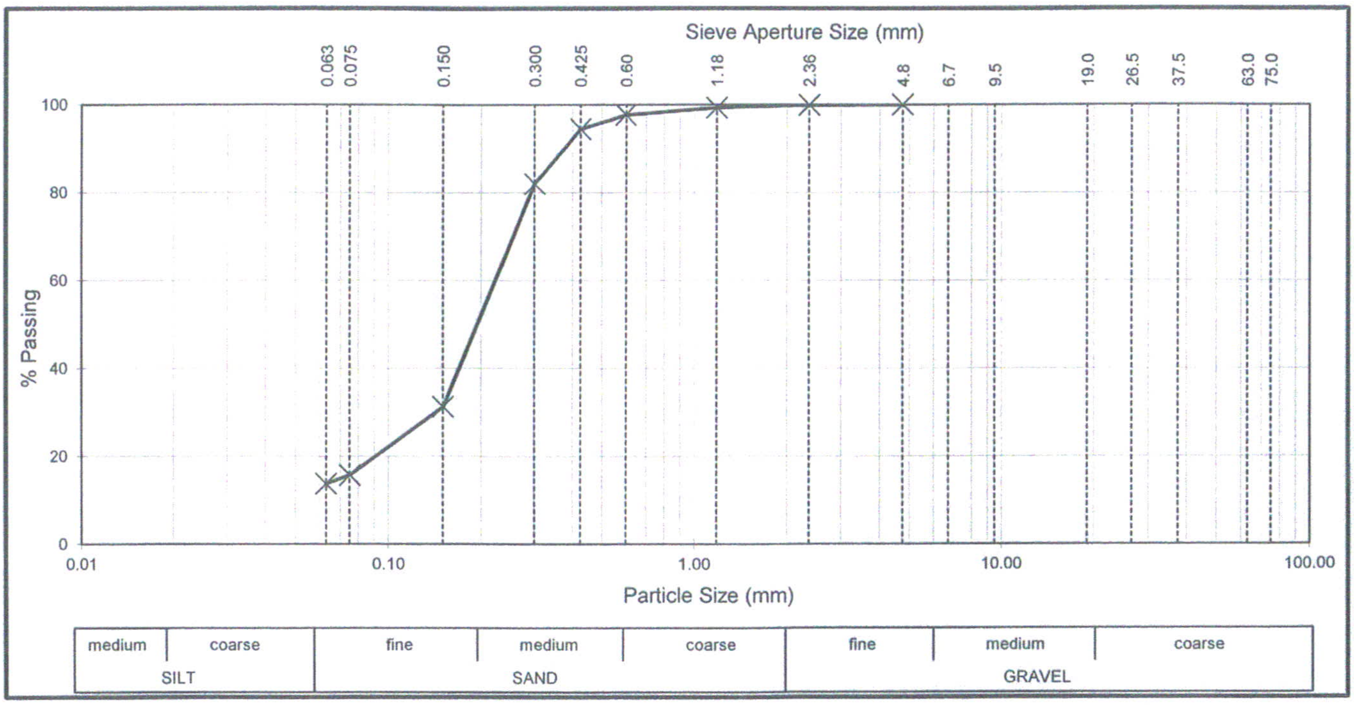
PARTICLE SIZE DISTRIBUTION TEST REPORT

Project :	**Lower Reid's Canal**
Location :	**Edgecumbe**
Client :	**Ice Geo & Civil Ltd**
Contractor :	**N/A**
Sampled by :	**M O'Halloran (Ice, Geo & Civil)**
Date sampled :	**Unknown**
Sampling method :	**Drilling**
Sample description :	**Fine - medium SAND with some Silt**
Sample condition	**Natural State (as received)**
Bore hole no :	**BH4**
Depth :	**9.5 Metres**

Project No :	**255549.00/0TL**
Lab Ref No :	**12/116E**
Client Ref No :	**--**

Sieve Analysis

Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing
75.00	-	19.00	-	2.36	**100**	0.300	**82**
63.00	-	9.50	-	1.18	**99**	0.150	**31**
37.50	-	6.70	-	0.60	**98**	0.075	**16**
26.50	-	4.75	**100**	0.425	**94**	0.063	**14**



Test Method	Notes
Particle Size Distribution - NZS 4402 : 1986 : Test 2.1	The fraction passing the finest seive was obtained by difference. This report may only be reproduced in full.

Date tested : 12 March 2012
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Date : 23 March 2012

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Website www.opus.co.nz

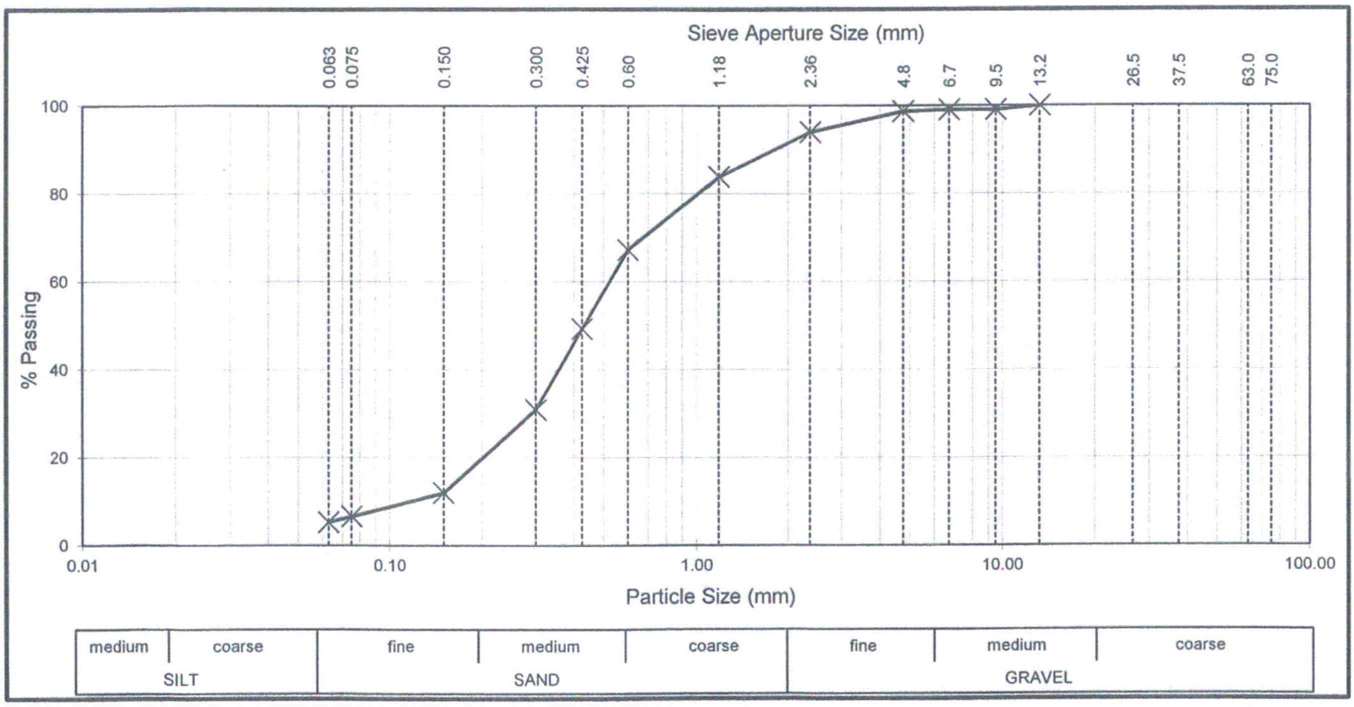
PARTICLE SIZE DISTRIBUTION TEST REPORT

Project :	**Lower Reid's Canal**
Location :	**Edgecumbe**
Client :	**Ice Geo & Civil Ltd**
Contractor :	**N/A**
Sampled by :	**M O'Halloran (Ice, Geo & Civil)**
Date sampled :	**Unknown**
Sampling method :	**Drilling**
Sample description :	**Medium - coarse SAND with minor Gravel & Silt**
Sample condition	**Natural State (as received)**
Bore hole no :	**BH5**
Depth :	**10.3 Metres**

Project No :	**255549.00/0TL**
Lab Ref No :	**12/116G**
Client Ref No :	**--**

Sieve Analysis

Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing
75.00	-	13.20	**100**	2.36	**94**	0.300	**31**
63.00	-	9.50	**99**	1.18	**84**	0.150	**12**
37.50	-	6.70	**99**	0.60	**67**	0.075	**7**
26.50	-	4.75	**99**	0.425	**49**	0.063	**5**



Test Method	Notes
Particle Size Distribution - NZS 4402 : 1986 : Test 2.1	The fraction passing the finest seive was obtained by difference. This report may only be reproduced in full.

