Outram Floodbank Stability Assessment

Seepage, Slope Stability and Flood Modelling

Prepared for Otago Regional Council
Prepared by Beca Limited

21 November 2024

Contents

Appendices

Revision History

Revision Nº	Prepared By	Description	Date
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on behalf of	Beca Limited		

Executive Summary

Otago Regional Council (ORC) is conducting engineering investigations and review relating to the 1.4-kilometre length of floodbank adjacent to Outram Township. Beca Limited (Beca) was commissioned to provide an engineering assessment to indicate the risk of floodbank failure, to provide high-level remedial options, and inform the Outram flood response protocols.

The assessment involved the following:

- Geotechnical assessment, including liquefaction and slope stability modelling.
- 2D seepage modelling of three select sections of the floodbank.
- Breach modelling of selected sections of the floodbank, based on existing ORC hydraulic model (to be undertaken at a later date).
- Preparation of a Floodbank Assessment Report (this report).

Key points from the geotechnical investigation were:

- Outram is relatively flat, with disconnected open paleochannels throughout the township area.
- The paleochannels in the western part of Outram generally had surface water in them, and act as windows into the underlying shallow aquifer. Water within the paleochannels rise as groundwater rises.
- The ground profile generally comprises loose sandy silt and silty sand, which overlie interbedded alluvial sands and gravels generally.
- The Taieri River loses water to the groundwater system which then flows beneath Outram and below the floodbank with groundwater levels been hydraulically linked to river stage.
- The groundwater flow gradient is broadly from northeast to southwest, moving beneath Outram towards Lake Waipori.
- Groundwater was encountered within installed piezometers between 2.5 and 3.5 m RL (3.52 and 7.16 m bgl) during investigations undertaken in March 2024 during a summer drought.
- Accurate long-term groundwater levels were not available.
- To accommodate for non-drought conditions and seasonal fluctuations, relatively conservative groundwater levels ranging from 5.8 to 6.1 m RL (1.0 to 2.5 m bgl at the landside toe) were adopted.

Key findings from the geotechnical assessment were:

- A sensitivity check of the floodbank importance level between IL2 and IL3 was considered given the likely impact on the community.
- Liquefaction is unlikely to trigger under a SLS earthquake but was estimated to occur in a ULS event.
- Free field settlements were estimated to range from 70 - 230 mm (IL2), 100 – 270 mm (IL3).
- The floodbank was calculated to be stable under static, rapid drawdown, and SLS seismic conditions.
- Floodbank instability is likely under both ULS seismic cases (IL2 and IL3).
- Lateral displacements (flow failure) are expected in under ULS events on both sides of the floodbank.
- As the stability risks under static, rapid drawdown, and SLS seismic loading were low, and the visual condition of the floodbank appeared to be in good condition, it is our conclusion that implementing immediate ground improvement, or geotechnical floodbank mitigation measures may not yield worthwhile short term benefits.
- Under ULS loading, liquefaction of the soils below and adjacent to the floodbank are what affects the floodbank's performance. Liquefaction mitigation measures will require reconstruction of the floodbank for which the costs are likely to be high, and a cost benefit analysis would need to be undertaken.

Key findings from the breach modelling were:

- ORC's existing HEC-RAS model for the Lower Taieri floodplain was used, with minor adjustments, to simulate breaching of the floodbank at two locations for a flood event with a peak flow of 3,939 m^3/s in the Taieri River (based on previous flood frequency analysis undertaken by ORC, this peak flow corresponds to a 200-yer ARI event with no allowance for climate change). The type of breaching investigated was piping failure of the floodbank.
- The model results showed significant inundation of Outram's buildings and roads for both breach locations. Flow velocities appear to be high in the immediate vicinity of the breach locations but quickly reduce with distance from the breach site.
- Flood hazard maps produced for each of the breach locations showed that nearly all public roads providing escape routes from Outram become unsafe for people and vehicles shortly after the breach begins to develop.

The key findings from the seepage modelling were:

- A 3D ground model was compiled to provide surface contacts of the main strata units and create 2D cross-sections across the area.
- 2D groundwater flow models were set up to provide indications of groundwater level changes due to river levels and seepage beneath and partially through the floodbank.
- Where the river level reaches near the top of the floodbank before receding, it can cause seepage-derived flooding in the low elevation areas across Outram i.e. paleochannels.
- Only when the river level is high, i.e., near the top of the floodbank, for multiple days does the seepage move partially through the floodbank and daylight near the inside toe.
- The ORC hydraulic model does not overtop the floodbank under a flow rate of 3,939 m^3/s which corresponds to a 1/200-year ARI flood without taking climate change into consideration.

High level options for improving the resilience of the floodbank include:

- Assessing whether the paleochannels could be used for drainage conveyance by connecting them and piping and/or pumping water across the floodbank into the Taieri River channel with back-flow prevention.
- Installation of a relief drain in the toe area of the floodbank on the landside which could intercept seepage water and convey it to a discharge point, possibly connecting into the same outlet pipe/pump as the paleochannels.

Further works recommended to progress an assessment of the feasibility of the potential remedial options:

- Install long-term groundwater level monitoring equipment into the recently installed piezometers adjacent to the floodbank and throughout Outram (including in some paleo-channels) to better understand seasonal groundwater fluctuations and response to large rainfall and river flow events.
- Given the floodbanks construction age, it may have more permeable or lower strength zones that were not encountered in the initial investigations. Additional investigations such as geophysics along the floodbank could be undertaken to assess the uniformity, and further CPT testing to confirm material consistency through the floodbank and in underlying material.
- As the risk of liquefaction leading to flooding in Outram is low, a reactive approach may be appropriate, making provisions for rapid inspections and repairs following an earthquake.
- The Bay of Plenty Regional Council Stopbank Design and Construction Guidelines (2014) provide detailed recommendations for operations and maintenance (Part 5) and emergency works (Part 6) plans for stopbanks. We recommend that these documents be created if they don't currently exist, and be regularly reviewed, especially after flood or seismic events.
- Inspection protocols should include provisions for identifying and monitoring for signs of seepage, scour and erosion.

- Remediation options to consider and include in the guidance documents for after a seismic event are further detailed at the end of this report.
- Improvements to conveyance and drainage across the paleo-channels in Outram including further consideration of a pumping station to move drainage water across the floodbank to river during flood events.
- Installing a relief toe drain along the landside of the stopbank. This would intercept seepage water in a more controlled manner, decreasing the risk of slope instability, and convey it to a discharge point, possibly connecting into the same outlet pipe as the paleochannels.

1 Introduction

1.1 Background

Otago Regional Council (ORC) has engaged Beca Limited (Beca) to provide a stability assessment and associated risk of failure for a 1.4 km section of floodbank adjacent to Outram. The boundaries of the section are the most northern extent of Holyhead Street, and Huntly Road. We are not aware of any records of the floodbank overtopping adjacent to Outram, but the township has experienced surface water flooding after high river level events both before and after the floodbank was constructed. Previous assessments of the floodbank adjacent to Outram have been conducted using visual inspections, monitoring data, and nearby investigations. ORC have highlighted the need for site specific investigations and modelling, including information through the floodbank, due to concerns about the integrity of the floodbank, piping, and the associated risk of failure.

An assessment of the floodbank was undertaken to determine the level of risk and potential type of floodbank failure, to provide high level remedial options for the floodbank, and to feed into a review of the Outram Flood Response protocols (to be carried out by others). An overview map of the site is shown in Figure 1-1.

1.2 Scope of Report

This report forms part of the overall scope of works for Otago Regional Council to assess the floodbank near Outram township. As part of these works, Beca compiled a factual report that included the site investigation data (Beca, 2024) which has been used in the assessments summarised in this report.

This report comprises the following items:

- Liquefaction and floodbank stability analysis.
- 2D seepage modelling of three select sections of the floodbank.
- Breach modelling of selected section of the floodbank, based on existing the ORC hydraulic model.
- Conceptual remedial options and recommendations for further works.

1.3 Site Description

Outram is located approximately 30 kilometres west of Dunedin City on the northern Taieri Plain, adjacent to the base of the Maungatua hills which form the northern boundary of Taieri Plain. The Taieri River flows out from the Maungatua hills to the east of Outram. A floodbank is sited along the true right bank of the Lower Taieri River, between the river and Outram. It is approximately 4 m high and 18 m wide at the toe.

Outram is relatively flat, with disconnected open paleochannels throughout the township area. Paleochannels are former Taieri River channels which are no longer connected to the active river channel. Some of the paleochannels in Outram have been infilled.

The Taieri Flood Hazard map on the ORC Natural Hazards Database shows the paleochannels through Outram, which act as seepage pathways beneath the floodbank, and are particularly noticeable near the northern section at Holyhead Street and in the southern section at Bell Street (Figure 1-1). The open paleochannels are predominantly in the western half of the town and are currently utilised as natural storage / soakage areas within the town, with rainwater and manmade culverts diverting surface water into them. There appears to be no remaining surface outlet from the paleochannels.

The floodbank has multiple access ramps throughout the section, both on the river and Outram side. The floodbank and riverside land is currently used for stock grazing, which at the time of investigations (March 2024) included sheep and horses.

A site walkover was conducted with Beca and Otago Regional Council Staff on the 28 April 2023, to assess access for investigations and agree testing locations, and to inspect the condition of the floodbank. No signs of scour, erosion or instability was noted during the walkover or during site investigations conducted in March 2024.

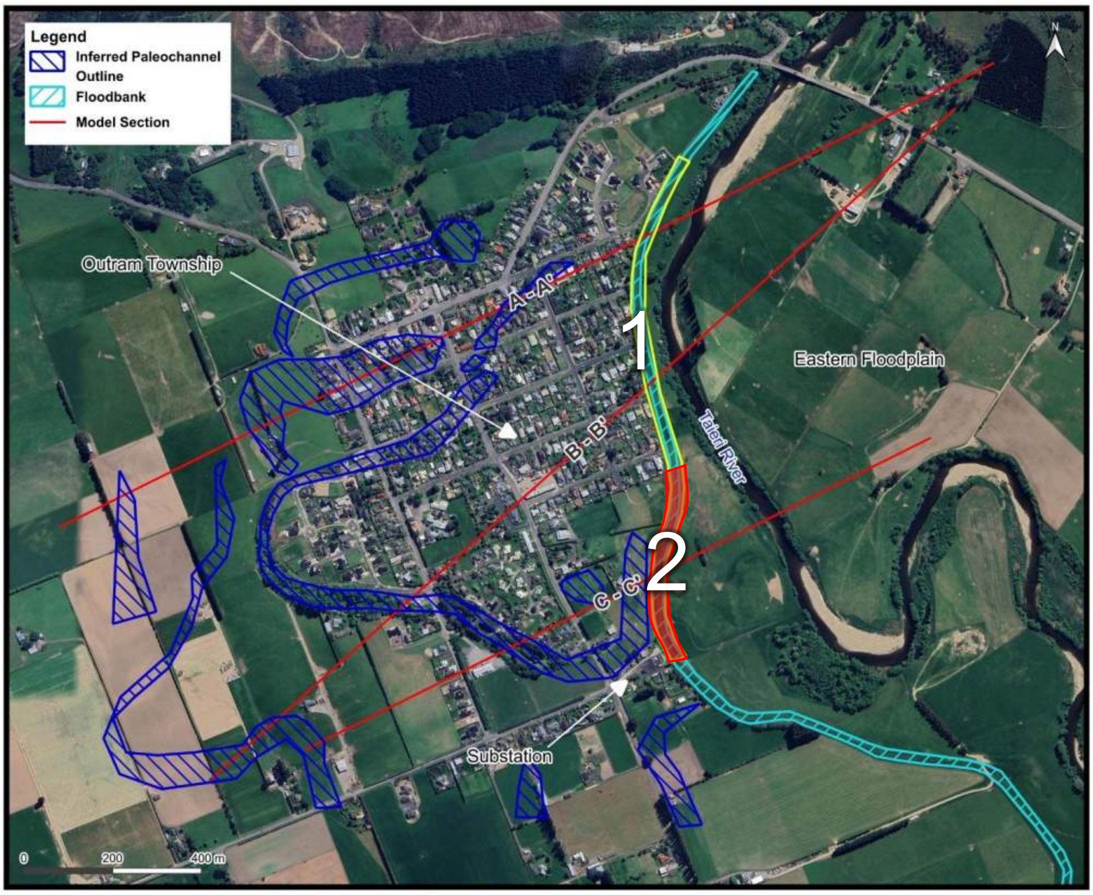


Figure 1-1. Overview Map of Outram Showing the Floodbank, Taieri River, Paleochannels, and 2D model Sections. The floodbank assessed in this report is outlined in yellow (Zone 1) and red (Zone 2). Paleochannels are inferred from Taieri Flood Hazard maps and LiDAR. (Image source: Google Earth)

2 Background Information

The following background information related to this section of floodbank has been reviewed as part of this assessment.

2.1 Information Supplied by ORC

- Tonkin & Taylor Limited. 2005. Lower Clutha and Taieri Floodbank Systems – Geotechnical Evaluation – Stage 2. Job no 890910.
- Barrell, D.J.A. 2015. Extent and characteristics of alluvial fans in the northeastern sector of the Taieri Plain, Otago, GNS Science Consultancy Report 2014/45. 23 p.
- Tonkin & Taylor Limited. 2017. Floodbank Condition and Structural Integrity Assessment. Job no. 1001453.
- GeoSolve Limited. 2022a. Specification for Earthworks, Lower Taieri Flood Protection Scheme Weighting Blanket, Outram Township, Ref: 210388.
- GeoSolve Limited. 2022b. Area A lateral Seepage Assessment Outram, East of Bell St, South of Orme St, Letter to Otago Regional Council, ref: 210388.
- Tonkin & Taylor Limited. 2023. Taieri Flood Protection Scheme, Floodbank Risk Assessment, 1001453.0153v1.

2.2 Prior Floodbank Assessments

2.2.1 2005 T&T Lower Clutha and Taieri Floodbank Systems Geotechnical Evaluation – Stage 2

An assessment of the Lower Taieri Floodbank system was undertaken as part of a wider *Otago Floodbank Study.* Tonkin & Taylor (T&T) assessed the Lower Taieri Floodbanks in 2005, which focussed on the floodbanks protecting Outram and included cross sections at their investigation locations.

A summary of the key findings of this report were:

- General visual evaluation noted the floodbanks on the true right bank were in good condition.
- Vegetation on the floodbank was generally well controlled.
- There were a number of crossing points, and some of these have created localised low spots in the floodbank crest. Along the Outram portion, the floodbank crossings did not show signs of causing adverse effects to the condition of the floodbank because the crest height remained constant and grass cover was well maintained.
- Slope stability safety factors were mostly high, and indicated no significant risk in static conditions, flood condition, or under strong seismic shaking. The lowest factor of safety reported was 1.2 for a rapid drawdown case.
- Willow trees were planted within 5 m of the landside toe of the floodbank within Outram (willow trees were not observed within 5 m on the riverside of the floodbank during the 2024 Beca investigations).

2.2.2 2017 T&T Floodbank Condition and Structural Integrity Assessment

The T&T 2017 report assessed the condition and integrity of 108.7 km of floodbank located on the Taieri Plains southwest of Dunedin. This report was prepared after the July 2017 flood event which caused widespread flooding in Otago and Canterbury (National Institute of Water and Atmospheric Research (NIWA), 2018). ORC reported that just upstream of the Outram Substation, seepage from the ground was observed on the landside of the floodbank.

Following the assessment, a weighting blanket was proposed by GeoSolve (2022) to attempt to remediate the seepage issues. The earthworks specification (GeoSolve Limited, 2022) recommended the weighting blanket be comprised of site-won sandy silt. The weighting blanket was constructed in the area directly landside of the floodbank, east of Bell Street and south of Orme Street.

2.2.3 2023 T&T Taieri Flood Protection Scheme Floodbank Risk Assessment

T&T undertook a high-level risk assessment of the Lower Taieri River Flood Protection Scheme in 2023, with a focus on relative risks to the community. Floodbank sections were delineated based on the T&T 2017 assessment, and each section given a risk rating defined as the product of the likelihood and consequence of failure. The report covered the likelihood of failure based on field conditions, assumed strengths, overtopping, the consequence of failure based on floodbank breach modelling, and a damage assessment of both infrastructure and impact on population. The risk rating (consequence x likelihood) was presented in four categories:

- Very low, low, medium
- High
- Very high
- Extreme

The report concluded that the risk rating for the floodbank from Outram bridge through to the Outram Substation was high. It should be noted that T&T rated the likelihood of a floodbank failure occurring through this section to be low to medium, however as the consequence of a failure is rated as catastrophic, this results in an overall ‘high’ risk rating. The ‘medium’ likelihood rating was determined from the condition of the floodbank observed by T&T in 2017.

2.3 Flood Event History

Flood events have been recorded in the Taieri Plains for over a century, with several significant floods occurring since European settlement in the mid-1800s. Reconstructed maps of the February 1868 and May 1923 floods show that most (approximately 120 km^2) of the Taieri Plains was inundated during these events. The significance of these two events, being just two of many floods on record, is that they occurred prior to the construction of any major, coordinated flood-protection works, and therefore reflect the underlying flood hazard of the Taieri Plains. More recent flooding and observations include the July 2017 flood event, which resulted in Outram experiencing flooding across the town, and observed seepage from underneath the floodbank, especially in the southern portion of the town near Bell Street.

2.4 Floodbank Construction and Alterations

The first floodbank material was placed by horse and cart in the 1870s as part of the original Outram floodbank construction (Otago Regional Council (ORC), 2024). From the 1980s through to the 1990s, new material was placed over the original banks, increasing the width and raising the height of the floodbank. The material added is a firmer silt which was generally encountered during ground investigations in the upper 1.5 m.

A weighting blanket was constructed in 2022 on the landward side of the floodbank at the southern end of Outram near the substation. Materials for this weighting blanket were taken from borrow pits located the riverside of the floodbank, and is assumed to have similar material properties to the loose sandy silt (Unit 3) described in this report.

3 Site Geology

3.1 Site Geology

Outram sits on the northern edge of the Taieri Plains immediately below the Maungatua hills, which rise to the north of the township. The main strata below Outram are comprised of outwash sediments (silts, sands, and gravel). These materials were deposited by alluvial processes by the Taieri River and its tributaries, forming the flat topography of the Taieri Plains. More detailed geological descriptions can be found in the accompanying Beca Geotechnical Factual Report (2024).

The main geological units in the Outram area are shown in Figure 3-1.

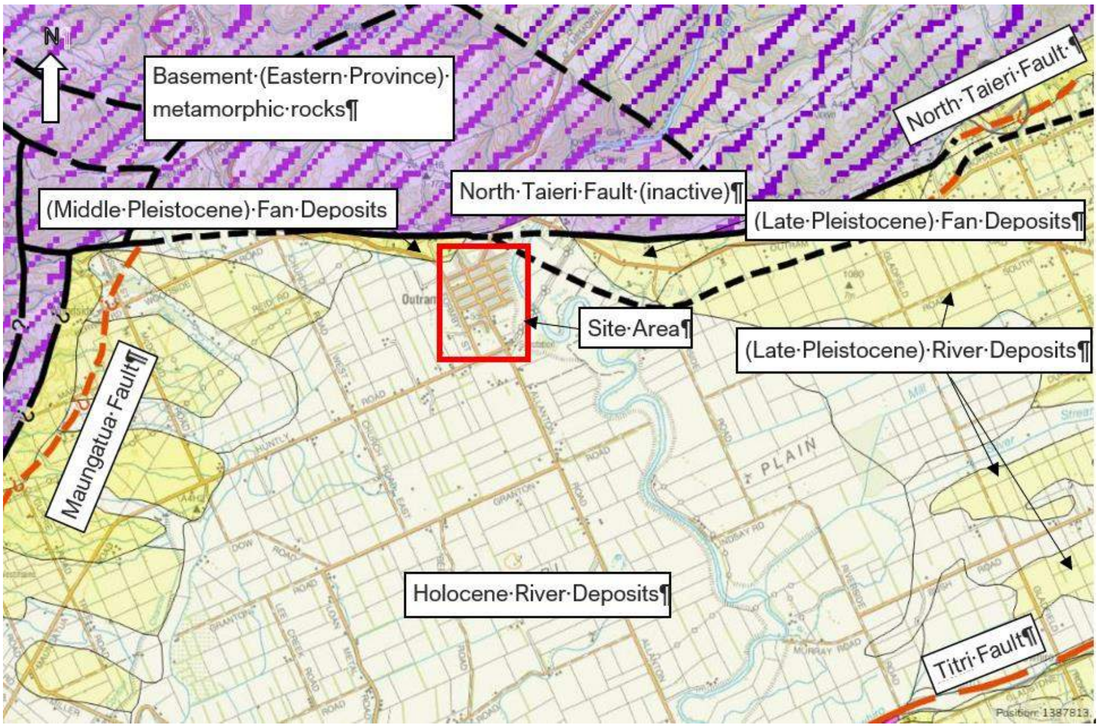


Figure 3-1. Annotated geological map of the area (Image source: GNS Webmap 250,000, not to scale).

3.1.1 Floodbank Geometry

The floodbank rises approximately 3 to 5 m in height above the surrounding ground level, with an approximate crest elevation between 12 to 13 m RL in the north near Holyhead Road. This gradually decreases in height to 11 to 12 m RL at the top of the floodbank in the southern section near the Outram Substation according to LiDAR data (Toitū Te Whenua Land Information New Zealand, 2021). The banks were grassed and periodically have stock grazing within the floodbank area and on the surrounding plain.

The floodbanks southern section (2) near Henley Street is the tallest section of the floodbank, approximately 5 m from natural ground on the riverside to the floodbank crest.

The elevation throughout the text is referenced to New Zealand Vertical Datum 2016 (NZVD2016) as meters reduced level (m RL). A photograph showing the floodbank, shoulder bank, Taieri River, and residential area is shown in Figure 3-2.

Figure 3-2. Photo of Floodbank, Shoulder Bank, Taieri River, and Residential Area (looking south, not to scale, Image source: Beca, 2024).

3.1.2 Paleochannels

The paleochannels discussed in Section 1.3 once formed part of the Taieri River system but are no longer directly linked to the main river channel and have no discharge point. Some portions of the paleochannel network have been infilled during the development of the township, and others were in their natural state with some holding water year-round. The open channels are utilised to capture surface water runoff, with an open meandering stream in the western portion of the town, near the Taieri Rugby Club, which has no clear outlet to the river or drainage system. The paleochannels are the first places to intercept rising groundwater levels, and will hold some surface runoff, hence play an important part in runoff conveyance and storage. The paleochannels can be observed in Figure 3-3 as red areas to the left (west) of the floodbank.

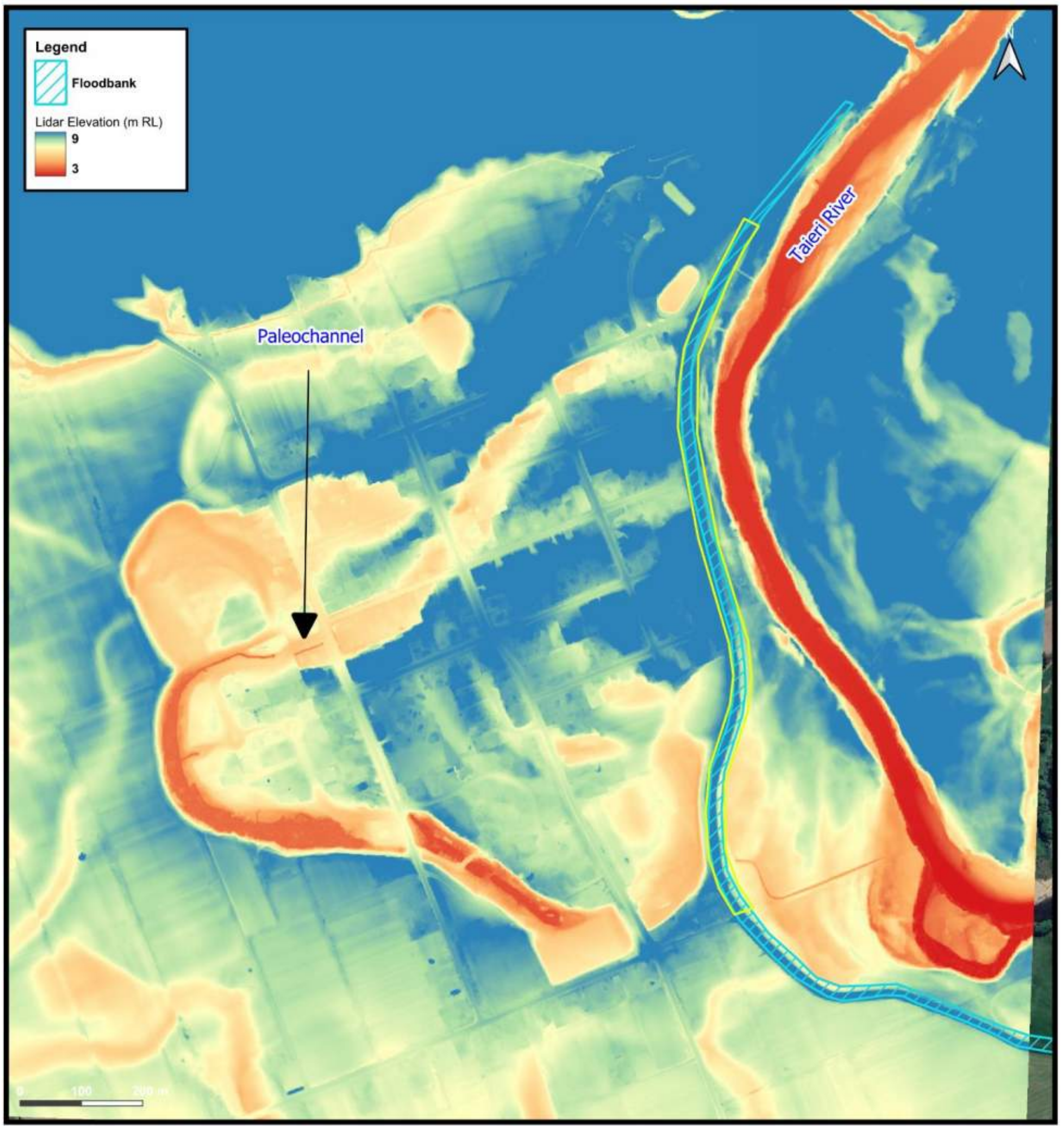


Figure 3-3. Map of LIDAR (2021) ground topography of the Outram area (created in QGIS), with the paleochannels and Taieri River channel indicated in red having the lowest elevation. The assessed floodbank is shown in yellow.

4 Geotechnical Site Investigations

4.1 Existing Geotechnical Data

Existing geotechnical information reviewed as part of this assessment included bore logs from water bores available from the ORC database, investigation data from the New Zealand Geotechnical Database (NZGD), and limited data from previous assessment reports by others in the area. The existing investigations are shown in Figure 4-2, along with testing undertaken as part of this scope of works and associated cross-section locations are presented in Figure 4-1.

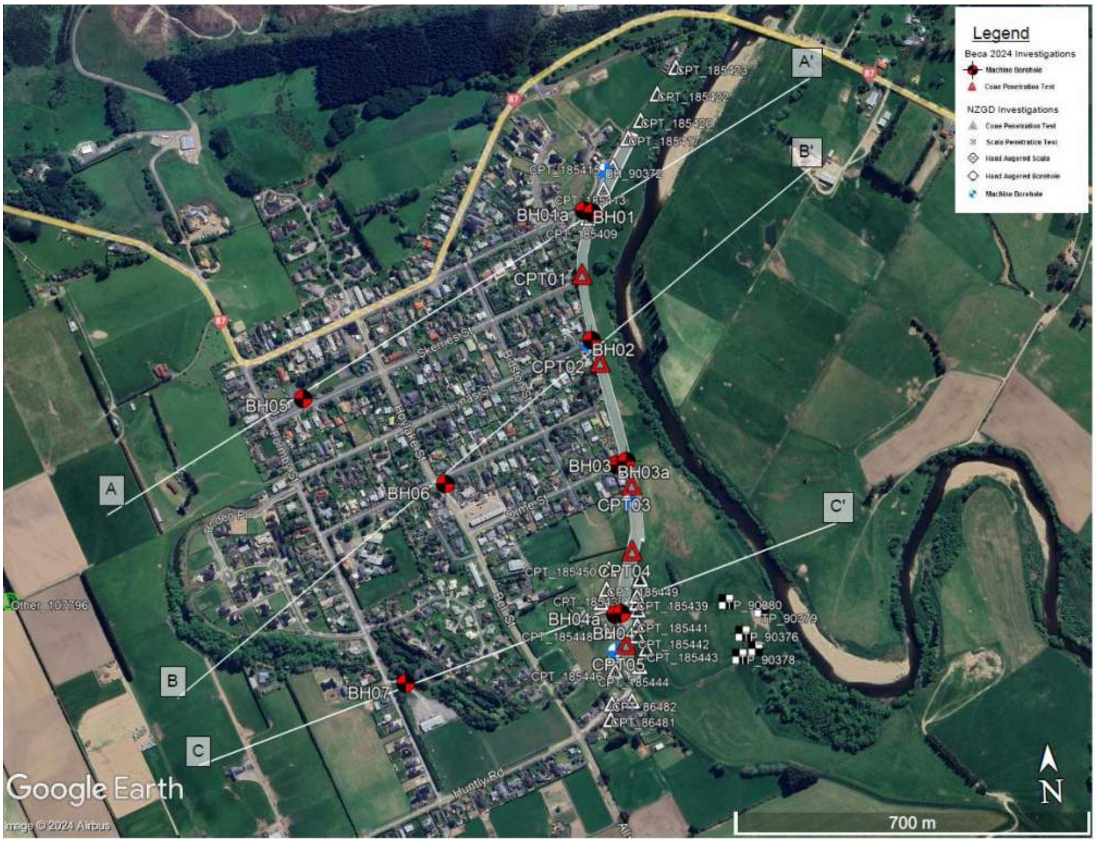


Figure 4-1. Beca 2024 and NZGD investigation locations, and corresponding cross sections used for analysis. (Image source: Google Earth)

4.1.1 2005 T&T Lower Clutha and Taieri Floodbank Systems Geotechnical Evaluation – Stage 2

T&T undertook a ground investigation in 2005 along the western floodbank of the Taieri River on behalf of the ORC. The investigation comprised shallow wash-bore holes which terminated at approximately 6 m below ground level (bgl).

4.1.2 New Zealand Geotechnical Database

A review of publicly available data on the NZGD (presented on Figure 4-2) shows the nearest available existing data consisted of:

- 5 test pits, terminated between 2.3 m and 4.1 m bgl, approximately 120 m east of the floodbank.
- 8 CPT tests, terminated from 12 and 15 m bgl along the northern part of the floodbank (BH01 to SH87).
- 18 CPT tests, terminated between 8.1 m and 15.2 m bgl along the southern part of the floodbank between the substation and 48 Bell Street.
- 4 boreholes, terminated between 6.0 and 6.3 m bgl along the landside toe of the floodbank.

Figure 4-2. Geotechnical data near the site (Image source: New Zealand Geotechnical Database, not to scale).

4.1.3 Beca (2024) Geotechnical Factual Report

Ground investigations were undertaken between 4th March 2024 and 19 March 2024 by Beca and are detailed in the factual report (Beca, 2024). Investigation locations are presented in Appendix A and bore logs are presented in Appendix B.

The investigations consisted of:

- 5 x 20 m cone penetrometer tests (CPTs).
- 4 x 19.5 – 19.95 m cored machine boreholes through the floodbank, with standard penetration tests (SPTs) at 1.5 m centres.
- 3 x 6 m wash-drilled machine boreholes adjacent to the floodbank.
- 1 x 8 m wash-drilled machine borehole on the corner of Bell and Beaumaris Streets.
- 2 x 9 and 15 m cored machine boreholes at 8 Skerries Street and 102 Formby Street.
- 6 piezometer installations within the boreholes not drilled through the floodbank.
- 1 rising head test within the piezometer installed in BH04a.
- 7 falling head tests within piezometers, including existing piezometer T&T_02.

The investigation and laboratory results were used to inform the ground model, presented in Section 5. Sample locations within the boreholes are shown in the borehole logs attached in Appendix B.

5 Ground Model

5.1 Ground Model

A combination of borehole data from recent drilling as well as surface topography and groundwater level data was used to create a 3D geological model of Outram, using the Leapfrog software (version 2023.2.3). The geological and groundwater model domain included the township, the floodbank, the Taieri River, and part of the eastern floodplain.

5.2 Ground Conditions

The ground profile generally comprises loose sandy silt and silty sand, which overlie interbedded alluvial sands and gravels generally from +3.0 m RL. The ground conditions were relatively consistent across the site, as shown on the cross sections presented in Appendix C. However, there were some non-continuous silt lenses encountered during investigations. The thicknesses and strength of sandy silt and gravelly sand (Units 3 and 4) vary and were related to the location of paleochannels. These materials are described further in the sections below.

5.2.1 Floodbank Materials

The floodbank embankment materials consisted of silty sand and sandy silt which were capped by clayey silts. ORC staff have indicated that the sandy material was site-won from the local area. Strength data was generally consistent through all floodbank boreholes.

5.2.2 Weighting Blanket

A weighting blanket was constructed in the southern section of the floodbank of site-won materials. From the GeoSolve (2022) report and ORC correspondence, we understand that the material was generally sandy silt, and was sourced from borrow pits on the riverside of the floodbank.

5.2.3 Unit 1 – Hard Silt (Embankment Fill)

Unit 1 is described as a hard silt with minor clay, gravel, and low plasticity. Unit 1 was only encountered from the surface of the floodbank down to 1.5 to 1.7 m bgl and was typically brown with orange mottles. From correspondence with ORC, and previous T&T reporting (Tonkin & Taylor Limited, 2005), we understand that this layer was added to raise the floodbank height to its current level.

5.2.4 Unit 2 – Loose Sandy Silt (Embankment Fill)

Unit 2 was encountered within the floodbank and consisted of site won fill and was inferred to have been derived from Unit 3. Unit 2 was generally 2 to 3 m thick and typically described as loose silty sand and sandy silt, non-plastic, and brown. Uncorrected standard penetration test (SPT) results ranged from 4 to 8 blows per 300 mm penetration.

5.2.5 Unit 3 – Loose Sandy Silt (Holocene River Deposits)

Unit 3 consisted of in-situ floodplain silty sands and sandy silts. The thickness was generally 3 to 5 metres throughout the investigations, and typically described as loose silty sand and sandy silt, non-plastic, and brown.

5.2.6 Unit 4 – Medium Dense Gravelly Sand (Holocene River Deposits)

Unit 4 was encountered throughout the site area and comprised thickly interbedded, medium dense gravelly sand and sandy gravel. Borehole investigations experienced some core loss within this lithology, and we assume this is due to the interbedded properties of the material.

5.2.7 Unit 5 – Stiff Silt (Holocene River Deposits)

Unit 5 was encountered in BH01 and CPT1 and comprised a grey to bluish grey, low plasticity silt with minor clay. The thickness of this unit ranged from 1.5 to 2.0 m and was interpreted to have been deposited by meandering river channels and, as such, thin discontinuous silt layers may be encountered on site.

5.2.8 Unit 6 – Dense to Very Dense Sandy Gravel (Holocene River Deposits)

Unit 6 was the basal unit encountered on site and underlies Units 1 to 5. It was generally encountered at -6.5 RL, being encountered at the shallowest in BH02 at -4.5 RL and deepest within BH03 at -7.5 RL. Unit 6 is generally described as a brown, well graded, dense to very dense fine to coarse sandy fine to coarse gravel with minor silt. The gravels were generally unweathered and subrounded to rounded, consisting of basalt, quartz, and schist. The uncorrected SPT N values ranged from 39 to 50+.

5.2.9 Ground Profile

A representative ground profile is summarised in Table 5-1. Cross sections are presented in Appendix C with cross section locations shown on Figure 4-1. Note that this ground profile is representative only, and actual conditions across the site are variable.

Table 5-1. Ground Profile

Unit No	Geological Unit	Unit Description	Thickness (m)	Depth to Top of Unit (m bgl)	Depth to Top of Unit (m RL[1])	SPT N Value Range (blows/ 300 mm)	CPT Cone Resistance q_c (MPa)
1	Embankment fill	Hard silt, some clay, minor fine sand, dry, low plasticity	1.5	0	12	31 – 34	15 - 30
2		Loose fine silty sand/sandy silt, moist, low plasticity	2.0	1.5	10.5	4 – 8	1 – 5
3	Holocene River deposits	Loose fine sandy silt/silty sand, moist	5.5	3.5	8.5	4 – 12	1 – 6
4		Medium dense fine to medium gravelly, fine to coarse sand/sandy gravel, some silt, interbedded	8.0[2]	9.0	3.0	17 – 27	9 – 16
5		Stiff silt, some clay	1.0	14	-2.0	N/A	5
6		Dense fine to coarse sandy fine to coarse gravel, minor silt	>3.0	15	-6.5	39 – 50+	20 - 40

Notes: [1] Elevations are based on LiDAR survey Otago - Coastal Catchments LiDAR 1 m DEM in terms of NZVD (2016).
[2] Depth of unit 4 is variable, and ranges from – 5 to – 7.5 m RL in investigations.

5.3 Groundwater

Groundwater was encountered within installed piezometers between 2.5 and 3.5 m RL (3.52 and 7.16 m bgl) during investigations undertaken in March 2024 during a summer drought (New Zealand Government, 2024).

Long term groundwater monitoring has not been undertaken near the floodbank. To accommodate for non-drought conditions and seasonal fluctuations, relatively conservative values ranging from 5.8 to 6.1 m RL (1.0 to 2.5 m bgl at the landside toe) were adopted for long term stability analysis and were intended to represent very high, conservative groundwater levels.

The groundwater conditions in the Outram area are discussed in more detail in Section 10.3.1.

5.4 Design Soil Parameters

Design soil parameters have been assigned to each of the soil units and are displayed in Table 5-2.

These parameters were generated based on in-situ data, laboratory testing results, and experience gained from similar soils in environments representative of the Taieri River.

Table 5-2. Adopted Material Parameters

Unit ID	Unit Name	Unit Weight $\gamma\left(\frac{kN}{m^3}\right)$	Friction Angle $\phi\ (°)$	Cohesion $C'\ (kPa)$
-	Weighting blanket	17	30	0
1	Hard silt (embankment fill)	18	30	3
2	Loose sandy silt (embankment fill)	17	28	0
3	Loose sandy silt	17	30	0
4	Medium dense gravelly sand	18	32	0
5	Stiff silt	18	28	2
6	Dense to very dense sandy gravel	20	38	0

5.5 Hydraulic Conductivity

The hydraulic conductivity (K) of encountered materials was derived from a combination of sources including falling head test (FHT) analysis in seven piezometers, calculations based on particle size distribution (PSD), CPT data, and textbook values.

There was some variance in the K values with the falling head test results generally resulting in lower K values than the other methods in similar strata+. This is likely because the piezometers tested were screened across several strata which generally included fine grain materials with lower conductivities (i.e., silt), hence bringing the overall K value down. The PSD and CPT analyses derive K values from smaller sections of ground sampled by the drillers, hence there was a larger spread of K values including many higher K values, particularly in the gravel and sand. K values derived from PSD and FHT analysis are summarised in Table 5-3.

Note that the unit assigned to each borehole ID below is an approximation based on the main lithology encountered. In some cases, for the FHT analysis, the screened zone covered two units, but the dominant unit is listed in the table.

Table 5-3. Hydraulic Conductivity (K) Values

Unit	Borehole ID	Depth Tested (m bgl)	Hydraulic Conductivity, K (m/s)	
			From PSD Analysis (geometric mean)	From FHT Analysis
1	BH01 Deep	1.2 – 1.5	7.7E-09	-
2	BH01 Shallow	2.3 – 2.6	2.7E-07	-
	BH03 Shallow	2.5 – 3.0	1.8E-06	-
3	BH02 Deep	4.2 – 4.5	2.8E-06	-
	BH04	2.7 – 3.0	9.7E-07	-
4	BH01 Deep	9.8 – 10.3	2.3E-04	-
	BH03 Deep	14.3 – 14.6	1.8E-04	-
	BH01a	6.0 – 12.0	-	4.2E-05
	BH03a	5.0 – 11.0	-	1.6E-05
	BH04a	2.0 – 6.0	-	1.6E-07
	BH06	2.0 – 8.0	-	7.9E-05
6	BH05	3.0 – 5.0	-	2.1E-05
	BH07	6.5 – 10.5	-	5.9D-05
-	T&T02	-	-	5.7E-05

6 Floodbank Stability Assessment Criteria

6.1 Floodbank Assessment Criteria and Profile

The Bay of Plenty Regional Council has produced a guideline for the design and construction of floodbanks titled "*Stopbank Design and Construction Guidelines*" (BOPRC, 2014) This guideline has been adopted by many councils around New Zealand and has been used in this assessment of the Outram floodbank.

6.1.1 Floodbank Profiles

Three cross sections were cut through the floodbank and into the wider Outram township on the 3D geological model. These profiles have been selected based on the proximity to ground investigation testing, locations of the paleochannels, and seepage observed during previous flooding. These cross-section locations are shown on Figure 4-1.

The floodbank geometry was generally consistent throughout the site. For the geometry, the 2021 LiDAR was reviewed throughout the Outram floodbank section, and the critical (i.e. steepest) slope angles were estimated within 100 m of each of the floodbank sections. The floodbank was 3 to 5 m in height, with the riverside slope angles being 24 to 27°, and 19 to 23° on the landside. Because a topographic survey was not undertaken on the floodbanks, slopes may be steeper locally to those modelled from the LiDAR data.

6.2 Site Subsoil Class

Based on the GNS geological map and associated cross section (Bishop, 1996), along with nearby borehole data (Opus Limited (Opus), 2004), the site subsoil class along the extent of the floodbank investigation is inferred to be D (deep or soft soil site) in accordance with NZS 1170.5:2004.

Investigations at the SH87 bridge, approximately 250 m north of the site, show the schist bedrock at approximately 12 m depth. However, investigations 20 to 30 m south of the bridge show the bedrock is no longer within the top 35 m in this area. This suggests the bedrock depth deepens out into the Taieri Plains from the toe of the Maungatua Range, which is also shown on published geological cross sections.

6.3 Seismic Criteria

The seismic criteria was determined in line with AS/NZS 1170.0 and NZS 1170.5, in conjunction with the BOPRC 2014 guideline. The importance level was determined based on the protection needs for people and infrastructure. The Outram floodbank currently protects the following structures:

- Urban housing.
- Outram School, 1 Beaumaris Street.
- Outram Hall – Civil Defence key emergency site, 45 Holyhead Road, Outram.
- Outram Fire Station, 5 Bell Street.
- Outram Substation, 526A Allanton Road.

The BOPRC (2014) guideline state that floodbanks protecting farmland or urban housing should be considered Importance Level 2 (IL2) structures. If the floodbank is protecting a hospital, school, or major electrical substation, a higher importance level could be assigned. We have carried out a sensitivity check of both IL2 and IL3 cases to compare the site response in each case using a design life of 50 years. Table 6-1 presents the seismic design criteria adopted for the Outram floodbank.

Table 6-1. Floodbank Design Criteria

Criteria	Value	Comment
Design Life	50 years	In accordance with NZS 1170.0.
Importance Level (IL)	IL2 / IL3	According to NZS 1170.0 Table 3.2 for Normal structures, or structures as a whole may contain people in crowds or contents of high value to the community or pose risks to people in crowds. Both IL2 and IL3 cases have been assessed for sensitivity analysis.

6.4 Seismic Loads

Table 6-2 presents the seismic loadings for the assessment of liquefaction, slope stability, and slope displacements based on MBIE Module 1 (2021). These loads were based on the Site Soil Class of C as recommended by MBIE Module 1 for all sites.

Table 6-2. Seismic Design Loadings

Design Case	Site Subsoil Class	Importance Level	Annual Probability of Exceedance	Peak Ground Acceleration (g)	Earthquake Magnitude (M)
SLS	C	2	1/25	0.06	6.0
		3			
ULS		2	1/500	0.23	
		3	1/1000	0.29	

7 Liquefaction and Cyclic Softening

7.1 Overview

Liquefaction describes the short-term loss of strength of a loosely packed cohesionless (sandy) soil during an earthquake or other dynamic loading. Liquefaction occurs when the soil particles are disturbed and densify during dynamic loading, temporarily raising pore water pressures and reducing the effective stress between particles to near zero. This causes the affected soil to behave essentially like a liquid until the excess pore pressures are dissipated.