Date tested : 12 March 2012
Date reported : 23 March 2012

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Designation : *Laboratory Manager*
Date : 23 March 2012

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laboratory

PF-LAB-099 (13/05/2011)

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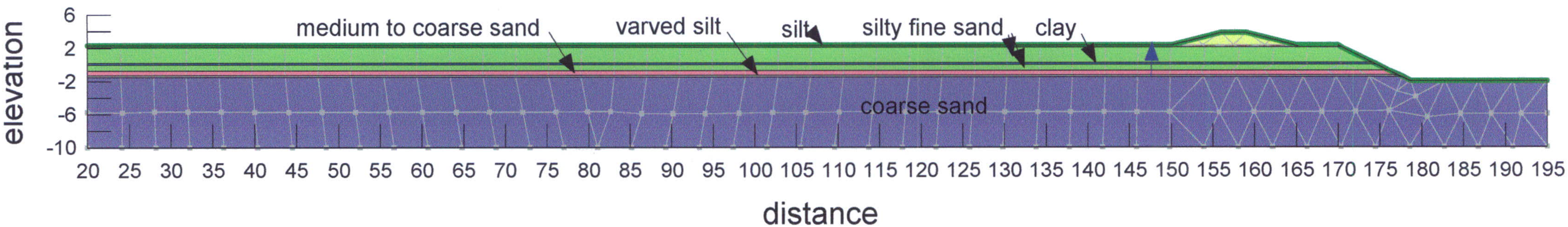
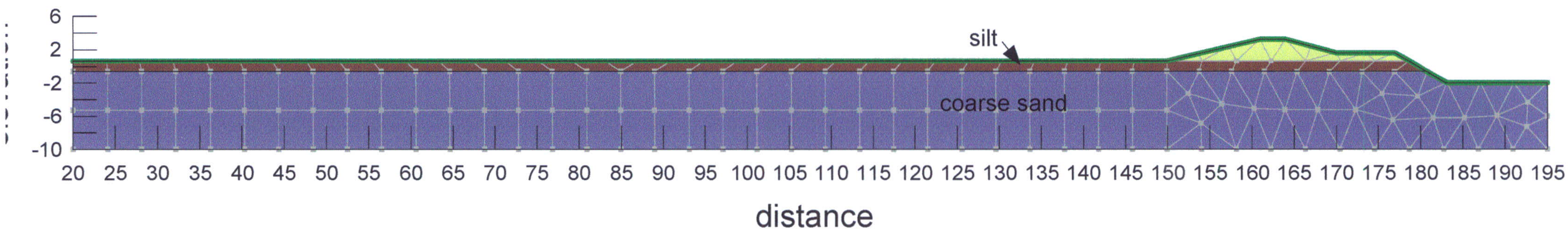
Appendix H

Soil Models

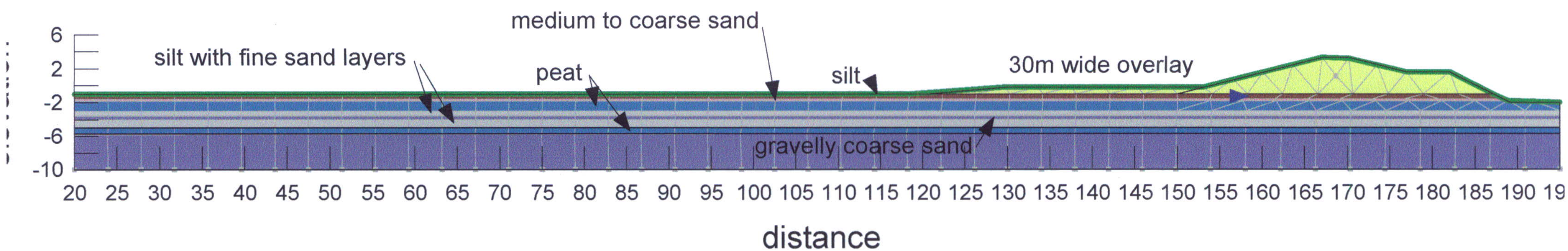
Name: Cross Section 1050L trans.gsz
Title: Lower Reid's Canal Upgrading - CS1050L - BH1
Comments: Left Bank 1050m
Date: 18/03/2012 Time: 11:08:45 p.m.



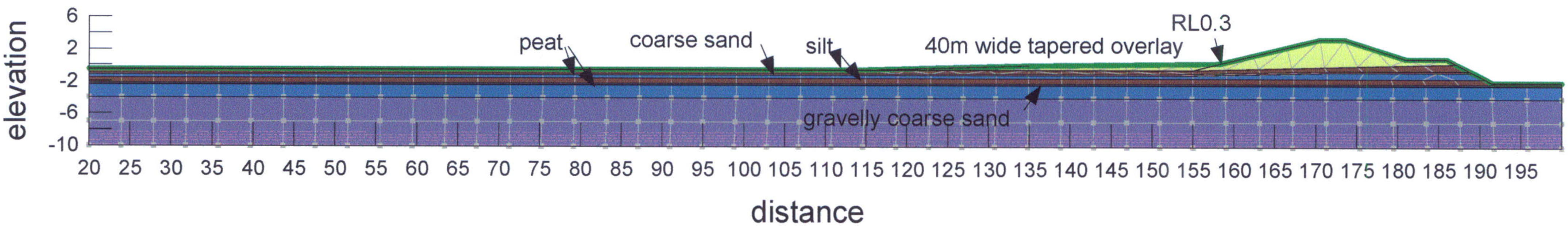
Name: Cross Section 1100L trans.gsz
Title: Lower Reid's Canal Upgrading - CS1050L - BH1
Comments: Left Bank 1050m
Date: 12/08/2012 Time: 11:16:24 a.m.



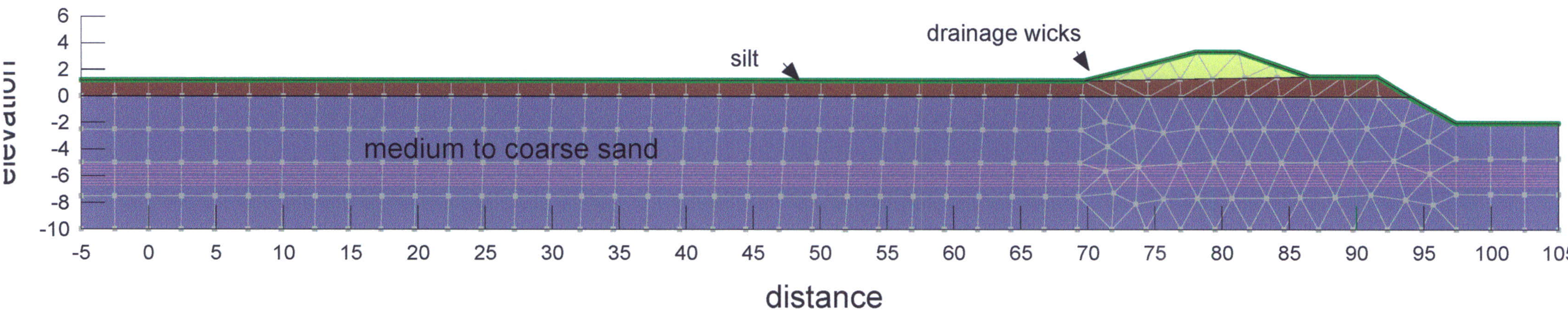
Name: Cross Section 1500L2 trans overlay.gsz
Title: Lower Reid's Canal Upgrading - CS1500L - BH3 modified
Comments: Left Bank 1500m
Date: 12/08/2012 Time: 11:51:50 a.m.



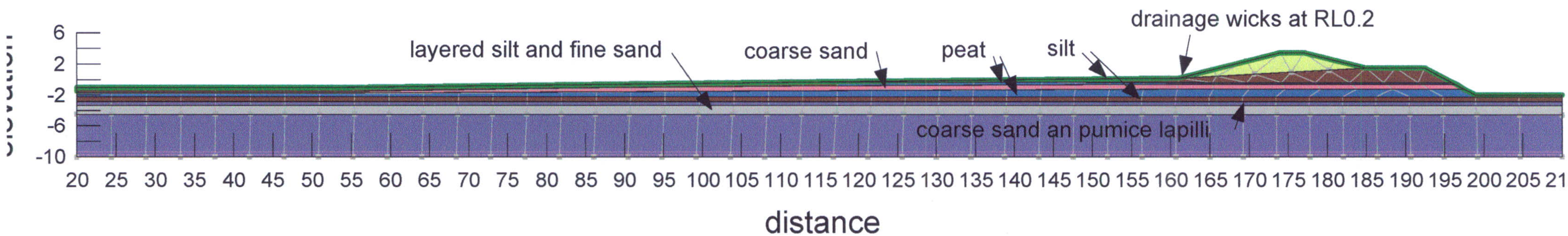
Name: Cross Section 2200L trans TP2 overlay.gsz
Title: Lower Reid's Canal Upgrading - CS2200 - BH5
Comments: Left Bank 2200m
Date: 27/06/2012 Time: 5:05:02 p.m.



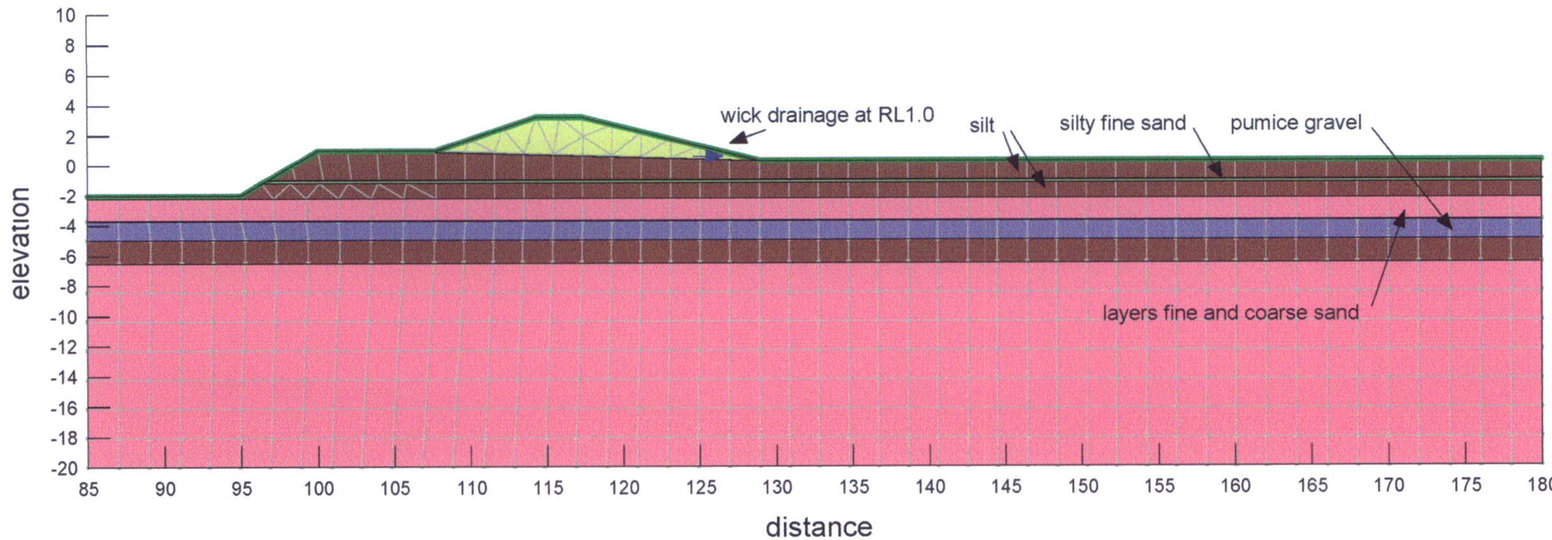
Name: Cross Section 2400L trans.gsz
Title: Lower Reid's Canal Upgrading - CS2400 - TP450
Comments: Left Bank 2400m
Date: 27/06/2012 Time: 7:18:00 p.m.