Liquefaction can have several significant effects where it occurs, including large lateral displacements (lateral spreading), post liquefaction settlements (due to the densification and loss of material to the surface) and potentially large and uneven settlement of shallow founded structures.

Cyclic softening is a liquefaction related phenomenon that occurs where cohesive soils are sheared during strong earthquake shaking. Cyclic softening can cause a significant strength loss in sensitive soils and may result in several consequences including slope instability, foundation settlement or tilting.

We have carried out a liquefaction analysis using CLiq (version 3.5.2.17), based on the data from the CPT investigations completed in March 2024, and also two CPTs from the NZGD (CPT185409 and CPT185413) which were within 10 m of BH01 at the northern end of the site. We used NZGD data to supplement the recent investigation data near BH01.

7.2 Liquefaction Assessment Methodology

7.2.1 Soil Susceptibility

Following Boulanger & Idriss (2014) recommendations, site soils were categorised into two types: those that behave in a 'sand-like' manner under seismic shaking (potentially subject to classical cyclic liquefaction) and those that behave in a 'clay-like' manner (not liquefiable but may undergo cyclic softening). Soils were quantitatively assessed from CPT tests using the soil behaviour type (SBT) index, Ic. Soils were generally classified as 'clay-like' where Ic > 2.6 and 'sand-like' where Ic < 2.6. Additionally, soils with a plasticity index (Ip) less than 12 were typically assumed to be 'sand-like', while those with an Ip greater than 12 were considered 'clay-like'.

The liquefaction assessment for the site considered:

- Unsaturated soils above the groundwater table were not considered susceptible to liquefaction (Units 1 and 2).
- Soils encountered below the groundwater level may be susceptible to liquefaction. Unit 6 is dense to very dense and was generally not shown to undergo liquefaction in our assessment.
- The soils encountered in the investigations were typically granular ('sand-like'), and therefore were not considered susceptible to cyclic softening. Unit 5 is stiff to very stiff and on that basis is not expected to undergo cyclic softening.
- A design groundwater level of +6 m RL (about 2.5 m bgl) has been adopted for the liquefaction assessment.

7.3 Liquefaction Assessment Results

The results of the liquefaction assessment are presented in Appendix D and summarised in Table 7-1.

Liquefaction assessment results indicate:

- Assessment of CPTs data indicated liquefaction is not continuous and occurs in discrete layers throughout Units 3 and 4 due to the interbedding of the medium dense sandy gravels and gravelly sands.
- Units 3 and 4 are potentially liquefiable, where Units 1 and 2 are likely not subject to liquefaction as they are above the groundwater table and unsaturated.
- Unit 6 is not likely to liquefy because its dense to very dense, based on the results of modelling.
- However, given the variable nature of the site geology and our limited investigation data, liquefaction may occur within units that are noted as non-liquefiable if they become saturated (Units 1 and 2) or if interbedding of softer granular soils is present (Unit 6).

The expected liquefaction and cyclic softening susceptibility and triggering assessments are discussed further below.

7.3.1 Liquefaction Triggering Assessment

The main findings from the assessment are summarised below:

- The assessment indicates widespread liquefaction is likely to occur under both IL2 and IL3 ULS earthquake cases (PGAs of 0.23g and 0.29g) with a return period of 500 and 1000 years respectively.
- Liquefaction triggering occurs from 0.15g (1/250 year event) with the majority of liquefaction triggering occurring by 0.25g (1/1000 year event).

Free field settlement was estimated as:

- Not anticipated under SLS.
- Between 70 and 230 mm under ULS (IL2).
- Between 100 and 270 mm under ULS (IL3).

Because of the interbedded nature of the river deposits, liquefaction occurs in multiple layers separated by non-liquefiable material. Liquefiable layers generally occur from +6 m RL, with layers generally being 0.5 to 1.5 m thick, with non-liquefiable layers between these on average being 0.5 to 1.5 m thick. CPT04 and 05 presented the thickest liquefiable layers, with CPT04 showing 5 to 6 m of liquefaction-susceptible soil below the groundwater table, and CPT05 showing 7 to 10 m of liquefaction-susceptible soil from 1 m below the groundwater table.

The residual liquefied shear strength values for the different materials encountered on site are presented below.

Table 7-1. Liquefaction Assessment Summary

Unit No	Geological Unit	Depth to Top of Unit (m RL)	Depth of Liquefaction (m RL)	SLS Seismic Event (1/25 year)[1]	ULS (IL2) Seismic Event (1/500 year)[1]	ULS (IL3) Seismic Event (1/1000 year)[1]	Adopted Liquefied Shear Strength Ratio
1	Hard silt (embankment fill)	12	n/a	NL	NL	NL	n/a
2	Loose sandy silt (embankment fill)	10.5	n/a	NL	NL	NL	n/a
3	Loose sandy silt	8.5	6.0 to 3.0	NL	P	L	0.9
4	Medium dense gravelly sand	3.0	3.0 to -6.5	NL	P	P	0.9
5	Stiff silt	-2.0	n/a	NL	NL	NL	n/a
6	Dense to very dense sandy gravel	-6.5	n/a	NL	NL	NL	n/a

Note: [1] NL = Non-Liquefied, P = Partially Liquefied, and L = Liquefied

7.4 Floodbank Settlements

7.4.1 Static

Long term consolidation settlements are not expected at this site given the granular nature of the subsurface soils. Settlements were likely to have occurred during construction of the floodbank and are not expected to increase with time. Should additional fill be added to increase the floodbank width or height, further static consolidation settlements analysis should be undertaken.

7.4.2 Seismic

The BOPRC (2014) guidelines' seismic vulnerability criteria (Table A1.1) recommends that floodbanks do not undergo significant deformation. Horizontal deformation should be limited to 0.91 m (maximum) with 0.3 m of vertical settlement. The seismic settlements estimated for this floodbank were within the thresholds of the BORPC guidelines, being less than 0.3 m of settlement.

Estimated settlements are provided in Table 7-2, which were rounded to the nearest 10 mm.

Table 7-2. Estimated Liquefaction-induced Settlements

Investigation Point ID	Settlement in ULS IL2 (mm)	Settlement in ULS IL3 (mm)
CPT185409	110	160
CPT185413	110	160
CPT01	70	100
CPT02	110	150
CPT03	130	170
CPT04	120	180
CPT05	230	270

8 Floodbank Stability Assessment

8.1 Slope Stability Assessment Criteria

The target factors of safety (FoS) for slope stability assessments were conducted in general accordance with the BOPRC guidance. The adopted minimum target FoS are presented in Table 8-1 for the different load cases considered.

Table 8-1. Target Factors of Safety for Slope Design

Load Case	Soil Conditions	Groundwater Conditions	Target Factor of Safety	Permanent Displacement Limit
Static Long Term	Drained	Long term Groundwater Levels	≥1.5	N/A
Static Short Term (rapid drawdown)	Undrained	Short term groundwater	≥1.2 (riverside)	N/A
Seismic Event (SLS)	Undrained, Liquefied	Long term Groundwater levels	>1.1[1]	No significant deformation, limited to 0.91 m (horizontal) with 0.3 m of vertical settlement
Seismic Event (ULS)	Undrained, Liquefied	Long term Groundwater levels	>1.0[1]	No significant deformation, limited to 0.91 m (horizontal) with 0.3 m of vertical settlement

Note: [1] Bridge Manual – 3rd Edition.

8.2 Slope Stability Assessment Methodology

Quantitative stability analyses of the existing floodbank under static and seismic cases have been carried out using the GeoStudio Slope/W software (Version 2024.1.0), utilising the Morgenstern and Price limit equilibrium method, and were coupled with the SEEP/W models. The Mohr-Coulomb material parameters shown in Section 7 were adopted.

The floodbank geometry (presented in Section 6.1.1) was generally consistent throughout the site, and the profile locations and associated zones are shown on Figure 4-1 and Figure 4-2. Zones 1 and 2 indicate similar levels of anticipated performance. The models have been run assuming the following:

- For the long term static case, a surcharge of 12 kPa was applied because the bank is trafficable and is currently used to access ORC owned grazing areas currently leased to nearby residents.
- No surcharge was added for static short term or seismic cases.
- The models have adopted the ground parameters presented in Table 5-2
- For liquefiable soils, a liquefied shear strength ratio of 0.09 has been adopted.
- Failure modes include non-circular.

The analysis considered the following failure mechanisms:

- Mechanism #1: Stability of the riverside (eastern slope) of the floodbank.
- Mechanism #2: Stability of the landside (western slope) of the floodbank.

The following groundwater levels were adopted:

- Long term static groundwater table of +6 m RL.

- Short term static/rapid drawdown model used:
  - 2 hr flood at top of floodbank.
  - 12 hr drawdown to river level from flood height.
  - Considered 0.5 day intervals (7 days).

Key assumptions made for the stability analyses are detailed below:

- Hard silt (Unit 1) caps the floodbank and does not extend down the side slopes.
- No liquefaction under SLS loading.
- Thin layers of silts and clays encountered in some CPTs were discontinuous and therefore have been modelled based on the total sum thickness of the liquefied layers and the depth of liquefaction in CPT04 and CPT05:
  - ULS IL2 – was modelled as a 5 m thick liquefiable layer below +6 m RL.
  - ULS IL3 – was modelled as a 7 m thick liquefiable layer below +6 m RL.
- Seismic yield cases were modelled with 5 m thick liquefiable layer below +6 m RL.
- A sensitivity check was undertaken for section C-C' which had a 2 m thick non-liquefiable layer. A 5 m thick layer of liquefiable soils from +4 m RL as modelled.
- A long-term groundwater level of +6 m RL has been adopted.

The results of the stability analysis are presented in Table 8-2. Green cells exceed the design FoS, yellow cells meet the design FoS, and red cells are less than the design FoS. Selected Slope/W analysis outputs are presented in Appendix E.

Table 8-2. Slope Stability Analysis Results Summary

Analysis Section	Stability Case	Design FoS	Landside Slope FoS	Riverside Slope FoS
A-A' (Zone 1)	Static – long term	1.5	2.0	1.6
	Static – short term (High GWL)	1.2	2.0	1.7
	Seismic SLS (1/25)	1.1	1.7	1.4
	Seismic ULS (IL2)	1.0	0.4	0.2
	Seismic ULS (IL3)	1.0	0.2	0.2
B-B' (Zone 1)	Static – long term	1.5	1.9	1.5
	Static – short term (High GWL)	1.2	1.8	1.5
	Seismic SLS (1/25)	1.1	1.6	1.3
	Seismic ULS (IL2)	1.0	0.3	0.2
	Seismic ULS (IL3)	1.0	0.3	0.2
C-C' (Zone 2)	Static – long term	1.5	1.5	1.3
	Static – short term (High GWL)	1.2	1.3	1.8
	Seismic SLS (1/25)	1.1	1.3	1.1
	Seismic ULS (IL2)	1.0	0.3	0.2
	Seismic ULS (IL3)	1.0	0.2	0.2

The long-term static cases showed the floodbank was stable, which is consistent with the observations of the floodbank performance. The short term (high groundwater) static case showed that both the landside and riverside banks were stable, which is also consistent with the observations of the floodbank performance and previous floodbank reporting by others. Further slope stability assessments will be required in future stages if optioneering for ground improvement is undertaken.

8.3 Lateral Seismic Displacements

8.3.1 Background

Permanent slope (or embankment) displacement resulting from earthquake loading may occur from the following three mechanisms:

- During an earthquake and prior to the development of liquefaction, the inertial load of the soil can temporarily exceed the soil strength resulting in global instability with displacement.
- During an earthquake and following the triggering of liquefaction, lateral spreading may be observed; lateral spreading is the lateral movement and consequential lateral stretch cracking of the ground surface that may be observed, when the ground translates towards nearby riverbanks, slopes, or cuttings (i.e. free faces). The assessment of lateral spreading is complex, and many phenomena influence the predicted magnitude of displacement. Variations in the earthquake characteristics, ground conditions (as observed across the site), groundwater levels, pore pressure dissipation pathways and free face heights all affect the magnitude of any lateral spreading displacement.
- Flow failure is a similar phenomenon to lateral spreading but occurs after earthquake shaking has stopped. As a result of liquefaction, the surface crust of soil 'flows' towards the free face and can occur on very shallowly sloping sites. Flow failure is typically associated with large magnitude ground surface displacements.

Much of the floodbank alignment is susceptible to all three mechanisms of seismic slope displacement. Liquefaction is expected to occur at the site following a 1/250 AEP design earthquake. Following triggering of liquefaction, the more damaging mechanisms of lateral spreading and flow failure may occur on both sides of the floodbank.

The ground displacement from lateral spreading and flow failure are greatest at the free face (i.e. river edge) and the magnitude and severity reduce with distance from the free face. CIRIA (2013) reports the effects of lateral spreading or flow failure mechanisms on flood defence performance can include:

- Loss of freeboard due to settlement and lateral displacement.
- Longitudinal and transverse cracking (particularly between the ends of areas of movement and nonmovement).
- Piping failure from seepage though the embankment due to crack formation.

8.3.2 Methodology

Seismic displacements were addressed using the long-term static groundwater models. The floodbank slopes were assessed for stability in 1/25 year (SLS), 1/500 year (ULS IL2), and 1/1000 year (ULS IL3) year earthquakes.

Key methodology details for assessing lateral seismic displacements are provided below:

Soil strength parameters are based on liquefied strength as presented in Table 7-1.

- Seismic displacements were assessed following three methods, Jibson (2007), Ambraseys and Srbulov 1995, and Bray and Travasaurou, 2007.
- For Ambraseys & Srbulov, the focal depth of earthquake was 7.5 km, with the horizontal distance from the earthquake to the site of about 26 km.

The slopes did not achieve the target FoS for ULS design cases (>1.0), indicate that seismic displacement may occur in these cases.

8.3.3 Assessment Results

The mechanisms of lateral spreading are expected to occur towards adjacent free faces leading to lateral translation and stretch of the ground. This stretch would result in cracking of the ground which could reflect up though earth embankments such as the floodbank (unless mitigated). The magnitude of lateral spread deformation is dependent on the severity of strong ground motion, height and offset of the free face and groundwater conditions at the time of the earthquake. The vertical component of deformation associated with laterally spreading ground is observed as settlement.

The lateral movement assessment indicated slope movements in the order of 50 to 590 mm are possible following a ULS earthquake event. No displacement of the slope is expected for a SLS earthquake event.

Lateral displacement calculations were not performed for yield PGAs = 0 (i.e., flow failure). These sections may have displacements post-earthquake resulting in failure of the floodbank.

Table 8-3. Seismic Slope Stability Analysis Results Summary

Section	Side	PGA (g)	FoS Achieved	Yield PGA (g)	Displacement (mm) 50th Percentile
A-A' (Zone 1)	Landside	0.23	1.0	0.02	110 - 420
	Riverside		1.0	0.03	70 – 260
	Landside	0.29	1.0	0.02	150 – 590
	Riverside		1.0	0.03	90 – 390
B-B' (Zone 1)	Landside	0.23	1.0	0	Flow Failure
	Riverside		1.0	0.035	50 – 210
	Landside	0.29	1.0	0	Flow Failure
	Riverside		1.0	0.035	70 – 320
C-C' (Zone 2)	Landside	0.23	0.9	0	Flow Failure
	Riverside		0.7	0	Flow Failure
	Landside	0.29	0.9	0	Flow Failure
	Riverside		0.7	0	Flow Failure

Lateral displacement yield PGA assessments are presented in Appendix E.

8.4 Discussion

The floodbank was calculated to be stable under static and SLS earthquake (1/25 year AEP) conditions. The floodbank was also found to be stable under a rapid drawdown flood case, which indicates the floodbank is expected to perform well during a 1/200-year flood event and failure is not expected as the water resides.

The investigations indicated the floodbank materials were generally consistent throughout the length of floodbank. However, our investigations were conducted at discrete locations, and given the construction methods at the time the floodbank was constructed, there may be portions of the floodbank that vary in strength and material than those modelled. Further CPT and geophysical investigations, specifically between CPT04 and BH01, would reduce this uncertainty.

In ULS seismic cases, free field liquefaction induced settlement was within the Bay of Plenty Stopbank Design and Construction Guidelines of 0.3 m. Lateral movements were assessed using yield PGAs and liquefied soil parameters, which assess the potential for movement of liquefaction prone soil. The yield PGAs were lower than the 1/25 seismic PGA (0.06g), which resulted in estimated horizontal displacements up to 600 mm. Where yield PGAs were 0, this indicated flow failure is likely to occur with movement towards the free face causing failure of the floodbank.

9 Floodbank Breach Modelling

9.1 Introduction

To inform a review of the Outram flood response protocols, ORC has requested that breach modelling be undertaken for the true right floodbank of the Taieri River, adjacent to Outram. A breach of the floodbank in this area during a period of high flow in the river has the potential to cause significant flooding in the township. The purpose of the breach modelling was to investigate the extent and severity of flooding caused by floodbank breaching in two different locations during a particular average recurrence interval (ARI) river flow event.

The following sections describe the breach modelling methodology and provide a summary of the results.

9.2 Hydraulic Model

In June 2023, ORC provided an existing HEC-RAS hydraulic model (‘*2018LowerTaieriSP*’) that they developed to investigate and better understand flooding in the Lower Taieri floodplain. A report (‘*20210121 Taieri Model Development Report DRAFT’*) discussing the methodology used to build the model and develop the model hydrology was also provided. The agreed scope for this project stated that Beca would use the provided model for the breach modelling and, if necessary, make minor changes to the 2D mesh around Outram and the adjacent floodbank.

9.2.1 Model Extents

Due to covering most of the Lower Taieri floodplain, the HEC-RAS model was large and complex. Figure 9-1 has been copied from *20210121 Taieri Model Development Report DRAFT* and shows the model extent.

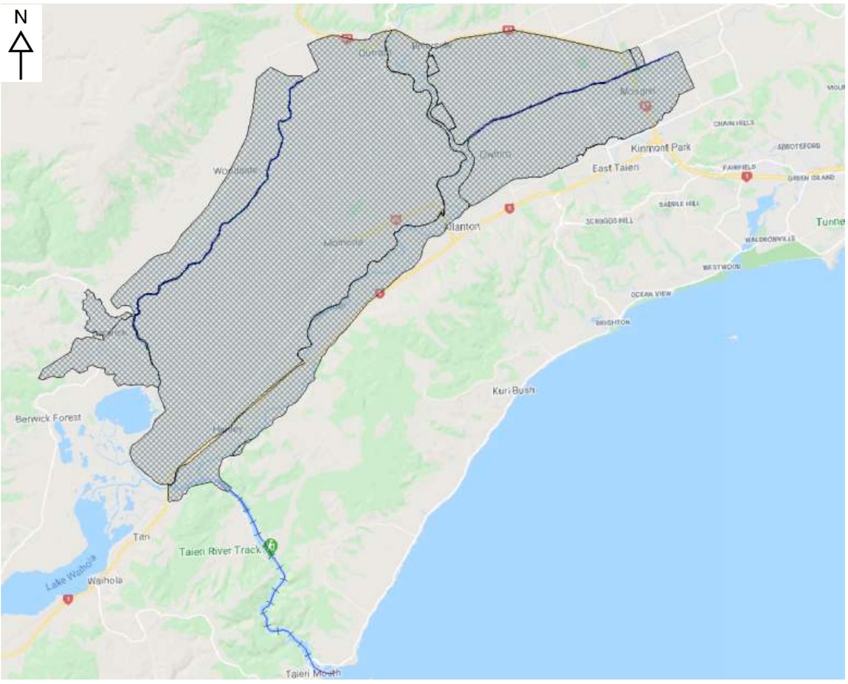


Figure 9-1. Extent of HEC-RAS model provided by ORC. Figure taken from *20210121 Taieri Model Development Report DRAFT (not to scale).*

Outram is located at the northern extent of the model, immediately downstream of the Taieri River inflow boundary. Figure 9-2 shows Outram, the adjacent reach of the Taieri River, and the model inflow location for the Taieri River.

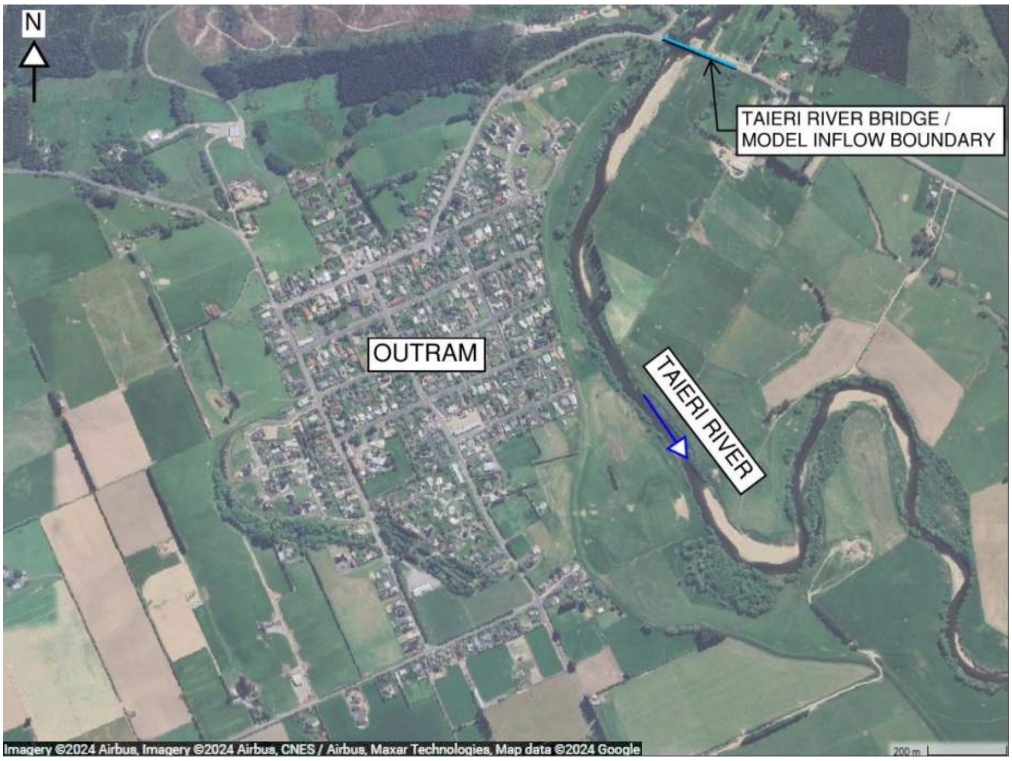


Figure 9-2. Locality plan of area of Outram and Taieri River. Changes to the HEC-RAS model provided by ORC have been limited to this area (Image source: Google Earth).

The following sections of this report focus on the details of the HEC-RAS model for the extents shown in Figure 9-2. The details of the model outside of these extents have not been changed as part of this project and can be found in *20210121 Taieri Model Development Report DRAFT*.

9.2.2 Terrain

As discussed in *20210121 Taieri Model Development Report DRAFT*, the HEC-RAS model terrain was built by ORC using a combination of LiDAR, river cross section data, and stopbank crest survey data. The LiDAR used was captured in 2016. Our review of more recent LiDAR (captured in 2021) indicated that there were no significant changes to the ground surface in Outram and its immediate surroundings since the 2016 LiDAR was flown. Because of this, we have not made any changes to the model terrain as part of this project.

9.2.3 2D Mesh

9.2.3.1 Taieri River

The ORC provided model has a mesh resolution of 15 m x 15 m for the Taieri River adjacent to Outram. A breakline has been included by ORC to better represent the channel bed. This was considered appropriate for the breach analysis, so no changes were made to the mesh in this area.

9.2.3.2 Outram Township

The ORC provided model has a mesh resolution of 50 m x 50 m for Outram and its surrounds. As ORC want to understand the flood risk to different properties and roads, particularly roads that provide escape routes out of the town. A mesh size of 50 m x 50 m is relatively coarse and is unlikely to provide results that are appropriate for this level of detail, so we have added a refinement region to reduce the mesh size to 5 m x 5 m for the area shown in Figure 9-3.

Figure 9-3. HEC-RAS model mesh resolutions within area of interest (Image source – Google Earth).

9.2.4 Manning's Roughness

We used satellite imagery to make minor changes to the existing Manning's layer in the provided model. These changes were made to represent areas of recent residential development within Outram and vegetation growth within Outram and the river channel that appear to have occurred in the time since ORC built the model. Roughness values used for the changes were consistent with what was already in the model.

9.2.5 Structures

The ORC provided model uses 2D flow area connections to represent floodbanks as broad crested weirs on either side of the Taieri River (and elsewhere in the model). *20210121 Taieri Model Development Report DRAFT* states that, for higher accuracy, the station-elevation data of the weirs was based on surveyed crest levels rather the LiDAR ground surface. We have not received any updated survey information as part of this project, so no updates to the station elevation data have been made to the Taieri River floodbank at Outram.

9.3 Hydrology

The report *20210121 Taieri Model Development Report DRAFT* provided by ORC discusses how 50 years of historic flow data have been used to estimate design flows and hydrograph shapes for the Taieri River at Outram. Figure 9-4 has been copied from the report and shows these design hydrographs.

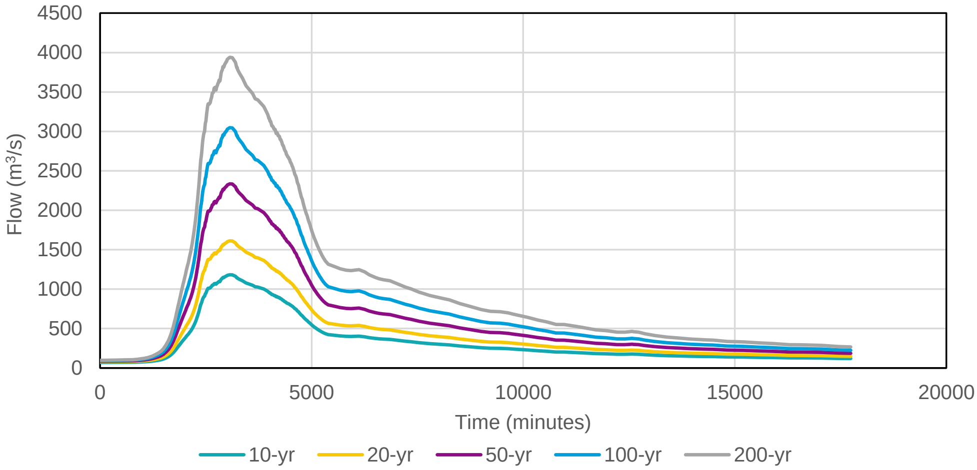


Figure 9-4. Design hydrographs for Taieri River at Outram. Copied from Figure 19 of *'20210121 Taieri Model Development Report DRAFT'.*

The provided HEC-RAS model contained hydrology files setup for the hydrographs shown in Figure 9-4, other than the 200-year. We created an inflow hydrograph for the 200-year design event for use in the breach modelling by plotting the hydrograph for the 100-year event and scaling it to the 200-year peak design flow of 3,939 m^3/s (taken from Table 12 of *20210121 Taieri Model Development Report DRAFT*).

9.4 Floodbank Breach

9.4.1 Type of Breach

Floodbank breaching typically occurs via one (or both) of the following failure mechanisms:

- Overtopping. This occurs when the water level in the river exceeds the crest level of the floodbank, causing water to spill over the top of the floodbank and erode it from the surface downwards.
- Piping failure. This occurs when water from the river seeps through or under the floodbank, creating flow channels that gradually expand. Over time, the loss of material through these channels causes a localised section of floodbank to collapse due to decreasing structural support.

These breach types behave, and are modelled in HEC-RAS, differently, so determining which type to investigate was an important input to the modelling process. Initial model runs were undertaken using the 100-year and 200-year ARI Taieri River inflow hydrographs to check peak water levels against the floodbank crest. These initial results showed that the 200-year ARI flow does not quite cause water levels in the river to overtop the floodbank at Outram, indicating a significant (i.e. greater than 200-year ARI) flood event is required to cause overtopping.

As discussed in Section 1.1, we are not aware of any records of the floodbank at Outram overtopping, despite surface water flooding having been observed in the township following periods of elevated water levels in the Taieri River. This has raised concerns over the structural integrity of the stopbank and its susceptibility to piping failure. Following discussion with ORC, it was agreed that the breach modelling would focus on breaching caused by piping failure of the floodbank.

9.4.2 Design Event

Although the floodbank at Outram has a 100-year level of service for flood protection (according to ORC), it was agreed with ORC that the breaching would be modelled using the 200-year ARI flood event. This is because the 200-year ARI flood is close to the maximum flow that the Taieri River can accommodate before overtopping the true right floodbank at Outram. Adopting this event for the breach modelling was a conservative approach as it represented a worst-case scenario for piping failure of the floodbank (i.e. the greatest possible driving head).

The 200-year ARI flood event has also been adopted for the seepage modelling, refer Section 10.

9.4.3 Breach Locations

The floodbank locations used for the breach modelling were mostly consistent with the cross-section locations used for the slope stability and seepage analyses discussed in Sections 8 and 10, respectively. Figure 4-1 shows these cross-section locations. Although these other analyses have used three cross sections, the breach modelling has only been undertaken for breaching of the floodbank at sections A-A and C-C, as agreed with ORC. This is because an additional set of model results for a breach at section B-B is unlikely to provide any additional understanding to the project.

9.4.4 Breach Details for Modelling

HEC-RAS requires a range of inputs to model floodbank breaching caused by piping failure. These inputs are summarised in Table 9-1. Refer to Figure 9-5 and Figure 9-6 for diagrams showing what these inputs represent.

Table 9-1. Summary table of breach details used as inputs for HEC-RAS modelling

Input	Value Selected for this Project	Comments/Justification
Failure location	Sections A-A and C-C as shown in Figure 1.	See section above discussing breach locations.
Failure mode	Piping failure	See section above discussing overtopping and piping failure.
Initial piping elevation	Base of floodbank • 8 m RL for A-A • 7 m RL for C-C	Worst case scenario – conservative approach.
Final base elevation	Base of floodbank • 8 m RL for A-A • 7 m RL for C-C	Worst case scenario – conservative approach.
Final base width	80 m	Mid-range value based on historic studies of stopbank breaches.
Side slopes	2H:1V	Typical value. Unlikely to have a significant impact on results due to high length to height ratio of breach profile.
Breach development time	2 hours	Based on a lateral erosion rate of 40 m/hour. This is a mid-range rate based on historic studies of stopbank breaches.
Trigger mechanism	Set time – 3 hours before peak flow in Taieri River occurs.	This allows the breach to fully develop 1 hour before peak river flow occurs. This is conservative as it represents a worst-case scenario of the maximum water level in the river coinciding with the fully developed breach profile.

Input	Value Selected for this Project	Comments/Justification
Piping and weir coefficients	Piping = 0.5 Weir = 1.44	Standard default values from HEC-RAS

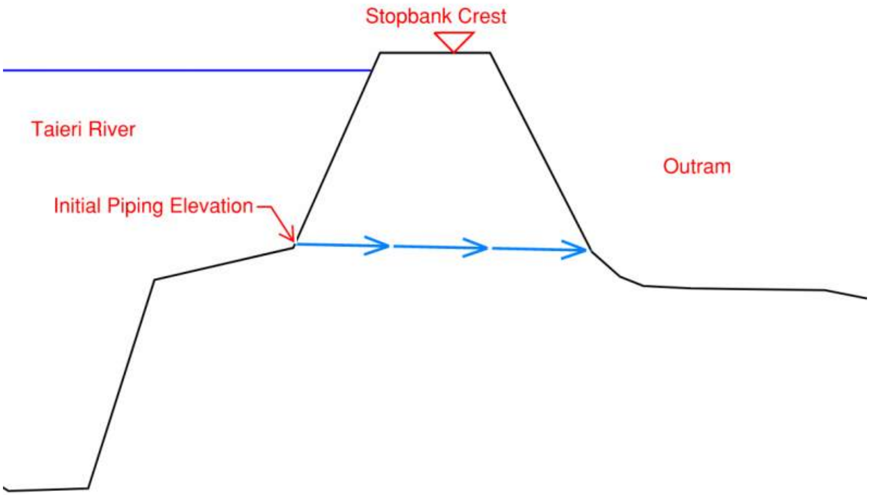


Figure 9-5. Cross section sketch of the Taieri River floodbank showing the initial stage of piping failure.

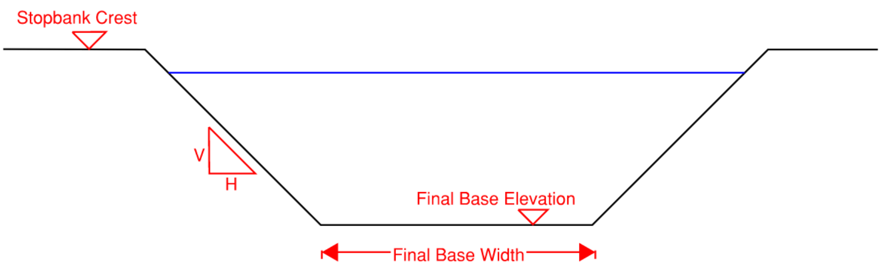


Figure 9-6. Long section sketch of fully developed breach profile.

9.4.5 Flood Hazard

For assessing flood hazard as part of this project, we have adopted the combined flood hazard curves produced by Smith et al. (2014) and reported in Australian Rainfall and Runoff (2019). Figure 9-7 presents these flood hazard curves, which reflect the vulnerability of people and assets when interacting with floodwater, as a combined function of water depth and velocity.

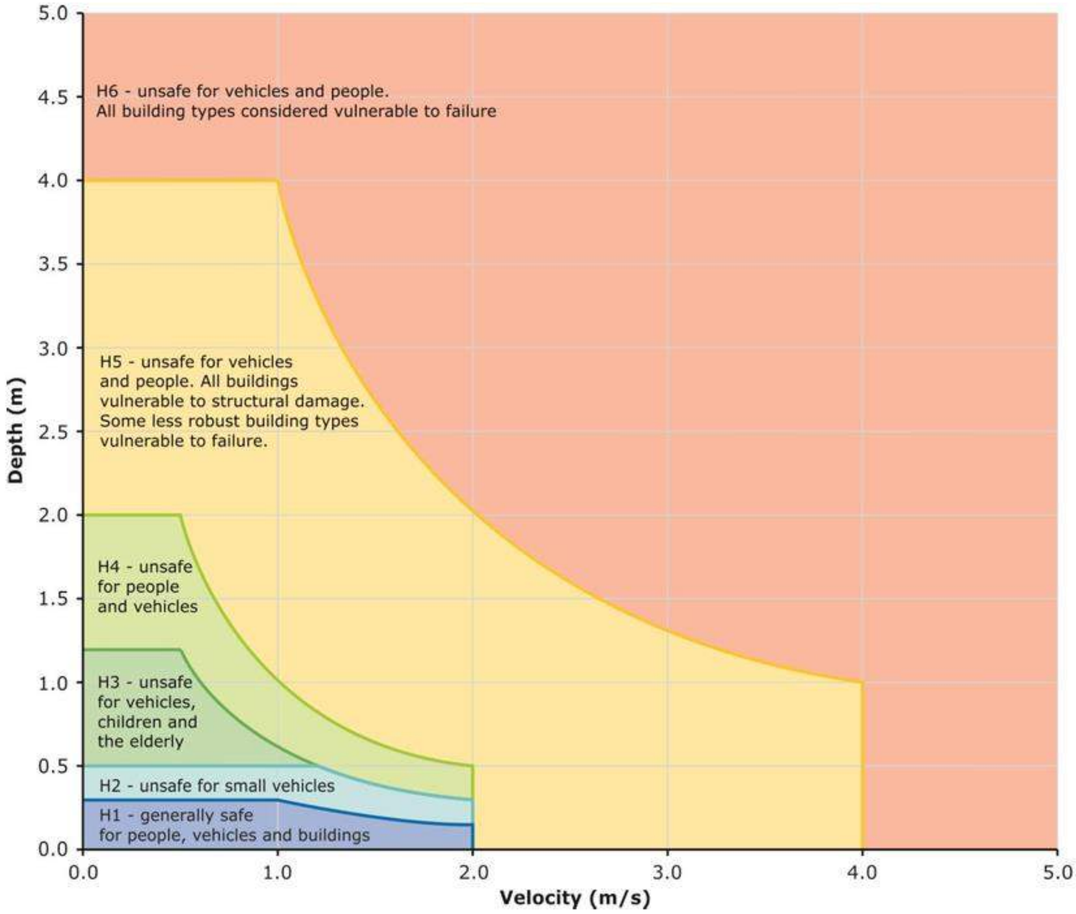


Figure 9-7. General flood hazard vulnerability curve.

We have used this method to define hazard categories in Outram and its immediate surroundings. The hazard maps for each of the breach locations are presented in Section 9.5.

9.5 Results

9.5.1 Overview

Results maps showing the maximum water depths for each of the breach model simulations are shown in Figure 9-8 and Figure 9-9.

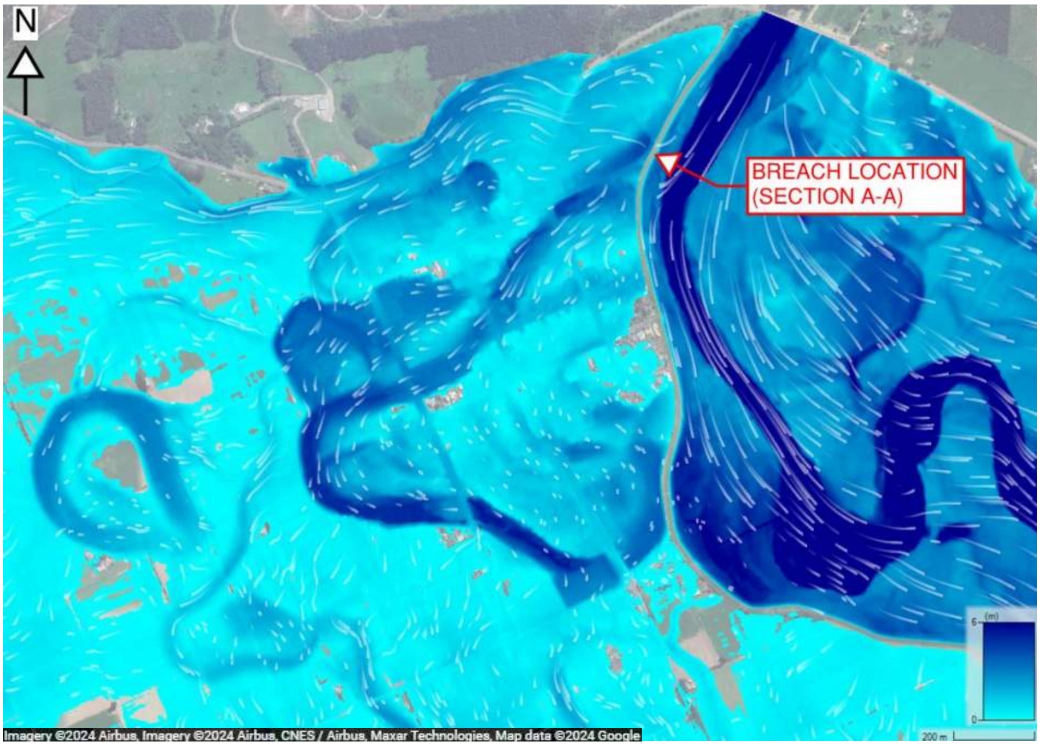


Figure 9-8. Maximum water depth model results for floodbank breach at Section A-A (Image source: Google Earth).

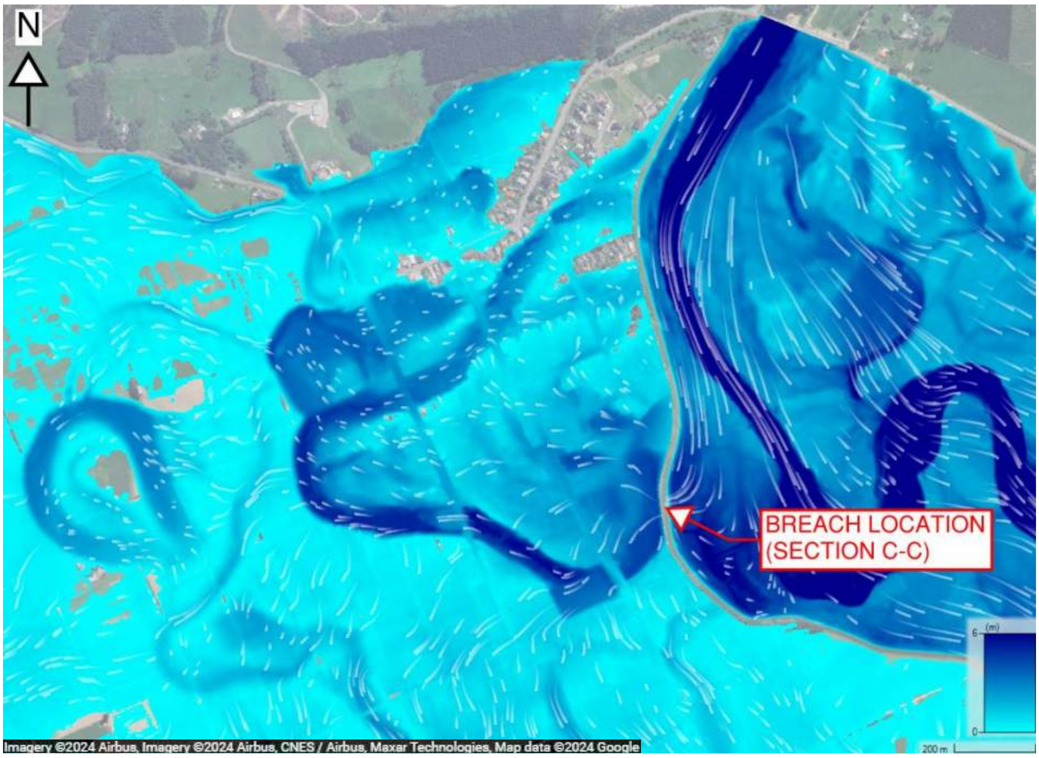


Figure 9-9. Maximum water depth model results for floodbank breach at Section C-C (Image source: Google Earth).

These results show significant inundation of Outram for both breach locations. The paleochannels (discussed in Section 3.1.2) appear to initially act as natural overland flow paths for floodwater and represent the deepest areas of inundation (up to almost 6 m water depth).

Appendix G contains maps showing the following results of each model simulation:

- Maximum depth.
- Maximum velocity.
- Maximum water surface elevation.
- Maximum flood hazard.

The maximum velocity results maps show localised areas of high velocity (3 to 4 m/s) in the immediate vicinity of the breach locations but indicate a rapid reduction to less than 2 m/s as water leaves the breach site. Flow velocities are generally low (less than 1 m/s) throughout the extent of Outram due to the flat topography of the area.

9.5.2 Flood Hazard Maps

Figure 9-10 and Figure 9-11 show the flood hazard maps for each of the breach locations. We have included the *NZ Building Outlines* layer from LINZ to show what individual buildings sit within the different hazard categories. We have also included the centrelines of the public roads providing access in and out of Outram to show the viability of residents using these roads to escape flooding.