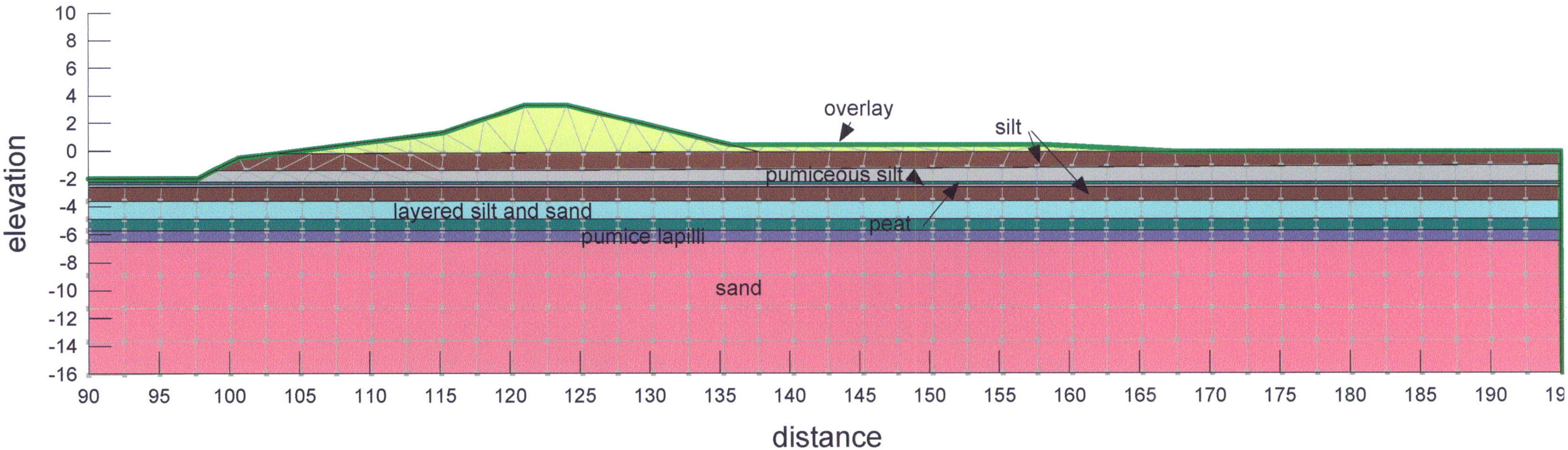
Name: Cross Section 2650L trans TP5.gsz
Title: Lower Reid's Canal Upgrading - CS2650 - TP5
Comments: Left Bank 2650m
Date: 12/08/2012 Time: 2:53:54 p.m.



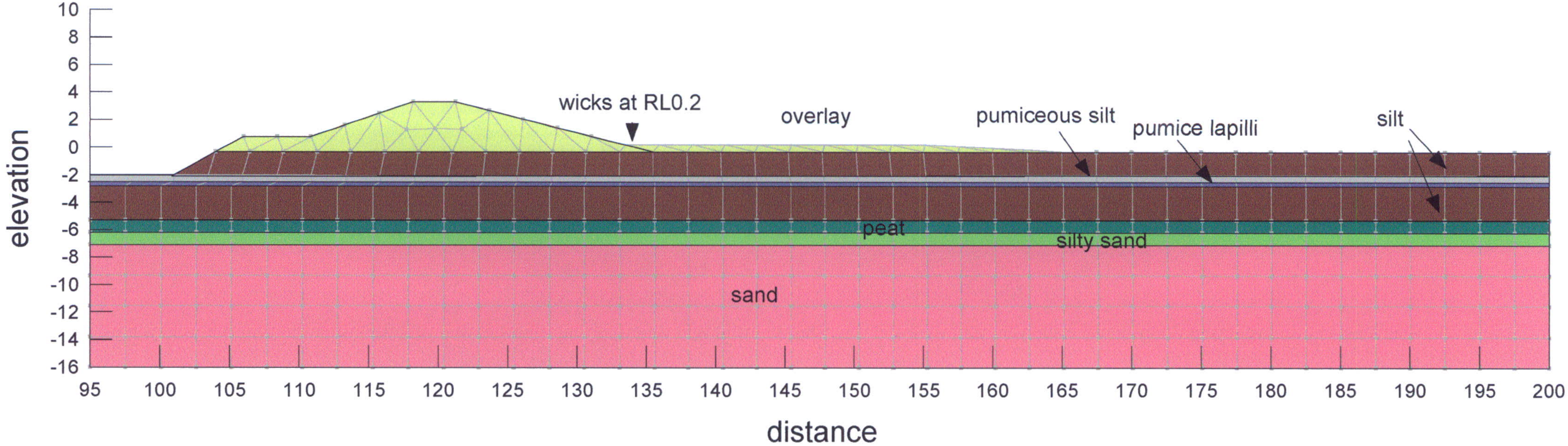
Name: Cross Section 1200R trans.gsz
Title: Cross Section 1200R Lower Reids Canal
Comments: 100 year flood
Date: 12/08/2012 Time: 6:46:31 p.m.



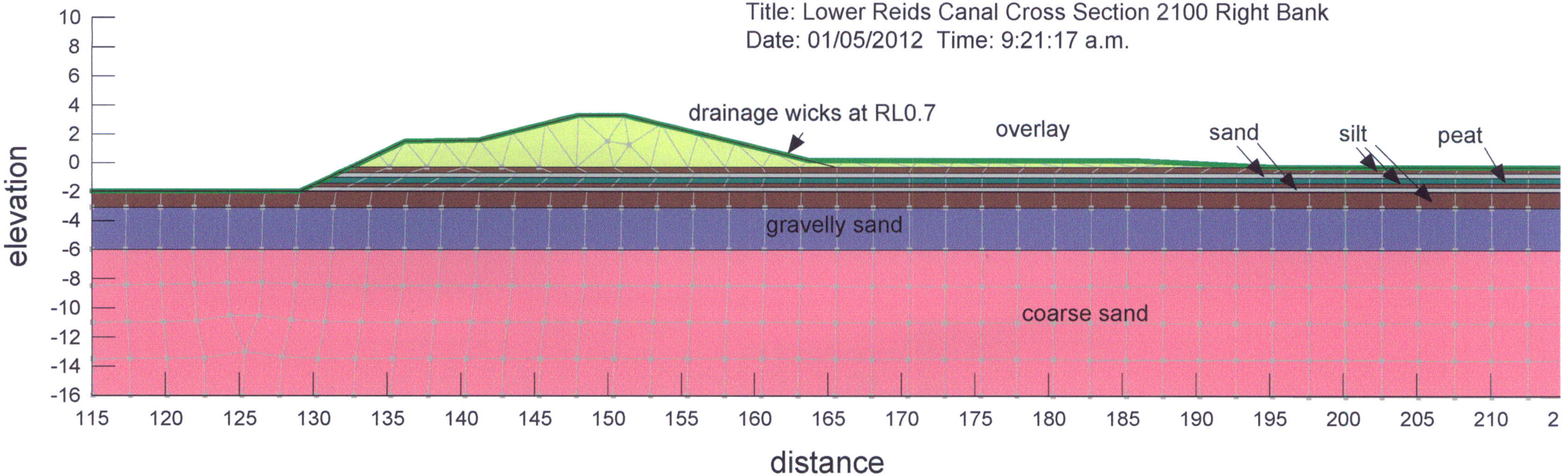
File Name: Cross Section 1500R trans overlay.gsz
Title: Lower Reids Canal Cross Section 1500 Right Bank
Comments: Static
Date: 12/10/2012 Time: 4:17:14 p.m.



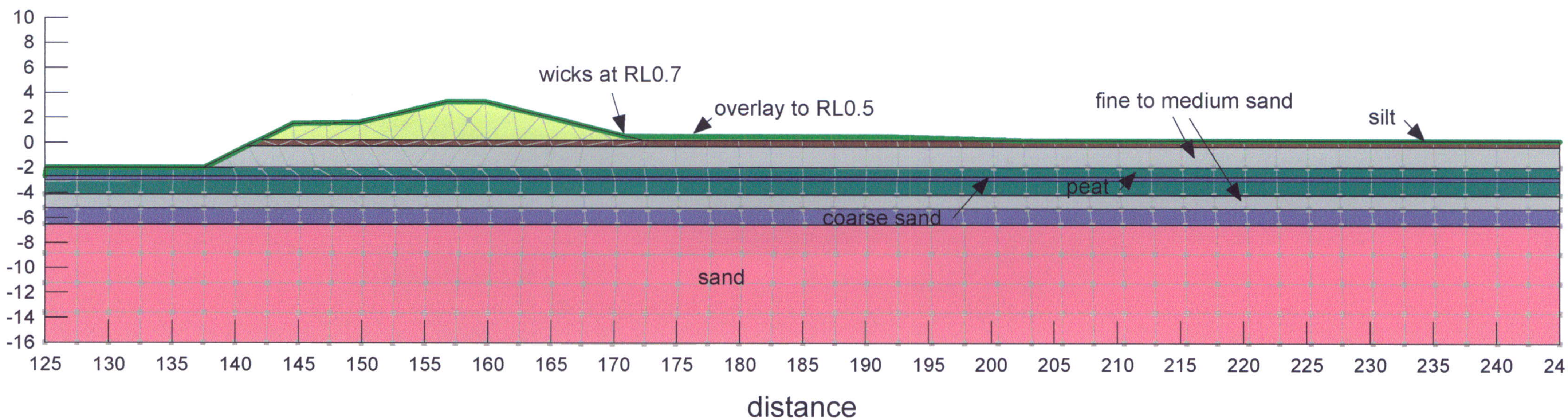
File Name: Cross Section 1700R trans overlay.gsz
Title: Lower Reids Canal Cross Section 1700m Right Bank
Comments: 100 year flood (climate change)
Date: 30/04/2012 Time: 4:21:37 p.m.



File Name: Cross Section 2100R trans overlay.gsz
Title: Lower Reids Canal Cross Section 2100 Right Bank
Date: 01/05/2012 Time: 9:21:17 a.m.



File Name: Cross Section 2300R trans overlay.gsz
Date: 01/05/2012 Time: 2:33:09 p.m.



Appendix I

Drainage Wick Information

Reids Canal Stage 2 Seepage Analysis

Wick drain modelling

Wick drain type Ceteau

width $w := 100$ mm

thickness $t := 3$ mm

discharge capacity at 300kPa ground pressure with 0.1 pressure gradient and kink in drain $q_w := 60 \cdot 10^{-6}$ $\frac{m^3}{s}$

$i_w := 0.1$

effective permeability $k_w := \frac{q_w}{w \cdot 10^{-3} \cdot t \cdot 10^{-3} \cdot i_w}$

$k_w = 2.00 \times 10^{0}$ $\frac{m}{s}$

assuming wick drain has a free outlet $i := 1.0$

assume two rows of wicks 0.65m apart with wicks and 0.75m spacings in 1m wide element

$sp := 0.75$ m

$w_e := 1.0$ m

effective area per wick $a_w := \frac{sp}{2} \cdot w_e$

$a_w = 3.75E\text{-}001$ m^2

assuming no vertical permeability in soil

vertical wick permeability for 1m wide element in model

$k_e := k_w \cdot w \cdot 10^{-3} \cdot t \cdot \frac{10^{-3}}{a_w}$

$k_e = 1.6E\text{-}003$ $\frac{m}{s}$

horizontal permeability in element

assume wicks are draining sand with $k_s := 5 \cdot 10^{-5}$ $\frac{m}{s}$

assume 3mm width of smeared clay/peat on surface of geotextile

$d_{sm} := 0.003$ m

permeability of smeared zone $k_{sm} := 5 \cdot 10^{-8}$ $\frac{m}{s}$

distance from edge of element to centre of wick drains $d_w := \frac{w_e}{2}$

$d_w = 5E\text{-}001$

$$k_{heq} := \frac{d_w}{\left[\left(\frac{d_{sm}}{k_{sm}}\right) + \frac{(d_w - d_{sm})}{k_s}\right]}$$

$k_{heq} = 7.149E\text{-}006$

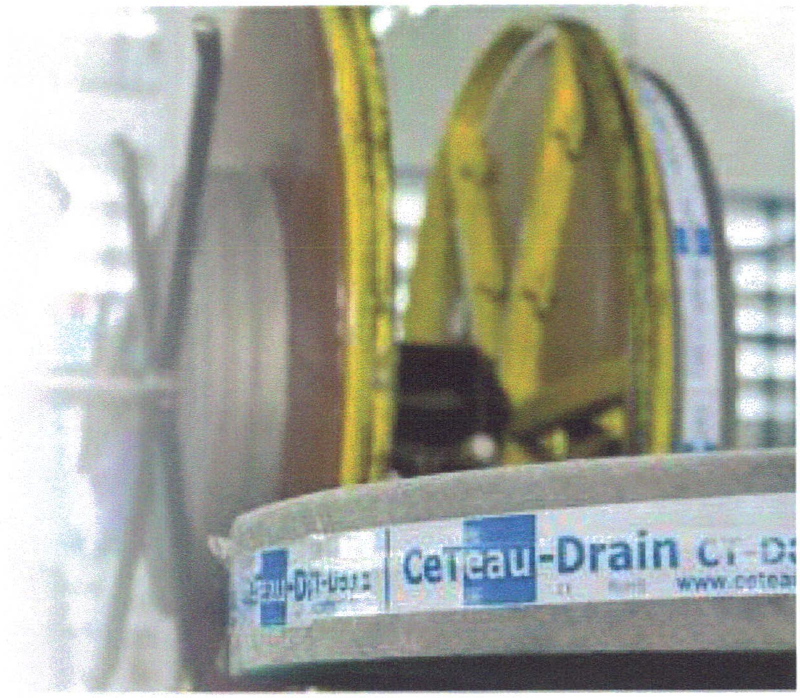
$$k_{ratio} := \frac{k_e}{k_{heq}}$$

$k_{ratio} = 223.8$

Prefabricated Vertical Drains

Technical Design Manual

CeTeau stands for innovative ground improvement technologies with Prefabricated Vertical Drains. Prefabricated Vertical Drains (PVD), also called Wick Drains, are prefabricated drain strips consisting of a polypropylene core extruded into a configuration to transmit a maximum water flow on both sides of the core. The core is wrapped in a non-woven filter, ultrasonically welded at the edges. The CeTeau® Vertical Drain System is one of the most widely used drain system in the world, with over 100,000,000 lm installed world wide. This manual serves as a guide to assist engineers with the selection and application of vertical wick drains.



www.ceteau.com

THE VERTICAL WICK DRAIN PRINCIPLE

When construction work such as road and airfield embankments, bridge approached, dykes, land reclamation or buildings on soft compressible soils, significant settlements may occur due to consolidation of these soils under the superimposed loads. To avoid serious and potentially expensive problems due to such settlements, it is desirable to cause this consolidation to occur at the outset of project, and in the shortest possible time – during the construction period.

Consolidation of compressible soils involves removal of pore water from the soil. This is traditionally done by applying a surcharge of preload to the construction area to "squeeze" the water out.
Unfortunately, compressible soils are also often low-permeability soils (peats, silts, clays), and as such the water is not easily squeezed out.

To facilitate the dewatering process, it is necessary to install vertical drains into the soil, to provide a conduit for the water flow. Traditionally, these drains took the form of sand columns – holes drilled into the low-permeability soil and filled with higher permeability sand. But these were relatively expensive, and inconvenient to place at close spacing.

PVD's are a very economical replacement for sand drains. They are relatively inexpensive, provide higher conductivity (up to 30 times more effective than a 300mm diameter sand drain) and can easy be installed at close spacing, thus shortening the path of the pore water in the impermeable soil and expediting the consolidation process.

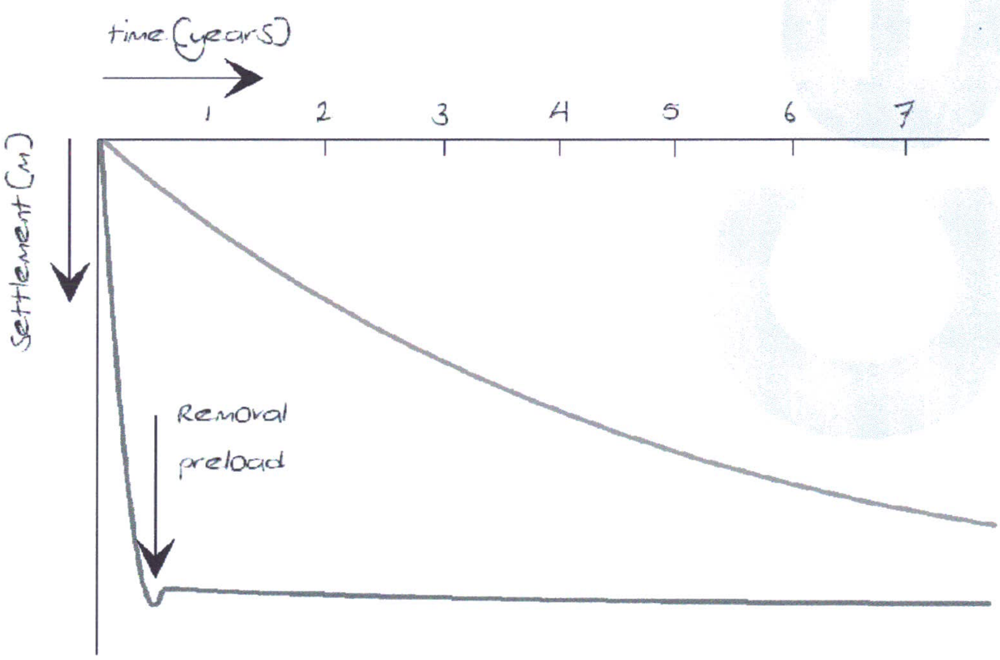


Fig. 1 – Effect of Prefabricated Vertical Drains During Consolidation

THE CETEAU® VERTICAL DRAIN SYSTEM

CeTeau® Vertical Drain is a prefabricated drainage strip. The core is a highly flexible polypropylene extrusion, having maximum water flow capacity along the grooves formed longitudinally on both sides of the core. Strict quality control is employed to insure the extrusion is consistent.

The filter fabric on the CeTeau® Vertical Drain is made from strong, durable, non-woven polypropylene or polyester geotextile, having a very high permeability. The geotextile fabric serves as a filter to allow passage of groundwater into the drain core while preventing piping of fines from the adjacent soils. The filter also serves as and outer skin to maintain the cross-sectional shape and hydraulic capacity of the core channels.

The graphic below shows a typical cross-section of the CeTeau® Vertical Drain

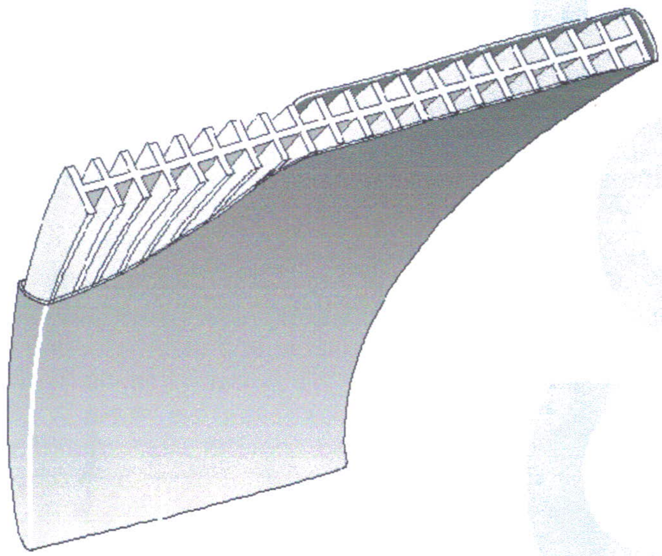


Fig. 2 – Cross-section of CeTeau® prefabricated vertical drain

THE CETEAU® VERTICAL DRAIN SYSTEM

CeTeau® Vertical Drain is installed using patented, proprietary equipment. The equipment is comprised of a structural mast (which in some cases also serves as equipment housing), a mandrel and mandrel propulsion equipment. The CeTeau® Vertical Drain, which is supplied in rolls 250-300m in length, is threaded through the mast into the mandrel and is held in place at the base of the mandrel by an anchor plate. The mandrel and the wick are then driven into the ground to the desired depth.