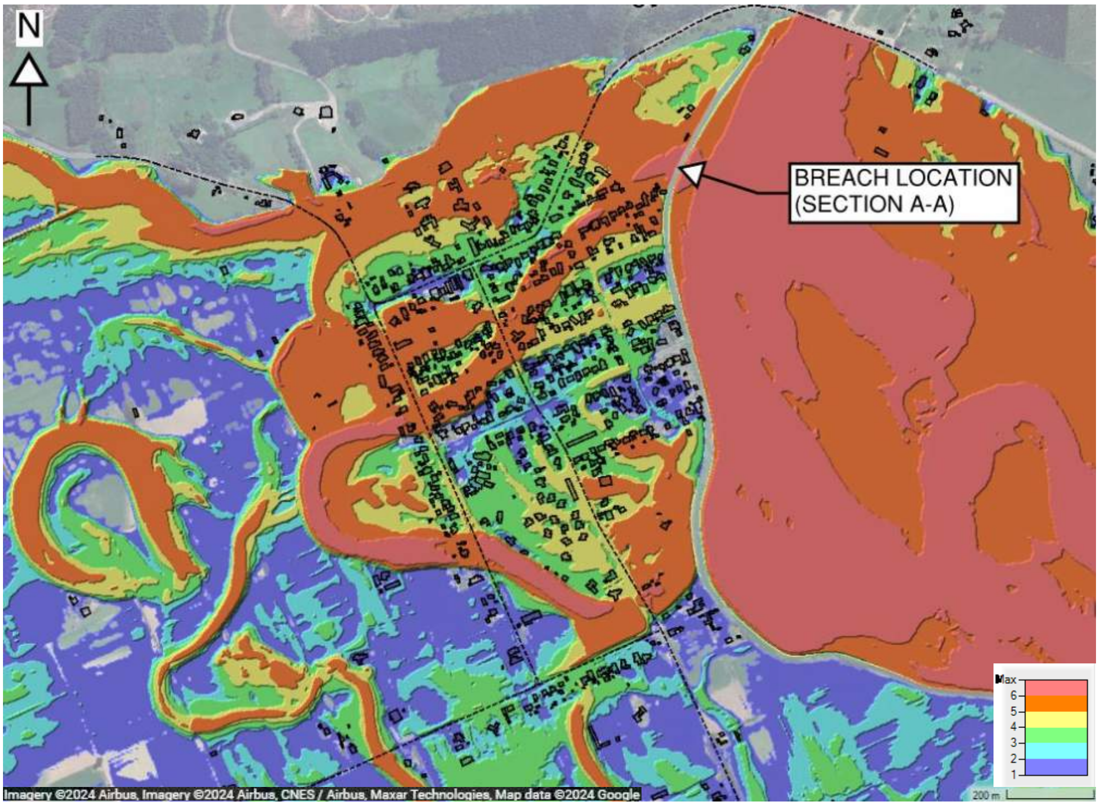


Figure 9-10. Flood hazard map for floodbank breach at Section A-A (Image source: Google Earth).

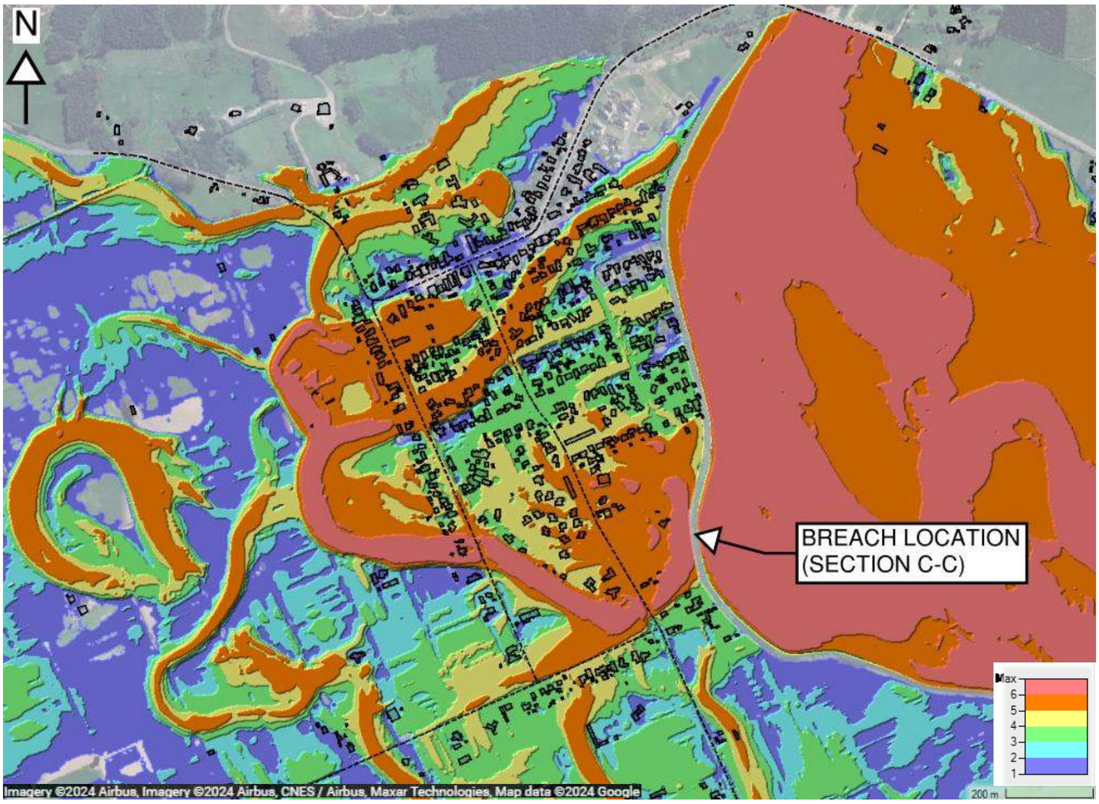


Figure 9-11. Flood hazard map for floodbank breach at Section C-C (Image source: Google Earth).

The flood hazard maps are similar for the two breach locations. In both cases the paleochannels (and areas adjacent to the channels) show a combination of mostly H5 and H6, representing areas of significant flood hazard. The flood hazard in other areas throughout Outram varies between no hazard and H4. The results are discussed in more detail in the following sections.

9.5.2.1 Buildings

Table 9-2 shows the approximate number of buildings located within each hazard category for each of the breach locations. It is important to note that these numbers are only indicative due to being manually counted.

Table 9-2. Number of buildings by hazard category

Hazard Category	Breach location A-A	Breach location C-C
H0 (no hazard)	28	75
H1	73	47
H2	61	34
H3	181	178
H4	73	82
H5	132	129
H6	3	6
Total	**551**	**551**

The number of buildings in the higher hazard categories (H3-H6) are relatively similar, while there is more variance in the lower hazard categories (H0-H2). Figure 9-7 shows that buildings are susceptible to structural failure in H5 and H6. There are a reasonably high number of buildings (roughly 25% of Outram's buildings) located within these hazard categories for each of the breach locations.

9.5.2.2 Roads / Access Routes

The roads shown as black dashed lines in Figure 9-10 and Figure 9-11 are the only public roads that provide access out of Outram. The hazard maps (and other results included in Appendix G) show that a breach at both locations has a significant impact on these access routes.

Figure 9-10 shows that the breach at section A-A causes all access routes to be cut off by areas of H5, meaning that most people located within Outram would have no way of evacuating the town once a breach has developed. Figure 9-11 shows that the breach at section C-C would have similar impacts, except State Highway 87 appears to provide a safe exit route from buildings located in the northern part of the town. It's important to note that the model inflow boundary for the Taieri River is located on the downstream side of the bridge, meaning that the impact of the flood event on the bridge has not been investigated as part of this project. This would need to be done to confirm whether State Highway 87 does in fact provide a safe access route from some of the town in the event of a floodbank breach at section C-C.

The hazard maps show maximum water depth multiplied by the maximum flow velocity, but do not provide any information on how long these hazard categories take to develop. The best opportunity for people to evacuate the town would be before the flooding reaches its maximum extents. To help understand the feasibility of this, the maps shown in Figure 9-12 and Figure 9-13 have been produced to show how long it takes, from the beginning of the breach formation, for 300 mm water depth to develop. A flow depth of 300 mm has been selected as it represents the upper depth limit of the H1 category, which is considered safe for people and vehicles (refer Figure 9-7), so would allow for people to safely evacuate the township.

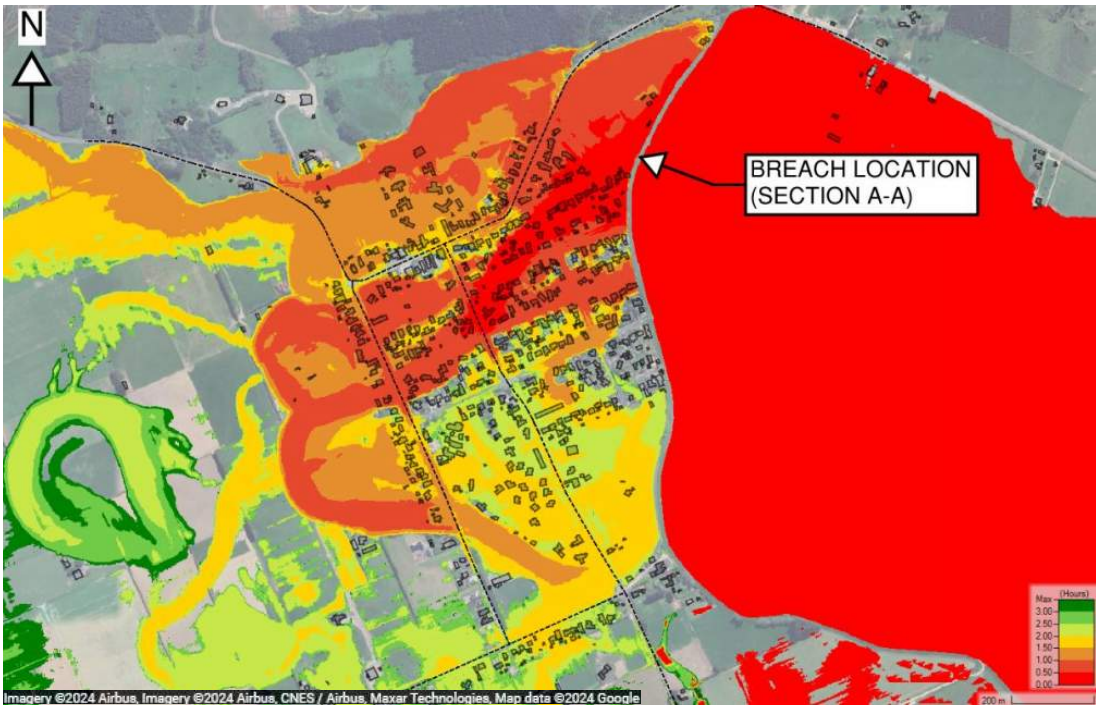


Figure 9-12. Arrival time results map for breach at section A-A. Colours represent time taken since beginning of breach formation for water depth to reach 0.30 m (Image source: Google Earth).

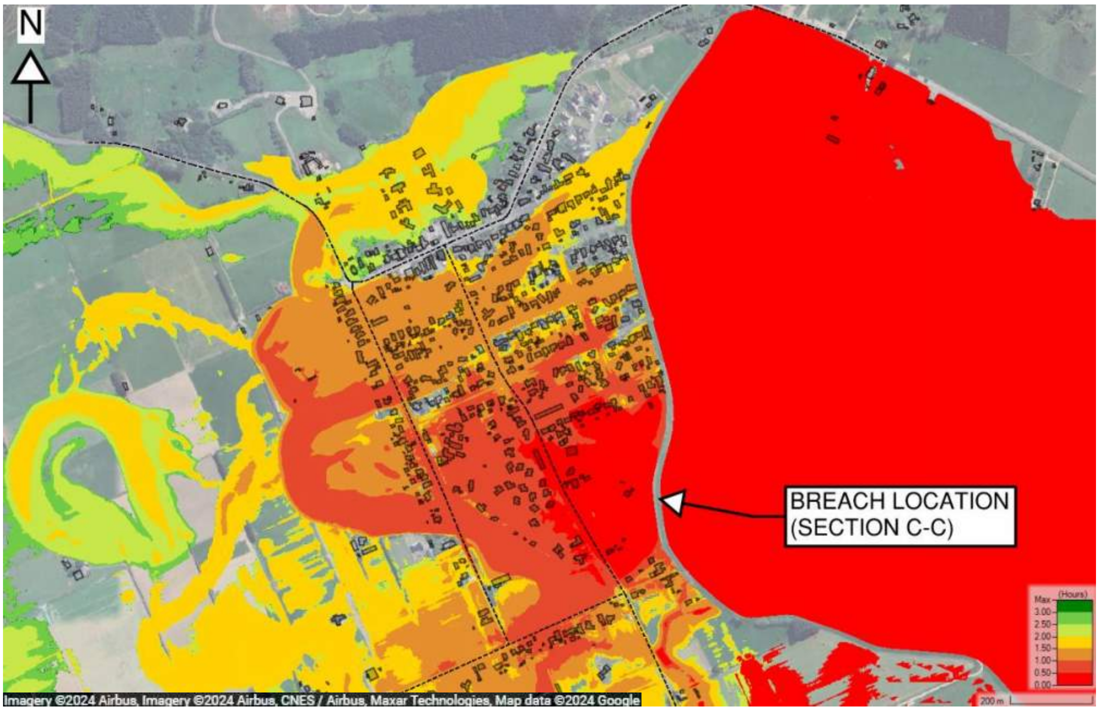


Figure 9-13. Arrival time results map for breach at section C-C. Colours represent time taken since beginning of breach formation for water depth to reach 0.30 m (Image source: Google Earth).

The results generally indicate that people will have a longer time window to evacuate the further they are from the breach site, as would be expected. For a breach at section A-A the roads on the south side of Outram would likely provide the most suitable means of leaving the town, while the roads on the north side of town would be most suitable for a breach at section C-C.

The results also indicate that, for both breach locations, it only takes one hour from the beginning of the breach formation for roughly 50% of the township to become inundated by at least 300 mm of water. After two hours this increases to almost the entire the town, potentially cutting off all evacuation routes. This means that, for the scenarios used in the breach modelling, the first hour of the breach development is crucial for allowing people to safely evacuate the town.

It's important to note that the alarm being raised immediately upon the start of the breach development is unlikely, especially at night. It is feasible that up to 30 minutes of potential evacuation time could be lost before a township-wide alarm could be raised. Any delay between the beginning of the piping failure and the alarm being raised would shorten the window available for safe evacuation and limit the effectiveness of that evacuation.

It is also important to note that these results will be heavily influenced by the breach formation time, which has been set as two hours in this instance (refer Table 9-1). Sensitivity testing of this time (and the other parameters in Table 9-1) could be undertaken to better understand the impact of a floodbank breach on evacuation routes.

10 Seepage Modelling

10.1 Introduction

Two-dimensional (2D) groundwater flow models were developed using the finite element software SEEP/W (version 2023.1.0) to indicate the response of groundwater to flood-induced seepage caused by high river levels in the Taieri River adjacent to Outram. Three locations were chosen for groundwater modelling using different flood scenarios and different antecedent (starting) groundwater conditions.

The objective of the seepage modelling was to indicate which scenarios (if any) may increase the risk of seepage failure in the floodbank and/or increase groundwater flooding risk in the township. The modelling utilised different river flood stages / recurrence intervals (RI) to estimate hydraulic responses in the groundwater levels across the floodbank, and to identify potential engineering interventions.

10.2 Model Development

The first part of building the groundwater models was to take the 3D Leapfrog model (as described in Section 5.1) as the 'parent' geological model and cut it into three, 2D cross sections which were exported into SEEP/W. These cross sections retained the stratigraphical and topographical outputs from the 3D geological model.

10.2.1 Model Extents

Each 2D groundwater model is centred through the Outram Township and the floodbank, extending beyond the Township extent to the west, and beyond the floodbank and Taieri River in the east. The cross-section locations are shown in 2D in Figure 10-1.

The extent of each seepage model was chosen to:

- Simulate the regional groundwater flow gradient, which generally moves in parallel with the elevation of the surface topography.
- Prevent undue influence of boundary conditions in the prime area of interest, i.e., near the floodbank.

The dimension details of the seepage models are shown in Table 10-1.

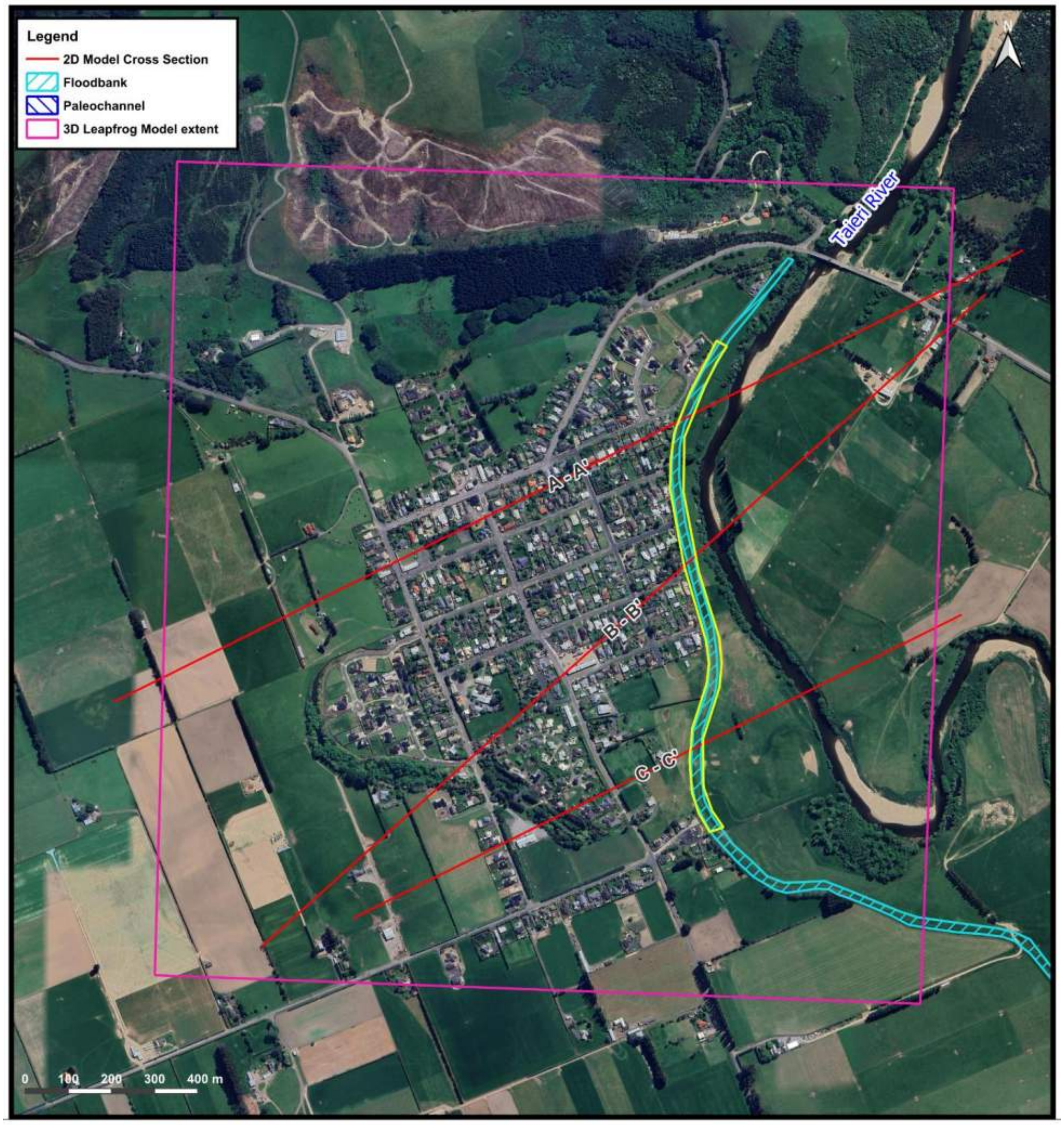


Figure 10-1. Overview map of Outram, its key features, and the Leapfrog and SEEP/W Model Extents. (Image source: Google Earth)

Table 10-1. SEEP/W model dimension details

Cross Section	Model Length (m)	Model Height (m)	Ground Level at Top of Floodbank (m RL)
A - A'	2,060	21.50	12.24
B - B'	2,177	20.40	12.17
C - C'	1,527	19.20	11.90

10.2.2 Model Topography

Paleochannels once formed part of the Taieri River system but are no longer directly linked to the main river channel and have no discharge point. The paleochannels are discussed in Section **3.1.2** and shown in Figure 3-3. ORC's overland flow path and paleochannel map is shown in Appendix F**.**

10.2.3 Model Layers and Hydraulic Parameters

The 2D models were developed with four main stratigraphic layers plus the floodbank fill within the model domain, as defined in Section 5 of this report. Note that cross section C- C' has an additional material layer which is a manmade 'weighting blanket' comprised mainly of locally borrowed silt (GeoSolve, 2022).

Broadly speaking, the cross sections have the following similarities:

- There is a sandy gravel at the base of each model.
- There is a gravelly silty sand along both banks of the Taieri River.
- There is a silt layer between the gravelly sand and the floodbank which continues across the entire surface of each model (apart from the floodbank).

While the hydraulic properties of each unit were kept the same in each section, their depths and extents vary in each model, which was based on available borehole data. The silt provides increased hydraulic separation between the gravelly sand and sandy gravel and the floodbank and can be seen in Figure 10-2 (note that the figure has 15 times vertical exaggeration).

The hydraulic conductivity values (K) adopted in the modelling were indicated by falling head test analysis as described in the Beca (2024) or were calculated based on laboratory PSD calculations using the HydrogeoSieveXL v 2.3.10 spreadsheet (Devlin, 2015). The K values used in the modelling are shown in Table 10-2**.** Assigning appropriate hydraulic conductivity values required balancing values from a range of sources as discussed in Section 5.5. The PSD to conductivity analysis results were preferred for use in the model as the higher conductivities represent a more conservative model.

A pragmatic approach was taken to assigning geological layers, and the material parameters described above by amalgamating similar materials and averaging out test values where there was significant variability.

There is uncertainty about the groundwater levels, particularly the high groundwater levels during flood events in the Taieri River, as there is very limited data available. Note that we recommend increasing the groundwater level monitoring regime.

The actual level of service offered by the floodbanks is not clear. The ORC hydraulic model does not overtop the floodbank with a flow rate of 3,939 m^3/s, though it represents a flood level near the top of the floodbank. This flow rate corresponds to a 1 in 200-year flood scenario which does not account for climate change.

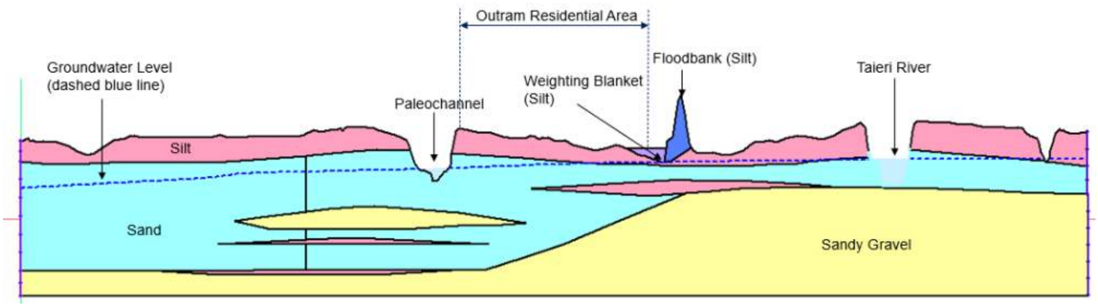


Figure 10-2. C – C' Cross Section Showing the Distribution and Thickness of Hydraulic Units (Note: 15x vertical exaggeration).

The coefficient of compressibility values shown in Table 10-2 were taken from textbook values (Freeze & Cheer 1979) based on their main material type, as were the anisotropy values. Low storage volumes were selected based on a mixture of PSD analysis (where available) and textbook values. These values were selected to model reasonably conservative parameters.

Table 10-2. SEEP/W material parameters

Material	Parameter			
	K (x) (m/s)	K (x) (m/d)	Anisotropy (ky'/kx')	Coefficient of Compressibility (x/1/kPa)
Sandy Gravel	2.0 E-04	17.28	0.60	1.0E-06
Gravelly Silty Sand	5.0E-06	0.43	0.30	1.0E-05
Silt	1.4 E-07	0.01	0.10	1.0E-05
Floodbank (Silt)	1.4 E-07	0.01	0.10	1.0E-06
Weighting Blanket (Silt)	1.0 E-07	0.01	0.05	1.0E-04

10.3 Boundary Conditions

Boundary conditions represent parts of the model where groundwater or surface water flow into or out of the model domain due to external factors. The key boundary conditions in this model are the Taieri River, the groundwater levels, and the rainfall recharge. Each of these boundaries is described in detail below.

10.3.1 Regional Groundwater Level and Flow

Constant head boundaries were applied on the side boundaries (the vertical edges) of the model to simulate sub-regional flow. These levels were based on a small number of observed data points from the recently constructed piezometers, and from scarce available historic data.

The groundwater head boundaries were set to different elevations to simulate approximate average conditions and approximate high groundwater conditions to account for the seasonal range in groundwater levels. Note that with the lack of long-term monitoring data, the groundwater levels in the model are approximate and require further monitoring to better understand groundwater levels in the area.

To derive an approximate seasonal range in groundwater levels, historic groundwater levels in bore I44/0838 on Orme Street were found, beginning in April 1997, shown in Figure 10-3 (note that the data references the Otago Datum). The important point to take away from this data is the seasonal range, which is about 1.5 m, with some short periods of significantly higher groundwater level in 2000, 2010, and 2013.

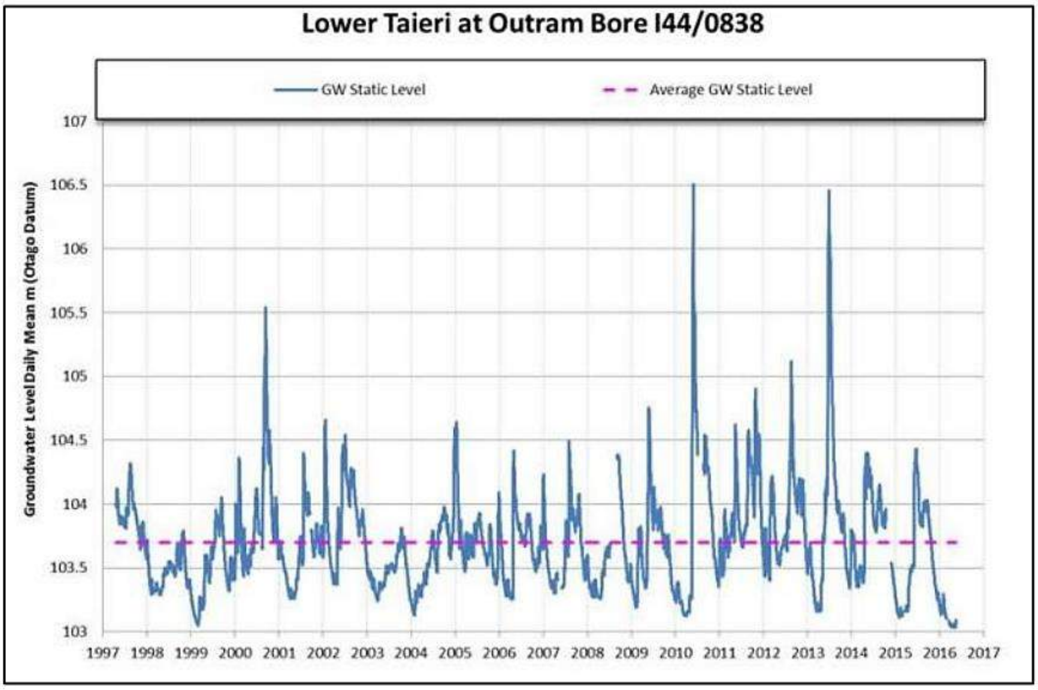


Figure 10-3. Groundwater Levels at Bore I44/0838 on Orme Street in Outram from 1997 to 2016.

Note that only average and peak groundwater levels were assessed, and no 'low' groundwater levels were used in any scenario as this would not be relevant in this flood modelling assessment.

The direction of regional groundwater flow is broadly from the northeast to the southwest. Regionally, groundwater moves perpendicular to the contour lines as shown in Figure 10-4**.**

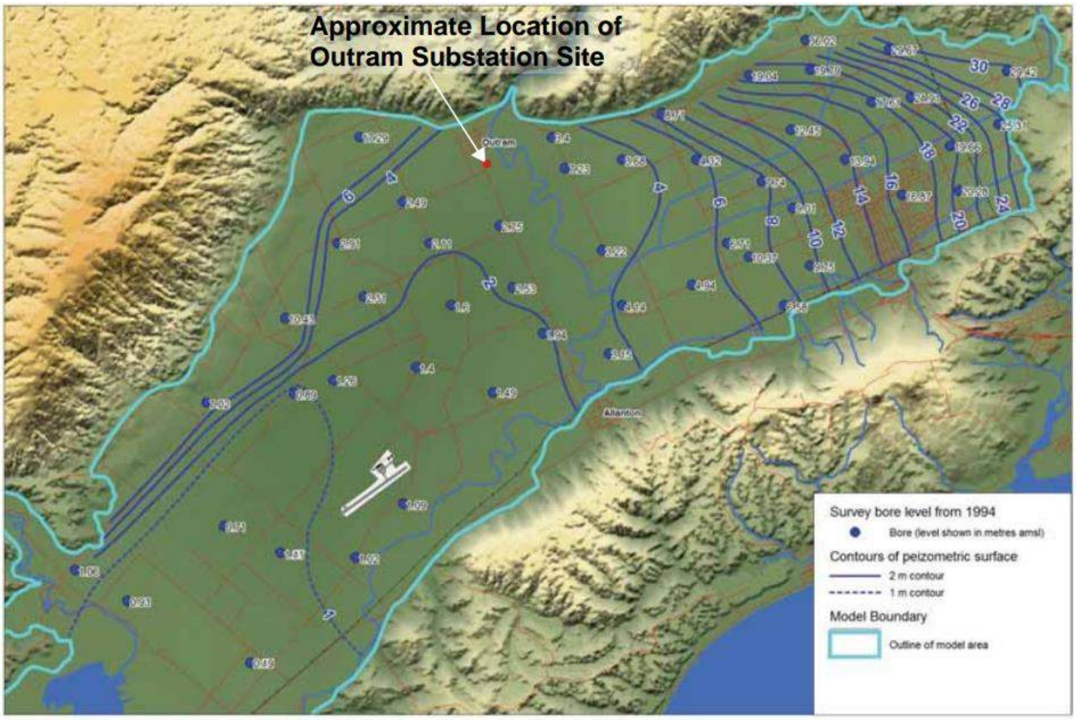


Figure 10-4. Contours / potentiometric surface from the 1994 survey of Groundwater Levels. Source: ORC, 2010. Lower Taieri Groundwater Allocation Study Report.

The groundwater levels assigned in the model were based on observed levels in the monitoring piezometers and are summarised in Table 10-3. These levels were measured in late summer when groundwater levels are typically at their lowest. High groundwater levels were calculated as the measured levels plus 1.5 m. The groundwater levels on the eastern side of the site (i.e., on the upgradient side of the model domain and over the floodbank and river from Outram), were set to be slightly higher than the 'average' river level to generate a groundwater gradient from northeast to southwest. Note that there is uncertainty around these levels until more monitoring data is available.

Table 10-3. Summary of constant head boundary conditions representing regional groundwater levels

Cross Section	Location	Average Conditions Specified Head (m RL)	Peak Groundwater Level Specified Head (approximate) (m RL)
A - A'	East	6.1	7.6
	West	3.5	5.0
B - B'	East	6.1	7.6
	West	3.0	4.5
C - C'	East	5.8	7.3
	West	3.0	4.5

10.3.2 Taieri River

The Taieri River is a large river which runs to the east of Outram Township after flowing across steep hill country of the Taieri Gorge into the flat terrain of the Taieri Plains, which it cuts across before discharging to the coast about 30 km south of Dunedin.

As it flows past Outram, the river has a mean flow of 42.2 cubic metres per second (cumecs), a median flow of 25.3 cumecs, and a mean annual low flow (MALF) of 6.6 cumecs (Booker, Woods, 2014). The river flows within 60 m of some residential properties on the eastern outskirts of Outram, with the floodbank between the river and the town. The highest flow recorded at Outram is 2,530 m^3/s in 1980, with other high flow events of 1,470 m^3/s in 1994 and 1,690 m^3/s in 2017.

The river stage level is input to the groundwater model as a step-datapoint function in the flood scenarios with levels rising from average flow conditions, up to the top of the floodbank and then gradually back to average flow (taken from the ORC hydraulic model).

At the approximate average river flow level, the river level is higher than the adjacent groundwater levels observed in early 2024 on the western side of the river and indicates that the river is losing water to ground, i.e., providing recharge to groundwater in the vicinity of Outram with preferential flow through the paleochannels under the floodbank.

The peak river flows recorded in the Taieri River in Outram each year over 50 years from 1968 to 2018 are shown in Figure 10-5. Note the large spike in 1980 which corresponds with a large flood event which resulted in significant damage in the local area.

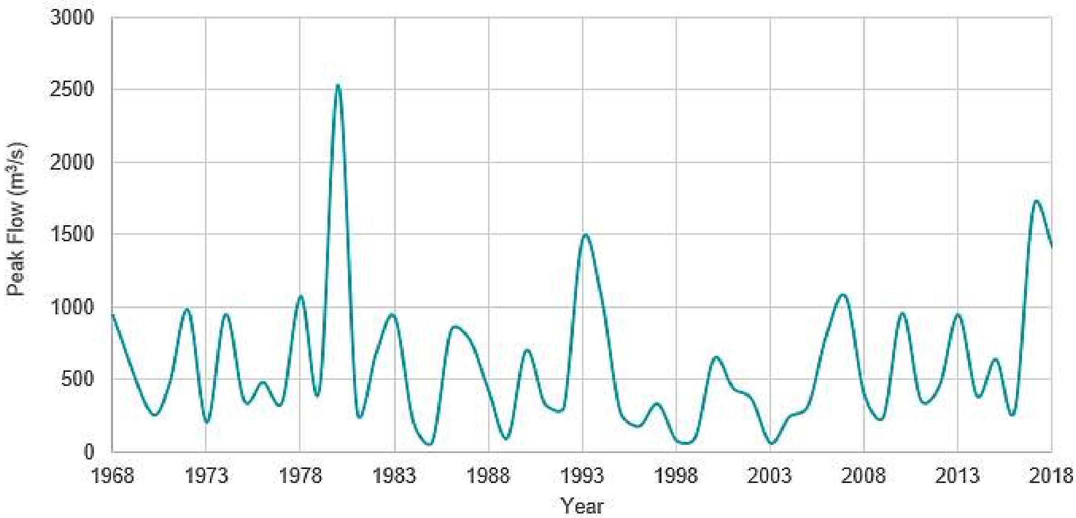


Figure 10-5. Taieri at Outram Annual Maxima Series. (Source: ORC, 2021)

A hydraulic model was provided to Beca from ORC which was used to derive the average or ‘starting’ river levels and to export both 1 in 100 and 1 in 200-year flood flows as shown in Figure 10-6.The flood responses are typical of most rivers with a sharp rise in river level followed by a gradual decline in flow after the peak. In the 1 in 200-year event, the model fails and crashes after the peak flow. This instability could not be resolved. Hence there is no data for most of the flow recession in the 200-year event. This does not impact our ability to assess the effects of flood flows on the floodbanks.

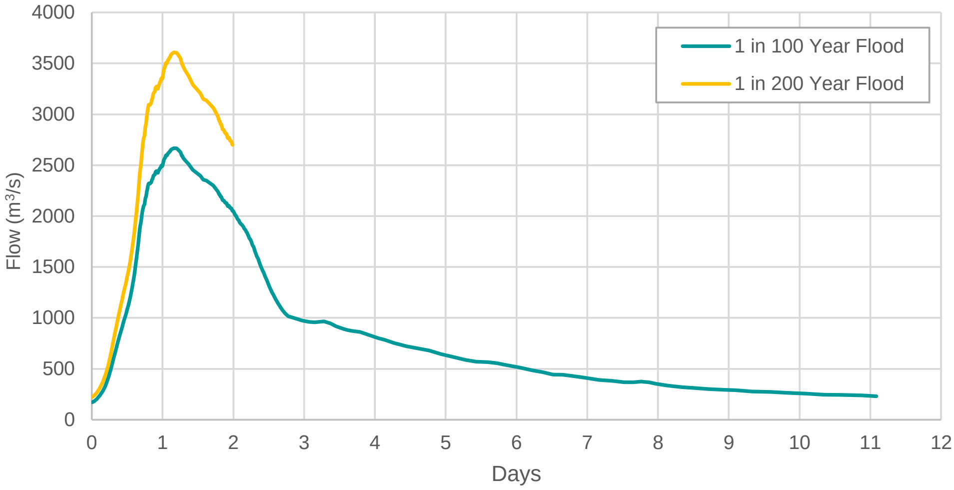


Figure 10-6. Hydraulic Model Flood Flow Outputs for 1 in 1—and 1 in 200-year Flood Events. (Source: ORC Hydraulic Model)

10.3.3 Rainfall Recharge

Rainfall recharge was added to the early groundwater model iterations to simulate recharge from the surface. The rainfall recharge applied was based on a 1 in 50-year rainfall volume over 48 hours from NIWA's *Climate and Weather of Otago* report (Macara, 2015). The rainfall volume used in the model is shown in the blue circle in Table 10-4**.** The percentage of rainfall used as recharge in the model was 5%.

Table 10-4. Maximum recorded short period rainfalls and calculated return periods from HIRDS (Source: Macara, 2015)

Location		10min	20min	30min	1hr	2hrs	6hrs	12hrs	24hrs	48hrs	72hrs
Dunedin (Musselburgh)	a	17.9	26.9	28.5	28.8	29.4	53.0	89.9	120.7	162.3	175.0
	b	Feb 2005	Feb 2005	Feb 2005	Feb 2005	Feb 2005	Jun 2015	Jun 2015	Jun 2015	Mar 1968	Mar 1968
	c	100+	100+	100+	100+	20	26	65	60	95	80
	d	4.1	5.8	7.2	10.3	14.8	26.5	38.2	55.2	67.2	75.5
	e	5.6	8.0	9.9	14.1	20.0	34.8	49.4	70.1	85.4	95.9
	f	6.9	9.9	12.2	17.4	24.4	41.8	58.6	82.1	100.1	112.3
	g	8.4	12.1	14.9	21.4	29.6	49.7	68.9	95.6	116.5	130.7
	h	10.9	15.7	19.4	27.8	37.9	62.3	85.1	116.4	141.8	159.1

Legend
a: highest fall recorded (mm)
b: month and year of occurrence
c: calculated return period of a (years)
d: max fall calculated with ARI 2 years (mm)
e: max fall calculated with ARI 5 years (mm)
f: max fall calculated with ARI 10 years (mm)
g: max fall calculated with ARI 20 years (mm)
h: max fall calculated with ARI 50 years (mm)

The model area is underlain by a silt material which inhibits rapid infiltration, meaning the direct rainfall recharge to groundwater over the area is expected to be relatively small and slow.

During the groundwater modelling process, it was discovered that when a recharge surface was applied to the model, (except for the river and paleochannels), the model was not able to render the surface flooding on the screen, hence having rainfall in the model made it difficult to interpret the results of each scenario and visually observe when and where groundwater was breaching the surface. As a result, Scenario 3 was created to account for a prior period of rainfall which had raised antecedent groundwater levels up to a higher level, closer to the ground surface in parts of Outram.

10.4 Simulation of Flood Levels

In the groundwater models, a conservative flood scenario is to place the river stage at the top of the floodbank. The ORC model indicates the top of floodbank level represents a flood condition in excess of a 1 in 200-year event, though the actual recurrence interval of the top of floodbank level reaching the top of the floodbank in Outram is not known.

Hydrographs of river discharge were sourced from ORC's hydraulic model simulating both 1 in 100 and 1 in 200-year events. River flood levels over time were derived by matching the shape of the discharge curve, starting from average river levels at the beginning of the storm and peaking with levels near the top of the floodbank (12 m RL in Section A – A') around 30 hours after the start of the flood.

The river levels used in the A – A' groundwater model are shown as blue dots in Figure 10-7.

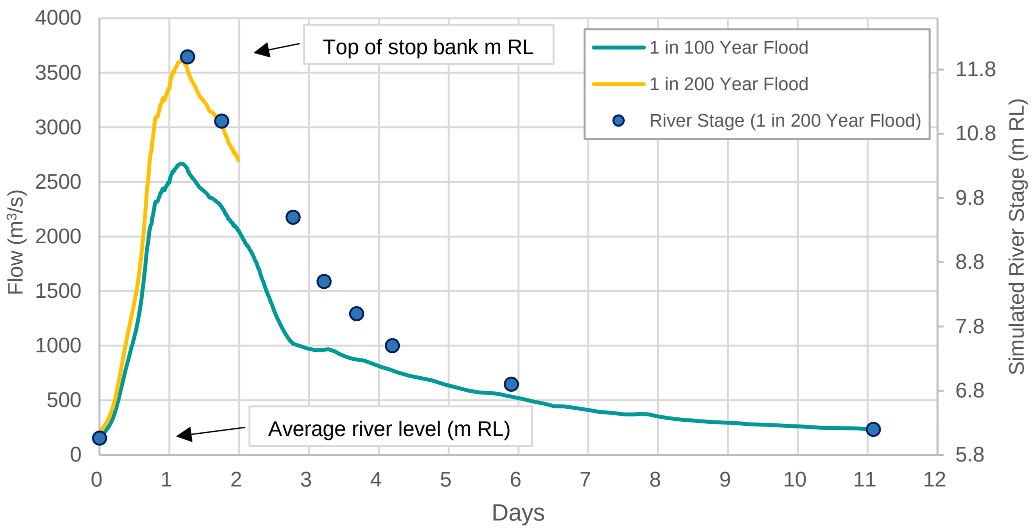


Figure 10-7. Plot Showing Flood Discharge Against Simulated Stage/ Level.

A screenshot of the top of the floodbank flood level for cross-section A – A' is shown in Figure 10-8 to indicate how the river stage is input into the groundwater model. Note the high-pressure head areas in red in the riverbed and extending out to the floodbank to the west and along the floodplain to the east. The phreatic surface or water table is shown by the dotted blue line. The model shown in the figure has five times vertical exaggeration.

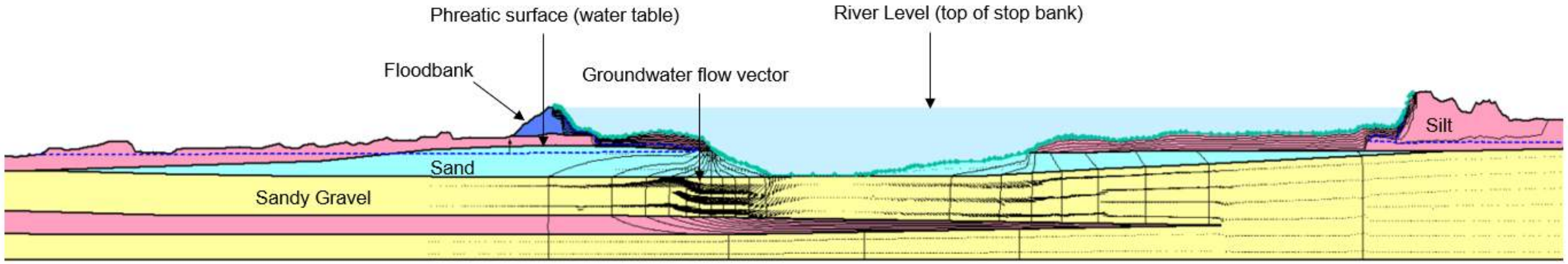


Figure 10-8. Peak Flood Scenario with River Level at the Top of Floodbank in Model A – A'.

10.5 Steady State Model

A steady-state model was developed to represent average groundwater and river levels prior to flood scenarios. Key observations of the antecedent conditions are summarised below:

- The groundwater gradient is from east to west (right to left on Figure 10-9) with higher head near the river and lower head on the western side of Outram. This reflects the trend of regional piezometric head shown in Figure 10-4.
- The river is generally losing water to ground through Outram, with the average river head being higher than average groundwater head (based on observed and available information). Note that there may be times when the groundwater level is at its peak, and contributes flow to the Taieri River, but in normal conditions the river appears to be losing water to ground.
- There is surface water in some parts of the paleochannel which can be seen in C – C' cross sections in Figure 10-9. Note that in the cross-sections below the vertical exaggeration is set to 15 to allow the main features to be visible.
- The steady state models represent average conditions and are shown in Figure 10-4.The groundwater level is shown by the dotted blue line, the different colours represent the different strata, and the light blue shape above the strata is the surface water level. These steady-state models fed into the transient models for each section.