The anchor plate serves two purposes in the operation. First, it prevents soil from entering and clogging the mandrel as it is being driven into the ground, and secondly, it anchors the drain in place at the desired depth as the mandrel is being retracted. When the mandrel has been withdrawn, the wick is cut off above the ground surface, leaving a tail approximately 300mm long. Then a new anchor plate is installed, the mast is repositioned over the next location and the cycle is repeated.

There are various means of driving the mandrel, including a simple cable pull powered by a conventional crane, a vibratory head attached directly to the mandrel (although this technique is not recommended because of its detrimental effects on the surrounding soil), and a hydraulic cylinder powered by the hydraulics of an excavator. The hydraulic system has a mechanical advantage, allowing deeper penetration and greater applied force. When stiffer soils are encountered extra weight can be added to the mast to assist penetration or holes can be predrilled before the mandrel and drain are inserted.

As the ground surface in areas requiring prefabricated vertical drains is often soft and unstable. It may be necessary to prepare a working mat to facilitate mobility of the installation equipment. This mat also serves a second purpose of providing a free draining layer for the water being discharged from the drains.

This working mat is generally constructed of sand, as part of the preload or structure fill, and is typically 300mm or more in thickness.

In the event that good quality natural materials for the working mat are scarce, several options exist to both improve the stability of the surface soil and reduce the thickness of the working mat. Geotextiles or geogrids are very effective in strengthening the sub-base, and can significantly reduce the amount of fill needed to provide a suitable and stable working mat.

Efficiency may also be increased by replacing the free draining sand mat with prefabricated horizontal drains connected to the protruding wick tails. This is a very effective method to ensure fast and complete removal of all water discharged from the wick drain project.

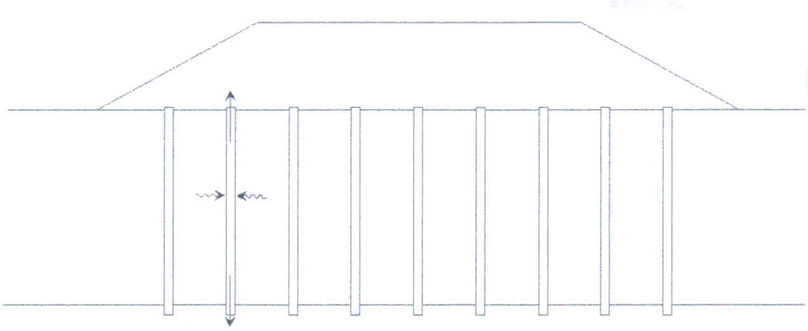


Fig. 3– Consolidation using prefabricated vertical drains

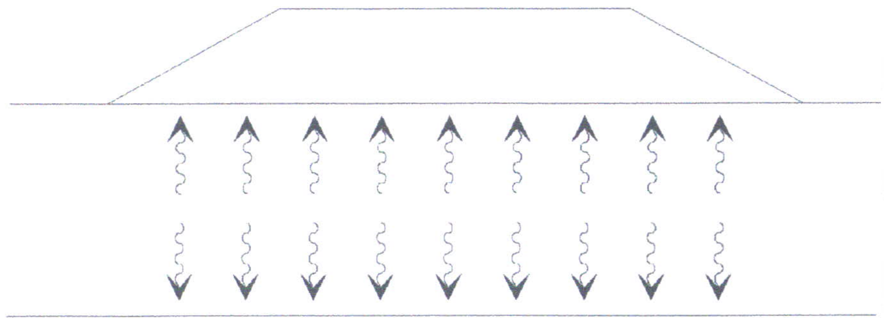


Fig. 4 – Consolidation without prefabricated vertical drains

THE VACUUM PRELOAD OPTION

A preload is usually required to properly compress the saturated soils and cause the water to flow through the drains to be discharged. When the applied preload becomes part of the structure, as in an embankment or bridge approach, the materials used for the preload are usually selected accordingly. However, when the ultimate required elevation is already close to the anticipated elevation after settlement, the added costs of applying the preload, and removing it again after consolidation has occurred, often renders the project economically unviable.

An attractive option to reduce costs in the case is to utilize a preload vacuum simulation technique called CeTeau Vacuo®. The system consists of installing prefabricated vertical drains, individually connected below the surface to vacuum transmission pipes. These pipes are then connected at surface level to a horizontal tubing system by means of specially developed airtight T-couplings. The so-called drainage screens, a row of vertical drains that are connected at the top to a horizontal line, are brought outside the surcharge (if any) and connected to a combined vacuum air pump that has been developed in-house.
The applied vacuum produces the same pressures as a traditional preload system of up to 3-5m in height.

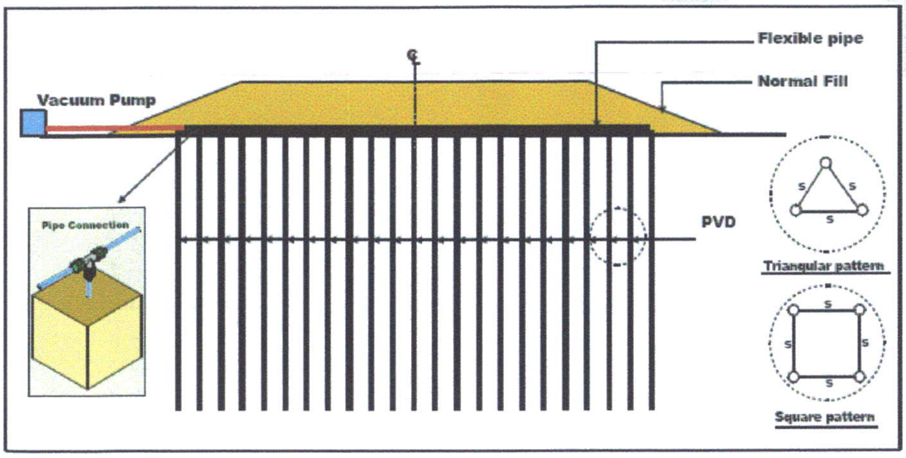


Fig. 5 – Consolidation using prefabricated vertical drains with vacuum preload arrangement

DESIGNING WITH THE CETEAU® VERTICAL DRAIN SYSTEM

The principle underlying vertical drainage is simple, but the theoretical description of the operating mechanism is quite complex.

Wick drain spacing is usually calculated by means of Barron's formula, as follows:

$$C_h = \frac{D^2}{8t}\left[\frac{1}{1-\left[\frac{d}{n}\right]^2} \times \ln\frac{D}{d} - 0.75 + 0.25\left[\frac{d}{D}\right]^2\right] \times \ln\frac{1}{1-U}$$

(Formula 1)

Where:

C_h	=	Consolidation Coefficient for Horizontal Flow (m^2/s)
D	=	Diameter of the Sphere of Influence of the Drain (m)
t	=	Consolidation Time (s)
d	=	Equivalent Diameter of the Drain (m)
U	=	Average Degree of Consolidation

The C_h value is determined from laboratory tests of soil samples. The compression test is the most common method, and the C_h value is a function the C_v value thus found. (For clay soils, $C_h \approx$ 1 to 4 times C_v.)

Drains are most efficiently placed in a triangular pattern, but they can be arranged in a square pattern (although a triangular pattern is nearly 2.5 times more efficient). The diameter of the sphere of influence (**D** in formula 1) is based on the existence of a soil cylinder, and to account for overlap and gaps between such cylinders. The design drain spacing for triangular pattern should be 0.95, and that of a square pattern should be 0.88 times that calculated value of **D.**

The drain diameter (**d** in formula 1) assumes a cylindrical drain. The equivalent diameter of the CeTeau® Vertical Drain is derived from the following equation:

$$d = \frac{\text{circumference}}{\pi}$$

At a width of 100mm and a thickness of 3mm, the circumference (perimeter in this case) of the drain is 206mm, making the equivalent diameter of the drain 65mm. The flow towards a flat drain is less efficient than flow towards a cylindrical drain, and therefore, the drain diameter is conservatively taken to be 50mm.

The average degree of consolidation (**U**) is usually expressed as a percentage, or a value between 0 and 1. Thus a 90% consolidation can be written as **U = 0.90.**

Experience has shown that the drain spacing is usually grater than 1.0 meter. For a CeTeau® Vertical Drain with effective diameter of 0.05m, the value $(d/D)^2$ is less than 2.5×10^{-3} and of little influence in the outcome of the calculation. Therefore, the following simplified formula is often preferred.

$$C_h = \frac{D^2}{8t}\left[\ln\frac{D}{d} - 0.75\right]\ln\frac{1}{1-U}$$

(Formula 2)

In this formula it is assumed that the vertical discharge capacity of the drain is infinite, However, the discharge capacity of the CeTeau® Vertical Drain is finite, and can be included in the formula as follows:

$$C_h = \frac{D^2}{8t}\left[\ln\frac{D}{d} - 0.75 + z\pi\,(2l - z)\frac{K_c}{q_w}\right]\ln\frac{1}{1-U}$$

(Formula 3)

Where:

C_h	=	Consolidation Coefficient for Horizontal Flow (m^2/s)
D	=	Diameter of the Sphere of Influence of the Drain (m)
t	=	Consolidation Time (s)
d	=	Equivalent Diameter of the Drain (m)
U	=	Average Degree of Consolidation
z	=	Distance to the Flowpoint (m)
l	=	Drain Length at Unilateral Flow (m) (half length at Bilateral Flow)
k_c	=	Permeability of the Soil (m/s)
q_w	=	Discharge Capacity of the Drain (m^s/s)

The discharge capacity (q_w) of the CeTeau® Vertical Drain is approx. 1.8 x 10^{-4} m^3/s. A sand column with a diameter of 300mm has a q_w of approx. 6 x 10^{-6} m^3/s, or *approx. 3% of the CeTeau® Vertical Drain* The k_c value of the soil to be consolidated generally varies from 10^{-7} to 10^{-10} m/s. The table below presents the k_c values and the k_c / q_w ratio in the orders of magnitude for various types of soil. These figures are based on a CeTeau® Vertical Drain with a q_w of 10^{-5} m^3/s.