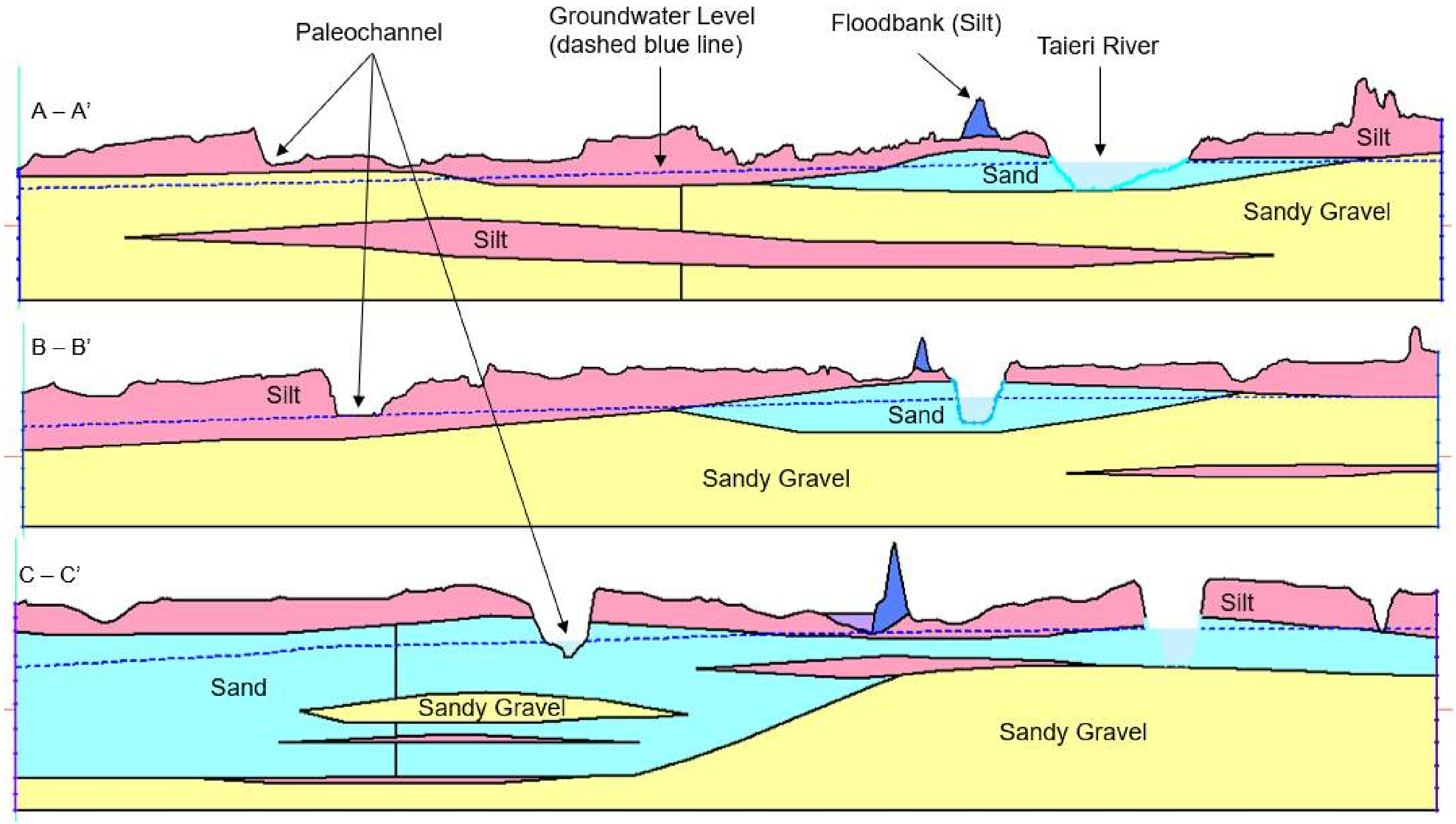


Figure 10-9. Simulated Model Head in Average Water Table Conditions: A – A' at the Top, B – B' in the Centre and C – C' at the Bottom

10.6 Transient Model Scenarios and Results

Transient models were created from each steady-state model and run for 30 days each. Three scenarios were used to assess the model's response to different conditions:

- Scenario 1: A flood event where the river level reached approximately 2/3rds of the way up the floodbank for a duration of 0.5 days, before returning to starting levels after about 6.5 days to model a 3,047 m^3/s flood flow, which corresponds to a 1 in 100-year flood event, with low – average antecedent groundwater levels.
- Scenario 2: A flood event where the river level reaches near the top of the floodbank for a duration of 0.5 days, before returning to starting levels about 10 days after the peak to model greater than a 3,939 m^3/s flood flow, or a 1 in 200-year flood event. This scenario was run with no rainfall recharge, and with low – average groundwater levels for the antecedent conditions.
- Scenario 3: The same river level conditions for Scenario 2 are used but coinciding with high groundwater levels (1.5 m higher than observed in April 2024), which were intended to simulate a period of higher rainfall infiltration before the increase in river levels. The key details of each scenario are summarised in Table 10-5.

Table 10-5. SEEP/W model scenario details

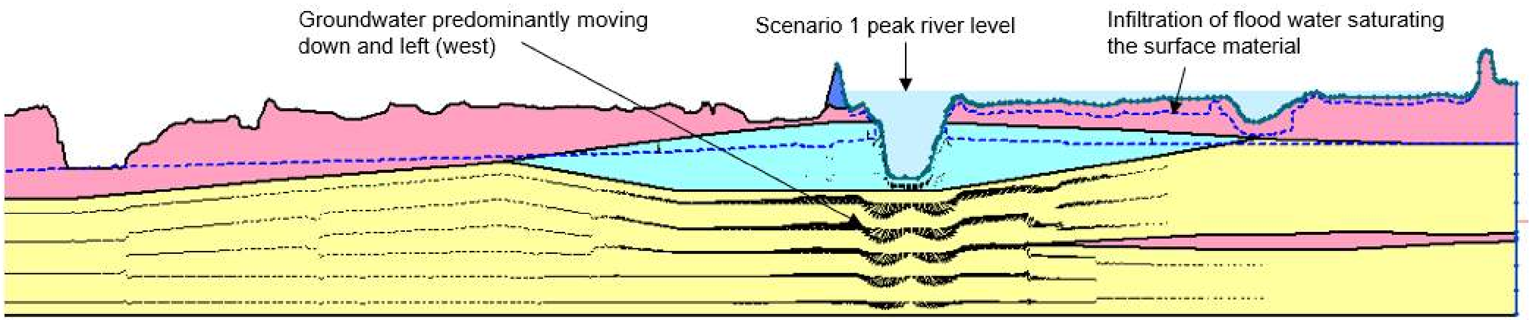
Scenario	Description	Cross Section	Starting Groundwater Level (m RL) on the Western Side of the Site	Peak River Level (m RL)
1	River Level at 2/3rds floodbank height with average GWL	A – A'	3.48	10.24
		B – B'	3.00	10.17
		C – C'	3.00	9.90
2	River Level at top of floodbank with average GWL	A – A'	3.48	12.24
		B – B'	3.00	12.17
		C – C'	3.00	11.90
3	River Level at top of floodbank with high GWL	A – A'	4.98	12.24
		B – B'	4.50	12.17
		C – C'	4.50	11.90

Note: m RL refers to NZVD2016.

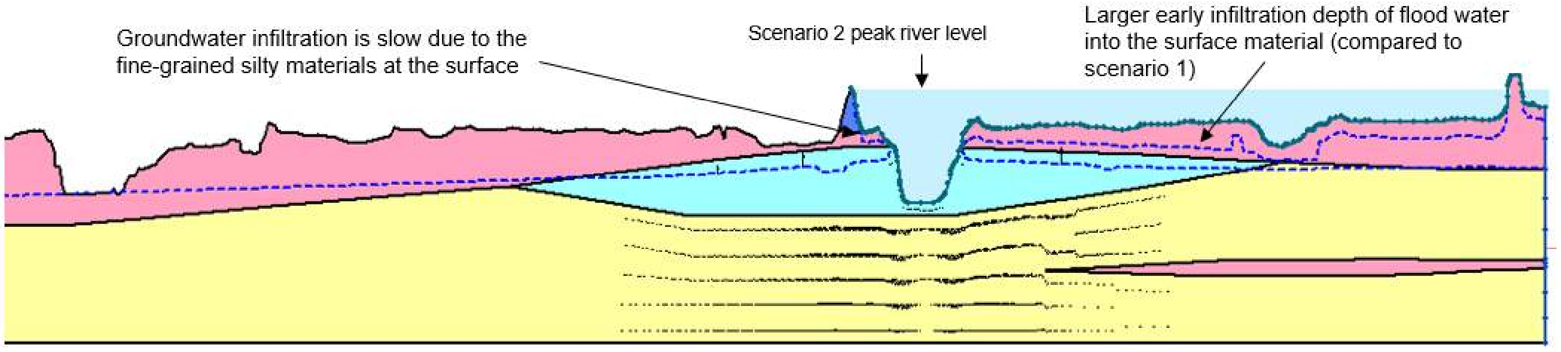
Key observations of each scenario in model B – B' are shown in Table 10-6.

Table 10-6. Key observations from model B-B' from each scenario run

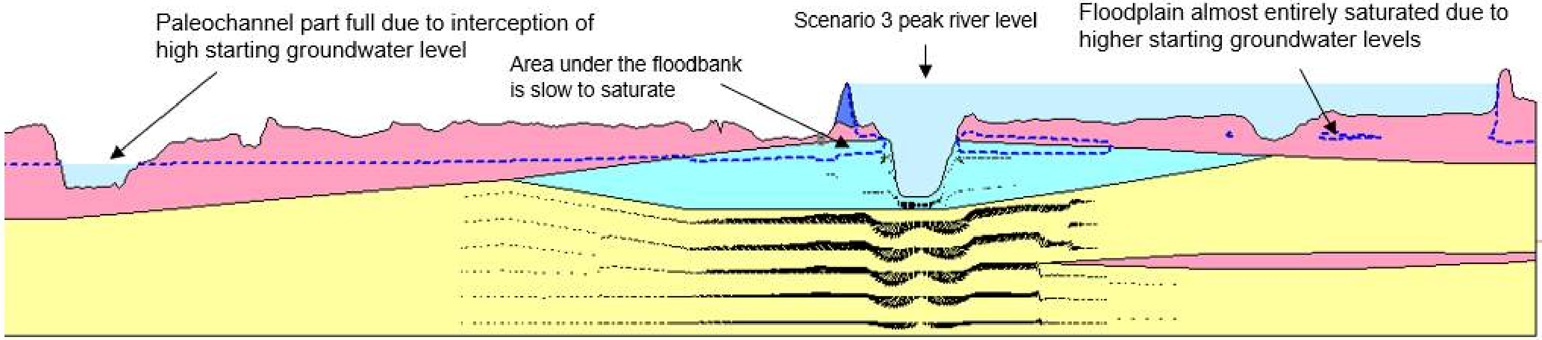
Scenario	Description	Results
1	1 in 100-year river stage and average starting groundwater levels	• In the model, the seepage face moved a small way through the floodbank during high river levels, but as the river level resided, the seepage face did not move through the entire floodbank. The permeability and storage properties of the floodbank material retards shorter duration groundwater flow. • In the model, surface flooding in Outram did not occur from groundwater breaching the surface. This is likely because the flood event was too short-lived, the river level was not high enough, and the antecedent groundwater levels did not have time to rise to the surface. • The flood scenario induced minor groundwater level rise underneath Outram and its floodbank, as well as increasing the water level in the paleochannels. In the model, this took about 3 days for peak groundwater/ paleochannel levels to occur after the peak river level occurred, i.e., there is a delay in the response. • The peak river level is shown in the row directly below.



Scenario	Description	Results
2	Top of floodbank stage and average starting groundwater levels	• In the model, the seepage face moved part way through the floodbank during high river event, but with the river level receding, the seepage face did not move through the entire floodbank for the same reasons described in Scenario 1 above. • There was some surface flooding in the lowest lying parts of Outram driven by groundwater pushing up through the surface strata. The groundwater reached the surface approximately 3 days after the peak of the flood but did not continue to rise significantly above the surface before it began to subside. This was a subdued and delayed response to the flood, as it took much longer for water to move through the ground than flowing over the surface as it would in a rainfall-runoff induced flood. • The levels in the main paleochannel increased by approximately 300 mm, about 3 days after the flood peak. For reference, the paleochannel in cross-section C – C' is about 200 m from the floodbank. • A screenshot of the top of floodbank river level is shown in the row directly below.

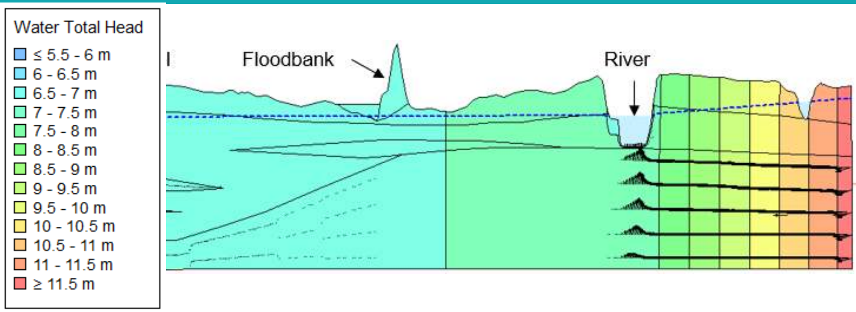
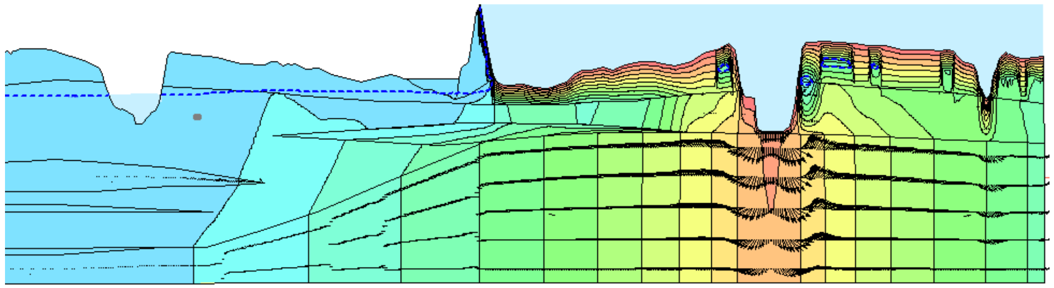


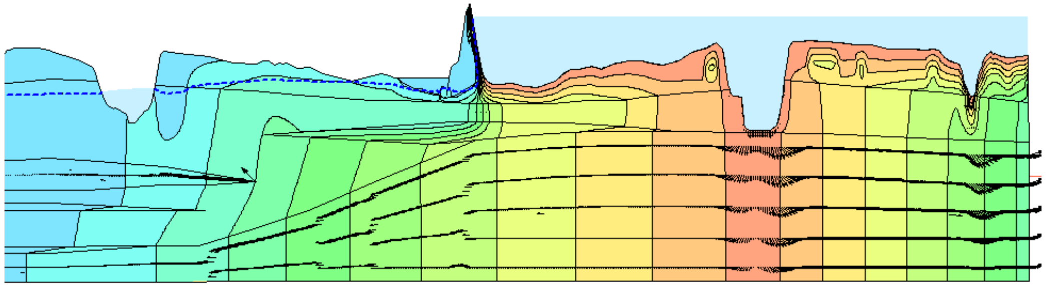
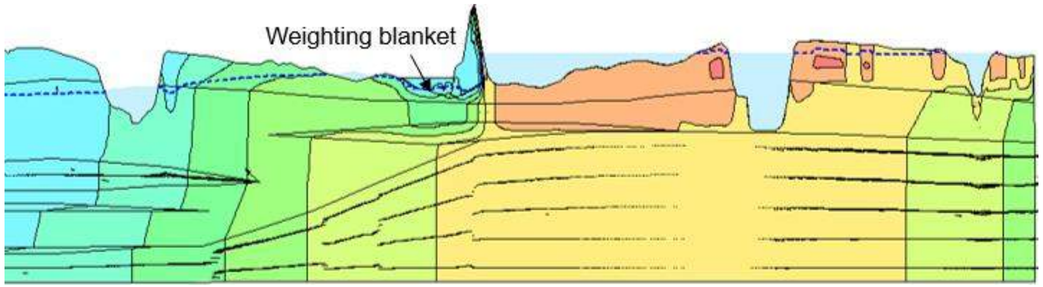
Scenario	Description	Results
3	Top of floodbank stage and high starting groundwater levels	• In the model, the seepage face did not migrate through the floodbank for the same reasons explained in Scenario 1 and 2. • Surface flooding in the low-lying parts of Outram was modelled to occur about 3 days after the peak river level. The flooding occurred as a result of groundwater pushing up through the upper sand and silt layers driven by the high head in the river. • The water level in the C – C' paleochannel increased by about 600 mm, peaking about 3 days after the peak river level. • Once the river level subsided, and groundwater levels were higher than the river level, the groundwater strata started to release water from storage and recharge the river until the original equilibrium was reached. • A screenshot of the top of floodbank river level is shown in the row directly below.

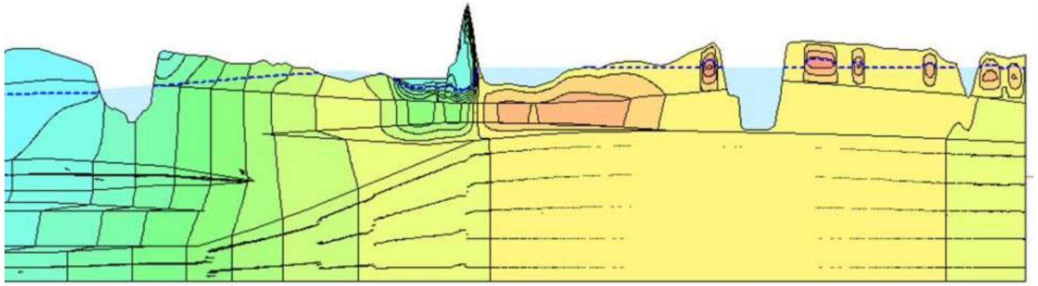
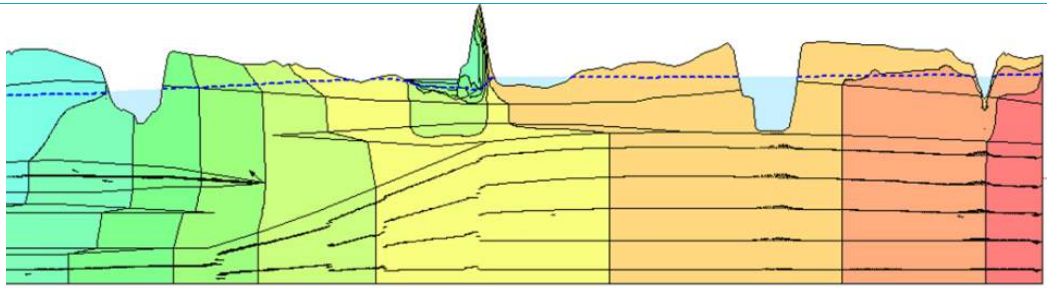


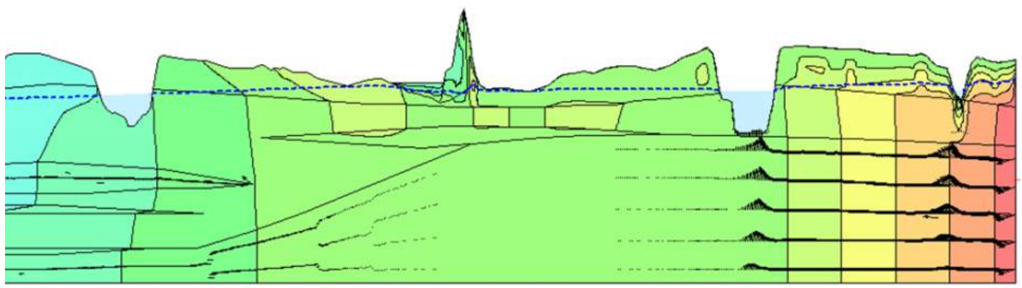
Screenshots of model C – C' through different timesteps are shown in Table 10-7. The table shows the model in chronological order with the early steps at the top and late steps at the bottom.

Table 10-7. Model C – C' – Scenario 3 groundwater flow model outputs indicating the change in groundwater head across various river stages

Step	Hours after Peak River Level	Description of Result	Model Image
1	0	The top screenshot is at initial conditions before the river level rise. Note the high starting groundwater levels. The colours on each screenshot represent the total water head in metres. The legend showing water total head to the right applies to all screenshots in this table, with high head in red and low head in blue colours.	
2	1	Then second screenshot is when the river reaches the top of the floodbank. This increases the pressure (head) on the bed of the river and on the floodbank as represented by the red/orange/yellow colours. The arrows show that water in the flood channel is infiltrating to ground and moving both left and right through the ground.	

Step	Hours after Peak River Level	Description of Result	Model Image
3	23	The third screenshot shows river levels beginning to decline, about 1-day (23 hours) days since the peak. Now the areas of high head are migrating outwards, and the phreatic surface is moving upwards. Groundwater levels and paleochannel water levels increase.	
4	54	The fourth screenshot shows the river level declining 2.25 days (54 hours) after the peak. The groundwater levels have now breached the surface on the township side of the floodbank, causing surface flooding. Groundwater levels are still increasing, and groundwater is moving west under Outram. Note that the weighting blanket reduces daylighting at the toe of the floodbank.	

Step	Hours after Peak River Level	Description of Result	Model Image
5	3.4 days	The fifth screenshot shows the peak surface flooding caused by high groundwater after about 3.4 days since the river level peak. Even though the river level is continuing to drop, the groundwater level has risen in a delayed fashion and reached its peak. This lag in response is a result of groundwater seepage being significantly slower than overland (surface) flow.	
6	8 days	The sixth screenshot shows surface floodwaters have soaked back to ground after about 8 days.	

Step	Hours after Peak River Level	Description of Result	Model Image
7	11 days	This image shows the river return to approximately an average level, about 11 days after the peak river level. The groundwater levels are now higher than the river level, hence groundwater flow direction under the floodbank has reversed and is now recharging the river. As groundwater levels gradually drop, the system returns to the conditions shown in the top screenshot.	

10.6.1 Seepage Through the Floodbank

The modelling in Scenarios 1 to 3 indicates that the seepage face does not migrate directly through the floodbank to the Outram side (landside) of the floodbank. This is largely due to the lower hydraulic conductivity parameters applied to the floodbank and shoulder bank representing the near surface siltier strata found in the boreholes. In the model, the presence of higher hydraulic conductivity materials (sand and gravel) at about 1 to 3 m depth allows groundwater to infiltrate more rapidly via the riverbed and reduces direct seepage around the toe of the floodbank.

A sensitivity test was carried out on model A-A' with the same parameters as assigned in scenario 1 to 3 in order to check whether or not the sand and gravel units were consistently relieving the pressure and preventing seepage fronts developing directly through the floodbank. To do this, an artificial (and unrealistic) modelling scenario was run where the river level was set to the top of the floodbank for one week to simulate how saturated the floodbank could become if given enough time. The model indicated that the seepage face does not migrate through the floodbank entirely, rather it travels via the in-situ soils beneath the floodbank to daylight at or near the inside toe of the floodbank and in the paleo-channels on the Outram side. Note that this is only true with the hydraulic conductivity and storage parameters shown in Section 10.2.3.

While the high river level boundary condition did not cause the seepage face to completely migrate through the floodbank, when high hydraulic conductivities in the order of 1E-05 m/s (i.e., higher than any test results in the floodbank material) were applied, seepage through the modelled floodbank did occur, but only after about 3 days of consistent top of floodbank river levels (which is well beyond a 3,939 m^3/s flow / 1 in 200 year river flood event). The intention of this case was to assess what factors may be necessary to cause seepage failure through the floodbank, and what could happen if there was an area in the floodbank prone to piping. It is important to note that the floodbank does not have completely homogeneous material properties, there are likely to be some sections which will be more resistant to seepage than others, hence it is possible that water could seep through sections containing higher permeability materials. This situation is discussed further in the Section 10.7.

It is important to note that the results described above relate only to seepage and not slope stability. Seepage moving through the floodbank does not indicate floodbank failure, and seepage moving part-way through the floodbank does not translate to a stability failure of the floodbank. However, good floodbank management practice includes prevent complete saturation of floodbank materials and maintaining suitably low hydraulic gradients to reduce the risk of piping failure.

One factor which initially reduces the rate of seepage through and under the floodbank is the shoulder bank between the main river channel and the floodbank which can be viewed in the photo in Figure and on the cross section in Figure . This mass of material takes a relatively long time to saturate and slows the rate of seepage through and under the floodbank area. In effect, the shoulder bank retards movement of groundwater into the floodbank. The flood scenarios which are based on real-world flow-duration curves tend to have a rapid rise in river level, short peak, followed by a slow drain-down. The modelling indicates that by the time the seepage saturates part of the floodbank and riverbank, the river levels are already in decline, and the pressure head is reducing. The mounded groundwater then moves downgradient, under the floodbank, and has the potential to flood the low-lying parts of Outram.

It is possible that infiltration into the ground would be slower through the riverbed due to the presence of a clogging layer, hence potentially placing more pressure on the floodbank. To test this, a low permeability layer of about 0.25 m thickness with a hydraulic conductivity of 1E-7 m/s was added near the bed of the river. The result was that infiltration to ground was slower, and that there was less groundwater induced flooding in Outram indicated by the model.

The rate of movement and depth of penetration of the seepage face into the floodbank did not change appreciably with the presence of the clogging layer, though there was a small increase in the size of the hydraulic gradient in the model with the clogging layer as seen by the comparison in Figure 10-10. Note that the hydraulic gradient as above are represented by arrows, with the groundwater flow direction matching the arrow direction, and the size of the arrow reflecting the magnitude of the hydraulic gradient.

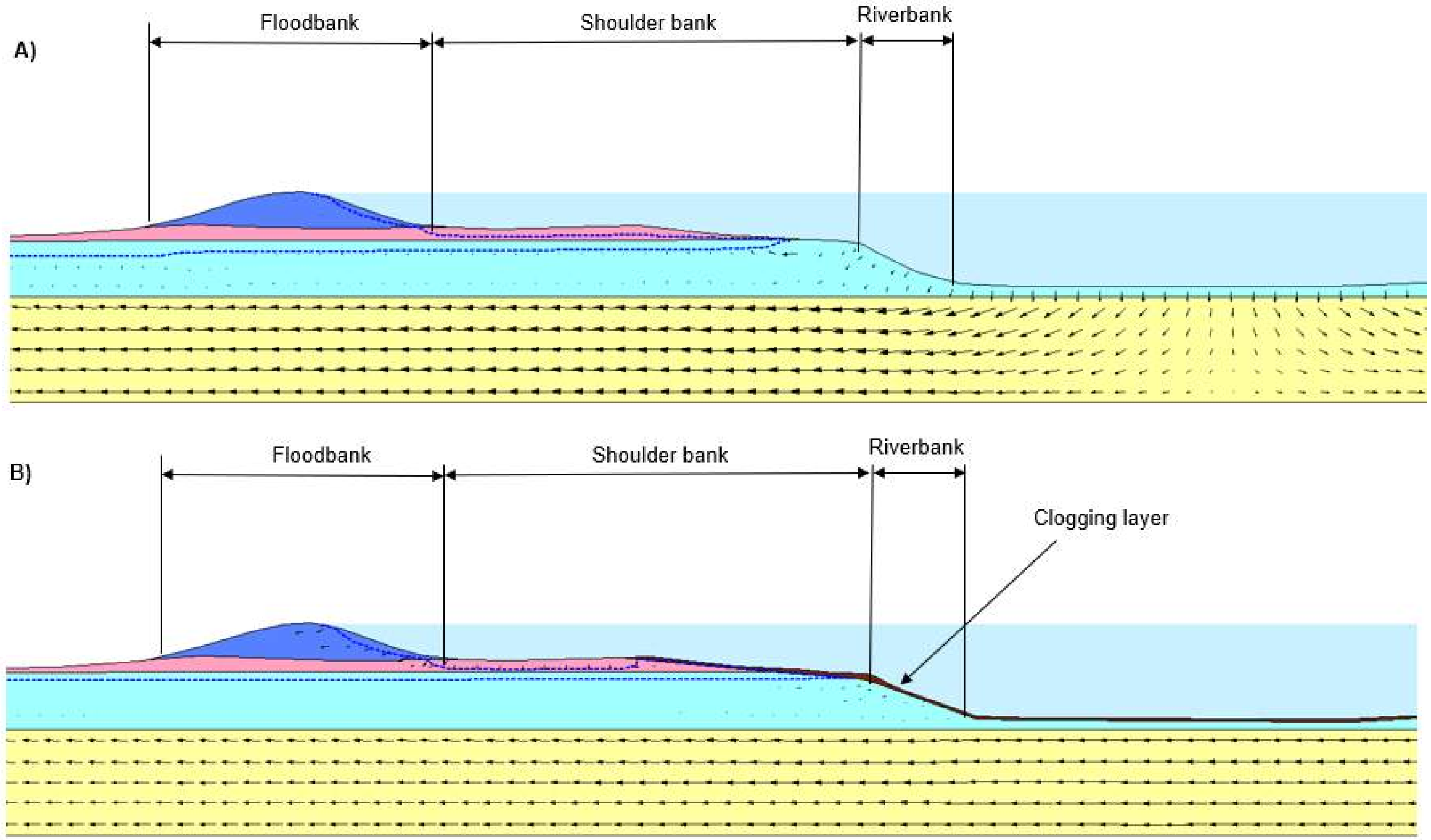


Figure 10-10. Figure Showing the 'Shoulder Bank,' in Cross Section A – A.' The top image (A) is from 3 hours after the river reached the top of floodbank (Scenario 3) without a clogging layer, and the bottom image (B) is the same but with the clogging layer in place.

10.6.2 Effects from Antecedent Groundwater Conditions

Antecedent conditions refer to the conditions present at the beginning of a modelling exercise. Two antecedent groundwater level conditions were simulated in the model: average and high.

The modelling indicates that the high groundwater levels do not have an appreciable influence on the rate at which water saturates the floodbank. However, antecedent groundwater levels have a significant impact on the depth and extent of flooding within Outram. When groundwater levels are at average levels, there is a large volume of unsaturated pore space in the upper strata which can be saturated before groundwater reaches the surface and contributes to surface flooding.

Whereas, if groundwater levels are already close to the surface, the additional water from a significant river flood event has nowhere to go, more rapidly causing flooding, mainly within the paleo-channel areas. The groundwater modelling indicates that when the river reaches the top of the floodbank and is coincident with seasonal maxima in groundwater levels, this will likely increase the likelihood of increased flooding in some areas of the Outram Township. Moreover, if groundwater is at seasonal maxima, and rainfall is coincident with high groundwater, surface flooding is likely to occur more quickly, especially within the paleo-channel areas which do not currently have a joined-up conveyance route.

10.7 Discussion

The variable which had the highest sensitivity in the groundwater modelling process, and therefore the greatest effect on the outcome of the modelling was the hydraulic conductivity of the materials, particularly the floodbank and the surficial silt units in the upper part of the model.

Another variable that the groundwater model was sensitive to, was the volumetric water content function. Broadly speaking, this function acts as the storage capacity of the material it is assigned to. A sensitivity analysis was carried out which found that a high volumetric water content function in the materials (particularly those near the floodbank) significantly slows the rate of movement of the phreatic surface (groundwater table) and hence the rate of groundwater movement under the flood scenario.

Groundwater modelling suggested that the ‘shoulder bank’ retards the seepage response of groundwater to flood events in the river, but it is important to note that the “clogging” effect of these material could very over time as river scour remove and deposit materials in different places.

Finally, the modelling suggests that the weighting blanket (only present in model section C – C’) may reduce the rate of groundwater rising to the surface at the inside toe of the floodbank. In effect it acts like a confining layer. With regards to surface flooding, this material retards surface water infiltrating to ground, hence surface water build up will not drain as easily on this material. ORC indicate there is the ability to drain surface water under gravity and pump it out during weather events.

10.8 Options to Address Seepage Risks

Three possible options to address groundwater flooding and floodbank seepage issues are listed and discussed below. It is important to note that these options are only hypothetical at this stage and require further investigation to determine whether they are feasible and/or cost effective.

- Connect the paleochannels via pipes and/or open channels to convey surface and groundwater away from Outram Township.
- Install a floodbank relief drain in the toe area on the Outram side of the floodbank and connect it to an improved paleochannel drainage system.
- Connect to and improve the current gravity outlet and consider a pump station to convey drainage water from Outram to the river during flooding events.

The paleochannels are natural historic flow paths for surface water. These channels could be better utilised to perform storage and drainage conveyance functions. Rising groundwater will discharge first into these paleochannels and fill them up, as they form the lowest lying parts of the town.

The major and remaining paleochannels are located across the western and southern areas of the township. These have been infilled on the eastern side of town nearer the floodbank. A subsoil relief drain in the toe area on the Outram side of the floodbank would provide additional groundwater and seepage protection locally to the floodbank. A drain in the toe area would help to reduce uplift pressures developing within the floodbank and assist in reducing seepage related failure as well as helping to remove excess flood water.

The paleochannels and relief drain in the toe area could be connected to the main river channel via the existing gravity outlet near the substation. A pump station could also be considered for high flow events. An indicative map of this system in shown in Figure 10-11.

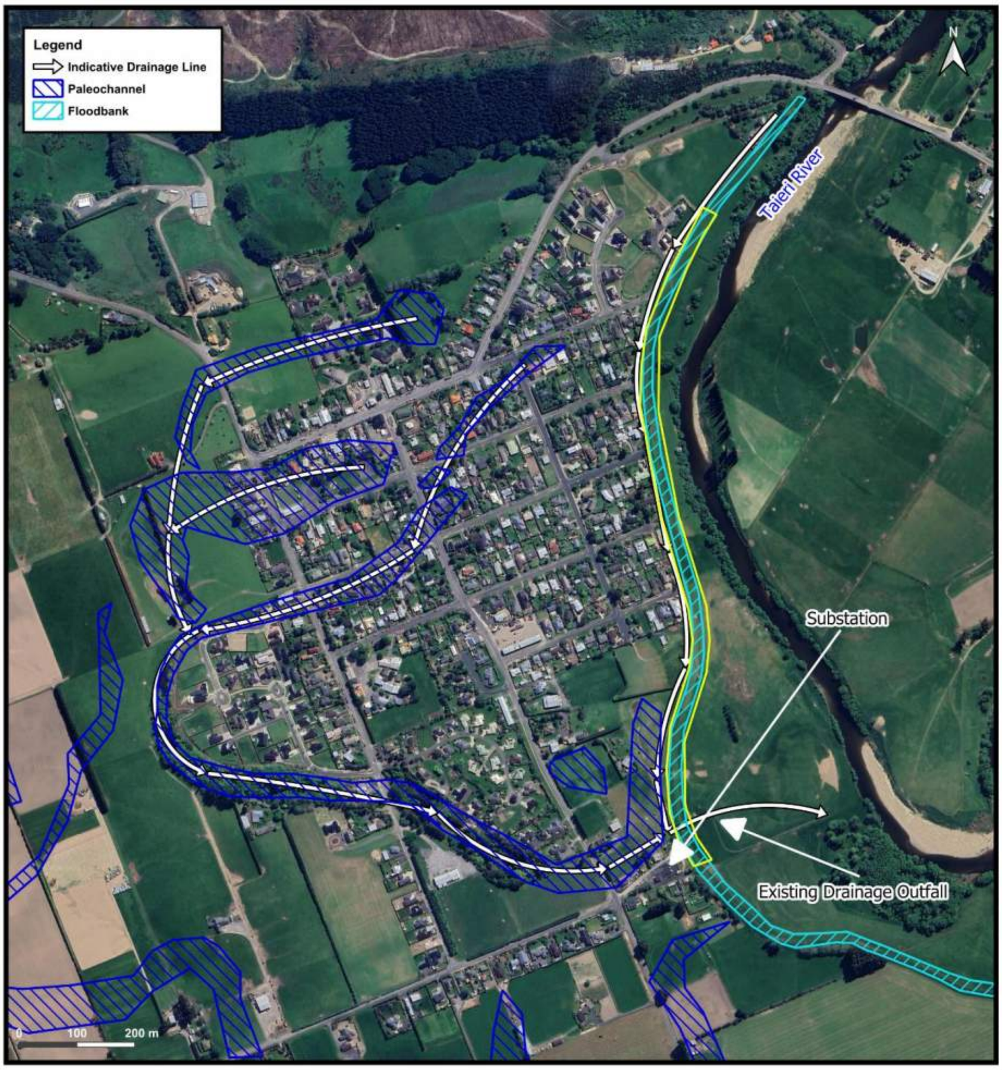


Figure 10-11. Sketch of possible future drainage option connecting the paleochannels and relief drain in the toe area to the existing gravity outlet near the substation. (Image source: Google Earth).

11 Conclusions

11.1 General

The visual condition of the floodbank appeared to be in good condition, and the investigations indicated relatively consistent and suitable embankment fill materials. One challenge however is the proximity of the existing housing and infrastructure to the landside of some sections of the floodbank. The limited space makes maintenance and future upgrades difficult to construct without moving (rebuilding) the stopbank closer towards the river. Although this doesn't affect the condition or resilience of the existing floodbank, it makes future planning and upkeep more challenging.

11.2 Slope Stability

Under static conditions, the floodbank was assessed as generally stable along the section of floodbank assessed (Zones 1 & 2). Under rapid drawdown conditions the floodbank is also considered stable, which is consistent with conclusions in the T&T (2005) report. Under SLS seismic conditions, the floodbank is not estimated to undergo liquefaction and the floodbank is estimated to be stable.

The assessment showed that the floodbank was unstable in ULS events, with a factor of safety less than 1.0, with the model showing failure through the underlying liquefiable soils.

Under ULS (IL2 and IL3) events, the potential modes of failure include slope instability and lateral spreading due to liquified foundation soils. Lateral spread towards the river was calculated to be within the 0.91 m threshold detailed in the Bay of Plenty Guidance for Zone 1, however there was a moderate risk that significant remediation will be required following a 1/500 year earthquake.

Section B-B' (landside) and C-C' (both sides) indicated the largest potential vertical settlements under ULS earthquake conditions and underwent flow failure in both IL2 and IL3 ULS cases. Rebuild of this section of the floodbank is likely to be required following a ULS event.

11.3 Groundwater Modelling

Groundwater modelling was used to indicate the effects of flooding in the Taieri River on the Outram floodbank and on local groundwater dynamics. The model indicates that seepage through the entire thickness of the floodbank is unlikely in a 1/100 or 1/200-year high river level event (which do not overtop the floodbank) when using material properties tested in the boreholes. However, the model indicates high-river level events can cause groundwater flooding in Outram if the groundwater levels are already at or near their seasonal maxima. The combination of high head in the river and additional saturated ground in the riverbank and floodplains tend to push groundwater underneath the floodbank and daylight at the surface near the inside toe of the floodbank, in the paleochannels, and in any other low-lying areas. Seepage occurs beneath the constructed floodbank and flows through the natural permeable sands and gravels. The implications of the modelled seepage pathways indicate groundwater flooding related issues in Outram which can be addressed by drainage and conveyance improvements.

12 Recommendations

Our assessment highlighted the risks associated with seepage under and through the floodbank and failure within it under static, flooding, and seismic events. Given our findings, we recommend the following:

- Limited long-term groundwater level data was available, and we recommend carrying out groundwater monitoring over multiple seasons to better understand seasonal variation. This data will help derisk the assumed groundwater levels used in our assessment, which will result in refined liquefaction susceptibility, slope stability, and seepage modelling. Monitoring loggers could easily be installed across the piezometer network in Outram, with data downloaded quarterly.
- As the stability risks under static, flooding, and SLS seismic loading are low, and the visual condition of the floodbank appeared to be in good condition, it is our conclusion that implementing immediate ground improvement, or geotechnical floodbank mitigation measures may not yield short term benefits.
- Under ULS loading, liquefaction of the soils below and adjacent to the floodbank are what affects the floodbank's performance. Liquefaction mitigation measures would require reconstruction of the floodbank for which the costs are likely to be high, and a cost benefit analysis is recommended.
- Mitigation measures could include the following:
  - Remove the existing floodbank, construct ground improvements to remediate the liquifiable soil below and around the floodbank and rebuild the floodbank. Ground improvements could consist of soil-cement mixed columns, stone columns, or displacement piles. These techniques could mitigate seismic settlement and help resist lateral spreading, leading to improved floodbank performance.
  - Remove the existing floodbank, install a geogrid-reinforced gravel raft, and rebuild the floodbank on top of the raft. This would not improve the settlement or lateral spreading risk but would help the integrity of the floodbank after a seismic event as it would provide a more stable base that could mitigate cracking and differential settlement of the floodbank.
  - Vibrofloatation is a technique that utilizes a module (vibrofloat) which vibrates and compacts the surrounding material at the probe depth. Depending on the soil type, the softer soil is either replaced surrounding insitu soil or with imported granular fill. This technique can be effective at the depths required for this project and requires an area for a crane and flat surface to work on. The vibrations induce liquefaction in the ground which can affect adjacent infrastructure. Equipment for shallow applications is readily available in New Zealand, however equipment for deeper (in excess of 10 m) may need to be sourced from overseas.
- If ORC considers ground improvements, we recommend further CPT and geophysical investigations through the floodbank and both landside and riverside to refine geological assumptions. Obtaining additional data would be used to create a more geologically accurate model that would assist with the ground improvement design.
- Other mitigation measures that were considered but were unlikely to provide robust, long term benefits given the depth of liquefaction and flow failure risk included:
  - Installing sheet piles adjacent to or through the stopbank to minimize lateral spreading. Sheet piles would need to be sufficiently keyed into a non-liquefiable layer in order to provide sufficient lateral resistance. Liquified soils were predicted up to 20 m depth, so sheet piles would need to be diven on the order of 30 to 40 m below the toe of the floodbank.
  - Dynamic compaction consisting of dropping a large weight on the ground surface to densify the near surface soils. This technique isn't applicable where shallow groundwater is present.

- The groundwater modelling indicated a hydraulic connection between the river level and groundwater levels with flows beneath the floodbank which could lead to increased groundwater flooding related issues in Outram. We recommend improvements to conveyance and drainage across the paleo-channels in Outram including further consideration of a pumping station to move drainage water across the floodbank to river during flood events.
- Although seepage directly through the floodbank during a flood event was modelled as a low risk, we recommend that a relief drain be installed along the landside of the stopbank. This would intercept seepage water in a more controlled manner, decreasing the risk of slope instability, and convey it to a discharge point, possibly connecting into the same outlet pipe as the paleochannels. Space to construct the drain is limited along some sections of the stopbank.

As the risk of liquefaction leading to flooding is low, a reactive approach may be appropriate, making provision for rapid inspections and repairs following an earthquake. We recommend that ORC undertake rapid inspections of Outram floodbank following an earthquake or flood event.

The BOPRC Stopbank Design and Construction Guidelines (2014) provide detailed recommendations for operations and maintenance (Part 5) and emergency works (Part 6) plans for stopbanks. These include creating an asset management plan, operations and maintenance manual, flood emergency management plan, and a plan identifying measures that can be implemented in the event of a failure. Critical to the repair guidance document should include identifying the type, amount, and location of any labour, plant, and materials required to make repairs at short notice. We recommend that these documents be created if they don’t currently exist, and be regularly reviewed, especially after flood or seismic events. Beca would be glad to assist with preparation of these documents.

The following table provide a summary of anticipated floodbank performance for Zone 1 and 2 along with commentary including estimated damage, seismic resilience, and high-level description of potential remedial measures following an earthquake that could be included in the repair guidance document.