SOIL	k_c (m/s)	k_c / q_w (m^{-2})
Coarse Sand	10^{-2} to 10^{-3}	10^{3} to 10^{2}
Medium Coarse Sand	10^{-3} to 10^{-4}	10^{2} to 10
Fine Sand	10^{-4} to 10^{-5}	10 to 1
Silty Sand	10^{-5} to 10^{-6}	1 to 10^{-1}
Sandy Silt	10^{-6} to 10^{-9}	10^{-1} to 10^{-4}
Peat	10^{-7} to 10^{-9}	10^{-2} to 10^{-4}
Clay	10^{-9} to 10^{-11}	10^{-2} to 10^{-6}

Fig. 6 –Discharge capacities of various soils

When working through the formula it will appear that when the ratio k_c / q_w becomes greater than 10^{-4} m^{-2}, the drain capacity will be of influence on the consolidation rate. For CeTeau® Vertical Drain, this condition occurs when the soil has a $k_c > 10^{-9}$ m/s.
The formula only offers the possibility of determining the consolidation at a given depth **z.** The following graph shows how consolidation time varies at various depths for unilateral flow and a 20m thick layer of soil.

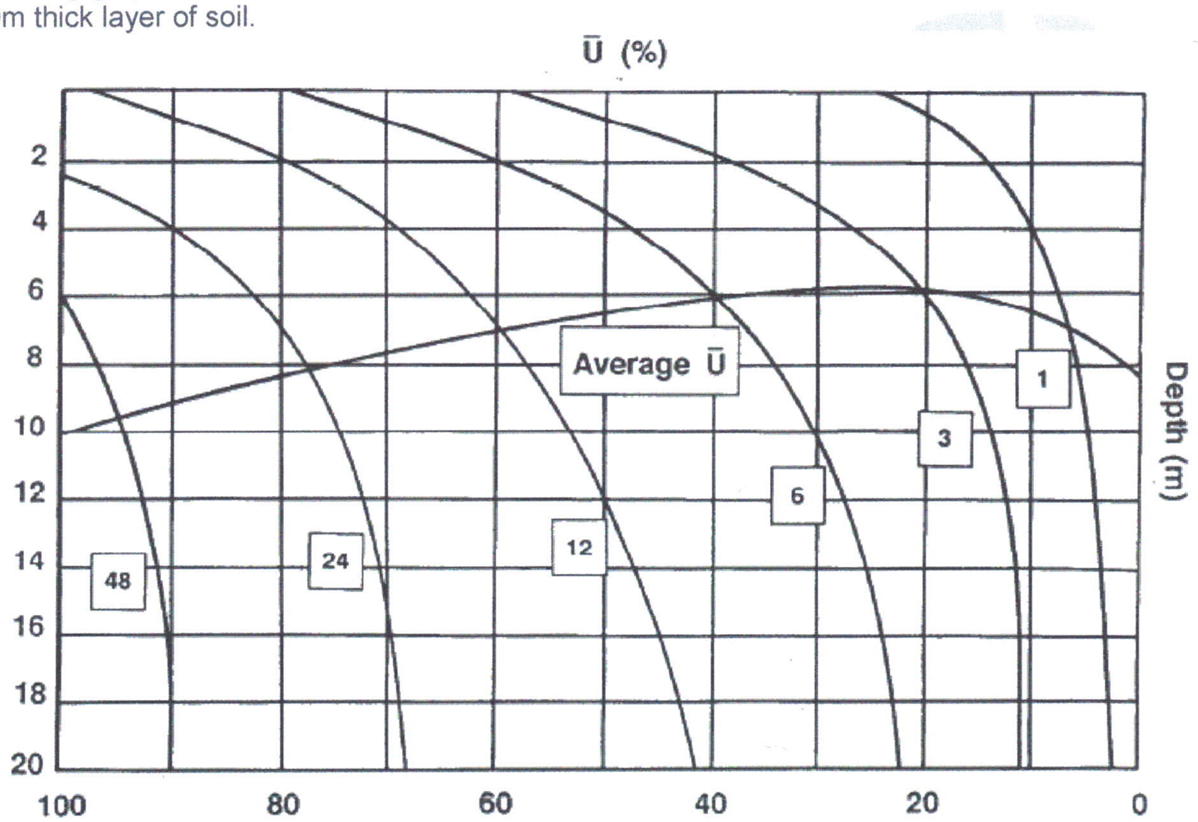


Fig. 7 –Effect of drain depth on consolidation time

The variation of average consolidation plotted against time follows a curve which remains between 0.3 ℓ and 0.5 ℓ. When **z** = 0.4 ℓ is substituted as an approach into formula (3), the following formula is obtained.

$$C_h = \frac{D^2}{8t}\left[\ln\frac{D}{d} - 0.75 + 0.64\,\pi\,\ell^2\,\frac{K_c}{q_w}\right]\ln\frac{1}{1-U}$$

(Formula 4)

This formula can be presented in graphical form, to determine wick spacing, as shown by Figure 8 (see Page 12). The following example demonstrates use of the graphical solution. For cases where $k_c / q_w = 10^{-2}, 10^{-3}$, and 10^{-4} respectively.

NOTE : *The given values are provided for illustrative purposes only, and values may not represent actual physical properties of CeTeau® Vertical Drain*

C_h	=	6.5×10^{-8} m² / s
t	=	12 months
U	=	70%
ℓ	=	20m
q_w	=	1.2×10^{-5} m3 /

Draw a vertical line from $C_h = 6.5 \times 10^{-8}$ m² / s to the oblique line corresponding to twelve months. From this point of intersection, draw a horizontal line to the oblique line corresponding o 70% consolidation. From this point, draw a vertical line to the oblique line corresponding to a depth of 20m, and from there a horizontal line to the scale along the edge indication the drain spacing. (Note that there are two sets of oblique lines for values of k_c / q_w 10^{-2} m^{-2} and 10^{-2} m^{-2} respectively, from which a horizontal line to the spacing scale is to be drawn, and that for k_c / q_w 10^{-4} m^{-2}, the vertical line is to be extended to the bottom scale.) The graphical solution shows that the required drain spacing is 1.09m for $k_c / q_w = 10^{-2}$ m^{-2}, 1.83m for $k_c / q_w = 10^{-3}$ m^{-2}1,2.03m for $k_c / q_w = 10^{-4}$ m^{-2}. In terms of drain quantities, these spacing represent ratios of **3.5:1.2:1**. Therefore, it can be seen that the drain capacity can be of considerable influence on the quantity of drain required.

When designing with the CeTeau® Vertical Drain system, it is not always practical to assume that the entire thickness of the compressible layer must be provided with drains. It is often more practical and economical to provide 50% or 75% of the layer thickness with drains. This decision will depend upon how settlement varies with depth and upon the different in C_h values at various depths. This is demonstrated in the example of a motorway which is planned through an area underlain by a 40m thick compressible layer. The expected settlement during the hydrodynamic period amounts to a total of 1m, 80% of which is to take place in the upper 20m of the layer. The variation of settlement over the total depth is illustrated by the graph on the following page:

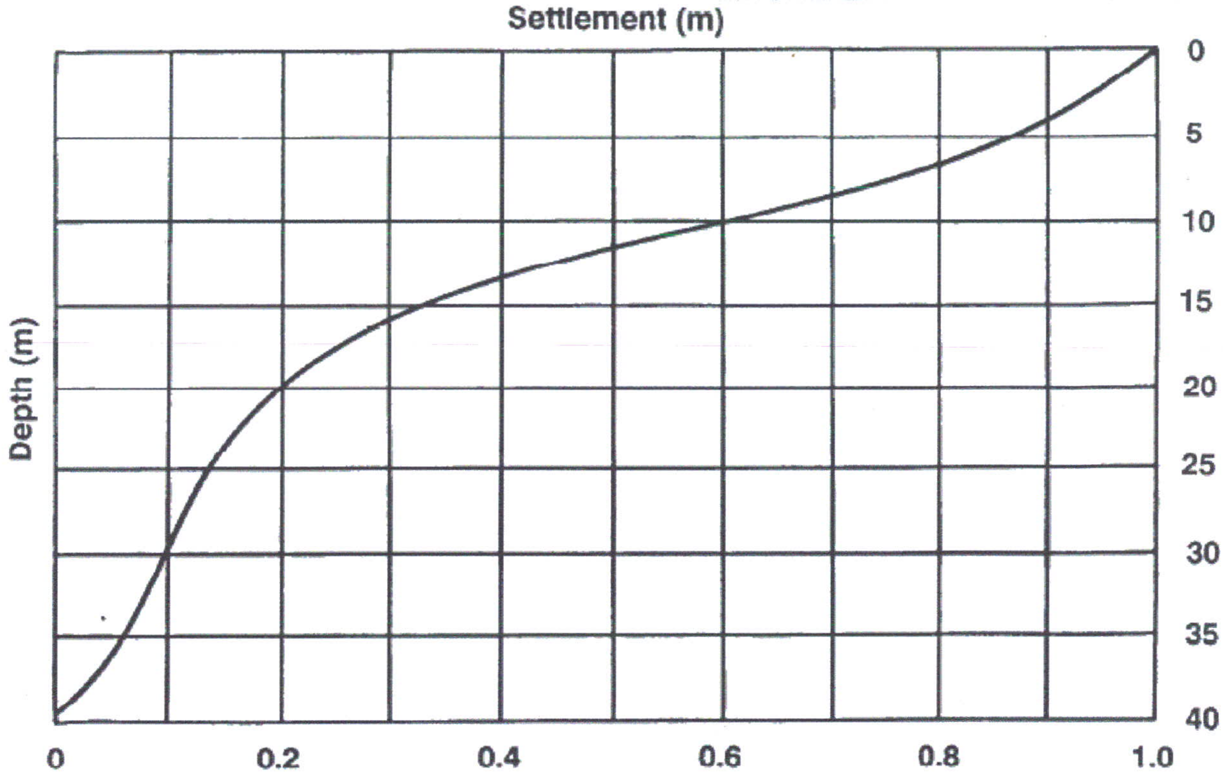


Fig. 9 – Variation of Settlement as Compared to the Total Depth of the Compressible Layer

The total area to be consolidated is 10,000m^2. The average C_h value of the entire layer is 10^{-7} m^2 / s. The road surface is to be applied at the end of twelve months, but reaching a 99% consolidation in twelve months does not seem feasible because the number of drains to be used would become excessive (240,000m).