Table 12-1. Floodbank performance, resilience, and potential remediation options

Section ID	**High Level Estimation of Land Damage Affecting the Floodbank**			**Commentary**		
	1/25 AEP Earthquake	1/500 AEP Earthquake	1/1000 AEP Earthquake	Floodbank Damage	Floodbank Resilience	Potential Remediation (Post Event)
A-A' + B-B' (Zone 1)	*Free Field Liquefaction Induced Settlement =* **Negligible** *Lateral Spread =* **Negligible**	*Free Field Liquefaction Induced Settlement =* **70 - 110 mm** *Lateral Spread =* **50 – 420 mm** **(Flow failure on landside)**	*Free Field Liquefaction Induced Settlement =* **100 – 160 mm** *Lateral Spread =* **90 – >600 mm** **(Flow failure on landside)**	• Cracking of the floodbank anticipated to be minor to negligible for return period earthquakes of less than 1/250 AEP. • For more severe earthquakes, settlement of up to 160 mm is anticipated within the floodbank. • Lateral spread is anticipated up to 600 mm towards the river. • Flow failure calculated to occur on the landside.	• Settlement could decrease the floodbank freeboard. Potential for overtopping of floodbank in subsequent flood events if not remediated. • Settlement for earthquakes with an AEP of less than 1/250 is anticipated to pose a low risk of failure. • Severe earthquakes may cause damage to the floodbank in the form of slumping, subsidence, and cracking. This damage poses a moderate risk of piping failure for a flood event where the floodbank provides protection, if the floodbank is not assessed and remediated following a ULS event.	• Remediate risk by filling to raise floodbank crest level. • Remediation of cracking after an earthquake could include observation and monitoring of seepage, filling cracks with sand or grout, or targeted localised excavation and compaction of floodbank core.
C-C' (Zone 2)	*Free Field Liquefaction Induced Settlement =* **Negligible** *Lateral Spread =* **Negligible**	*Free Field Liquefaction Induced Settlement =* **120 – 230 mm** *Lateral Spread =* **>900 mm** **(Flow failure both sides)**	*Free Field Liquefaction Induced Settlement =* **180 – 270 mm** *Lateral Spread =* **>900 mm** **(Flow failure both sides)**	• Settlement of the floodbank is anticipated to be dominated by liquefaction free field settlement and lateral spreading. • Damage to the floodbank is anticipated to be minor to negligible for return period earthquakes of less than 1/250 AEP. • For more severe earthquakes, damage such as cracking and slumping is anticipated.	• Crest settlement could be significant removing freeboard and other risk buffer allowances. Potential for overtopping of floodbank for subsequent flood events if not repaired. • Floodbank damage from earthquakes with an AEP of less than 1/250 is anticipated to pose a low risk. • For more significant earthquakes, severe damage of the floodbank is anticipated with moderate to high risk of failure for a flood event where the floodbank provides protection, leading to functional failure of floodbank.	• Anticipate requirement for rapid inspection and implementation of emergency works to address critical and acute defects affecting floodbank (e.g., cracking, slumping, or settlement). • For earthquakes exceeding an AEP of 1/500, extensive rebuild of the floodbank is anticipated.

13 Applicability Statement

This report has been prepared by Beca Limited **(Beca)** on the specific instructions of the Otago Regional Council **(Client)**. It is solely for our Client's use for the purpose for which it is intended in accordance with the agreed scope of work. Any use or reliance by any person contrary to the above, to which Beca has not given its prior written consent, is at that person's own risk.

Should you be in any doubt as to the applicability of this report and/or its recommendations for the proposed development as described herein, and/or encounter materials on site that differ from those described herein, it is essential that you discuss these issues with the authors before proceeding with any work based on this document.

In preparing this report Beca has relied on key information including the following:

- New Zealand Geotechnical Database (NZGD) investigation data.
- Otago Regional Council Environmental data portal, including readings for flow and rainfall.
- Other data sources as detailed in the reference list in Section 13.

Unless specifically stated otherwise in this report, Beca has relied on the accuracy, completeness, currency, and sufficiency of all information provided to it by, or on behalf of, the Client, including the information listed above, and has not sought independently to verify the information provided.

This report should be read in full, having regard to all stated assumptions, limitations and disclaimers. No part of this report shall be taken out of context and, to the maximum extent permitted by law, no responsibility is accepted by Beca for the use of any part of this report in any context, or for any purpose, other than that stated herein.

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A

Appendix A – Site Plan

Drawing Plotted: 28 May 2024 10:09 am

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No.	Revision	By	Chk	Appd	Date

Original Scale (A3) 1:5000

Design
Drawn LM 02/05/24
Dsg Verifier
Drg Check
* Refer to Revision 1 for Original Signature

Approved For Construction*
Date

Beca

Client: OTAGO REGIONAL COUNCIL

Project: OUTRAM FLOODBANK INVESTIGATION

Title: SITE INVESTIGATION PLAN

Discipline: GEOTECHNICAL

Drawing No. 01

Rev. 01

Document No. OUTRAM FLOODBANK.DWG

DO NOT SCALE FOR SET OUT DIMENSIONS

B

Appendix B – Geotechnical Investigation Logs

Geotechnical Log Key Sheet

SOIL AND ROCK DESCRIPTIONS

Soil and Rock Descriptions are in general accordance with the NZ Geotechnical Society (NZGS), 2005.
Hand-held Vane Shear Strength measurements are in general accordance with the NZGS, 2001.

METHODS

BH	Machine Borehole
CPT	Cone Penetration Test
DCP	Dynamic Cone Penetration
HA	Hand Auger
SPT	Standard Penetration Test
IVAN	In-situ Vane Test
MA	Machine Auger
OB	Open Barrel
SNC	Sonic Core Drilling
TP	Test Pit/Trench
TT	Triple Tube
PT	Thin-walled Open Drive Tube
VE	Vacuum Excavation
W	Wash Boring

WEATHERING

CW	Completely Weathered
HW	Highly Weathered
MW	Moderately Weathered
SW	Slightly Weathered
UW	Unweathered

SAMPLES

B	Bulk Disturbed Sample
C	Core Sample
D	Small Disturbed Sample
PT	Thin-wall Open Drive (Push) Tube Sample

WATER

▼ Groundwater Level (GWL)

IN-SITU TESTS

Shear Vane

Su	In-situ peak undrained shear strength and remoulded undrained shear strength
UTP	Unable to Penetrate
CB	Pilcon-type vane tested in Core Barrel
DH	Pilcon-type vane tested in-situ (downhole)
GV	Geonor vane, tested in-situ
IcV	Icone vane, tested in-situ

Standard Penetration Test (SPT)

N	SPTn Sampler (Split-spoon)
Nc	SPTn Solid Cone
HB	SPT Hammer Bouncing

TERMINOLOGY

RL	Relative Ground Level
RQD	Rock Quality Designation

GRAPHIC LOG (1 or a combination of the following)

Clay	Silt	Sandstone (SST)	Conglomerate	Fine Igneous
Gravel	Sand	Siltstone (ZST)	Limestone	Coarse Igneous
Shells	Organic Material	Mudstone	Foliated Metamorphic	Ignimbrite
Cobbles / Boulders	Fill	Interbedded SST & ZST	Asphalt	No Core

MONITORING INSTALLATION

Backfill Material

Sand
Grout
Bentonite
Gravel
Cement Mixes

Standpipe

Plain
Slotted
Vibrated Wire

ORGANIC SOILS

Von Post Degree of Humidification

H1	Completely unconverted and mud-free peat, when pressed gives clear water and plant structure is visible.
H2	Partially unconverted and mud-free peat, when pressed gives almost clear water and plant structure is visible.
H3	Very slightly decomposed or very slightly muddy peat, when pressed gives marked muddy water, no peat substance passes through the fingers and plant structure is less visible.
H4	Slightly decomposed or slightly muddy peat, when pressed gives muddy water and plant structure is less visible.
H5	Moderately decomposed or very muddy peat with growth structure evident but slightly obliterated.
H6	Moderately decomposed or very muddy peat with indistinct growth structure.
H7	Fairly well decomposed or very muddy peat but the growth structure can just be seen.
H8	Well decomposed or very muddy peat with very indistinct growth structure.
H9	Practically decomposed or mud-like peat in which almost no growth structure is evident.
H10	Completely decomposed or mud peat where no growth structure can be seen, entire substance passes through the fingers when pressed.

Machine Borehole Log

Borehole ID: BH01
Sheet 1 of 2

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client name:**	Otago Regional Council
Location:	End of Holyhead Rd on top of Floodbank	**Coordinate system:**	NZTM2000
		Northing:	4918298.0
		Easting:	1385331.0
Vertical datum:	NZVD 2016	**Ground level (mRL):**	12.00
Location method:	Webmap, +/- 1m		

Recovery	Method	SPT	Samples	Depth (m)	Soil / Rock Description	Geological Unit
0%	HA			0.0–0.25	0.0 - 0.25m, Hand Auger pre-drill, no recovery	Floodbank Fill
100%	SNC				'Hard', SILT, some clay, minor fine to coarse gravel; brown, with orange and grey mottling; dry, gap graded, low plasticity. Gravel is angular to sub-rounded, basalt, schist.	Floodbank Fill
67%	SPT	6, 10, 11, 10, 7, 6 N=34			Stiff, clayey SILT, some fine to coarse gravel, minor fine to coarse sand; brown, mottled orange and dark grey; moist, low plasticity. Gravel is angular, weak, moderately to highly weathered, schist, some gravels are friable.	Floodbank Fill
100%	SNC		B		'Firm', fine to coarse gravelly SILT, minor coarse sand; brown, mottled orange; moist, low plasticity. Gravel is weak to moderately strong, angular to sub-angular, slightly weathered to highly weathered, schist.	Floodbank Fill
73%	SPT	3, 4, 2, 3, 3, 3 N=11			Firm, ORGANIC SILT; dark brown; moist, low plasticity, slight organic odor, thinly bedded with laminae of brown silt.	Buried Topsoil
76%	SNC				Stiff, SILT, some fine to coarse sand, some fine to coarse gravel; brown, mottled orange; moist, low plasticity. Gravel is angular to sub-angular, weak, moderately weathered to highly weathered schist. *3.90 - 4.10m: intermixed dark grey/brown silt, some fine sand*	Holocene River Deposits
67%	SPT	2, 1, 1, 1, 1, 1 N=4			Loose, fine SAND, some silt; brown; moist.	Holocene River Deposits
19%	SNC				*5.15 - 6.00m: No recovery. Re-drilling caused wash out of material and loss through the run* *5.70 - 6.28m: No recovery (depth inferred).*	Holocene River Deposits
38%	SPT	4, 4, 4, 3, 2, 3 N=12			*6.00m: Medium dense*	Holocene River Deposits
86%	SNC				Loose, fine SAND, some silt; brown; moist. *6.40 - 7.00m: quick*	Holocene River Deposits
51%	SPT	4, 3, 3, 3, 4, 3 N=13			7.73 - 7.95m: No recovery (depth inferred).	Holocene River Deposits
86%	SNC				Loose, fine SAND, some silt; brown; moist. *8.40 - 8.60m: with trace of fine to coarse gravel, rounded, basalt, brown staining.*	Holocene River Deposits
					Medium dense, fine to coarse, silty sandy GRAVEL, brown; wet, well graded. Gravel is rounded to angular, basalt, schist, quartz. Schist is highly weathered, weak. *8.60 - 9.00m: some fines may have washed away*	Holocene River Deposits
					8.85 - 9.00m: No recovery (depth inferred).	Holocene River Deposits
28%	SPT	5, 4, 4, 2, 3, 2 N=11			Medium dense, fine to coarse, silty sandy GRAVEL, brown; wet, well graded. Gravel is rounded to angular, basalt, schist, quartz. Schist is highly weathered, weak. *9.13 - 9.45m: No recovery (depth inferred).* *9.45 - 9.70m: no fines, silt and sand absent, likely washed away, indicated by SPT containing fines, and water loss during sonic drilling*	Holocene River Deposits
95%	SNC				Medium dense, fine to medium gravelly medium to coarse SAND; brown, wet. Gravel is rounded to angular, basalt, schist, quartz. Schist is highly weathered, weak.	Holocene River Deposits

Depth scale (m): 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0, 9.5
RL (m): 11.5, 11.0, 10.5, 10.0, 9.5, 9.0, 8.5, 8.0, 7.5, 7.0, 6.5, 6.0, 5.5, 5.0, 4.5, 4.0, 3.5, 3.0, 2.5

Date started:	08/03/2024	**Date end:**	11/03/2024
Logged by:	LM	**Drilled by:**	Speight Drilling
Vane ID:	N/A	**Equipment:**	Sonic/HA
Vane type:	N/A	**Method:**	SNC/SPT/HA
Vane width:	N/A	**Inc/Az:**	90° / N/A
SPT ID:	CD51	**Diameter:**	145mm
SPT efficiency:	68%	**Fluid type:**	Water

Comments:
Hole terminated at target depth.

Ground water measured at 9.45 m below ground level on 11/03/2024 after hole left over 48 hrs (Casing at 15 m depth at time of measurement).

For Explanation of Symbols and Abbreviations See Key Sheet

Machine Borehole Log

Borehole ID: BH01
Sheet 2 of 2

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client name:**	Otago Regional Council
Location:	End of Holyhead Rd on top of Floodbank	**Coordinate system:**	NZTM2000
		Northing:	4918298.0
		Easting:	1385331.0
		Vertical datum:	NZVD 2016
		Ground level (mRL):	12.00
		Location method:	Webmap, +/- 1m

Drilling / In Situ Tests

Recovery	Method	SPT	Samples
			B
56%	SPT	5, 5, 6, 4, 3, 2, N=15	
100%	SNC		
56%	SPT	7, 6, 6, 1, 6, 5, N=18	
100%	SNC		
49%	SPT	10, 7, 4, 3, 3, 4, N=14	
100%	SNC		
56%	SPT	14, 11, 9, 7, 5, 6, N=27	
48%	SNC		
67%	SPT	23, 13, 13, 9, 9, 8, N=39	
100%	SNC		
67%	SPT	11, 11, 9, 6, 8, 20, N=43	
86%	SNC		
69%	SPT	27, 23/55mm, N=50+	

Depth (m): 10.5, 11.0, 11.5, 12.0, 12.5, 13.0, 13.5, 14.0, 14.5, 15.0, 15.5, 16.0, 16.5, 17.0, 17.5, 18.0, 18.5, 19.0, 19.5
RL (m): 1.5, 1.0, 0.5, 0.0, -0.5, -1.0, -1.5, -2.0, -2.5, -3.0, -3.5, -4.0, -4.5, -5.0, -5.5, -6.0, -6.5, -7.0, -7.5

Soil / Rock Description (Geological Unit: Holocene River Deposits)

Medium dense, fine to medium gravelly medium to coarse SAND; brown, wet. Gravel is rounded to angular, basalt, schist, quartz. Schist is highly weathered, weak.

10.75 - 10.95m: No recovery (depth inferred).

12.25 - 12.45m: No recovery (depth inferred).

13.72 - 13.95m: No recovery (depth inferred).

13.95 - 14.00m: orange staining

Stiff, SILT, minor clay; bluish grey; moist, homogenous, low plasticity.

14.50 - 14.60m: greyish brown

Medium dense, fine to coarse sandy, fine to medium GRAVEL; brown; wet, well graded, sub-rounded to angular.
15.25 - 16.00m: No recovery (depth inferred).

Soft, SILT, some clay, minor fine to medium gravel; grey; saturated, low plasticity. Gravel is sub-rounded, basalt, quartz river gravels. Soft on recovery.
16.00 - 16.45m: gradually increasing gravel content from some to gravelly SILT

Dense, silty, fine to coarse sandy, fine to coarse GRAVEL; greyish brown; saturated. Gravel is well graded, sub-rounded to sub-angular, basalt, schist, quartz river gravels.

17.60 - 18.90m: with minor cobbles, sub-angular to sub-rounded, schist, basalt

19.63m - End of Borehole, Hole terminated at target depth.

Date started:	08/03/2024	**Date end:**	11/03/2024
Logged by:	LM	**Drilled by:**	Speight Drilling
Vane ID:	N/A	**Equipment:**	Sonic/HA
Vane type:	N/A	**Method:**	SNC/SPT/HA
Vane width:	N/A	**Inc/Az:**	90° / N/A
SPT ID:	CD51	**Diameter:**	145mm
SPT efficiency:	68%	**Fluid type:**	Water

Comments:
Hole terminated at target depth.

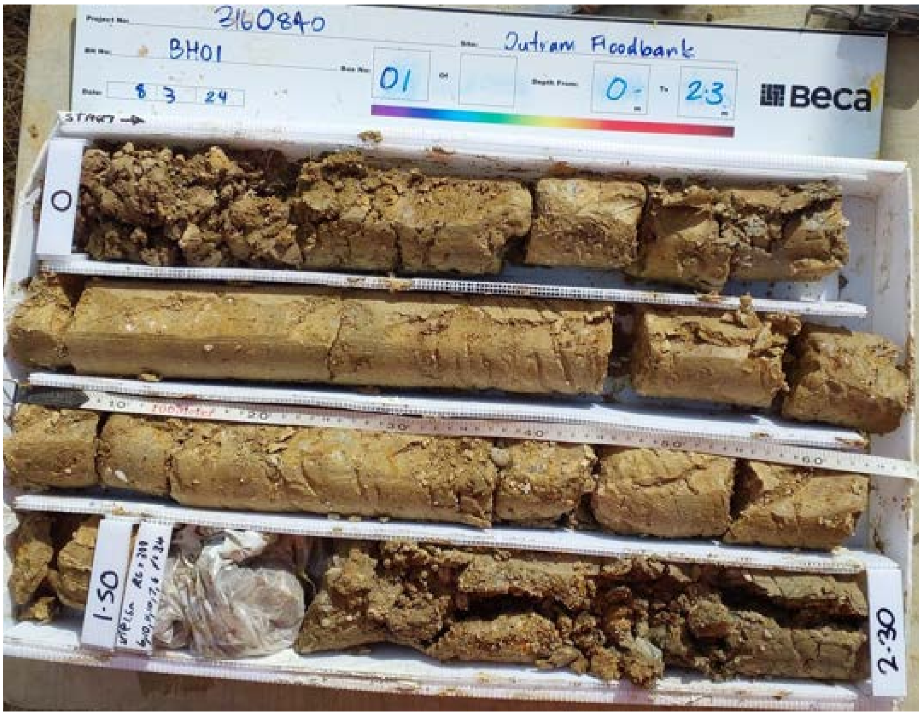
Ground water measured at 9.45 m below ground level on 11/03/2024 after hole left over 48 hrs (Casing at 15 m depth at time of measurement).

For Explanation of Symbols and Abbreviations See Key Sheet

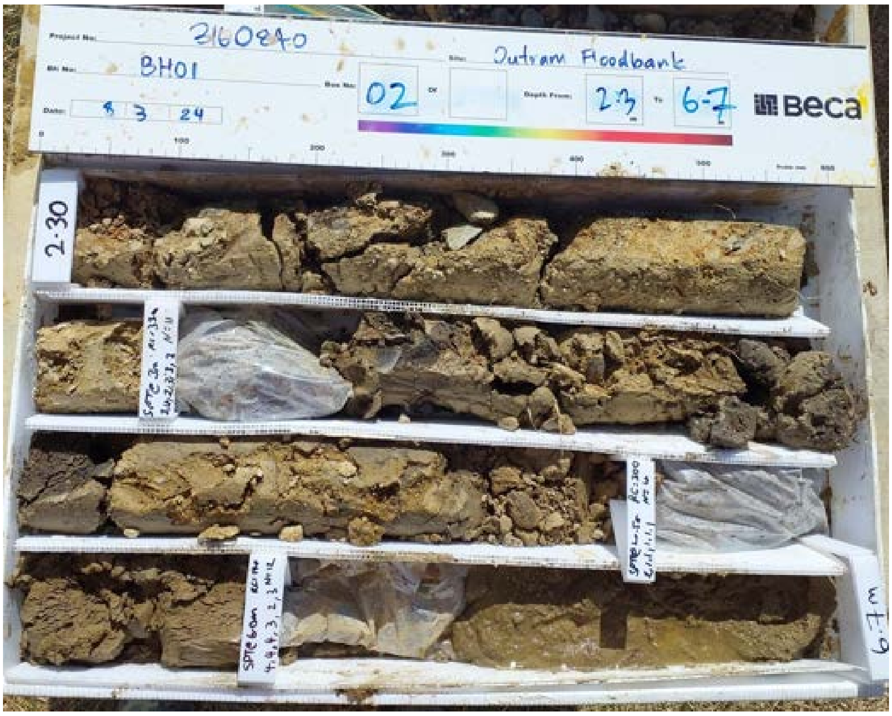
Beca	Photo Log	Location ID: BH01 Sheet 1 of 4

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client Name:**	Otago Regional Council

Location:	End of Holyhead Rd on top of Floodbank	**Coordinate system:**	NZTM2000	**Vertical datum:**	NZVD 2016
		Northing:	4918298.0	**Ground level (mRL):**	12.00
		Easting:	1385331.0	**Location method:**	Webmap, +/- 1m



Core Box 01 - 0.00mbgl to 2.30mbgl



Core Box 02 - 2.30mbgl to 6.70mbgl

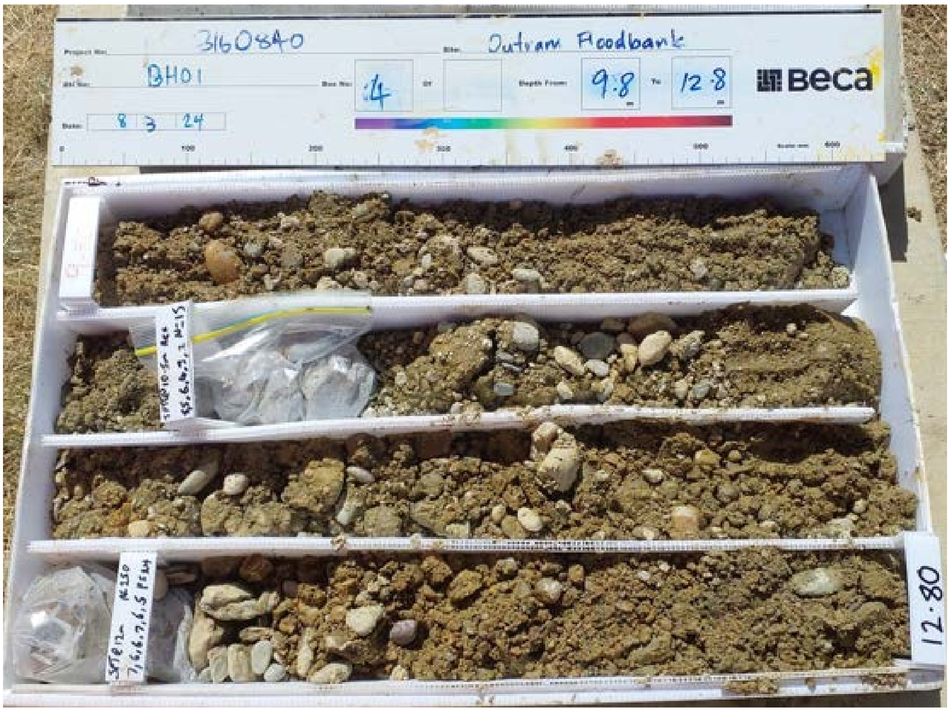
Photo Log

Location ID: BH01

Sheet 2 of 4

Project:	Outram Floodbank Assessment		**Project number:**	3160840	
Site location:	Outram		**Client Name:**	Otago Regional Council	
Location:	End of Holyhead Rd on top of Floodbank	**Coordinate system:**	NZTM2000	**Vertical datum:**	NZVD 2016
		Northing:	4918298.0	**Ground level (mRL):**	12.00
		Easting:	1385331.0	**Location method:**	Webmap, +/- 1m

Core Box 03 - 6.70mbgl to 9.80mbgl



Core Box 04 - 9.80mbgl to 12.80mbgl

Beca	**Photo Log**	**Location ID:**	**BH01** Sheet 3 of 4

Project:	Outram Floodbank Assessment		**Project number:**	3160840	
Site location:	Outram		**Client Name:**	Otago Regional Council	
Location:	End of Holyhead Rd on top of Floodbank	**Coordinate system:**	NZTM2000	**Vertical datum:**	NZVD 2016
		Northing:	4918298.0	**Ground level (mRL):**	12.00
		Easting:	1385331.0	**Location method:**	Webmap, +/- 1m

Core Box 05 - 12.80mbgl to 15.45mbgl

Core Box 06 - 15.45mbgl to 19.10mbgl

Photo Log

Location ID: BH01

Sheet 4 of 4

Project:	Outram Floodbank Assessment		**Project number:**	3160840	
Site location:	Outram		**Client Name:**	Otago Regional Council	
Location:	End of Holyhead Rd on top of Floodbank	**Coordinate system:** NZTM2000		**Vertical datum:**	NZVD 2016
		Northing: 4918298.0		**Ground level (mRL):**	12.00
		Easting: 1385331.0		**Location method:**	Webmap, +/- 1m

Core Box 07 - 19.10mbgl to 19.63mbgl

Machine Borehole Interpretation

Borehole ID: BH01a

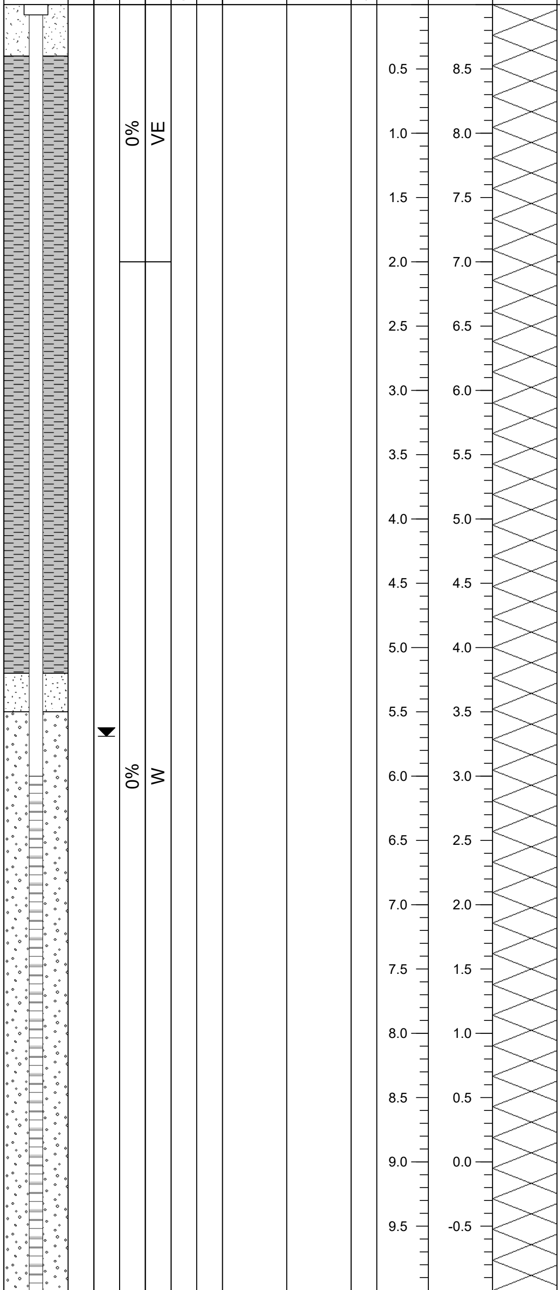
Sheet 1 of 2

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client:**	Otago Regional Council

Location:	Toe of bank, Outram township side of BH01	**Coordinate system:**	NZTM2000	**Vertical datum:**	NZVD 2016
		Northing:	4918304.0	**Ground level (mRL):**	9.00
		Easting:	1385313.0	**Location method:**	Webmap, +/- 1m

Depth (m)	RL (m)	Recovery	Method	Soil/ Rock Description	Geological Unit
0.0 – 2.0	9.0 – 7.0	0%	VE	No recovery from vacuum excavation	Holocene River Deposits (inferred)
2.0 – 10.0	7.0 – -1.0	0%	W	Wash drilling, (cuttings not recovered)	Holocene River Deposits (inferred)

Column headings: Installations; Drilling (Return, GWL, Recovery, Method, Casing, RQD); In Situ Tests (Su (kPa), SPT); Samples; Depth (m); RL (m); Graphic Log; Soil/ Rock Description; Geological Unit; Engineering Unit



Date started:	12/03/2024	**Date end:**	12/03/2024	**Comments:**
Logged by:	LM	**Drilled by:**	Speight Drilling	Hole terminated at target depth.
Vane ID:	N/A	**Equipment:**	Sonic	Groundwater measured at 5.69 m below ground level on 19/03/2024.
Vane type:	N/A	**Method:**	W/VE	
Vane width:	N/A	**Inclination:**	90°	
SPT No:	N/A	**Diameter:**	145mm	
SPT efficiency:	N/A	**Fluid type:**	Water	

For Explanation of Symbols and Abbreviations See Key Sheet

Machine Borehole Interpretation

Borehole ID: BH01a

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client:**	Otago Regional Council

Location:	Toe of bank, Outram township side of BH01	**Coordinate system:**	NZTM2000	**Vertical datum:**	NZVD 2016
		Northing:	4918304.0	**Ground level (mRL):**	9.00
		Easting:	1385313.0	**Location method:**	Webmap, +/- 1m

Installations	Drilling: Return	GWL	Recovery	Method	Casing	RQD	In Situ Tests: Su (kPa)	SPT	Samples	Depth (m)	RL (m)	Graphic Log	Soil/ Rock Description	Geological Unit	Engineering Unit
			0%	W						10.5 – 15.0	-1.5 – -6.0		Wash drilling, (cuttings not recovered) *10.50 - 15.00m: silty mud recovered*	Holocene River Deposits (inferred)	
										15.0	-6.0		15.00m - End of Borehole, Hole terminated at target depth.		

Depth scale (m): 10.5, 11.0, 11.5, 12.0, 12.5, 13.0, 13.5, 14.0, 14.5, 15.0, 15.5, 16.0, 16.5, 17.0, 17.5, 18.0, 18.5, 19.0, 19.5

RL scale (m): -1.5, -2.0, -2.5, -3.0, -3.5, -4.0, -4.5, -5.0, -5.5, -6.0, -6.5, -7.0, -7.5, -8.0, -8.5, -9.0, -9.5, -10.0, -10.5

Date started:	12/03/2024	**Date end:**	12/03/2024
Logged by:	LM	**Drilled by:**	Speight Drilling
Vane ID:	N/A	**Equipment:**	Sonic
Vane type:	N/A	**Method:**	W/VE
Vane width:	N/A	**Inclination:**	90°
SPT No:	N/A	**Diameter:**	145mm
SPT efficiency:	N/A	**Fluid type:**	Water

Comments:
Hole terminated at target depth.

Groundwater measured at 5.69 m below ground level on 19/03/2024.

For Explanation of Symbols and Abbreviations See Key Sheet

Machine Borehole Log

Beca

Borehole ID: BH02
Sheet 1 of 3

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client name:**	Otago Regional Council

Location:	End of Lynas Street, top of floodbank	**Coordinate system:**	NZTM2000	**Vertical datum:**	NZVD 2016
		Northing:	4918033.0	**Ground level (mRL):**	12.00
		Easting:	1385327.0	**Location method:**	Webmap, +/- 1m

Drilling and In Situ Tests

Drilling: Recovery	Drilling: Method	In Situ Tests: SPT	Samples
0%	HE		
100%	SNC		B (approx. 1.30–1.50 m)
78%	SPT	2, 2, 2, 1, 1, 2 N=6	
100%	SNC		
44%	SPT	2, 2, 1, 2, 1, 3 N=7	
90%	SNC		B (approx. 4.30–4.50 m)
78%	SPT	2, 2, 2, 1, 1, 1 N=5	
100%	SNC		
84%	SPT	1, 1, 0, 1, 1, 1 N=3	
86%	SNC		
82%	SPT	7, 5, 5, 4, 3, 5 N=17	
100%	SNC		
58%	SPT	10, 9, 8, 11, 9, 8 N=36	
95%	SNC		

GWL: groundwater marked at approx. 9.4–9.5 m.

Soil / Rock Description

Depth (m)	RL (m)	Soil / Rock Description	Geological Unit
0.0 - 0.25	12.00 - 11.75	0.0 - 0.25m, Hand Auger pre-drill, no recovery	Floodbank Fill
0.25 - 1.70	11.75 - 10.30	'Hard', SILT, some clay, minor fine to medium gravel; brown, mottled orange and grey; dry, low plasticity. Gravel is sub-rounded, basalt and schist. *1.30m: becomes moist, soft*	Floodbank Fill
1.70 - 2.50	10.30 - 9.50	Loose, fine SAND, some silt; brown; moist.	Floodbank Fill
2.50 - 3.45	9.50 - 8.55	Loose, intermixed clayey SILT/ fine SAND. Clayey SILT is mottled brown, orange, grey; moist, low plasticity. Sand is brown; moist, moderately sensitive. *3.20 - 3.45m: No recovery (depth inferred).*	Floodbank Fill
3.45 - 7.50	8.55 - 4.50	Loose, fine SAND some silt; brown; wet on recovery. *3.70m: with some silt*	Holocene River Deposits
7.50 - 10.0	4.50 - 2.00	Medium dense, fine to coarse SAND, some silt, minor fine gravel; brown; saturated, well graded. Gravel is sub-rounded, basalt, quartz, minor schist. *8.10m: with some fine to coarse gravel, silt becomes minor* *9.00m: Dense*	Holocene River Deposits

Date started:	07/03/2024	**Date end:**	08/03/2024
Logged by:	LM	**Drilled by:**	Speight Drilling
Vane ID:	N/A	**Equipment:**	Sonic
Vane type:	N/A	**Method:**	SNC/HE/SPT
Vane width:	N/A	**Inc/Az:**	90° / N/A
SPT ID:	CD51	**Diameter:**	145mm
SPT efficiency:	68%	**Fluid type:**	Water

Comments:
Hole terminated at target depth.

Groundwater measured measured at 9.46 m below ground level on 08/03/2024.

For Explanation of Symbols and Abbreviations See Key Sheet

Beca — Machine Borehole Log

Borehole ID: BH02
Sheet 2 of 3

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client name:**	Otago Regional Council
Location:	End of Lynas Street, top of floodbank	**Coordinate system:**	NZTM2000
		Vertical datum:	NZVD 2016
		Northing:	4918033.0
		Ground level (mRL):	12.00
		Easting:	1385327.0
		Location method:	Webmap, +/- 1m

Columns: Drilling (GWL, Fluid Return, Recovery, Method, Casing, RQD); In Situ Tests (Su (kPa), SPT); Samples; Depth (m); RL (m); Graphic Log; Soil / Rock Description; Geological Unit

Depth (m)	Recovery	Method	SPT
10.5 – 11.0	0%	SPT	2, 2, 2, 1, 2, 1 N=6
11.0 – 12.0	67%	SNC	
12.0	80 %	SPT	16, 24 N=50+
12.0 – 13.5	81%	SNC	
13.5 – 14.0	49%	SPT	5, 8, 7, 4, 6, 4 N=21
14.0 – 15.0	43%	SNC	
15.0 – 15.5	40%	SPT	7, 7, 4, 4, 4, 5 N=17
15.5 – 16.0	100%	SNC	
16.0 – 16.5	100%	SNC	
16.5 – 17.0	67%	SPT	10, 7, 8, 8, 12, 12 N=40
17.0 – 18.0	100%	SNC	
18.0 – 18.5	51%	SPT	11, 9, 7, 5, 3, 9 N=24
18.5 – 19.5	95%	SNC	
19.5 – 19.9	62%	SPT	8, 5, 14, 14

Depth / RL: 10.5 / 1.5; 11.0 / 1.0; 11.5 / 0.5; 12.0 / 0.0; 12.5 / -0.5; 13.0 / -1.0; 13.5 / -1.5; 14.0 / -2.0; 14.5 / -2.5; 15.0 / -3.0; 15.5 / -3.5; 16.0 / -4.0; 16.5 / -4.5; 17.0 / -5.0; 17.5 / -5.5; 18.0 / -6.0; 18.5 / -6.5; 19.0 / -7.0; 19.5 / -7.5

Soil / Rock Description

Medium dense, fine to coarse SAND, some silt, minor fine gravel; brown; saturated, well graded. Gravel is sub-rounded, basalt, quartz, minor schist.

10.5 - 11.3 m: No recovery (depth inferred).

Loose, medium to coarse sandy, fine to medium GRAVEL; brown; saturated. Gravel has some orange staining, sub-angular to sub-rounded.

11.70 - 11.90m: coarse SAND

12.00 - 13.50m: Very dense

13.25 - 13.50m: No recovery (depth inferred).

13.50 - 16.50m: Medium dense

14.40 - 15.00m: No recovery (depth inferred).

Medium dense, medium to coarse sandy, fine to medium GRAVEL; brown; saturated. Gravel has some orange staining, sub-angular to sub-rounded.

16.50 - 18.00m: Dense

16.95 - 18.00m: Fines likely washed away, assumed to be sandy GRAVEL

17.40 - 17.60m: with coarse sand

18.00 - 19.50m: Medium dense

18.23 - 18.45m: No recovery (depth inferred).

19.50 - 19.90m: Very dense

19.90m - End of Borehole, Hole terminated at target depth.

Geological Unit: Holocene River Deposits

Date started:	07/03/2024	**Date end:**	08/03/2024
Logged by:	LM	**Drilled by:**	Speight Drilling
Vane ID:	N/A	**Equipment:**	Sonic
Vane type:	N/A	**Method:**	SNC/HE/SPT
Vane width:	N/A	**Inc/Az:**	90° / N/A
SPT ID:	CD51	**Diameter:**	145mm
SPT efficiency:	68%	**Fluid type:**	Water

Comments:
Hole terminated at target depth.

Groundwater measured measured at 9.46 m below ground level on 08/03/2024.

For Explanation of Symbols and Abbreviations See Key Sheet

Machine Borehole Log

Borehole ID: BH02
Sheet 3 of 3

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client name:**	Otago Regional Council

Location:	End of Lynas Street, top of floodbank	**Coordinate system:**	NZTM2000	**Vertical datum:**	NZVD 2016
		Northing:	4918033.0	**Ground level (mRL):**	12.00
		Easting:	1385327.0	**Location method:**	Webmap, +/- 1m

Drilling						In Situ Tests							
GWL	Fluid Return	Recovery	Method	Casing	RQD	Su (kPa)	SPT	Samples	Depth (m)	RL (m)	Graphic Log	Soil / Rock Description	Geological Unit
							17 5/30mm N=50+						
									20.5	-8.5			
									21.0	-9.0			
									21.5	-9.5			
									22.0	-10.0			
									22.5	-10.5			
									23.0	-11.0			
									23.5	-11.5			
									24.0	-12.0			
									24.5	-12.5			
									25.0	-13.0			
									25.5	-13.5			
									26.0	-14.0			
									26.5	-14.5			
									27.0	-15.0			
									27.5	-15.5			
									28.0	-16.0			
									28.5	-16.5			
									29.0	-17.0			
									29.5	-17.5			

Date started:	07/03/2024	**Date end:**	08/03/2024
Logged by:	LM	**Drilled by:**	Speight Drilling
Vane ID:	N/A	**Equipment:**	Sonic
Vane type:	N/A	**Method:**	SNC/HE/SPT
Vane width:	N/A	**Inc/Az:**	90° / N/A
SPT ID:	CD51	**Diameter:**	145mm
SPT efficiency:	68%	**Fluid type:**	Water

Comments:
Hole terminated at target depth.

Groundwater measured measured at 9.46 m below ground level on 08/03/2024.

For Explanation of Symbols and Abbreviations See Key Sheet

Photo Log

Location ID: BH02

Sheet 1 of 4

Project:	Outram Floodbank Assessment			**Project number:**	3160840
Site location:	Outram			**Client Name:**	Otago Regional Council
Location:	End of Lynas Street, top of floodbank	**Coordinate system:**	NZTM2000	**Vertical datum:**	NZVD 2016
		Northing:	4918033.0	**Ground level (mRL):**	12.00
		Easting:	1385327.0	**Location method:**	Webmap, +/- 1m

Core Box 01 - 0.00mbgl to 2.50mbgl

Core Box 02 - 2.50mbgl to 5.60mbgl

Photo Log				**Location ID:**	**BH02**
					Sheet 2 of 4
Project:	Outram Floodbank Assessment			**Project number:**	3160840
Site location:	Outram			**Client Name:**	Otago Regional Council
Location:	End of Lynas Street, top of floodbank	**Coordinate system:**	NZTM2000	**Vertical datum:**	NZVD 2016
		Northing:	4918033.0	**Ground level (mRL):**	12.00
		Easting:	1385327.0	**Location method:**	Webmap, +/- 1m

Core Box 03 - 5.60mbgl to 8.70mbgl

Core Box 04 - 8.70mbgl to 12.50mbgl

Beca	Photo Log	Location ID:	BH02
			Sheet 3 of 4

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client Name:**	Otago Regional Council

Location:	End of Lynas Street, top of floodbank	**Coordinate system:**	NZTM2000	**Vertical datum:**	NZVD 2016
		Northing:	4918033.0	**Ground level (mRL):**	12.00
		Easting:	1385327.0	**Location method:**	Webmap, +/- 1m

Core Box 05 - 12.50mbgl to 16.00mbgl

Core Box 06 - 16.00mbgl to 19.10mbgl

Photo Log

Location ID: BH02

Sheet 4 of 4

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client Name:**	Otago Regional Council

Location:	End of Lynas Street, top of floodbank	**Coordinate system:**	NZTM2000	**Vertical datum:**	NZVD 2016
		Northing:	4918033.0	**Ground level (mRL):**	12.00
		Easting:	1385327.0	**Location method:**	Webmap, +/- 1m

Core Box 07 - 19.10mbgl to 19.90mbgl

Machine Borehole Log

Borehole ID: BH03
Sheet 1 of 3

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client name:**	Otago Regional Council
Location:	End of Orme Street, top of floodbank	**Coordinate system:**	NZTM2000
Vertical datum:	NZVD 2016	**Northing:**	4917799.0
Ground level (mRL):	12.00	**Easting:**	1385391.0
Location method:	Webmap, +/- 1m		

Drilling / In Situ Tests

Depth (m)	Recovery	Method	SPT	Samples
0.0 – 0.2	0%	HA		
0.2 – 1.5	100%	SNC		
1.5 – 1.95	58%	SPT	5, 3, 4, 9, 13, 5 N=31	
1.95 – 3.0	100%	SNC		B (2.5 – 3.0)
3.0 – 3.45	42%	SPT	3, 3, 2, 1, 1, 2 N=6	
3.45 – 4.5	100%	SNC		
4.5 – 4.95	60%	SPT	2, 1, 1, 2, 2, 1 N=6	
4.95 – 6.0	46%	SNC		
6.0 – 6.45	40%	SPT	3, 3, 3, 3, 4, 5 N=15	
6.45 – 7.5	38%	SNC		
7.5 – 7.95	60%	SPT	5, 10, 6, 5, 4, 5 N=20	
7.95 – 9.0	100%	SNC		
9.0 – 9.45	44%	SPT	11, 8, 7, 5, 6, 5 N=23	
9.45 –	100%	SNC		

GWL markers shown at approx. 7.5 m and 9.2 m.

Soil / Rock Description

Depth (m)	RL (m)	Soil / Rock Description	Geological Unit
0.0 – 0.20	12.0 – 11.8	0.0 - 0.20m, Hand Auger pre-drill, no recovery	Floodbank Fill
0.20 – 1.40		Hard, SILT, minor clay, fine to medium gravel; brown, mottled orange and light brown; dry, low plasticity. *1.25 - 1.40m: becomes stiff, moist, with some fine grained sub-rounded gravel.*	Floodbank Fill
1.40 – 4.25		Dense, silty fine SAND; brown; moist, insensitive. *3.00m: Loose* *3.19 - 3.45m: No recovery (depth inferred)* *3.65 - 3.75m: becomes reddish brown*	Floodbank Fill
4.25 – 6.00		Firm, SILT, minor clay; brown; wet, low plasticity, insensitive. *4.30 - 4.40m: becomes reddish brown* *5.43 - 6.00m: No recovery (depth inferred).*	Holocene River Deposits
6.00 – 8.30		Medium dense, fine to medium SAND, minor silt; brown; saturated, well graded. *6.18 - 7.10m: No recovery (depth inferred).* *7.40 - 8.00m: sand becomes fine, some silt, with orange mottling* *8.00 - 8.30m: Trace medium gravel, sub-rounded, quartz and basalt with red staining.*	Holocene River Deposits
8.30 – 8.60		'Medium dense', coarse SAND, some fine to medium gravel; brown; wet, well graded. Gravel is sub-rounded to sub-angular, unweathered to slightly weathered, basalt, quartz, dark grey schist, red schist.	Holocene River Deposits
8.60 – 8.90		'Medium dense', fine to coarse gravelly SAND; brown; wet, well graded. Gravel is sub-rounded, unweathered; with minor red staining observed from 8.8m	Holocene River Deposits
8.90 –		Medium dense, fine to coarse sandy, fine to coarse GRAVEL, minor silt; reddish brown; wet, well graded. Gravel is sub-rounded, unweathered to slightly weathered; with orange staining, basalt, quartz, some weakly foliated quartz veined schist. 9.20 - 9.45m: No recovery (depth inferred).	Holocene River Deposits

Date started:	06/03/2024	**Date end:**	07/03/2024
Logged by:	LM	**Drilled by:**	Speight Drilling
Vane ID:	N/A	**Equipment:**	Sonic/Sonic
Vane type:	N/A	**Method:**	SNC/SPT/HA
Vane width:	N/A	**Inc/Az:**	90° / N/A
SPT ID:	CD51	**Diameter:**	145mm
SPT efficiency:	68%	**Fluid type:**	Water

Comments:
Hole terminated at target depth.