A residual settlement of 25% after twelve months is considered acceptable. Therefore, a consolidation of 75% is required within twelve months. The following solutions are feasible :

1. Installation of drains down to 40m. Degree of consolidation then becomes 0.75. For a square pattern, formula (1) then yields a drain spacing of 2.14m. For the entire area this means the installation of 87,300m of drain.
2. It is assumed that the first 0.75m of settlement occurs only in the upper 20m thick compressible layer, which implied that **U** in this upper portion of the layer must become 0.75/0.80 = 0.937. For a square pattern, this requires a drain spacing of 1.59m (formula 1). The drain length will be 20m. and thus the total length of drain required will be 79,100m. This is a reduction of 10% compared to solution 1.
3. Installation of drains down to 25m. A 100% consolidation of the upper 25m means a settlement of 0.89m. Therefore, a consolidation of 75% in twelve month period requires that **U** = 72,300m of drain, resulting in a further saving of 10%

A probable further advantage of solutions 2 and 3 is that the residual settlement will take place over a longer period than would have been the case if the entire thickness of the layer had been provided with a drainage system as in solution 1. Besides the saving s in the quantity of wick, the shorter length of the wicks will also result in saving in the costs of installation.

The difference in the quantity of drains in the above example becomes even greater when the $\mathbf{k_c}$ / $\mathbf{q_w}$ ratio is taken into account.
Furthermore, the variation of the $\mathbf{C_h}$ value can be of influence on the drain spacing.

There have been situations where the rate of consolidation is not influenced by the drain spacing. This is believed to be the result of layering of the soil. If there are closely spaced highly permeable layers of sand between the clay or pet layers. The overstressed pore water will find these sand layer and follow this path to the nearest drains.

CONCLUSION

The technology surrounding the use and application of prefabricated vertical drain is continually growing. The concept of vertical drainage utilizing prefabricated drains has been applied to many non-traditional applications and end uses. CeTeau encourage innovative proposals from our clients for new and novel applications.

Our involvement with a wide variety of geosynthetics such as geomembranes, geotextiles, geogrid, geocell, gabion and prefabricated drains uniquely qualifies us to combine prefabricated vertical drains with other products for economical and effective solutions to complex geotechnical problems.

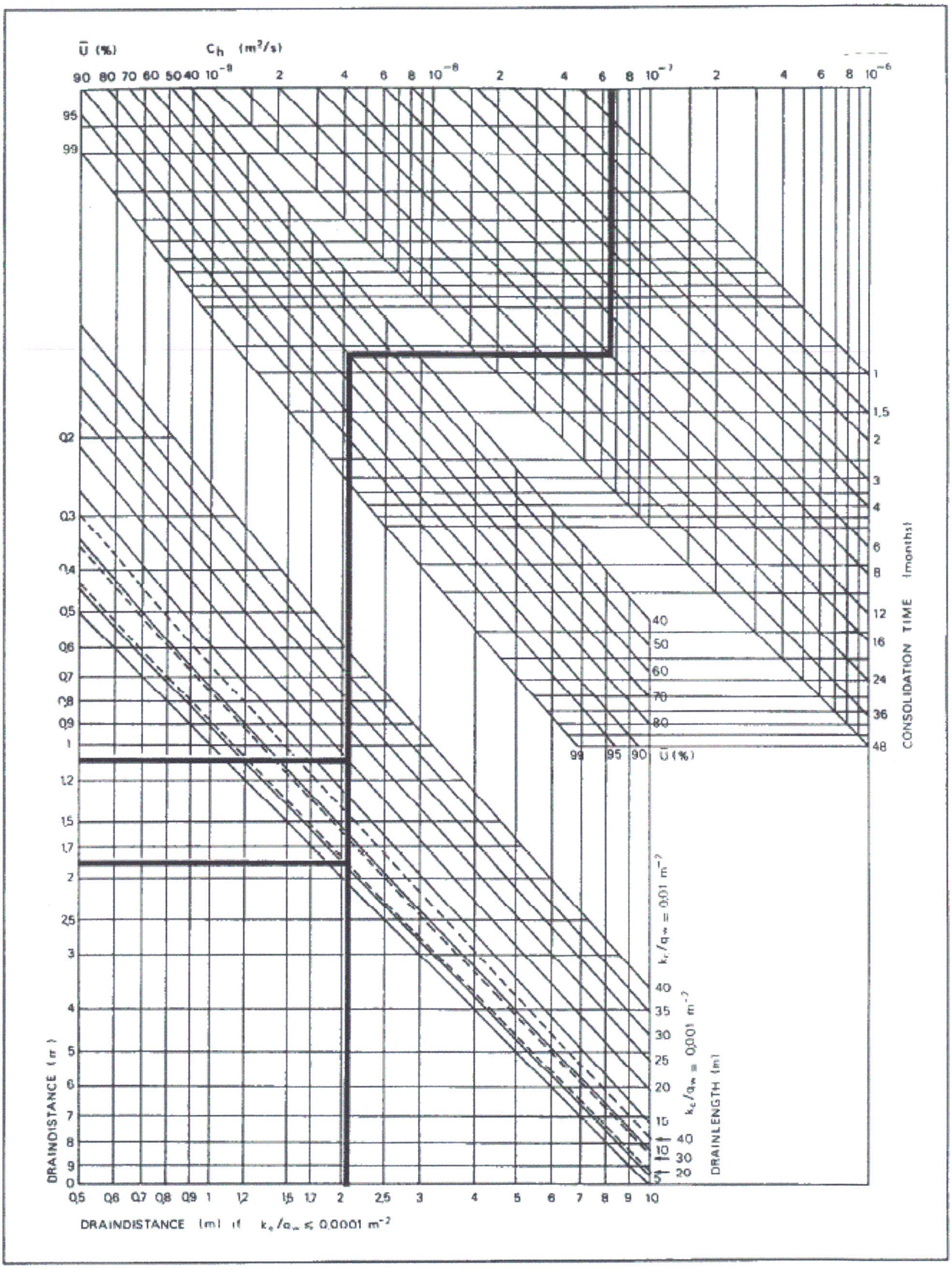


Fig. 8 – Prefabricated vertical drain spacing graph

STANDARD WICK DRAIN INSTALLATION SPECIFICATIONS

Scope:

The work covered under this specification includes the installation of vertical wick drains at the locations shown on the drawings and as directed by the Engineer.

Construction:

Where shown on the plans, or as directed by the Engineer, vertical drains shall be installed subsequent to the construction of the sand drainage blanked, and prior to placement of the surcharge material, or permanent embankment. The Contractor shall take all reasonable precautions to preserve the survey stakes.

The Contractor shall demonstrate that his equipment, methods, and materials produce a satisfactory installation in accordance with these specifications. For this purpose, the Contractor will be required to install several trial drains at locations within the work area, as designated by the Engineer. Trial drains conforming to these specifications will be paid for at the same unit price as the production drains.

The vertical drains shall be installed in the locations shown on the plans, or as directed by the Engineer. Drains that deviate from the plan location by more than 15cm, or that are damaged, or improperly installed will be rejected. Rejected drains may be removed or abandoned in place, at the Contractor's option. Replacement drains shall be offset approximately 500mm from the location of the rejected drain. All rejected drains will be replaced at the Contractor's expense.

Drains shall be installed vertically, within a tolerance of not more than 1cm per 50cm. The equipment shall be carefully checked for plumpness, and the Contractor shall provide the Engineer with a suitable means of verifying the plumpness of the mandrel and of determining the depth of the drain at any time.

Connections in the vertical drain material shall be done in a professional manner that ensures continuity of the drain without diminishing the flow characteristics of the wick material. Splices shall be a minimum of 15 cm in length. The prefabricated drain shall be cut such that at least a 15cm length protrudes above the top of the sand drainage blanket at each drain location.

It may be necessary to pre-auger or use some other method to clear obstructions and facilitate the installation of the drains through the working platform or stiffer natural deposit above the compressible soil strata. The depth in which pre-augering is used shall be subject to the approval of the Engineer, but should not extend more than 50cm into the underlying compressing soils.

Where obstructions are encountered within the compressible strata, which cannot be penetrated by augering or spudding, the Contractor shall abandon the hole. At the direction of the Engineer, the Contractor shall then install a new drain within 50cm of the obstructed drain. A maximum of two attempts shall be made, as directed by the Engineer, for each obstructed drain

The prefabricated vertical drain shall be installed to the depth specified on the drawings or refusal. The refusal length of each wick drain may vary based on the geological formations encountered over the site. Refusal shall be defined as installation of the prefabricated vertical drain to non compressible layer underlying the compressible layer of soil to be consolidated. Through the use of the soils logs taken at the project site the engineer shall define the compressible layer versus the non compressible layer. The prefabricated drain installation equipment will indicate refusal when the tip of the mandrel meet resistance and stops or slows at the approximate dept of the non-compressible layer. The finished installation depth of the wick drain shall not extend more than 0.3m into the non-compressible layer. In some cases the Engineer may wish to limit this depth based in the design of the vertical drain.

Installation of the drains should be coordinated with the placement of geotechnical instrumentation as shown on the plane. Special care should be taken to install drains in such a manner so as not to disturb instrumentation already in place. The replacement of instrumentation damaged as a result of the Contractor's activities will be the responsibility of the Contractor.