Groundwater measured at 9.36 m below ground level on 07/03/2024

For Explanation of Symbols and Abbreviations See Key Sheet

Machine Borehole Log

Borehole ID: BH03
Sheet 2 of 3

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client name:**	Otago Regional Council
Location:	End of Orme Street, top of floodbank	**Coordinate system:**	NZTM2000
		Vertical datum:	NZVD 2016
		Northing:	4917799.0
		Ground level (mRL):	12.00
		Easting:	1385391.0
		Location method:	Webmap, +/- 1m

Recovery	Method	SPT	Samples	Depth (m)	RL (m)	Soil / Rock Description	Geological Unit
				10.20		*10.20m: becomes greyish brown, orange staining absent*	Holocene River Deposits
44%	SPT	6, 5, 4, 3, 2, 3, N=12		10.5	1.5	Medium dense, fine to medium SAND, trace silt; grey; wet. *10.70 - 10.95m: No recovery (depth inferred).*	
95%	SNC			11.0–11.5	1.0–0.5		
58%	SPT	13, 13, 13, 12, 10, 9, N=44		12.0	0.0	Dense, fine to coarse sandy fine to coarse GRAVEL, minor silt; greyish brown; wet, gravel mostly fine, minor coarse gravel, sub-rounded to sub-angular, unweathered.	
76%	SNC			12.5–13.0	-0.5 – -1.0	*12.60 - 12.80m: Fine SAND, with minor silt, grey.* *13.25 - 13.73m: No recovery (depth inferred).*	
49%	SPT	5, 4, 3, 3, 3, 5, N=14		13.5–14.0	-1.5 – -2.0	*13.50m: Medium dense*	
100%	SNC		B	14.5	-2.5	Medium dense, fine to coarse SAND, some fine to coarse gravel, minor silt; brown; saturated, well graded. Gravel is sub-angular to sub-rounded, unweathered, minor orange staining	
51%	SPT	8, 9, 8, 7, 5, 6, N=26		15.0–15.5	-3.0 – -3.5	15.23 - 15.83m: No recovery (depth inferred).	
62%	SNC			16.0	-4.0		
93%	SPT	10, 9, 7, 6, 5, 4, N=22		16.5–17.0	-4.5 – -5.0	Medium dense, coarse sandy fine to coarse GRAVEL; grey, white, orange, brown; wet, well graded. Gravel is sub-angular to rounded, unweathered, some orange staining, basalt, quartz, schist. Fines may be washed out, poor recovery.	
36%	SNC			17.5	-5.5	17.33 - 18.20m: No recovery (depth inferred)	
47%	SPT	13, 9, 6, 6, 6, 6, N=24		18.0–18.5	-6.0 – -6.5	Medium dense, silty fine to medium gravelly fine to coarse SAND; brown, mottled orange; wet, insensitive. Gravel is sub-angular to sub-rounded, quartz, basalt. 18.67 - 19.50m: No recovery (depth inferred).	
21%	SNC			19.0	-7.0		
67%	SPT	17, 17, 12, 10		19.5	-7.5	*19.50 - 19.95m: Dense*	
				19.95		19.95m - End of Borehole, Hole terminated at target depth.	

Date started:	06/03/2024	**Date end:**	07/03/2024
Logged by:	LM	**Drilled by:**	Speight Drilling
Vane ID:	N/A	**Equipment:**	Sonic/Sonic
Vane type:	N/A	**Method:**	SNC/SPT/HA
Vane width:	N/A	**Inc/Az:**	90° / N/A
SPT ID:	CD51	**Diameter:**	145mm
SPT efficiency:	68%	**Fluid type:**	Water

Comments:
Hole terminated at target depth.

Groundwater measured at 9.36 m below ground level on 07/03/2024

For Explanation of Symbols and Abbreviations See Key Sheet

Machine Borehole Log

Borehole ID: BH03
Sheet 3 of 3

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client name:**	Otago Regional Council

Location:	End of Orme Street, top of floodbank	**Coordinate system:**	NZTM2000	**Vertical datum:**	NZVD 2016
		Northing:	4917799.0	**Ground level (mRL):**	12.00
		Easting:	1385391.0	**Location method:**	Webmap, +/- 1m

Drilling						In Situ Tests							
GWL	Fluid Return	Recovery	Method	Casing	RQD	Su (kPa)	SPT	Samples	Depth (m)	RL (m)	Graphic Log	Soil / Rock Description	Geological Unit
							15 8 N=45						
									20.5	-8.5			
									21.0	-9.0			
									21.5	-9.5			
									22.0	-10.0			
									22.5	-10.5			
									23.0	-11.0			
									23.5	-11.5			
									24.0	-12.0			
									24.5	-12.5			
									25.0	-13.0			
									25.5	-13.5			
									26.0	-14.0			
									26.5	-14.5			
									27.0	-15.0			
									27.5	-15.5			
									28.0	-16.0			
									28.5	-16.5			
									29.0	-17.0			
									29.5	-17.5			

Date started:	06/03/2024	**Date end:**	07/03/2024
Logged by:	LM	**Drilled by:**	Speight Drilling
Vane ID:	N/A	**Equipment:**	Sonic/Sonic
Vane type:	N/A	**Method:**	SNC/SPT/HA
Vane width:	N/A	**Inc/Az:**	90° / N/A
SPT ID:	CD51	**Diameter:**	145mm
SPT efficiency:	68%	**Fluid type:**	Water

Comments:
Hole terminated at target depth.

Groundwater measured at 9.36 m below ground level on 07/03/2024

For Explanation of Symbols and Abbreviations See Key Sheet

Photo Log

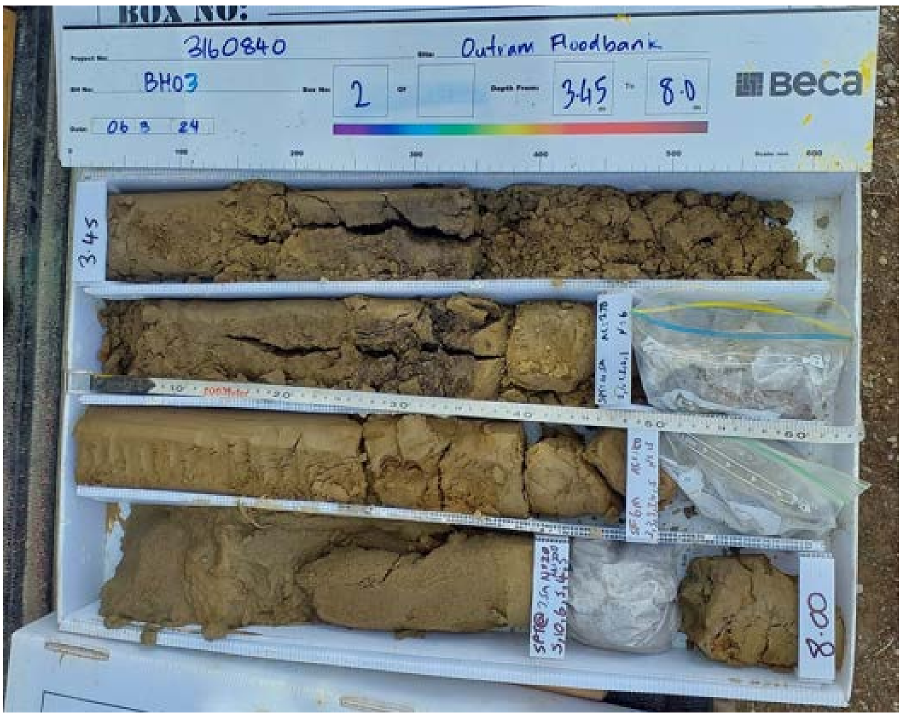
Location ID: BH03

Sheet 1 of 3

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client Name:**	Otago Regional Council

Location:	End of Orme Street, top of floodbank	**Coordinate system:**	NZTM2000	**Vertical datum:**	NZVD 2016
		Northing:	4917799.0	**Ground level (mRL):**	12.00
		Easting:	1385391.0	**Location method:**	Webmap, +/- 1m

Core Box 01 - 0.00mbgl to 3.45mbgl

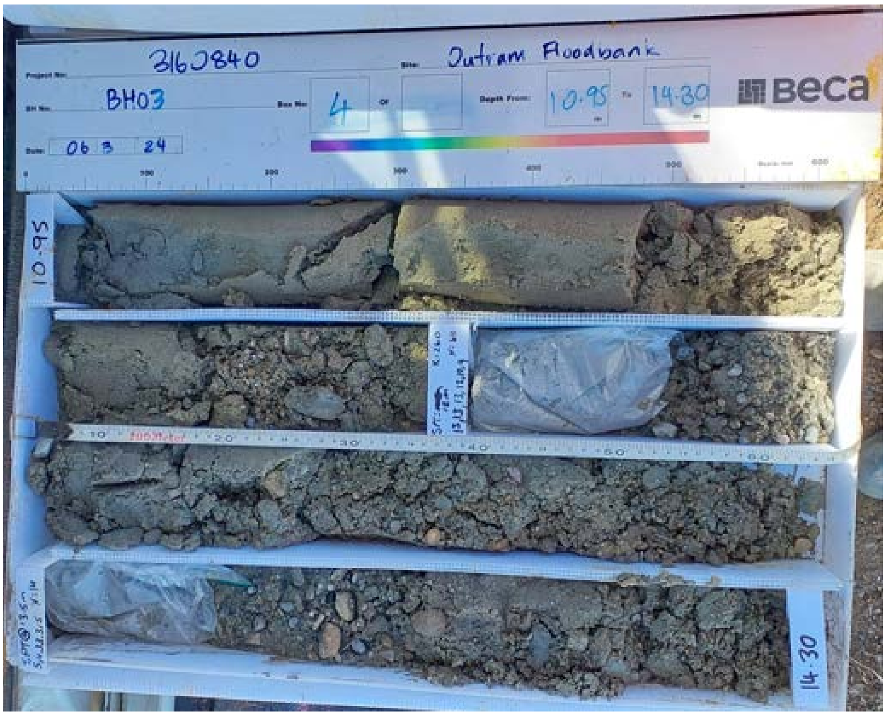


Core Box 02 - 3.45mbgl to 8.00mbgl

Beca	**Photo Log**	**Location ID:**	**BH03**
			Sheet 2 of 3

Project:	Outram Floodbank Assessment		**Project number:**	3160840	
Site location:	Outram		**Client Name:**	Otago Regional Council	
Location:	End of Orme Street, top of floodbank	**Coordinate system:**	NZTM2000	**Vertical datum:**	NZVD 2016
		Northing:	4917799.0	**Ground level (mRL):**	12.00
		Easting:	1385391.0	**Location method:**	Webmap, +/- 1m

Core Box 03 - 8.00mbgl to 10.95mbgl

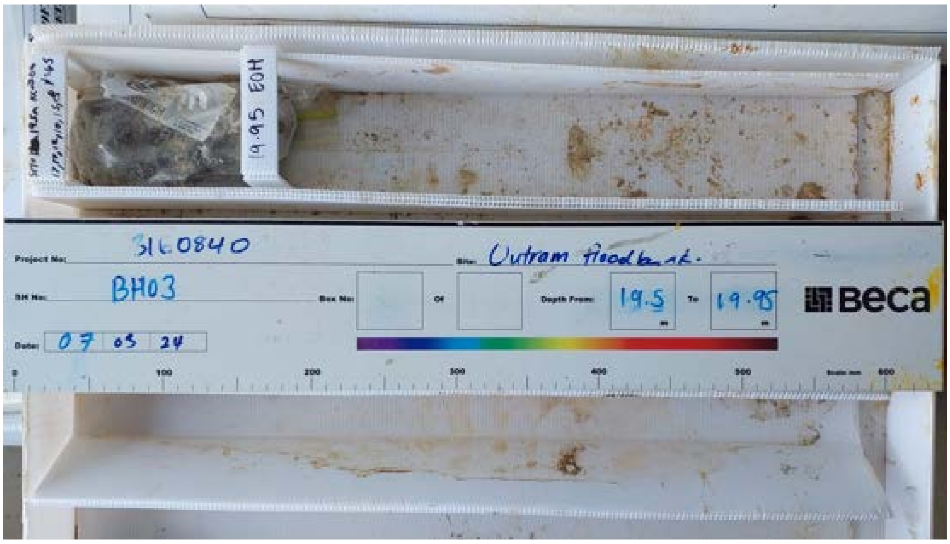


Core Box 04 - 10.95mbgl to 14.30mbgl

Beca	Photo Log	Location ID: BH03 Sheet 3 of 3

Project:	Outram Floodbank Assessment		**Project number:**	3160840	
Site location:	Outram		**Client Name:**	Otago Regional Council	
Location:	End of Orme Street, top of floodbank	**Coordinate system:**	NZTM2000	**Vertical datum:**	NZVD 2016
		Northing:	4917799.0	**Ground level (mRL):**	12.00
		Easting:	1385391.0	**Location method:**	Webmap, +/- 1m

Core Box 05 - 14.30mbgl to 19.50mbgl



Core Box 06 - 19.50mbgl to 19.95mbgl

Machine Borehole Interpretation

Borehole ID: BH03a

Sheet 1 of 2

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client:**	Otago Regional Council

Location:	End of Orme street, at toe of floodbank on township side	**Coordinate system:**	NZTM2000	**Vertical datum:**	NZVD 2016
		Northing:	4917795.0	**Ground level (mRL):**	10.00
		Easting:	1385380.0	**Location method:**	Webmap, +/- 1m

Depth (m)	RL (m)	Method	Soil/ Rock Description	Geological Unit
0.0–2.0	10.0–8.0	VE	No recovery from vacuum excavation.	Holocene River Deposits
2.0–10.0	8.0–0.0	W	Wash drilling, (cuttings not recovered).	Holocene River Deposits

Column headings: Installations; Drilling (Return, GWL, Recovery, Method, Casing, RQD); In Situ Tests (Su (kPa), SPT); Samples; Depth (m); RL (m); Graphic Log; Soil/ Rock Description; Geological Unit; Engineering Unit

Date started:	12/03/2024	**Date end:**	12/03/2024
Logged by:	LM	**Drilled by:**	Speight Drilling
Vane ID:	N/A	**Equipment:**	Sonic
Vane type:	N/A	**Method:**	VE/W
Vane width:	N/A	**Inclination:**	90°
SPT No:	N/A	**Diameter:**	145mm
SPT efficiency:	N/A	**Fluid type:**	Water

Comments:
Hole terminated at target depth.

Groundwater measured at 7.16 m below ground level on 18/03/2024.

For Explanation of Symbols and Abbreviations See Key Sheet

Machine Borehole Interpretation

Borehole ID: BH03a

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client:**	Otago Regional Council

Location:	End of Orme street, at toe of floodbank on township side	**Coordinate system:**	NZTM2000	**Vertical datum:**	NZVD 2016
		Northing:	4917795.0	**Ground level (mRL):**	10.00
		Easting:	1385380.0	**Location method:**	Webmap, +/- 1m

Installations	Drilling: Return	GWL	Recovery	Method	Casing	RQD	In Situ Tests: Su (kPa)	SPT	Samples	Depth (m)	RL (m)	Graphic Log	Soil/ Rock Description	Geological Unit	Engineering Unit
				W						10.0–12.0	0.0 to -2.0		Wash drilling, (cuttings not recovered).	Holocene River Deposits	
										12.0	-2.0		12.00m - End of Borehole, Hole terminated at target depth.		

Depth scale: 10.5, 11.0, 11.5, 12.0, 12.5, 13.0, 13.5, 14.0, 14.5, 15.0, 15.5, 16.0, 16.5, 17.0, 17.5, 18.0, 18.5, 19.0, 19.5
RL scale: -0.5, -1.0, -1.5, -2.0, -2.5, -3.0, -3.5, -4.0, -4.5, -5.0, -5.5, -6.0, -6.5, -7.0, -7.5, -8.0, -8.5, -9.0, -9.5

Date started:	12/03/2024	**Date end:**	12/03/2024
Logged by:	LM	**Drilled by:**	Speight Drilling
Vane ID:	N/A	**Equipment:**	Sonic
Vane type:	N/A	**Method:**	VE/W
Vane width:	N/A	**Inclination:**	90°
SPT No:	N/A	**Diameter:**	145mm
SPT efficiency:	N/A	**Fluid type:**	Water

Comments:
Hole terminated at target depth.

Groundwater measured at 7.16 m below ground level on 18/03/2024.

For Explanation of Symbols and Abbreviations See Key Sheet

Machine Borehole Log

Borehole ID: BH04
Sheet 1 of 3

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client name:**	Otago Regional Council
Location:	Top of floodbank, near Bell Road	**Coordinate system:**	NZTM2000
		Vertical datum:	NZVD 2016
		Northing:	4917500.0
		Ground level (mRL):	11.00
		Easting:	1385382.0
		Location method:	Webmap, +/- 1m

Drilling / In Situ Tests

Depth (m)	Recovery	Method	SPT	Samples
0.00 - 0.40	25%	HA		
0.40 - 1.50	91%	SNC		
1.50 - 1.95	62%	SPT	3, 2, 4, 2, 2, 2 N=10	
1.95 - 3.00	100%	SNC		B (approx. 2.75 - 3.00)
3.00 - 3.45	58%	SPT	2, 1, 1, 1, 1, 1 N=4	
3.45 - 4.50	76%	SNC		
4.50 - 4.95	73%	SPT	3, 4, 3, 2, 3, 3 N=11	
4.95 - 6.00	58%	SNC		
6.00 - 6.45	82%	SPT	3, 3, 3, 2, 2, 3 N=10	
6.45 - 7.50	25%	SNC		
7.50 - 7.95	80%	SPT	2, 1, 1, 1, 1, 1 N=4	
7.95 - 9.00	100%	SNC		
9.00 - 9.45	71%	SPT	4, 7, 4, 3, 5, 6 N=18	
9.45 - 10.00	87%	SNC		

GWL: ▼ at approx. 9.35 m

Soil / Rock Description

Geological Unit	Soil / Rock Description
Floodbank Fill	0.00 - 0.40m, Hand Auger pre-drill, 0.01m recovery
Floodbank Fill	'Hard', SILT minor fine sand; brown, mottled orange, with greyish silt inclusions; dry, low plasticity.
Floodbank Fill	Loose, silty fine SAND; brown; moist. *3.25 - 3.75m: No recovery (depth inferred).* *3.80 - 4.20m: sand becomes fine to medium*
Holocene River Deposits	Medium dense, fine to coarse SAND, some silt, minor fine to coarse gravel; brown; wet. Gravel is sub-angular to sub-rounded, basalt, schist, quartz with minor orange staining.
Holocene River Deposits	Medium dense, fine to medium SAND, minor silt, trace fine to medium gravel; brown; saturated, gap graded. Gravel is sub-angular to sub-rounded. 4.95 - 5.39: No recovery. *5.80 - 6.10m: fine to coarse sand, saturated* *6.00m: Loose* *6.10m: gravel becomes absent* *6.45 - 7.24m: No recovery.* *7.35 - 8.30m: with orange mottling* *7.50m: Loose*
Holocene River Deposits	'Loose', silty fine SAND; grey; saturated, moderately sensitive.
Holocene River Deposits	Medium dense, silty SAND, minor coarse sand, minor fine gravel; dark grey; saturated, minor fibrous organics.
Holocene River Deposits	Medium dense, medium to coarse GRAVEL; grey; wet, well graded. Gravel is unweathered, basalt, with minor quartz veining, fines likely washed away.
Holocene River Deposits	Medium dense, fine to coarse sandy fine to coarse GRAVEL, minor silt; matrix is brown; gravels are grey, brown, and green; saturated, well graded. Gravel is sub-angular to rounded, basalt, quartz, greenschist, rusty biotite schist.

Date started:	05/03/2024	**Date end:**	06/03/2024
Logged by:	LM	**Drilled by:**	Speight Drilling
Vane ID:	N/A	**Equipment:**	Sonic
Vane type:	N/A	**Method:**	SNC/HA/SPT
Vane width:	N/A	**Inc/Az:**	90° / N/A
SPT ID:	CD51	**Diameter:**	145mm
SPT efficiency:	68%	**Fluid type:**	Water

Comments:
Hole terminated at target depth.

Groundwater measured at 9.35 m below ground level on completion of drilling.

For Explanation of Symbols and Abbreviations See Key Sheet

Machine Borehole Log

Borehole ID: BH04

Sheet 2 of 3

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client name:**	Otago Regional Council
Location:	Top of floodbank, near Bell Road	**Coordinate system:**	NZTM2000
		Vertical datum:	NZVD 2016
		Northing:	4917500.0
		Ground level (mRL):	11.00
		Easting:	1385382.0
		Location method:	Webmap, +/- 1m

Recovery	Method	SPT	Depth (m)	RL (m)	Soil / Rock Description	Geological Unit
			10.0 – 11.23		Medium dense, fine to coarse sandy fine to coarse GRAVEL, minor silt; matrix is brown; gravels are grey, brown, and green; saturated, well graded. Gravel is sub-angular to rounded, basalt, quartz, greenschist, rusty biotite schist. *10.40 - 15.70m: gravel becomes fine grained, trace coarse grained.*	Holocene River Deposits
51%	SPT	8, 5, 4, 5, 4, 4 N=17	10.5	0.5		
27%	SNC		11.0	0.0		
			11.23 – 12.00		11.23 - 12.00m: No recovery (depth inferred).	
73%	SPT	6, 10, 7, 6, 4, 4 N=21	12.0	-1.0		
100%	SNC		12.5 – 13.0	-1.5 – -2.0		
44%	SPT	7, 7, 7, 6, 5, 5 N=23	13.5	-2.5		
			14.0	-3.0	Medium dense, fine to coarse gravelly, fine to coarse SAND, minor silt; greyish brown; saturated, well graded. Gravel is sub-angular to rounded, unweathered, basalt, quartz, schist. *14.65 - 15.90m: Orangish brown*	
100%	SNC		14.5	-3.5		
44%	SPT	6, 6, 4, 5, 5, 5 N=19	15.0 – 15.5	-4.0 – -4.5		
98%	SNC		16.0	-5.0		
44%	SPT	10, 9, 6, 7, 7, 7 N=27	16.5 – 17.0	-5.5 – -6.0	*17.00 - 17.10m: Orangish brown*	
51%	SNC		17.49	-6.5	17.49 - 18.00m: No recovery (depth inferred).	
71%	SPT	34, 16/20mm, HB, HB, HB N=50+	18.0	-7.0	Medium dense, fine to coarse sandy fine to coarse GRAVEL, minor silt; brown with orange mottling; saturated, well graded. Gravel is sub-angular to rounded, basalt, quartz, schist. *18.62 - 19.50m: No recovery (depth inferred).*	
34%	SNC		18.5 – 19.0	-7.5 – -8.0		
		50/30mm, HB, HB	19.5	-8.5	19.53m - End of Borehole, Hole terminated at target depth.	

Date started:	05/03/2024	**Date end:**	06/03/2024
Logged by:	LM	**Drilled by:**	Speight Drilling
Vane ID:	N/A	**Equipment:**	Sonic
Vane type:	N/A	**Method:**	SNC/HA/SPT
Vane width:	N/A	**Inc/Az:**	90° / N/A
SPT ID:	CD51	**Diameter:**	145mm
SPT efficiency:	68%	**Fluid type:**	Water

Comments:
Hole terminated at target depth.

Groundwater measured at 9.35 m below ground level on completion of drilling.

For Explanation of Symbols and Abbreviations See Key Sheet

Machine Borehole Log

Borehole ID: BH04
Sheet 3 of 3

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client name:**	Otago Regional Council

Location:	Top of floodbank, near Bell Road	**Coordinate system:**	NZTM2000	**Vertical datum:**	NZVD 2016
		Northing:	4917500.0	**Ground level (mRL):**	11.00
		Easting:	1385382.0	**Location method:**	Webmap, +/- 1m

Drilling						In Situ Tests							
GWL	Fluid Return	Recovery	Method	Casing	RQD	Su (kPa)	SPT	Samples	Depth (m)	RL (m)	Graphic Log	Soil / Rock Description	Geological Unit
							HB N=50+						
									20.5	-9.5			
									21.0	-10.0			
									21.5	-10.5			
									22.0	-11.0			
									22.5	-11.5			
									23.0	-12.0			
									23.5	-12.5			
									24.0	-13.0			
									24.5	-13.5			
									25.0	-14.0			
									25.5	-14.5			
									26.0	-15.0			
									26.5	-15.5			
									27.0	-16.0			
									27.5	-16.5			
									28.0	-17.0			
									28.5	-17.5			
									29.0	-18.0			
									29.5	-18.5			

Date started:	05/03/2024	**Date end:**	06/03/2024
Logged by:	LM	**Drilled by:**	Speight Drilling
Vane ID:	N/A	**Equipment:**	Sonic
Vane type:	N/A	**Method:**	SNC/HA/SPT
Vane width:	N/A	**Inc/Az:**	90° / N/A
SPT ID:	CD51	**Diameter:**	145mm
SPT efficiency:	68%	**Fluid type:**	Water

Comments:
Hole terminated at target depth.

Groundwater measured at 9.35 m below ground level on completion of drilling.

For Explanation of Symbols and Abbreviations See Key Sheet

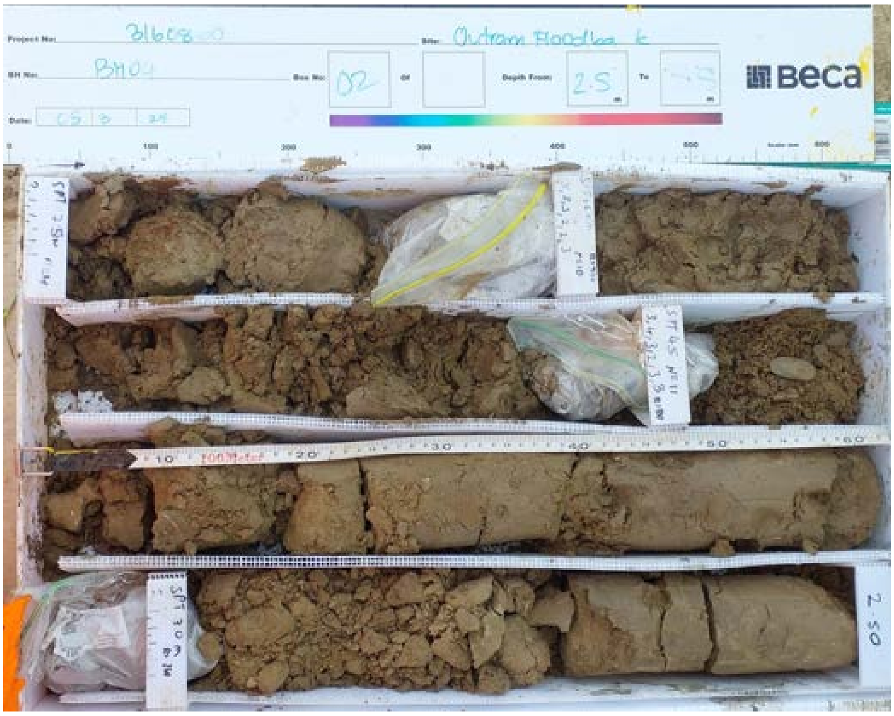
Photo Log

Location ID:	BH04
	Sheet 1 of 3

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client Name:**	Otago Regional Council

Location:	Top of floodbank, near Bell Road	**Coordinate system:**	NZTM2000	**Vertical datum:**	NZVD 2016
		Northing:	4917500.0	**Ground level (mRL):**	11.00
		Easting:	1385382.0	**Location method:**	Webmap, +/- 1m

Core Box 01 - 0.00mbgl to 2.50mbgl



Core Box 02 - 2.50mbgl to 7.50mbgl

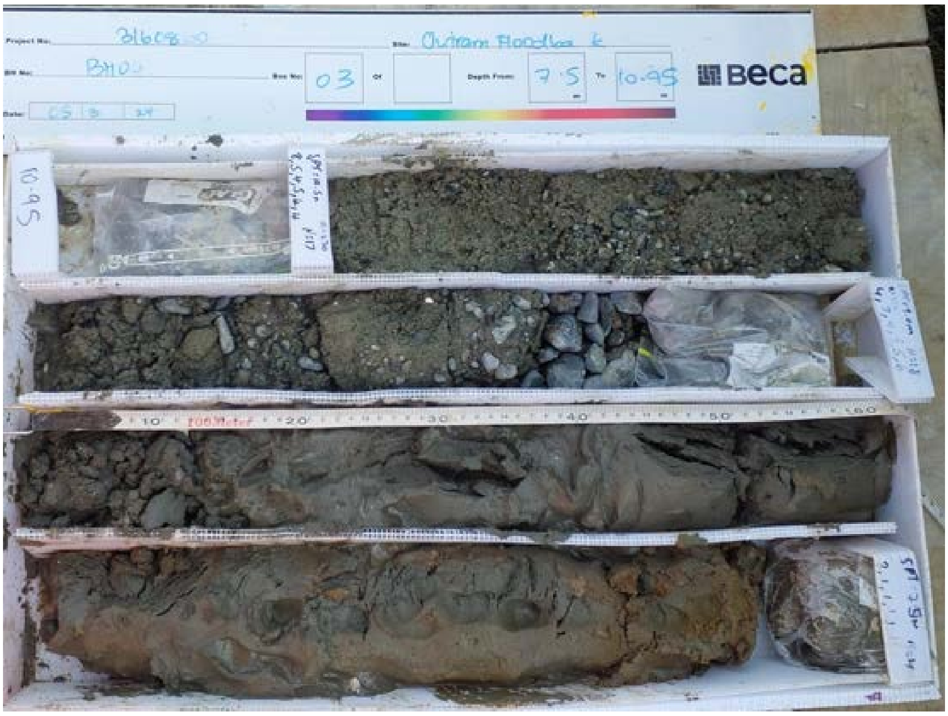
Photo Log

Location ID: BH04

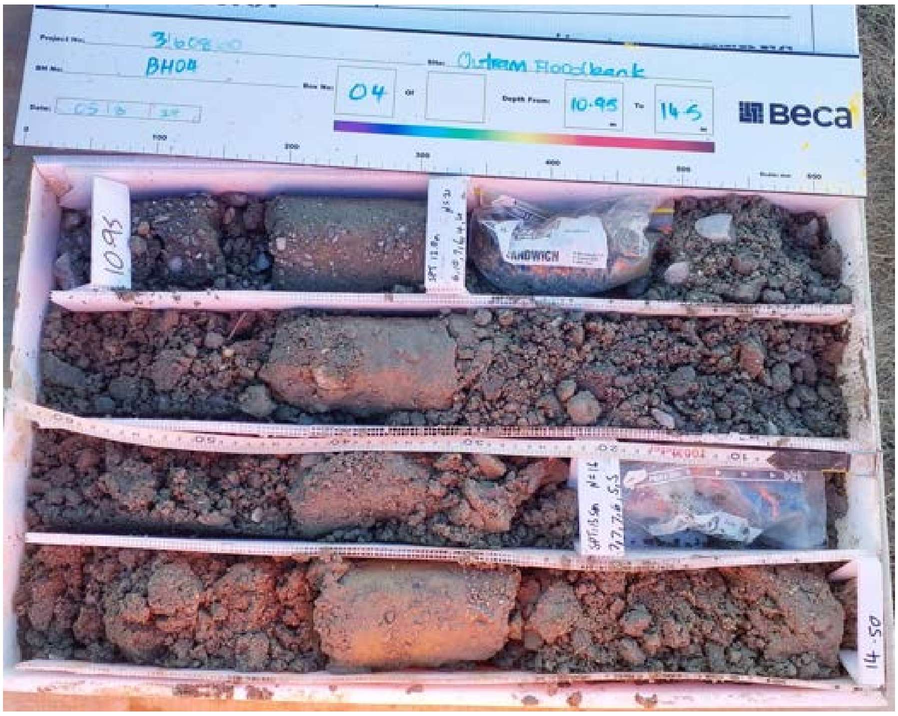
Sheet 2 of 3

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client Name:**	Otago Regional Council

Location:	Top of floodbank, near Bell Road	**Coordinate system:**	NZTM2000	**Vertical datum:**	NZVD 2016
		Northing:	4917500.0	**Ground level (mRL):**	11.00
		Easting:	1385382.0	**Location method:**	Webmap, +/- 1m



Core Box 03 - 7.50mbgl to 10.95mbgl



Core Box 04 - 10.95mbgl to 14.50mbgl

Beca	Photo Log	Location ID:	BH04
			Sheet 3 of 3

Project:	Outram Floodbank Assessment		**Project number:**	3160840	
Site location:	Outram		**Client Name:**	Otago Regional Council	
Location:	Top of floodbank, near Bell Road	**Coordinate system:**	NZTM2000	**Vertical datum:**	NZVD 2016
		Northing:	4917500.0	**Ground level (mRL):**	11.00
		Easting:	1385382.0	**Location method:**	Webmap, +/- 1m

Core Box 05 - 14.50mbgl to 19.20mbgl

Core Box 06 - 19.20mbgl to 19.53mbgl

Machine Borehole Interpretation

Borehole ID: BH04a

Sheet 1 of 1

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client:**	Otago Regional Council
Location:	Landside toe of floodbank adjacent to BH04.	**Coordinate system:**	NZTM2000
		Northing:	4917488.0
		Easting:	1385362.0
		Vertical datum:	NZVD 2016
		Ground level (mRL):	8.00
		Location method:	Webmap, +/- 1m

Installations | Drilling: Return, GWL, Recovery, Method, Casing, RQD | In Situ Tests: Su (kPa), SPT | Samples | Depth (m) | RL (m) | Graphic Log | Soil/ Rock Description | Geological Unit | Engineering Unit

Depth (m)	RL (m)	Method	Soil/ Rock Description	Geological Unit
0.0 – 2.0	8.0 – 6.0	HE	No recovery from hand auger pre-drill.	Holocene River Deposits
2.0 – 6.1	6.0 – 1.9	W	Wash drilling, (cuttings not recovered).	Holocene River Deposits
6.10			6.10m - End of Borehole, Hole terminated at target depth.	

Depth scale (m): 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0, 9.5

RL scale (m): 7.5, 7.0, 6.5, 6.0, 5.5, 5.0, 4.5, 4.0, 3.5, 3.0, 2.5, 2.0, 1.5, 1.0, 0.5, 0.0, -0.5, -1.0, -1.5

Date started:	04/03/2024	**Date end:**	04/03/2024
Logged by:	LM	**Drilled by:**	Speight Drilling
Vane ID:	N/A	**Equipment:**	Sonic
Vane type:	N/A	**Method:**	W/HE
Vane width:	N/A	**Inclination:**	90°
SPT No:	N/A	**Diameter:**	145mm
SPT efficiency:	N/A	**Fluid type:**	Water

Comments:
Hole terminated at target depth.

Groundwater measured at 4.89 m below ground level on 19/03/2024.

For Explanation of Symbols and Abbreviations See Key Sheet

Machine Borehole Interpretation

Borehole ID: BH05

Sheet 1 of 1

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client:**	Otago Regional Council
Location:	8 Skerries Street, Outram. Outram Bowling Club carpark	**Coordinate system:** NZTM2000	**Vertical datum:** NZVD 2016
		Northing: 4917928.0	**Ground level (mRL):** 7.00
		Easting: 1384745.0	**Location method:** Webmap, +/- 1m

Depth (m)	RL (m)	Drilling: Recovery	Drilling: Method	Samples	Soil/ Rock Description	Geological Unit
0.00 – 1.00	7.00 – 6.00		VE		No recovery from vacuum excavation. Downhole observations indicate the material is SILT.	Holocene River Deposits
1.00 – 2.00	6.00 – 5.00		VE	C	*1.00 - 2.00m: Backfill material captured in core (sand).*	
2.00 – 2.50	5.00 – 4.50	90%	SNC	C	'Loose', fine to medium SAND, minor silt; brown; moist, well graded.	
2.50 – 4.20	4.50 – 2.80	90% / 100%	SNC	C	'Medium dense', sandy fine to medium GRAVEL; reddish brown; saturated, well graded. Gravel is rounded to sub-angular, unweathered; basalt, schist, and quartz.	
4.20 – 4.50	2.80 – 2.50	100%	SNC	C	'Medium dense', medium SAND; grey; wet, poorly graded.	
4.50 – 5.60	2.50 – 1.40	100%	SNC	C	'Medium dense', fine to coarse sandy fine to medium GRAVEL, minor silt; grey; saturated, well graded, rounded to sub-angular. *5.00 - 5.10m: silty fine sand* *5.15 - 5.25m: fine to medium grained SAND* *5.30m: thin layer of dark brown silt*	
5.60 – 7.10	1.40 – -0.10	100% / 47%	SNC	C	'Medium dense', silty fine SAND; grey; saturated, extra sensitive. *6.00 - 6.80m: No recovery (depth inferred).*	
7.10 – 7.60	-0.10 – -0.60	47% / 100%	SNC	C	'Medium dense', fine to medium gravelly fine SAND; grey; moist, gap graded. Gravel is rounded to sub-angular, unweathered; dark staining on basalt.	
7.60 – 7.80	-0.60 – -0.80	100%	SNC	C	'Stiff', fine sandy SILT, minor clay; grey; saturated, low plasticity.	
7.80 – 9.00	-0.80 – -2.00	100%	SNC	C	'Firm', SILT, minor clay, trace organics; grey and dark brown; moist, laminated, low plasticity. Organics are amorphous, and spongy fibrous wood, some leaves: dark brown laminae contains minor organics. slight organic odor.	
9.00	-2.00				9.00m - End of Borehole, Hole terminated at target depth.	

GWL: groundwater marker at approx. 3.5 m.

Date started:	14/03/2024	**Date end:**	14/03/2024	**Comments:**
Logged by:	LM	**Drilled by:**	Speight Drilling	Hole terminated at target depth.
Vane ID:	N/A	**Equipment:**	Sonic	
Vane type:	N/A	**Method:**	SNC/VE	Groundwater measured 3.52 m below ground level on 18/03/2024.
Vane width:	N/A	**Inclination:**	90°	
SPT No:	N/A	**Diameter:**	145mm	
SPT efficiency:	N/A	**Fluid type:**	Water	

For Explanation of Symbols and Abbreviations See Key Sheet

Machine Borehole Interpretation

Borehole ID: BH06

Sheet 1 of 1

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client:**	Otago Regional Council

Location:	Corner Bell Street and Beaumaris Street	**Coordinate system:**	NZTM2000	**Vertical datum:**	NZVD 2016
		Northing:	4917752.0	**Ground level (mRL):**	9.00
		Easting:	1385034.0	**Location method:**	Webmap, +/- 1m

Depth (m)	RL (m)	Method	Soil/ Rock Description	Geological Unit
0.0 – 2.0	9.0 – 7.0	VE	No Recovery from vacuum excavation	Holocene River Deposits
2.0 – 8.0	7.0 – 1.0	W	Wash drilling (cuttings not recovered).	Holocene River Deposits
8.0	1.0		8.00m - End of Borehole, Hole terminated at target depth.	

Column headings: Installations; Drilling (Return, GWL, Recovery, Method, Casing, RQD); In Situ Tests (Su (kPa), SPT); Samples; Depth (m); RL (m); Graphic Log; Soil/ Rock Description; Geological Unit; Engineering Unit.

Depth scale: 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0, 9.5

RL scale: 8.5, 8.0, 7.5, 7.0, 6.5, 6.0, 5.5, 5.0, 4.5, 4.0, 3.5, 3.0, 2.5, 2.0, 1.5, 1.0, 0.5, 0.0, -0.5

Date started:	13/03/2024	**Date end:**	13/03/2024
Logged by:	LM	**Drilled by:**	Speight Drilling
Vane ID:	N/A	**Equipment:**	Sonic
Vane type:	N/A	**Method:**	VE/W
Vane width:	N/A	**Inclination:**	90°
SPT No:	N/A	**Diameter:**	
SPT efficiency:	N/A	**Fluid type:**	Water

Comments:
Hole terminated at target depth.

Groundwater measured at 6.34 m on 14/04/2024 post development.

For Explanation of Symbols and Abbreviations See Key Sheet

Beca — Machine Borehole Interpretation

Borehole ID: BH07

Sheet 1 of 2

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client:**	Otago Regional Council
Location:	102 Formby Street, Outram.	**Coordinate system:**	NZTM2000
		Northing:	4917302.0
		Easting:	1384984.0
		Vertical datum:	NZVD 2016
		Ground level (mRL):	8.50
		Location method:	Webmap, +/- 1m

Depth (m)	RL (m)	Recovery	Method	Samples	Soil/ Rock Description	Geological Unit
0.0 – 2.0	8.5 – 6.5	0%	VE		0.0 - 2.0m, No recovery from vacuum excavation	Holocene River Deposits
2.0 – 3.0	6.5 – 5.5	90%	SNC	C (2.0 – 4.5)	'Loose' fine to medium SAND, minor silt; brown; moist, well graded. *2.60m: silt becomes trace* *3.00 - 3.50m: No recovery (depth inferred).* *4.10m: becomes silty fine SAND, brown, trace orange mottling* *4.50 - 4.90m: No recovery (depth inferred).*	Holocene River Deposits
3.0 – 4.5	5.5 – 4.0	67%	SNC			
4.5 – 6.0	4.0 – 2.5	73%	SNC	C (4.5 – 7.5)		
5.8					'Medium dense', fine to medium gravelly, fine to coarse SAND, some silt; brown; wet, well graded. Gravel is sub-angular to rounded, basalt, quartz, schist, unweathered, minor reddish staining on basalt. *6.30m: becomes grey, staining absent* *7.10 - 7.50m: No recovery (depth inferred).*	Holocene River Deposits
6.0 – 7.5	2.5 – 1.0	73%	SNC			
7.5 – 9.0	1.0 – -0.5	87%	SNC	C (7.5 – end of sheet)	'Medium dense', fine to coarse sandy fine to coarse GRAVEL; grey; saturated, well graded. Gravel is rounded to sub-angular, unweathered; greywacke, schist, quartz. Schist is unweathered to moderately weathered, some clasts with orange staining/rusting.	Holocene River Deposits
9.0 – end of sheet	-0.5 –	80%	SNC			
9.7	-1.2				'Medium dense', fine to medium gravelly fine to coarse SAND, some silt; grey; wet, well graded. Gravel is sub-angular to rounded.	Holocene River Deposits

Groundwater level symbol shown at approx. 5.8 m.

Date started:	13/03/2024	**Date end:**	14/03/2024
Logged by:	LM	**Drilled by:**	Speight Drilling
Vane ID:	N/A	**Equipment:**	Sonic
Vane type:	N/A	**Method:**	SNC/VE
Vane width:	N/A	**Inclination:**	90°
SPT No:	N/A	**Diameter:**	145mm
SPT efficiency:	N/A	**Fluid type:**	Water

Comments:
Hole terminated at target depth.
Groundwater measured at 5.87 m below ground level on 19/03/2024.