Equipment:

Vertical drains shall be installed with equipment which will cause a minimum of disturbance to the sand blanket or the subsoil during the installation. The prefabricated drains shall be installed using a mandrel or sleeve that will be advanced through the compressible soils to the required depth using constant load, or constant rate of advancement methods, only. Use of vibratory or failing weight impact hammers will not be allowed. Jetting shall not be permitted for installation of the drain, except, with the approval of the Engineer, to lubricate the mandrel when working in highly plastic clays.

The mandrel shall protect the prefabricated drain material from tears, cuts and abrasions during installation and shall be withdrawn after the installation of the drain. The drain shall be provided with an "anchor plate "or rod at the bottom, to anchor the drain at the required depth at the time of mandrel removal. The projected cross-sectional area of the mandrel and anchor combination shall not be greater than $70cm^2$.

At least three weeks prior to the installation of the drains, the Contractor shall submit to the Engineer, for review and approval, details of the sequence and method of installation. The submittal shall at the minimum contain the following specific information :

1. Size, type, weight, maximum pushing force, and configuration of the installation rig
2. Dimensions and length of mandrel
3. Details of drain anchorage,
4. Detailed description of proposed installation procedures
5. Proposed methods for overcoming obstructions
6. Proposed methods for splicing drains

Approval by the Engineer will not relieve the Contractor of his responsibilities to install prefabricated vertical drains in accordance with the plans and specifications. If, at any time, the Engineer considers the method of installation does not produce a satisfactory drain, the Contactor shall alter his method and/or equipment as necessary to comply with the plans and specifications.

Materials:

The prefabricated vertical drain material shall consist of a continuous plastic drainage core wrapped in a non-woven geotextile material. The geotextile wrap shall be tight around the core, and shall be securely seamed in a manner that will not introduce any new materials nor present an obstruction that will impede flow in the channels of the core. The prefabricated wick drain material used shall meet the following specifications:

Width drain	$\geq$ 100 mm
Thickness drain	$\geq$ 3 mm
Shape of Core	Rib core
Drainage Channel	> 40 channels
Tensile strength drain	> 2.5 kN
Discharge capacity at 300 kPa i=0.1	> 80x10-6 m^3/s
Discharge capacity buckled at i=0.5,200 kpa 25% deformation	> 25x10-6 m^3/s
Discharge capacity at 300 kPa i=0.1 and30° Z kinked	> 60x10-6 m^3/s
Grab tensile strength Filter	>0.5 kN
Tear strength filter	>0.1 kN
Permittivity filter	> 1 s^{-1}
Soil retention filter O90	< 80 μm

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Contractor requirements:

The contractor shall submit a 1m sample of the vertical drain material to the Engineer prior to usage and shall allow three weeks for the Engineer to evaluate the material. The sample shall be stamped or labeled by the manufactured as being representative of the drain material having the specified trade name. Approval of the sample material by the Engineer shall be required prior to site delivery of the wick drain material.
The Contractor shall state which prefabricated vertical drain he intends to install at the time of the preconstruction conference. The drains shall be free of defects, rips, holes or flaws. During shipment, the drain shall be protected from damage, and during storage on-site the storage area shall be such that the drain is protected from sunlight, mud, dirt, dust, debris, and detrimental substances. Manufactured certification shall be provided for all drain material delivered to the project.

Measurement for payment:

Prefabricated vertical drains will be measured by the linear meter. Quantity shall be rounded to the nearest meter including protruding portion, of drains installed, in accordance with the plans or as directed by the Engineer.

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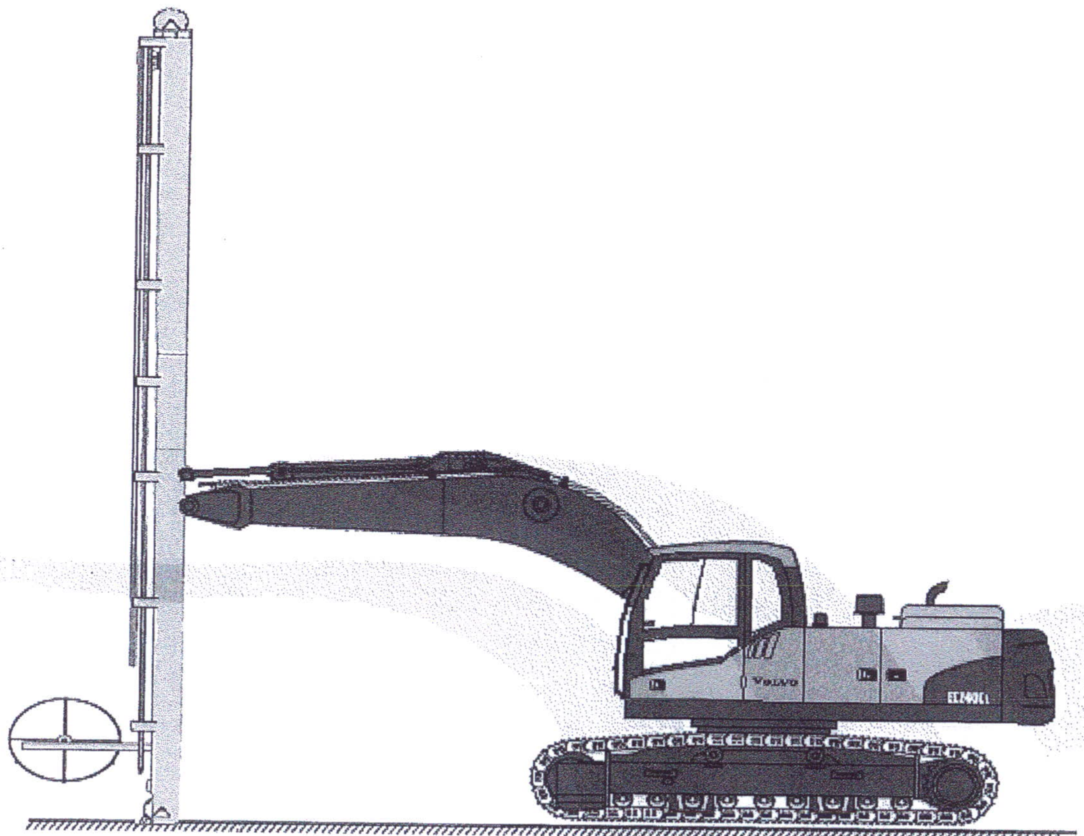
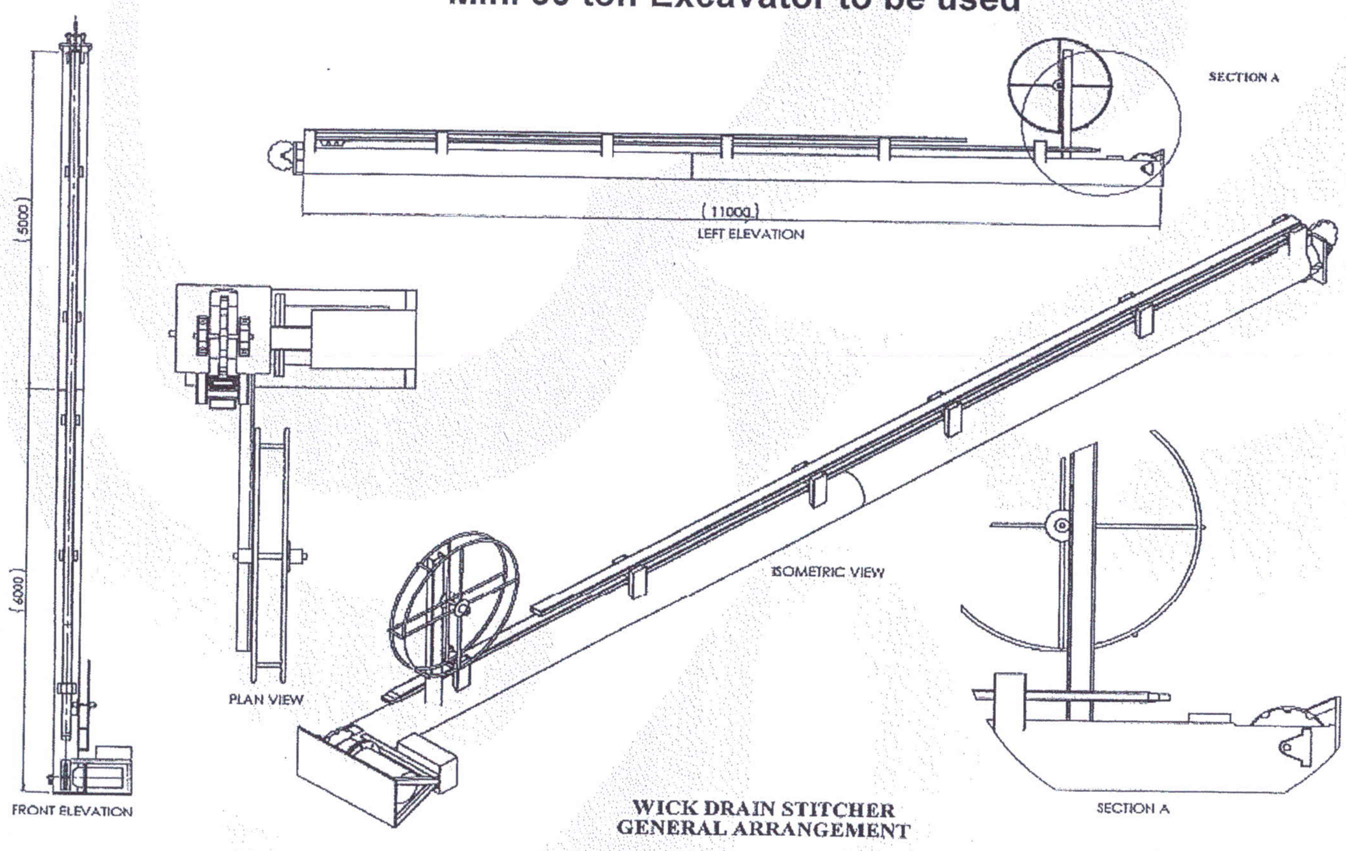
Wick Drain Stitcher (P/N 2304)



Min. 30 ton Excavator to be used



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