For Explanation of Symbols and Abbreviations See Key Sheet

Machine Borehole Interpretation

Borehole ID: BH07

Sheet 2 of 2

Project:	Outram Floodbank Assessment	**Project number:**	3160840
Site location:	Outram	**Client:**	Otago Regional Council
Location:	102 Formby Street, Outram.	**Coordinate system:**	NZTM2000
		Vertical datum:	NZVD 2016
		Northing:	4917302.0
		Ground level (mRL):	8.50
		Easting:	1384984.0
		Location method:	Webmap, +/- 1m

Recovery	Method	Samples	Depth (m)	RL (m)	Soil/ Rock Description	Geological Unit
80%	SNC	C	10.0 – 10.5	-1.5 – -2.0	'Medium dense', fine to medium gravelly fine to coarse SAND, some silt; grey; wet, well graded. Gravel is sub-angular to rounded. *10.20 - 10.40m: silty* *10.30m: gravel becomes fine*	Holocene River Deposits
53%	SNC	C			'Medium dense', silty fine to coarse SAND; grey; wet, well graded.	Holocene River Deposits
					'Firm', fine sandy SILT; dark brown, mottled brown; wet, low plasticity. Layer with .20mm of fine gravelly fine to medium grained sand at base.	Holocene River Deposits
					'Medium dense', fine to coarse SAND, some fine to medium gravel, some silt; grey; wet, well graded. Gravel is rounded to sub-angular.	Holocene River Deposits
					11.30 - 12.00m: No recovery (depth inferred)	Holocene River Deposits
53%	SNC				'Medium dense', fine to medium SAND, minor silt; grey; saturated. *12.50 - 13.30m: sand becomes fine to coarse*	Holocene River Deposits
					WOOD; pink, fibrous, able to be crushed and pulled apart with fingers, a silt plug overlays the wood, ~ 5cm thick, dark grey and grey.	Holocene River Deposits
					12.80 - 13.50m: No recovery (depth inferred)	Holocene River Deposits
87%	SNC		13.5	-5.0	'Medium dense', silty fine to medium SAND, minor clay; grey; wet, laminated with brownish grey clayey SILT, firm, wet, slight organic odor.	Holocene River Deposits
					'Medium dense', silty, sandy, fine to coarse GRAVEL, grey; saturated, well graded, matrix bound. Gravel is unweathered, basalt, schist, quartz.	Holocene River Deposits
			15.0	-6.5	15.00m - End of Borehole, Hole terminated at target depth.	

Depth scale: 10.5, 11.0, 11.5, 12.0, 12.5, 13.0, 13.5, 14.0, 14.5, 15.0, 15.5, 16.0, 16.5, 17.0, 17.5, 18.0, 18.5, 19.0, 19.5
RL scale: -2.0, -2.5, -3.0, -3.5, -4.0, -4.5, -5.0, -5.5, -6.0, -6.5, -7.0, -7.5, -8.0, -8.5, -9.0, -9.5, -10.0, -10.5, -11.0

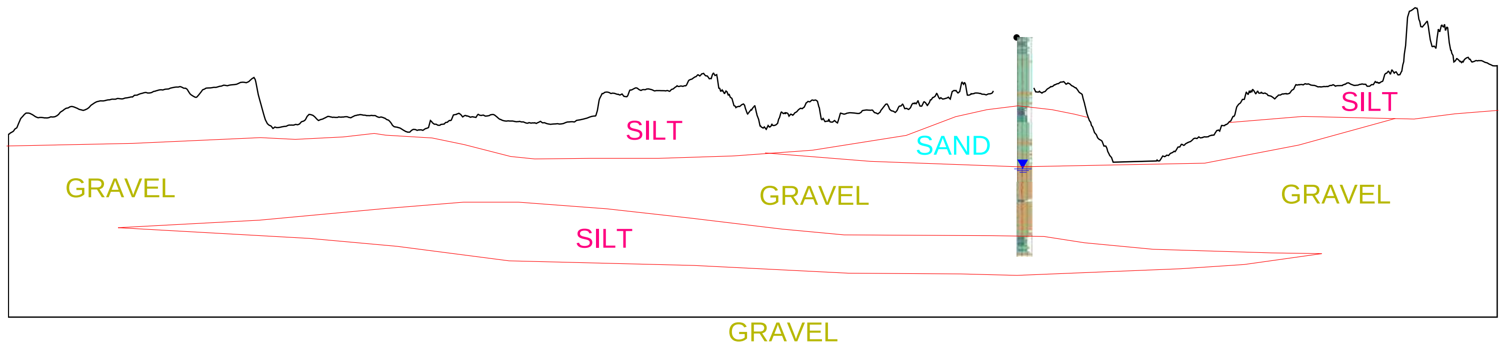
Date started:	13/03/2024	**Date end:**	14/03/2024
Logged by:	LM	**Drilled by:**	Speight Drilling
Vane ID:	N/A	**Equipment:**	Sonic
Vane type:	N/A	**Method:**	SNC/VE
Vane width:	N/A	**Inclination:**	90°
SPT No:	N/A	**Diameter:**	145mm
SPT efficiency:	N/A	**Fluid type:**	Water

Comments:
Hole terminated at target depth.
Groundwater measured at 5.87 m below ground level on 19/03/2024.

For Explanation of Symbols and Abbreviations See Key Sheet

C

Appendix C – Cross Sections



Silt

Outram_Floodbank_Water_Strike_General

Soil Behaviour Type SBT$_n$ - Robertson et al. 1990

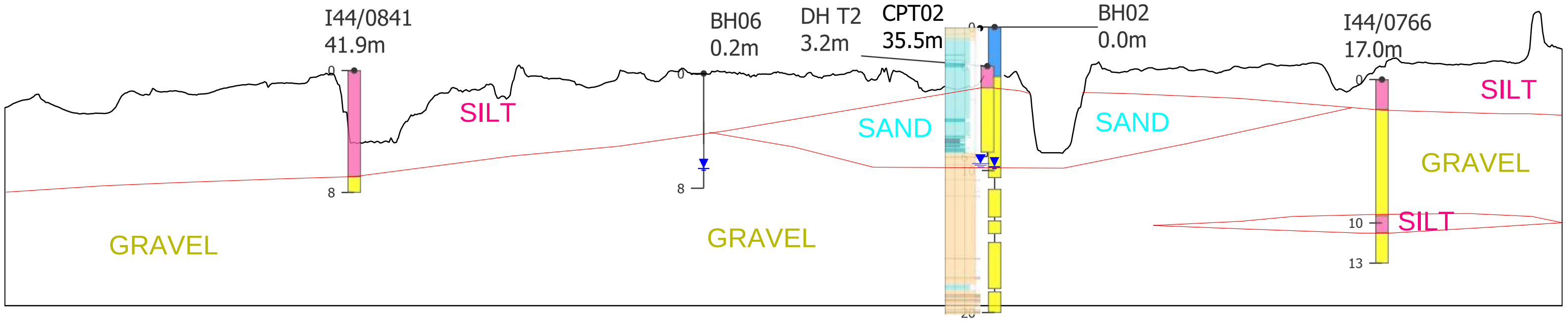
0	Undefined	5	Sand mixtures: silty sand to sandy silt
1	Sensitive fine grained	6	Sands: clean sands to silty sands
2	Organic: Organic clay/silt, peat	7	Dense sand to gravelly sand
3	Clay: clay to silty clay	8	Stiff sand to clayey sand
4	Silt mixtures: clayey silt & silty clay	9	Stiff silt/clay

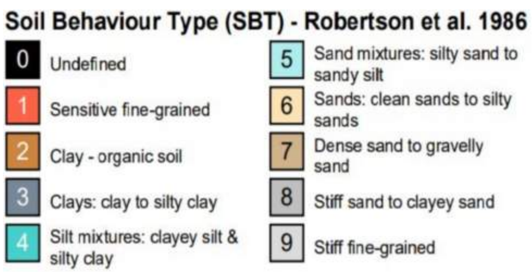
Location

1384157, 4917556

1385936, 4918680

0m 400m



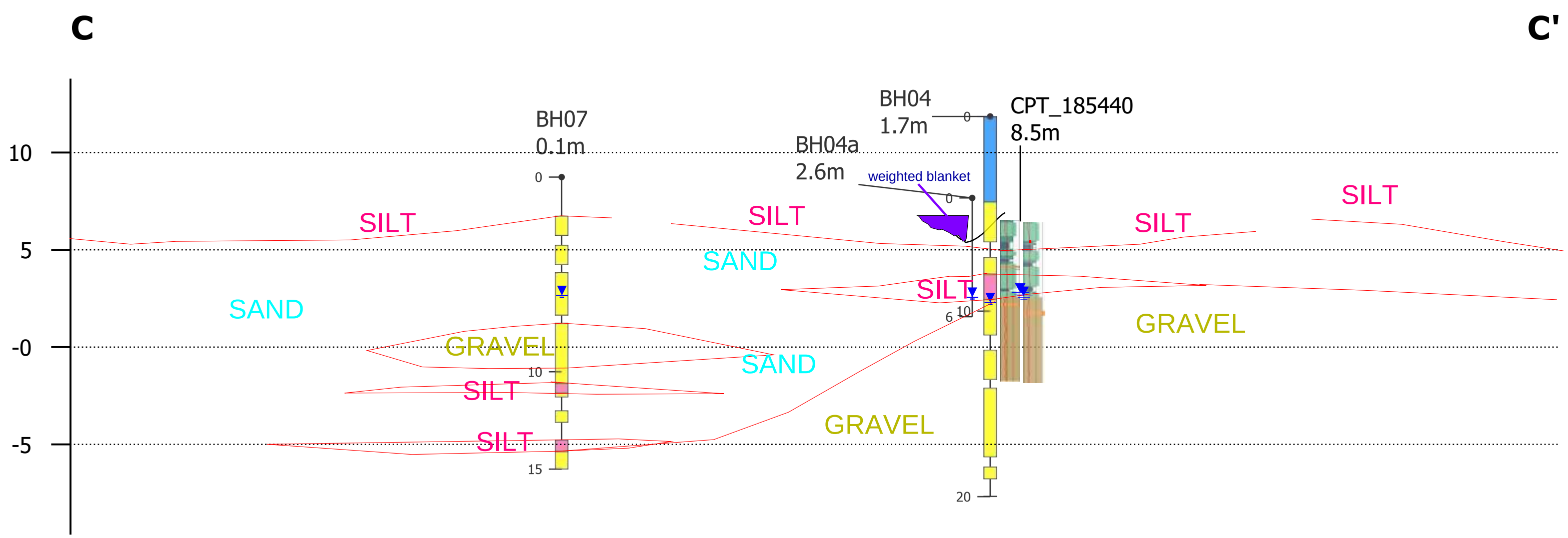


B: 1384328, 4917076

B':

0m 400m

C-C'



Legend

- Fill
- Sandy Gravel

Water

- Outram_Floodbank_Water_Strike_General

Soil Behaviour Type SBT_n - Robertson et al. 1990

- 0 Undefined
- 1 Sensitive fine grained
- 2 Organic: Organic clay/silt, peat
- 3 Clay: clay to silty clay
- 4 Silt mixtures: clayey silt & silty clay
- 5 Sand mixtures: silty sand to sandy silt
- 6 Sands: clean sands to silty sands
- 7 Dense sand to gravelly sand
- 8 Stiff sand to clayey sand
- 9 Stiff silt/clay

C: 1384532, 4917077

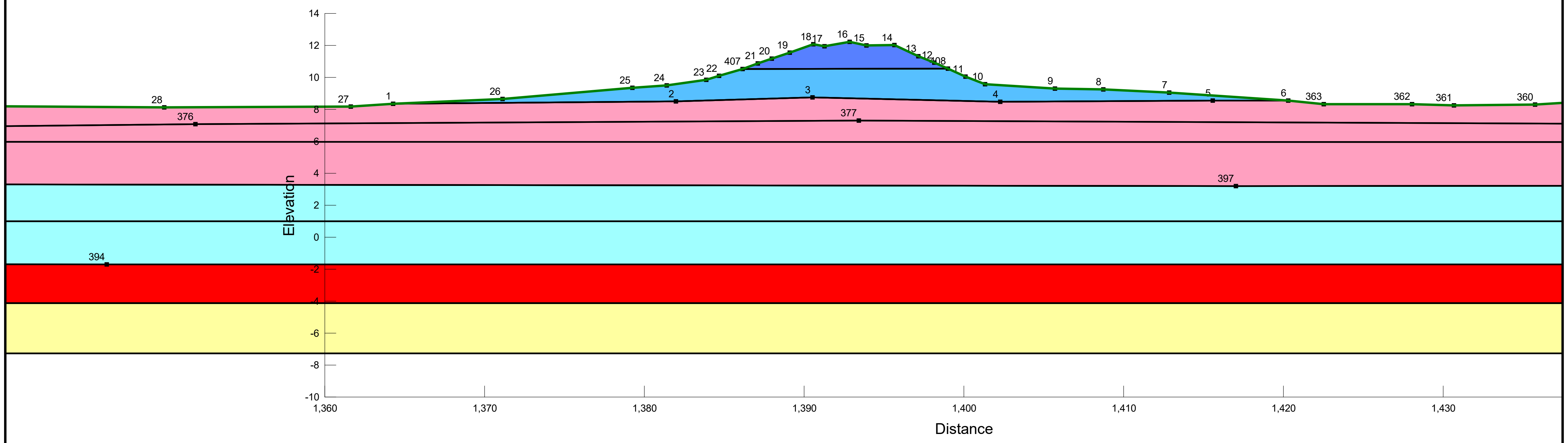
C': 1385899, 4917759

Scale: 1:6,600

Vertical exaggeration: 20x

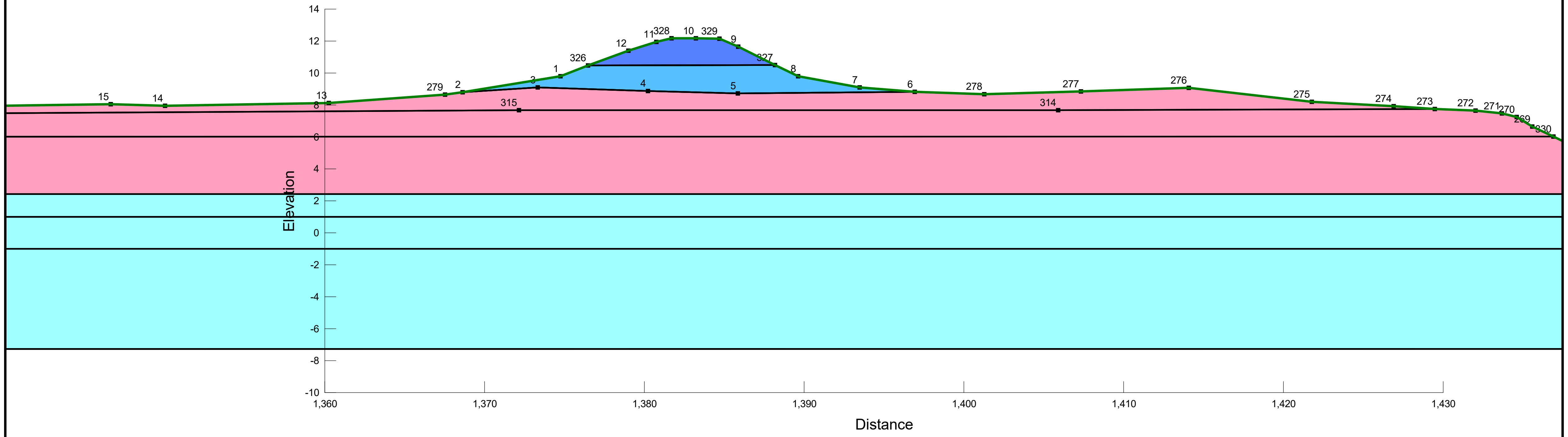
0m 400m

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20	0	38	0
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18	3	30	0
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17	0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17	0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18	0	32	0
	Stiff SILT	Mohr-Coulomb	18	2	28	0



Section A-A'	
Outram_SEEP-W Model_Average Conditions.gsz	
08/08/2024	1:250

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18	3	30	0
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17	0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17	0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18	0	32	0

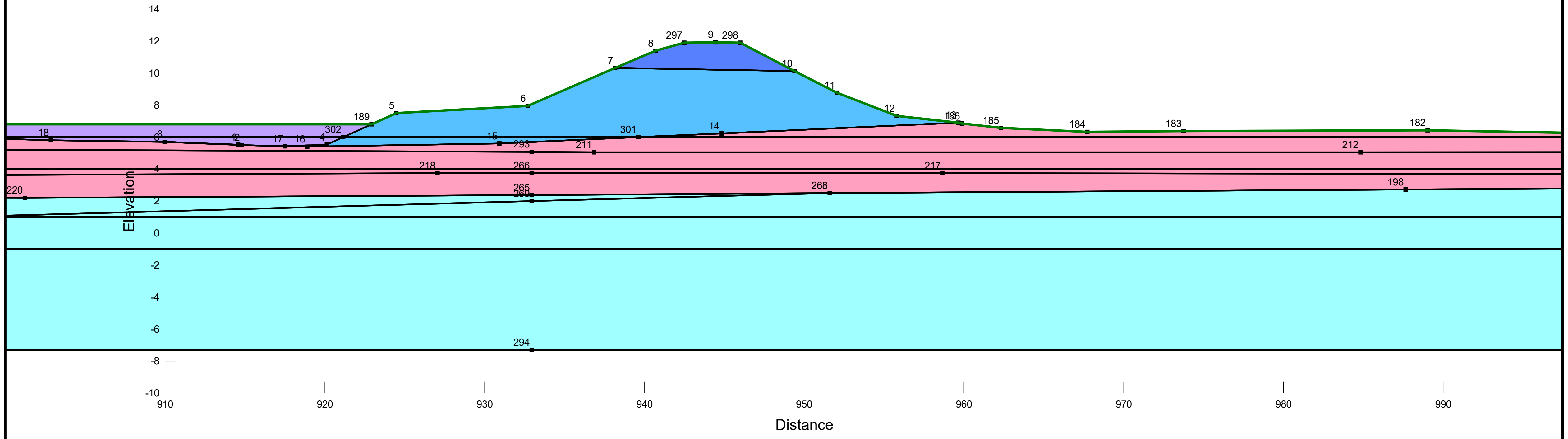


Section B-B'

Outram_SEEP-W Model_Average Conditions.gsz

08/08/2024 1:250

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20	0	38	0
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18	3	30	0
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17	0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17	0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18	0	32	0
	Weighted Blanket - Alluvial SILT	Mohr-Coulomb	17	1	28	0



Section C-C'	
Outram_SEEP-W Model_Average Conditions.gsz	
08/08/2024	1:250

D

Appendix D – Liquefaction Assessment

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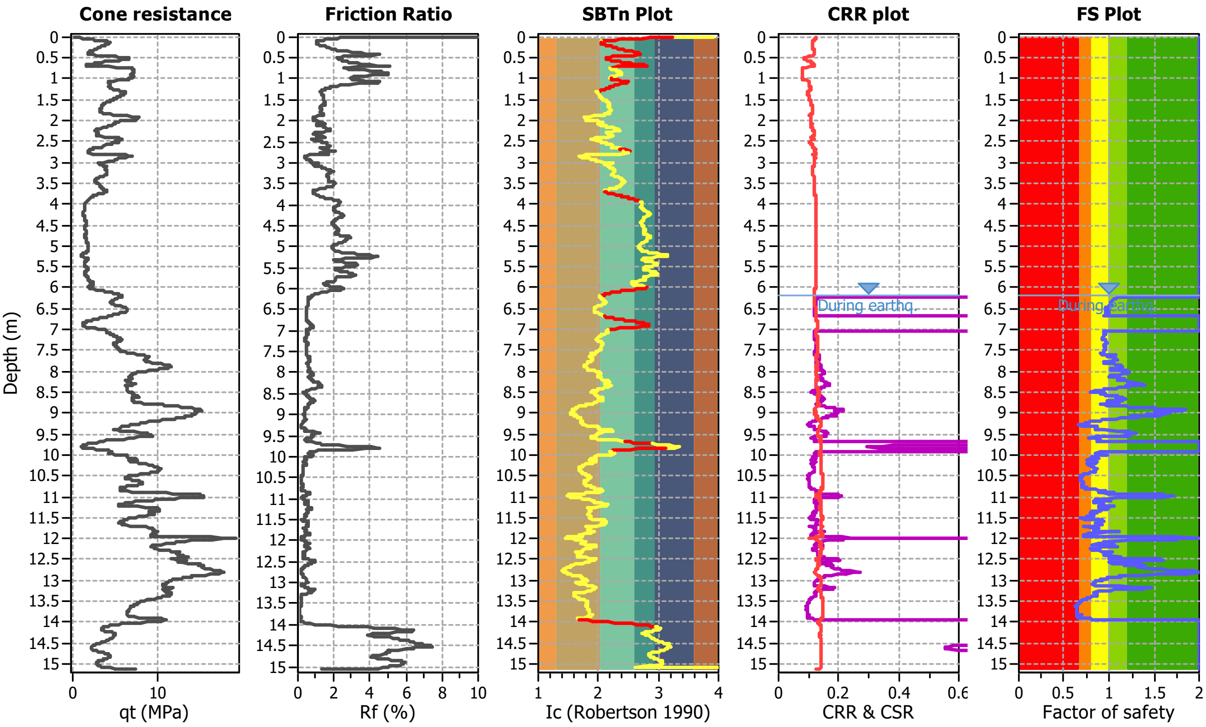
LIQUEFACTION ANALYSIS REPORT

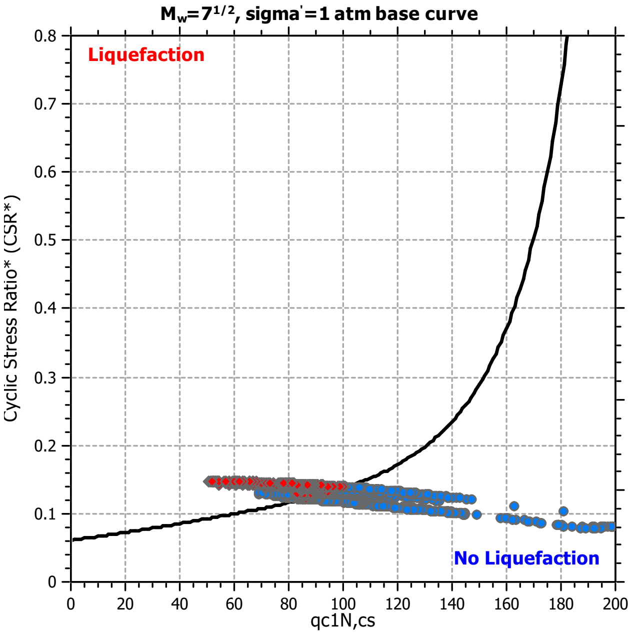
Project title : Outram Floodbank Investigation **Location : Outram, Otago**

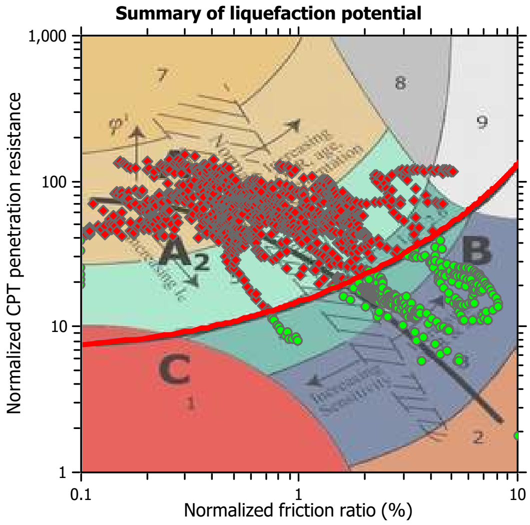
CPT file : CPT_185409

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	6.20 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	6.20 m	Fill height:	N/A		
Points to test:	Based on Ic value	Average results interval:	3	Fill weight:	N/A	Limit depth applied:	No
Earthquake magnitude M_w:	6.00	Ic cut-off value:	2.60	Trans. detect. applied:	Yes	Limit depth:	N/A
Peak ground acceleration:	0.23	Unit weight calculation:	Based on SBT	K_σ applied:	Yes	MSF method:	Method based

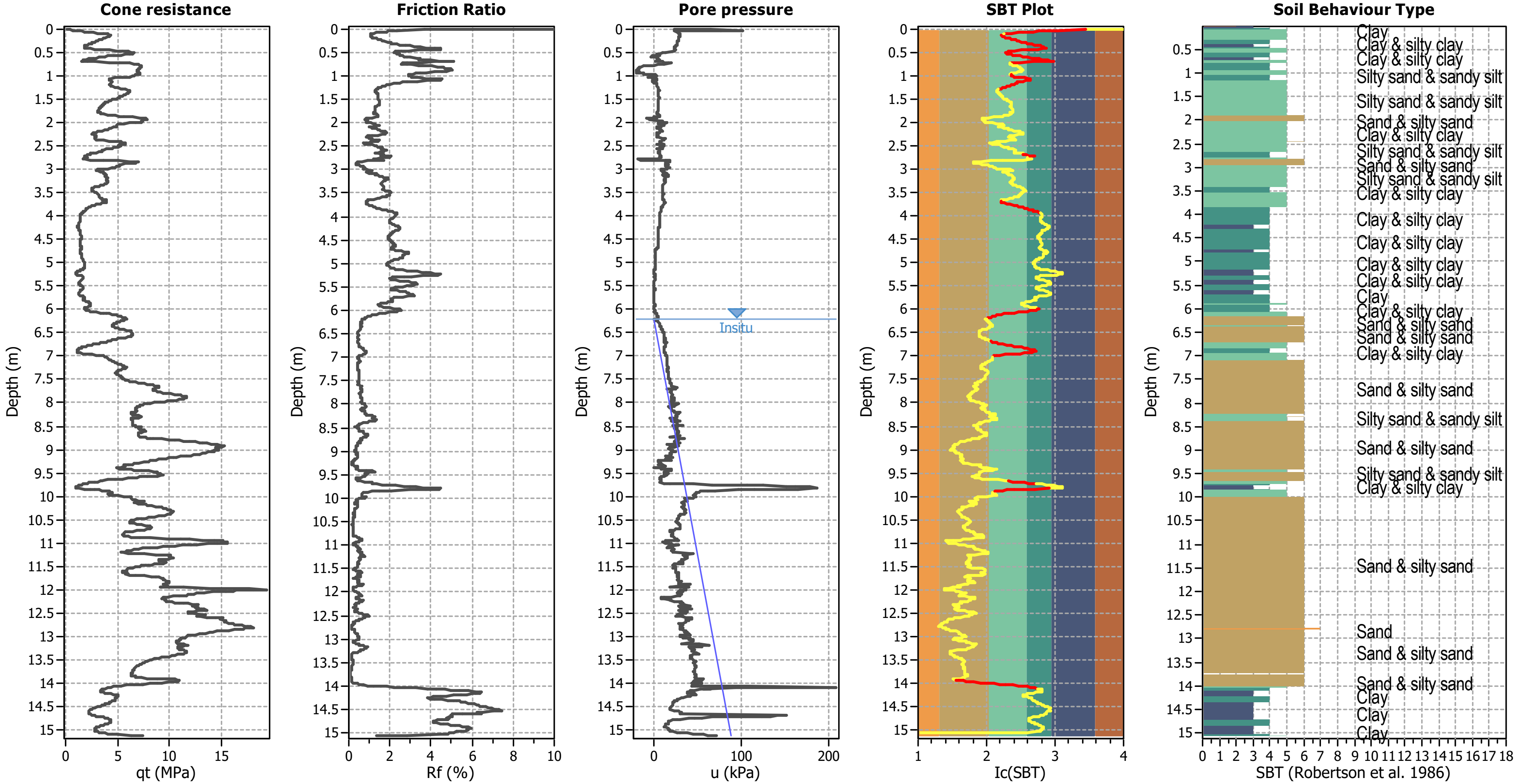






Zone A_1: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A_2: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and strength loss possible depending on soil plasticity, brittleness/sensitivity, strain to peak undrained strength and ground geometry

CPT basic interpretation plots



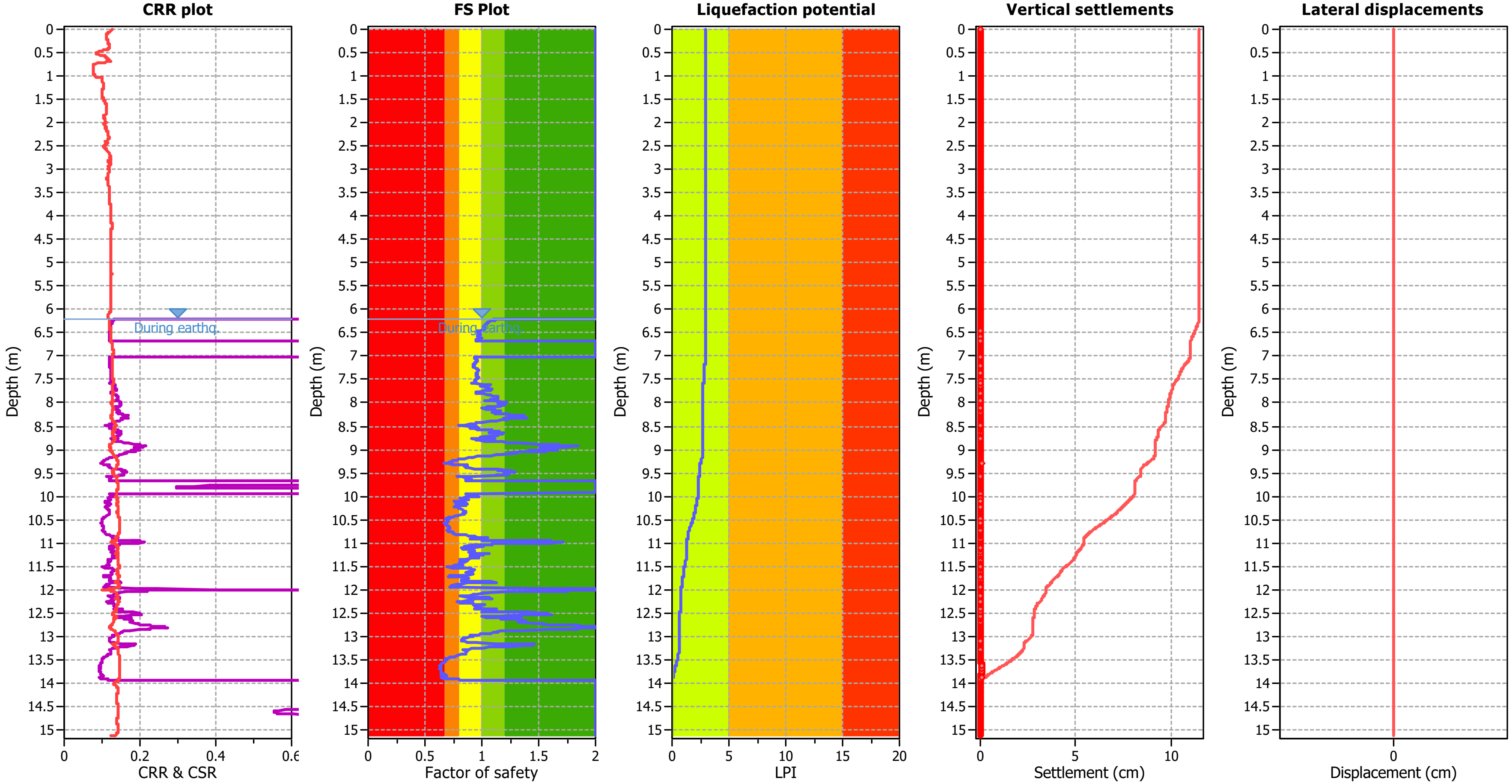
Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.20 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.23	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.20 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

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.20 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.23	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.20 m	Fill height:	N/A	Limit depth:	N/A

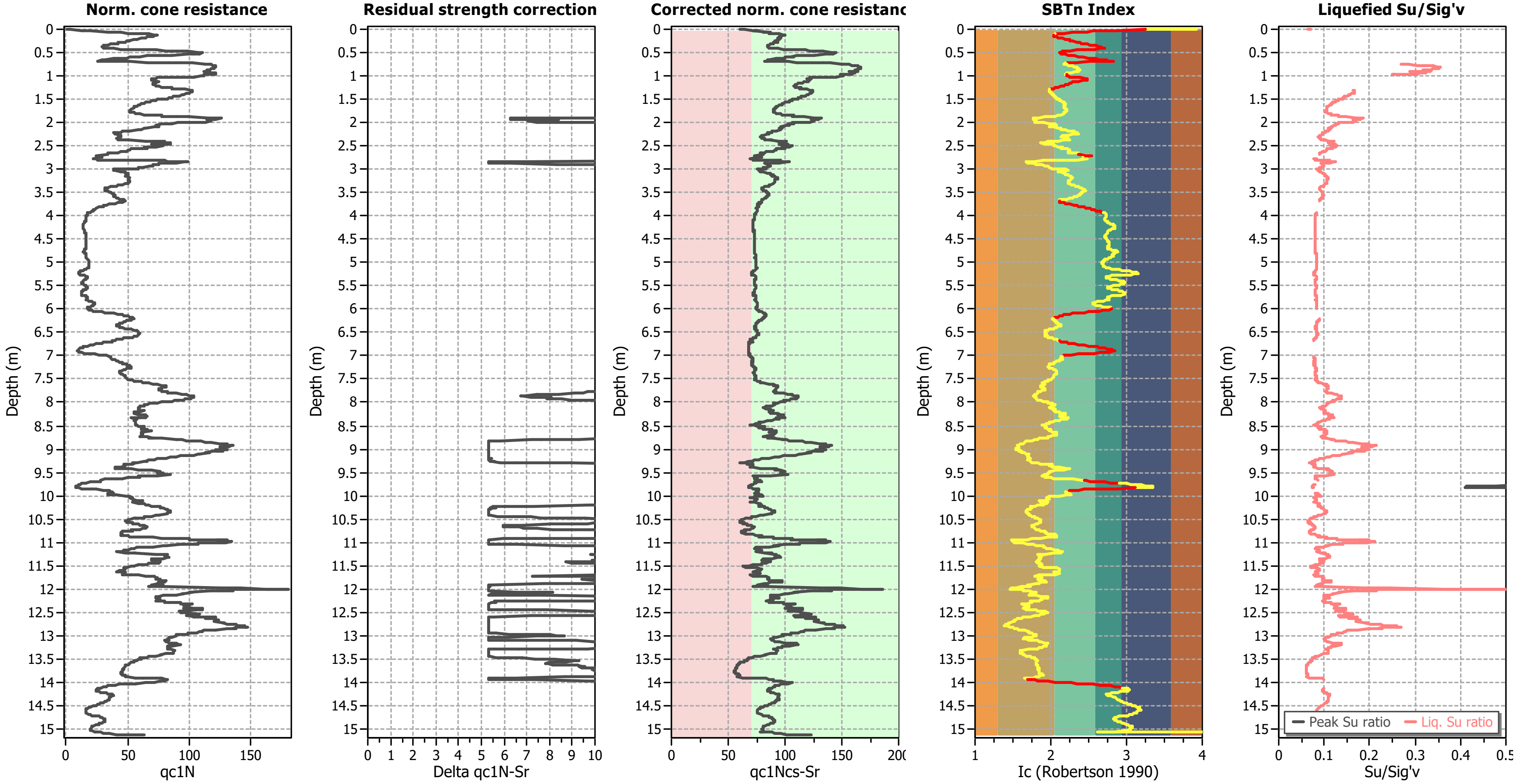
F.S. color scheme

- Almost certain it will liquefy
- Very likely to liquefy
- Liquefaction and no liq. are equally likely
- Unlike to liquefy
- Almost certain it will not liquefy

LPI color scheme

- Very high risk
- High risk
- Low risk

Check for strength loss plots (Idriss & Boulanger (2008))



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.20 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.23	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.20 m	Fill height:	N/A	Limit depth:	N/A

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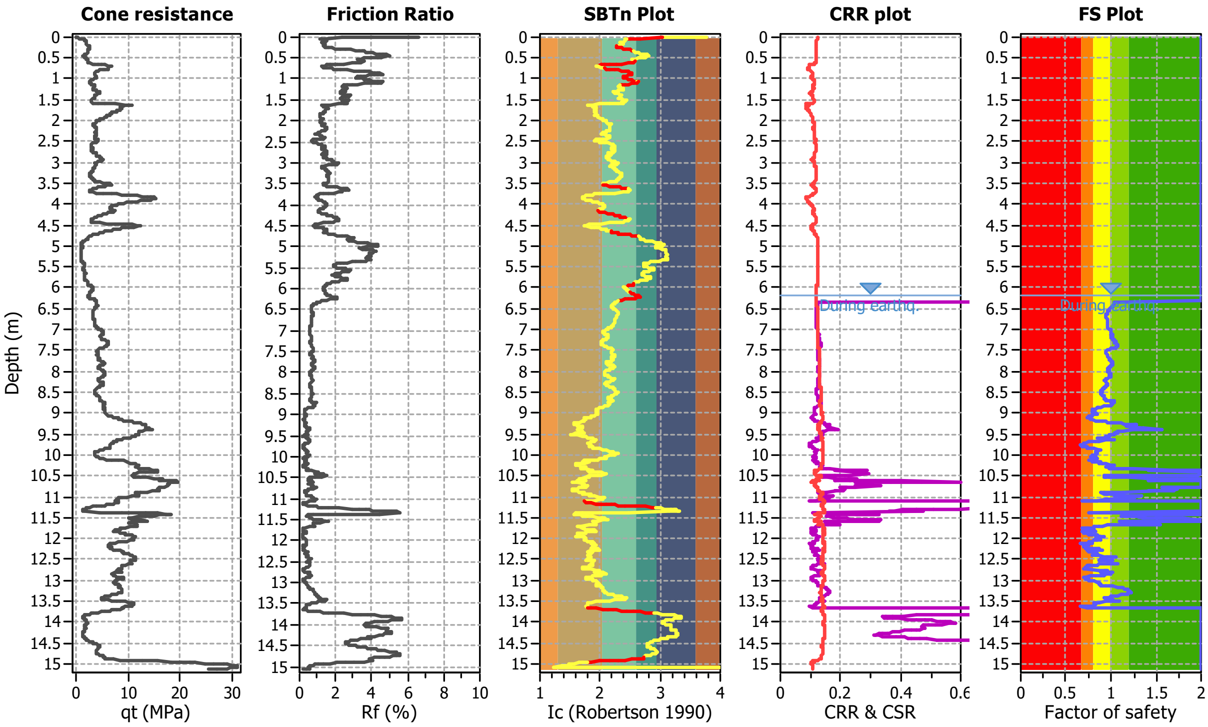
LIQUEFACTION ANALYSIS REPORT

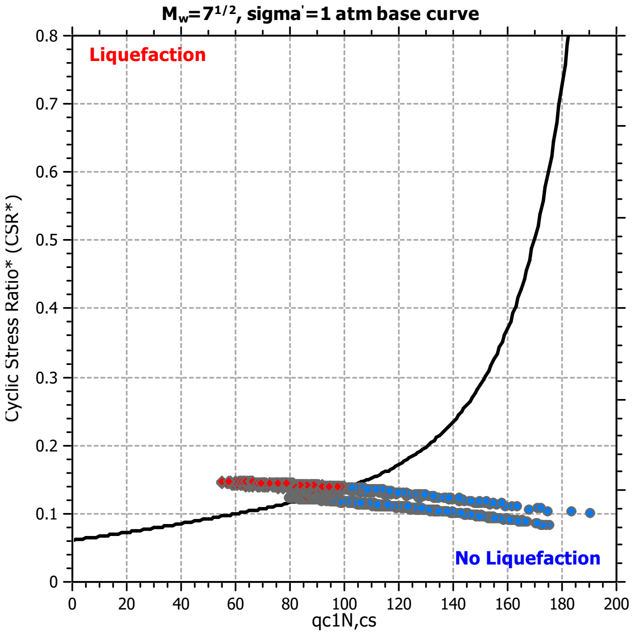
Project title : Outram Floodbank Investigation **Location : Outram, Otago**

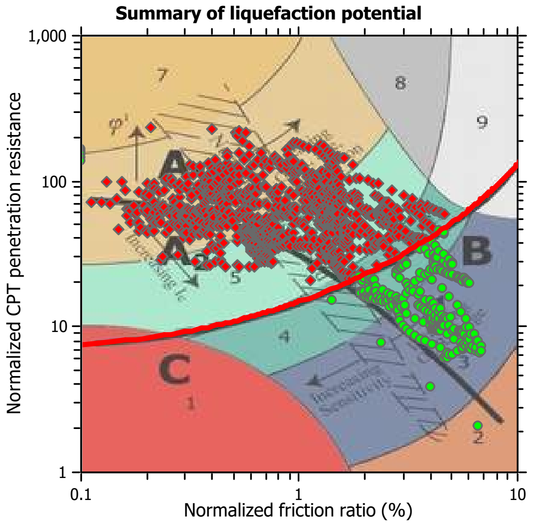
CPT file : CPT_185413

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	6.20 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	6.20 m	Fill height:	N/A	Limit depth applied:	No
Points to test:	Based on Ic value	Average results interval:	3	Fill weight:	N/A	Limit depth:	N/A
Earthquake magnitude M_w:	6.00	Ic cut-off value:	2.60	Trans. detect. applied:	Yes	MSF method:	Method based
Peak ground acceleration:	0.23	Unit weight calculation:	Based on SBT	K_σ applied:	Yes		

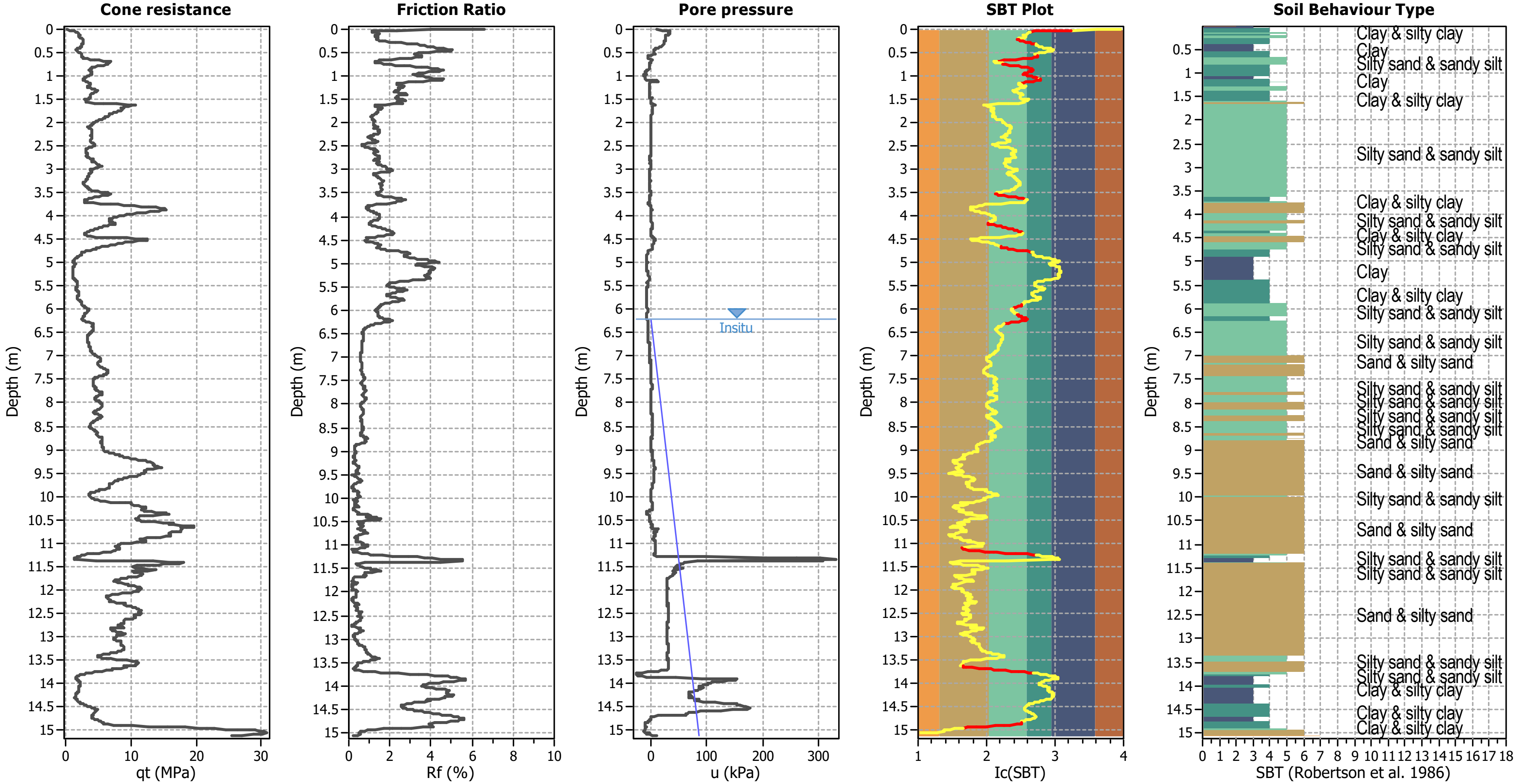






Zone A_1: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A_2: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and strength loss possible depending on soil plasticity, brittleness/sensitivity, strain to peak undrained strength and ground geometry

CPT basic interpretation plots



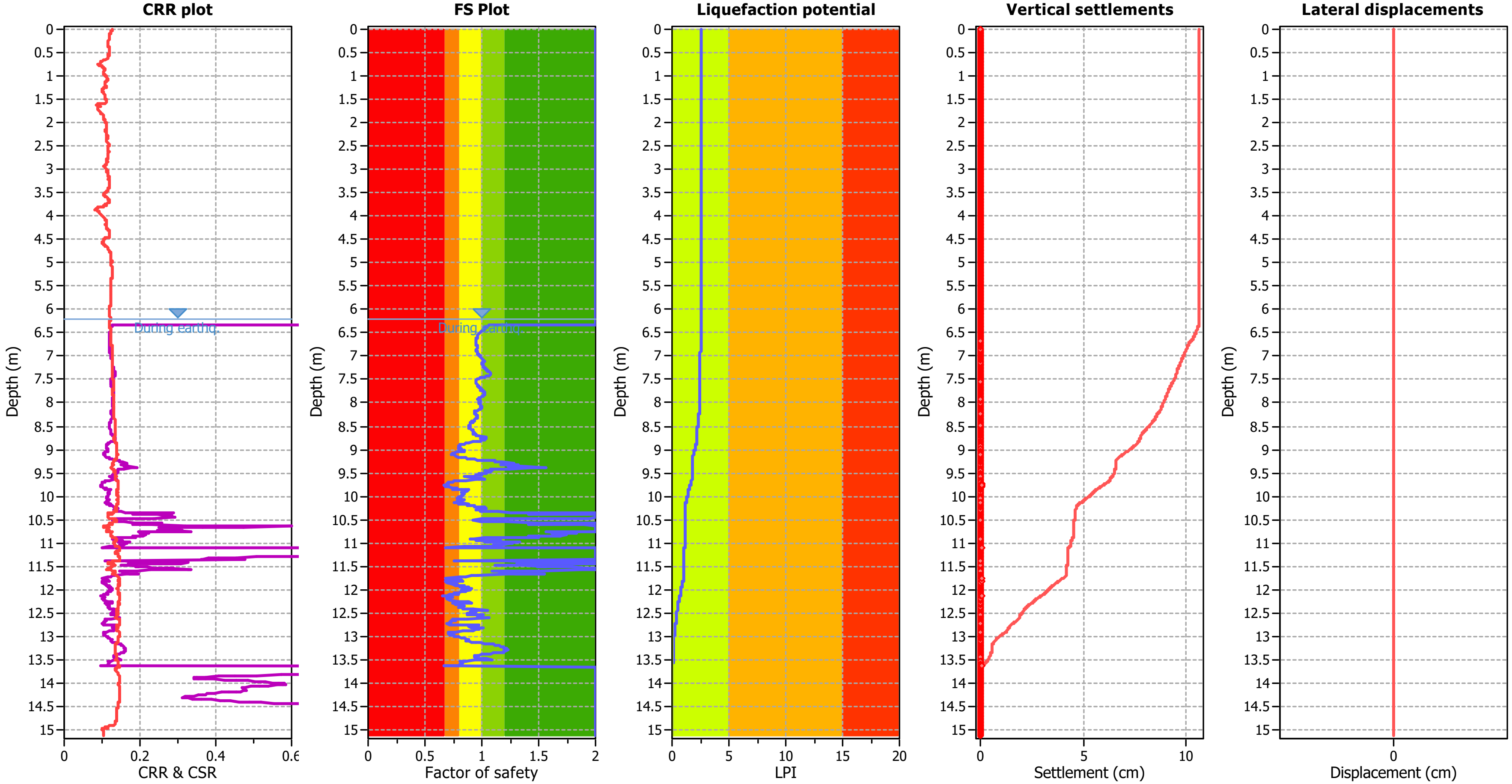
Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.20 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.23	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.20 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

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.20 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.23	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.20 m	Fill height:	N/A	Limit depth:	N/A

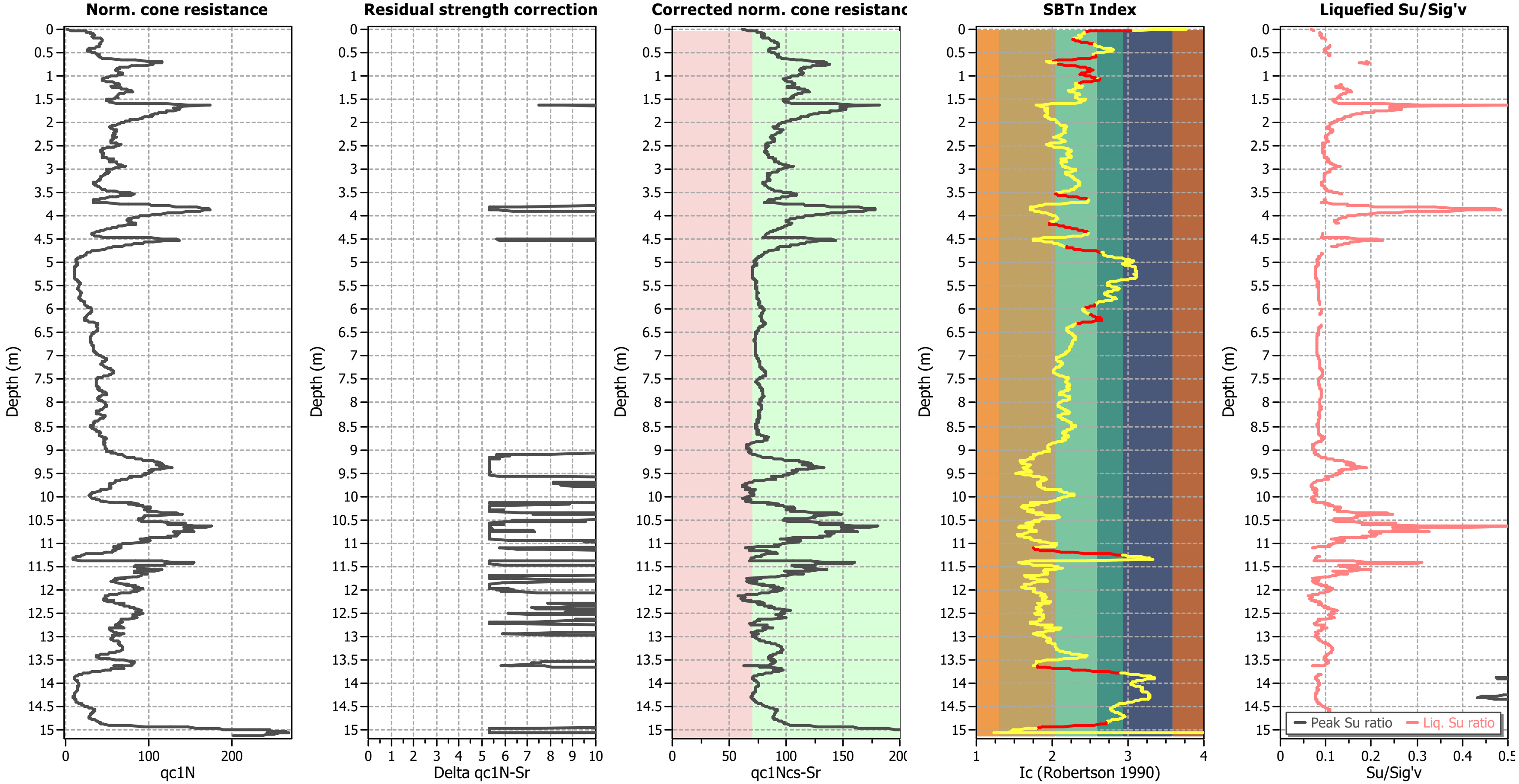
F.S. color scheme

- Almost certain it will liquefy
- Very likely to liquefy
- Liquefaction and no liq. are equally likely
- Unlike to liquefy
- Almost certain it will not liquefy

LPI color scheme

- Very high risk
- High risk
- Low risk

Check for strength loss plots (Idriss & Boulanger (2008))



Input parameters and analysis data

Analysis method: B&I (2014)
Fines correction method: B&I (2014)
Points to test: Based on Ic value
Earthquake magnitude M_w: 6.00
Peak ground acceleration: 0.23
Depth to water table (insitu): 6.20 m

Depth to GWT (erthq.): 6.20 m
Average results interval: 3
Ic cut-off value: 2.60
Unit weight calculation: Based on SBT
Use fill: No
Fill height: N/A

Fill weight: N/A
Transition detect. applied: Yes
K_σ applied: Yes
Clay like behavior applied: Sand & Clay
Limit depth applied: No
Limit depth: N/A

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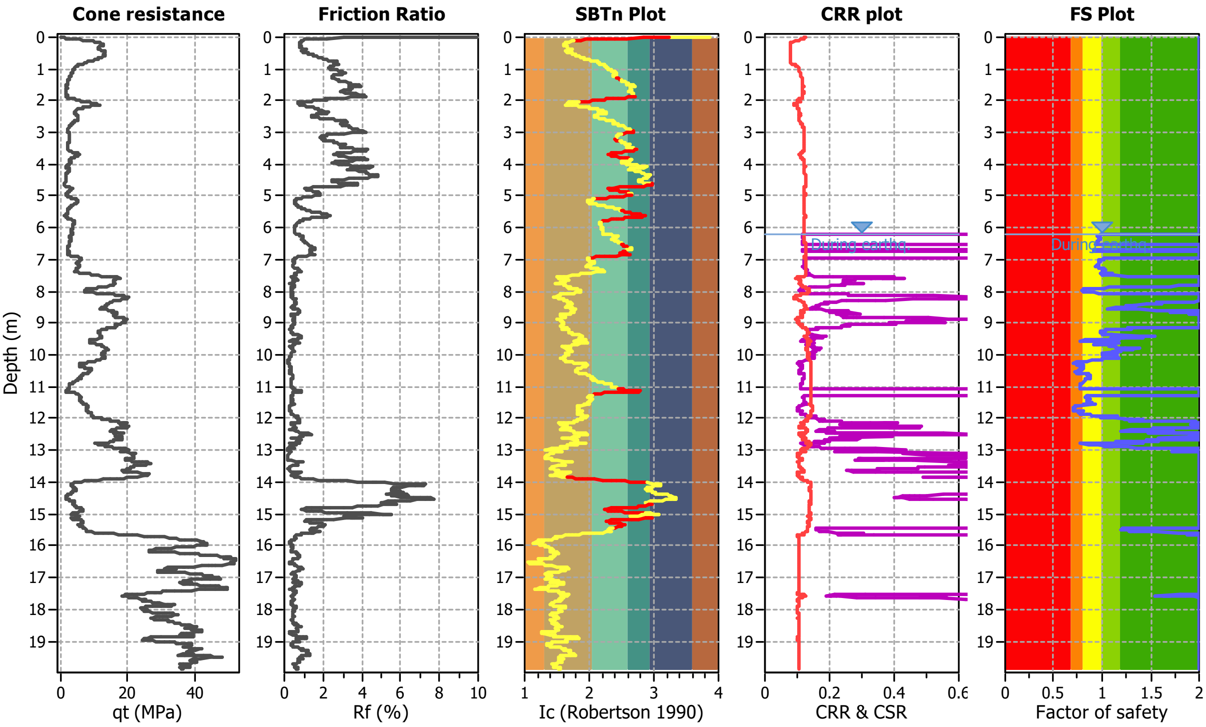
LIQUEFACTION ANALYSIS REPORT

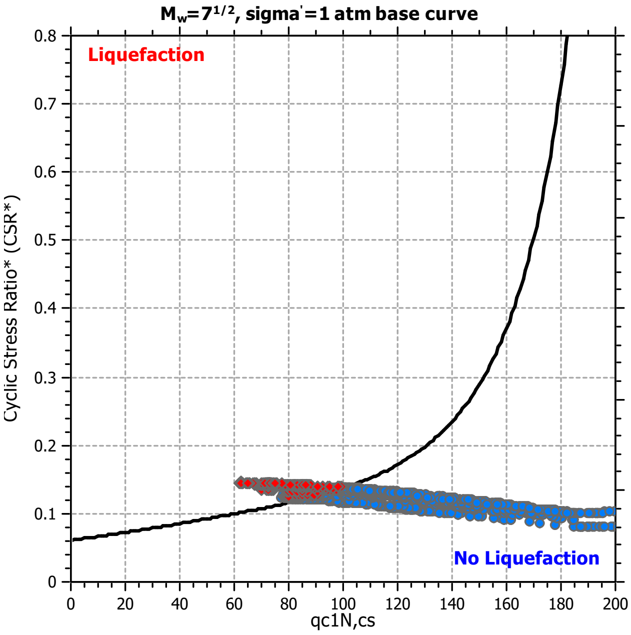
Project title : Outram Floodbank Investigation **Location : Outram, Otago**

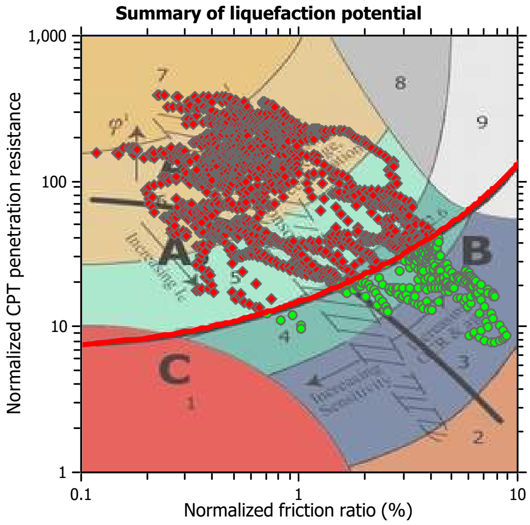
CPT file : CPT01

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	6.20 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	6.20 m	Fill height:	N/A	Limit depth applied:	No
Points to test:	Based on Ic value	Average results interval:	3	Fill weight:	N/A	Limit depth:	N/A
Earthquake magnitude M_w:	6.00	Ic cut-off value:	2.60	Trans. detect. applied:	Yes	MSF method:	Method based
Peak ground acceleration:	0.23	Unit weight calculation:	Based on SBT	K_σ applied:	Yes		

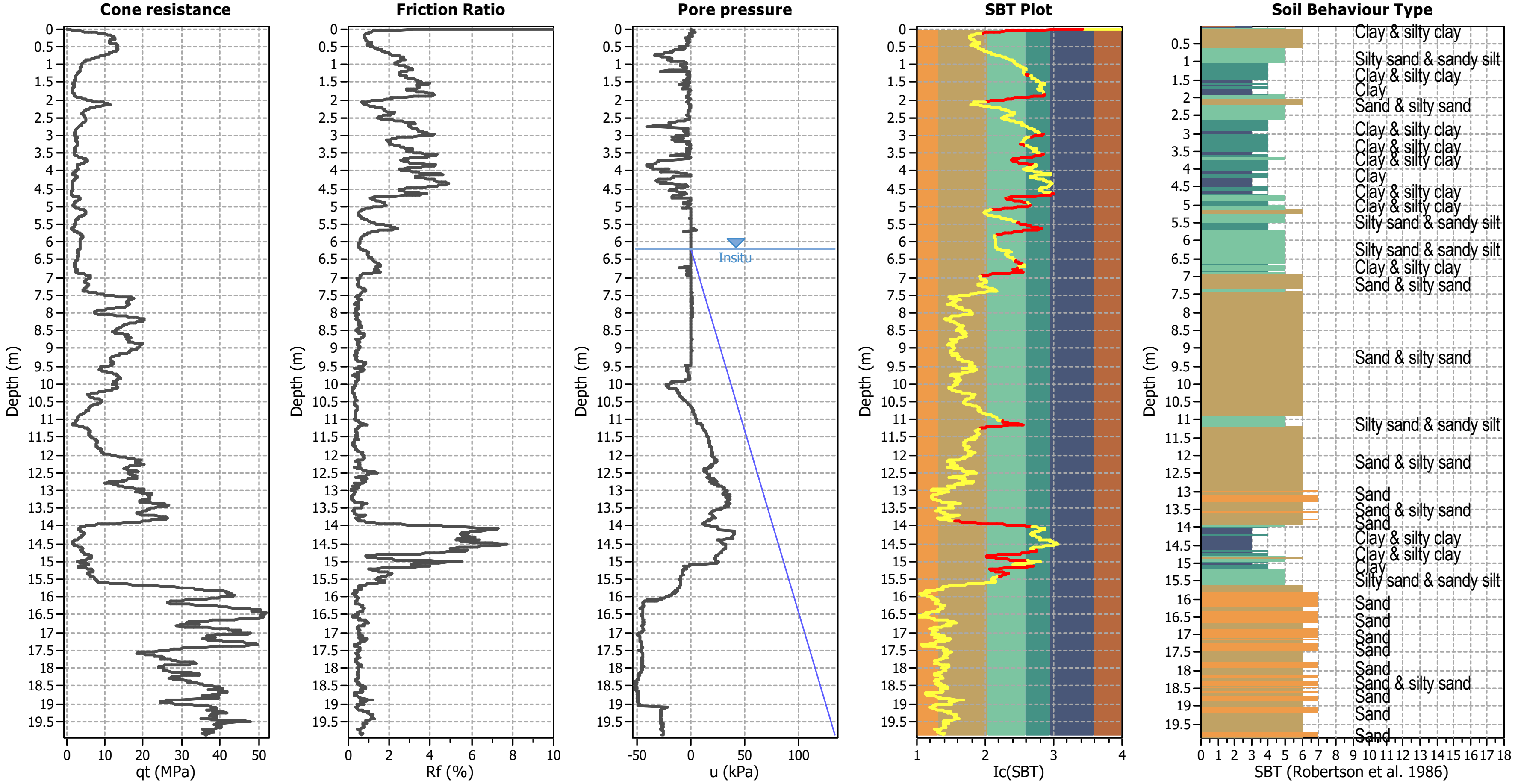






Zone A_1: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A_2: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and strength loss possible depending on soil plasticity, brittleness/sensitivity, strain to peak undrained strength and ground geometry

CPT basic interpretation plots



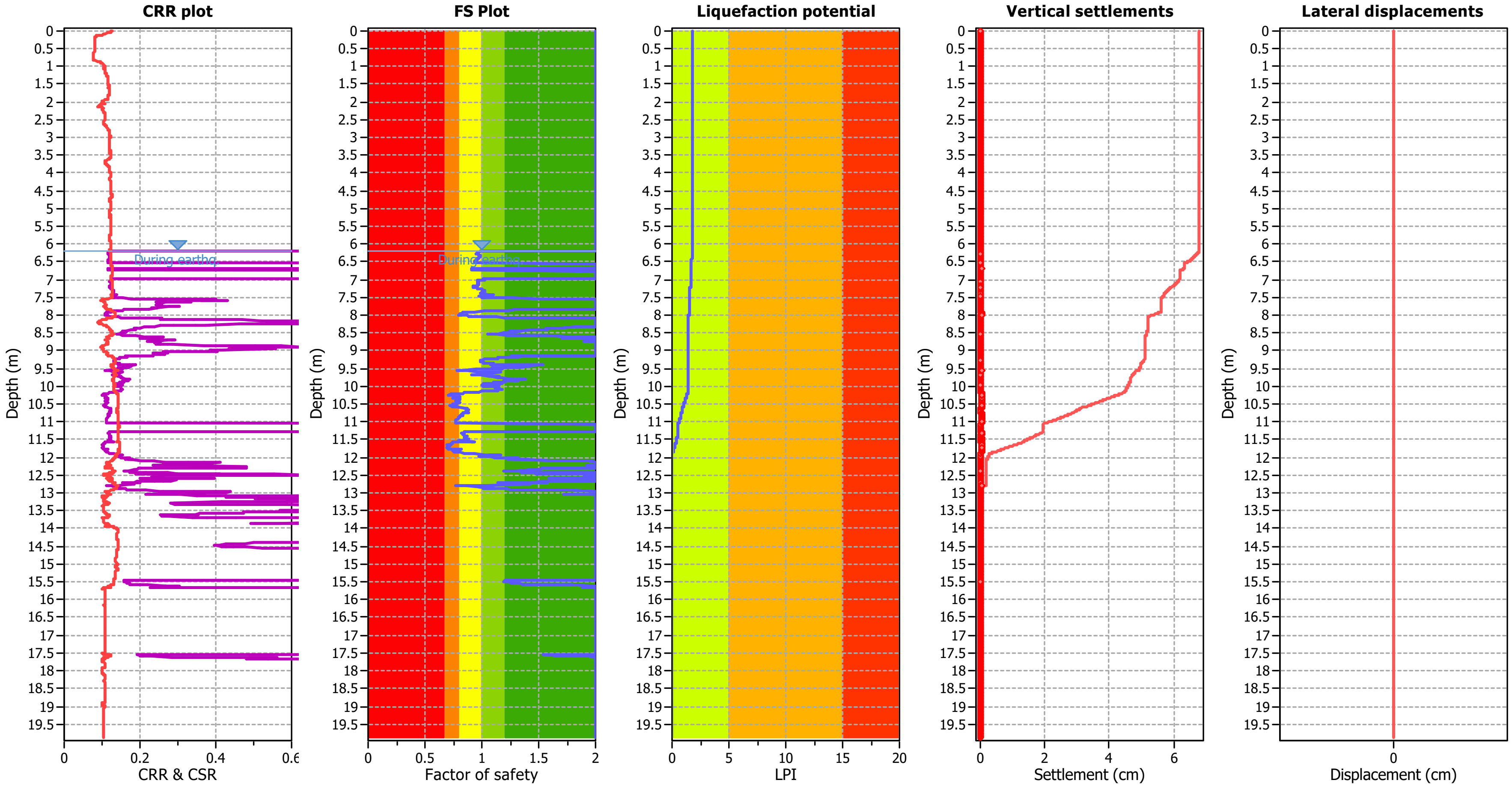
Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.20 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.23	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.20 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

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.20 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.23	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.20 m	Fill height:	N/A	Limit depth:	N/A

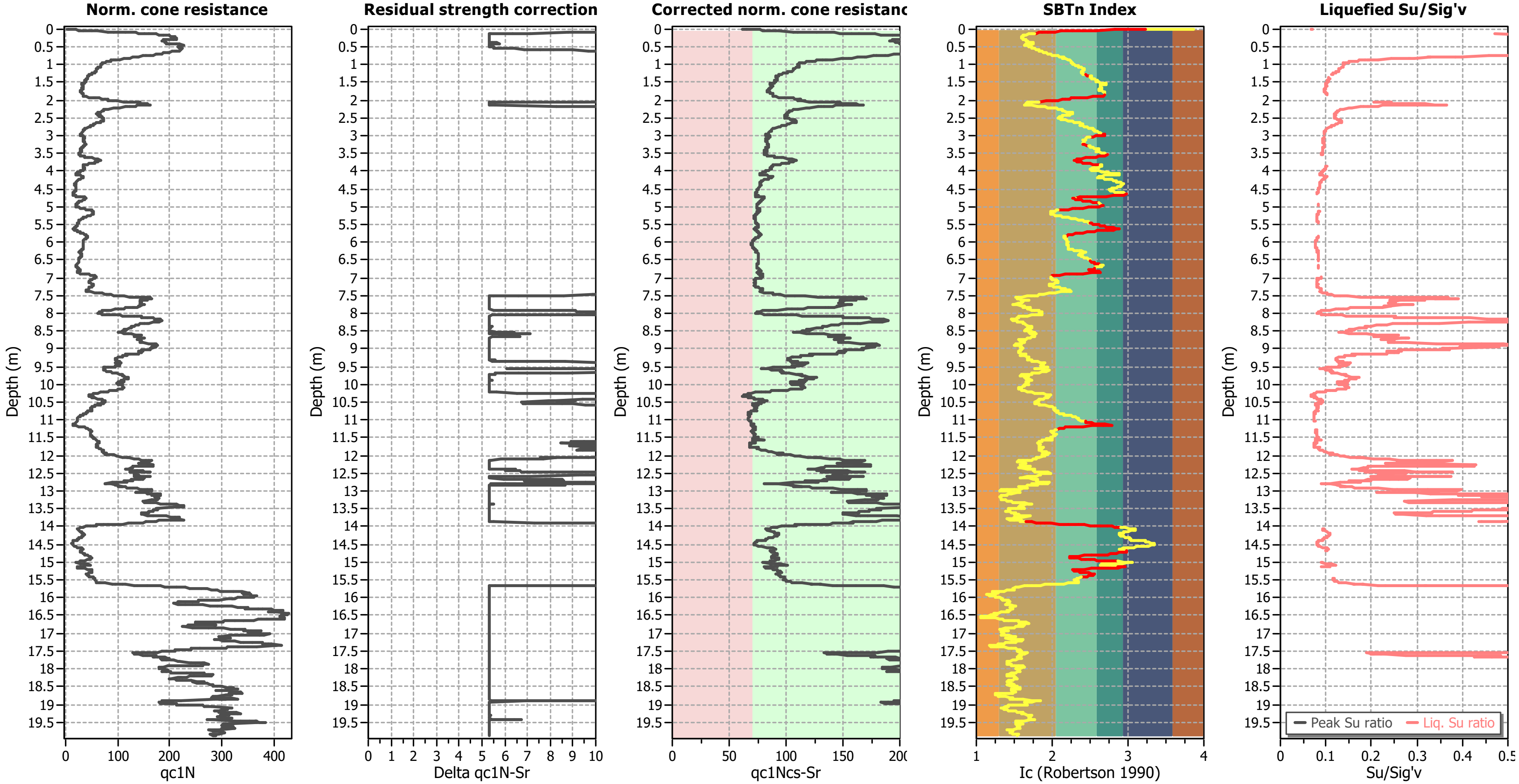
F.S. color scheme

- Almost certain it will liquefy
- Very likely to liquefy
- Liquefaction and no liq. are equally likely
- Unlike to liquefy
- Almost certain it will not liquefy

LPI color scheme

- Very high risk
- High risk
- Low risk

Check for strength loss plots (Idriss & Boulanger (2008))



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.20 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.23	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.20 m	Fill height:	N/A	Limit depth:	N/A

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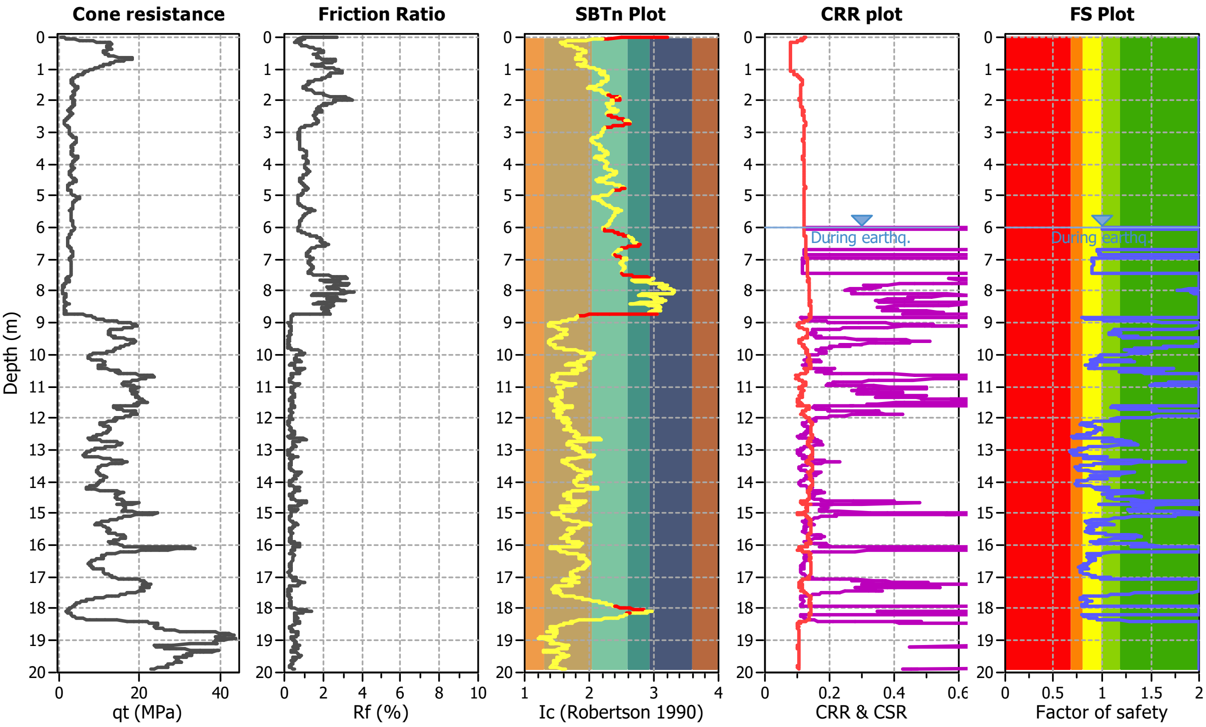
LIQUEFACTION ANALYSIS REPORT

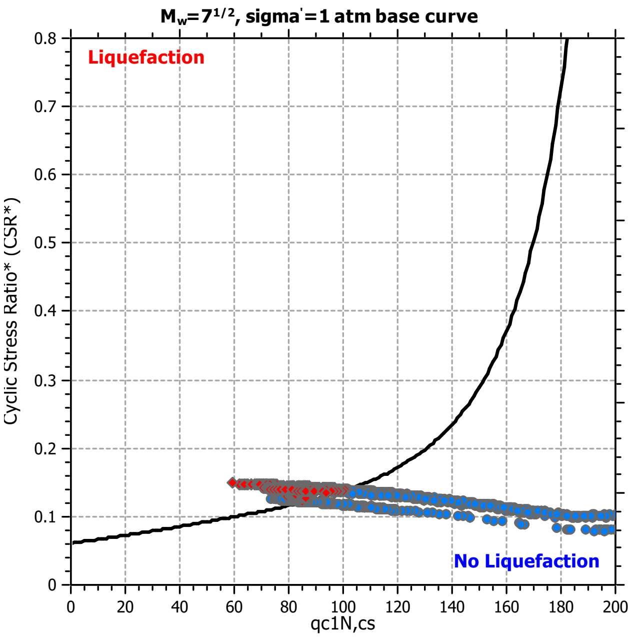
Project title : Outram Floodbank Investigation **Location : Outram, Otago**

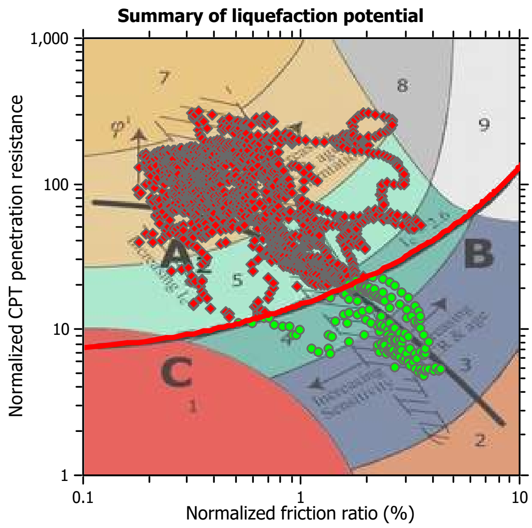
CPT file : CPT02

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	6.00 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	6.00 m	Fill height:	N/A	Limit depth applied:	No
Points to test:	Based on Ic value	Average results interval:	3	Fill weight:	N/A	Limit depth:	N/A
Earthquake magnitude M_w:	6.00	Ic cut-off value:	2.60	Trans. detect. applied:	Yes	MSF method:	Method based
Peak ground acceleration:	0.23	Unit weight calculation:	Based on SBT	K_σ applied:	Yes		

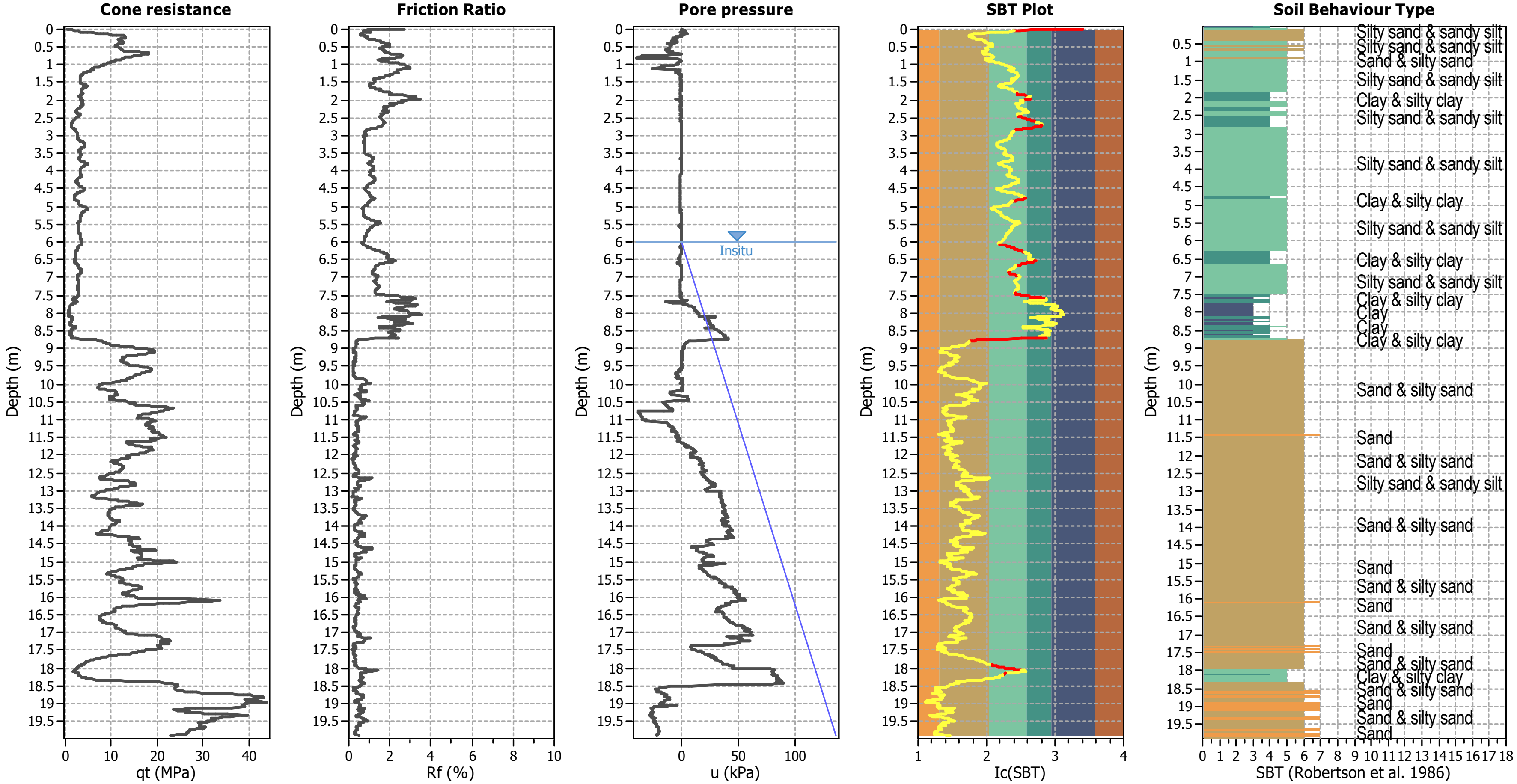






Zone A_1: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A_2: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and strength loss possible depending on soil plasticity, brittleness/sensitivity, strain to peak undrained strength and ground geometry

CPT basic interpretation plots



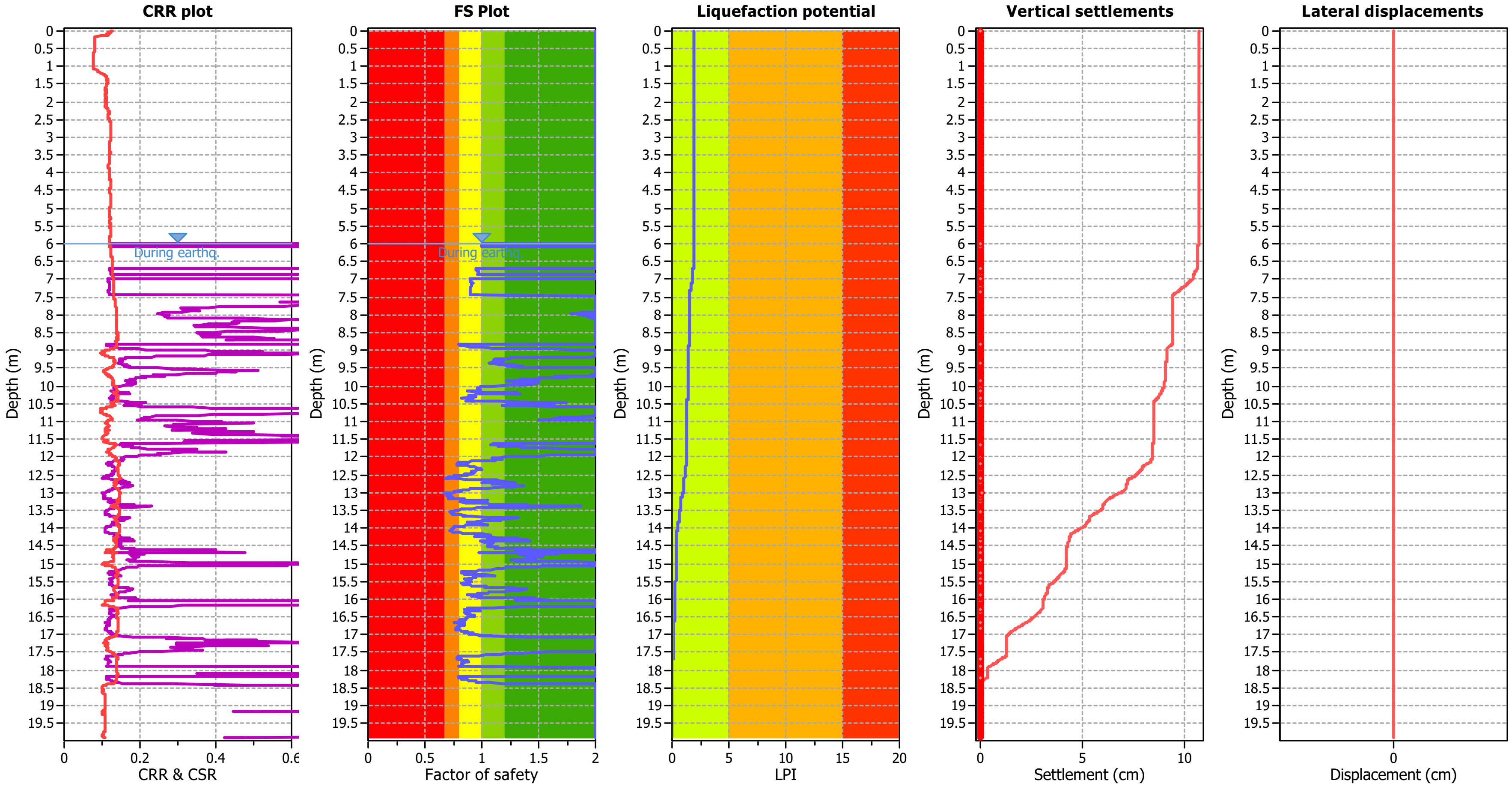
Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.00 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.23	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.00 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

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.00 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.23	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.00 m	Fill height:	N/A	Limit depth:	N/A

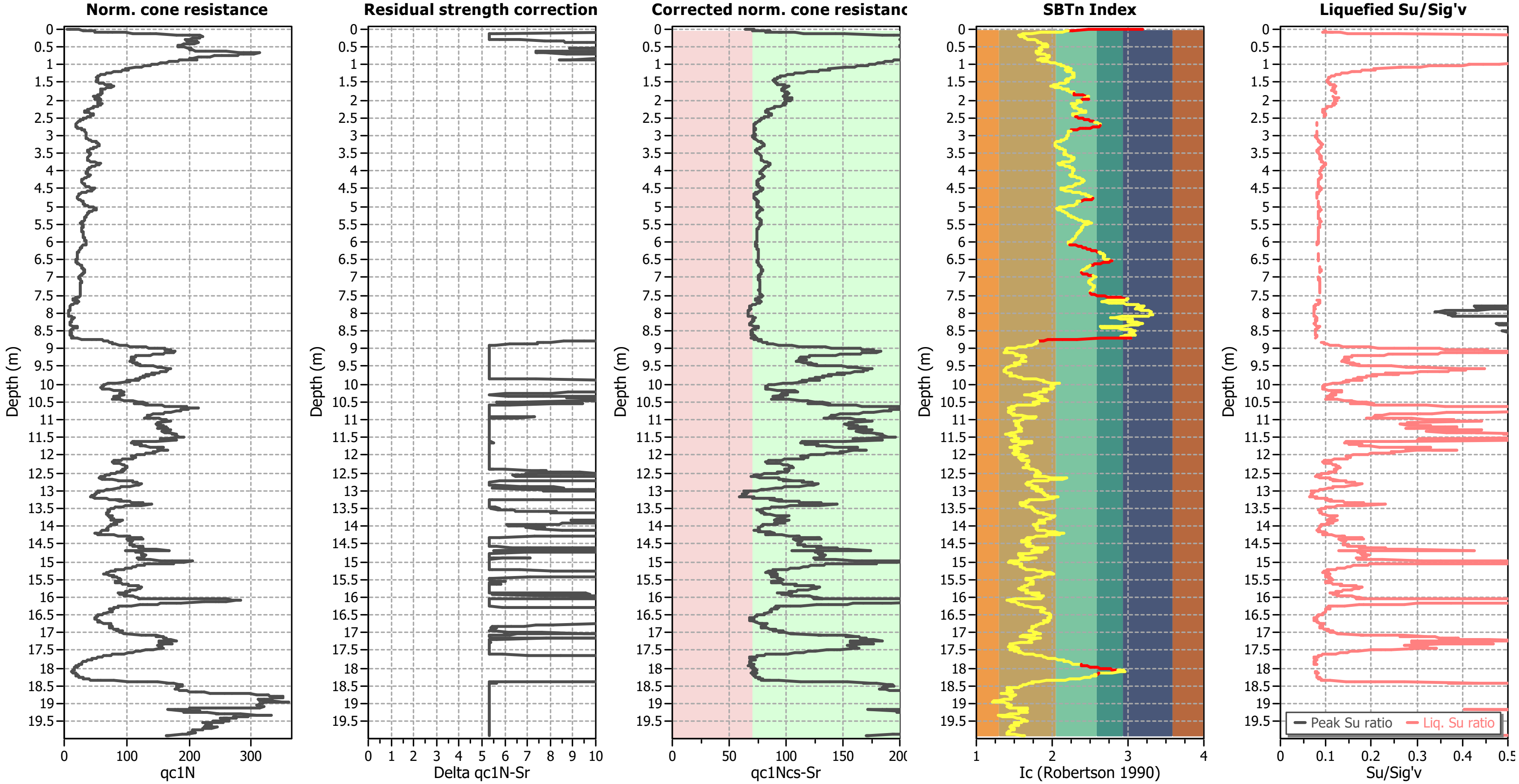
F.S. color scheme

- Almost certain it will liquefy
- Very likely to liquefy
- Liquefaction and no liq. are equally likely
- Unlike to liquefy
- Almost certain it will not liquefy

LPI color scheme

- Very high risk
- High risk
- Low risk

Check for strength loss plots (Idriss & Boulanger (2008))



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.00 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.23	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.00 m	Fill height:	N/A	Limit depth:	N/A

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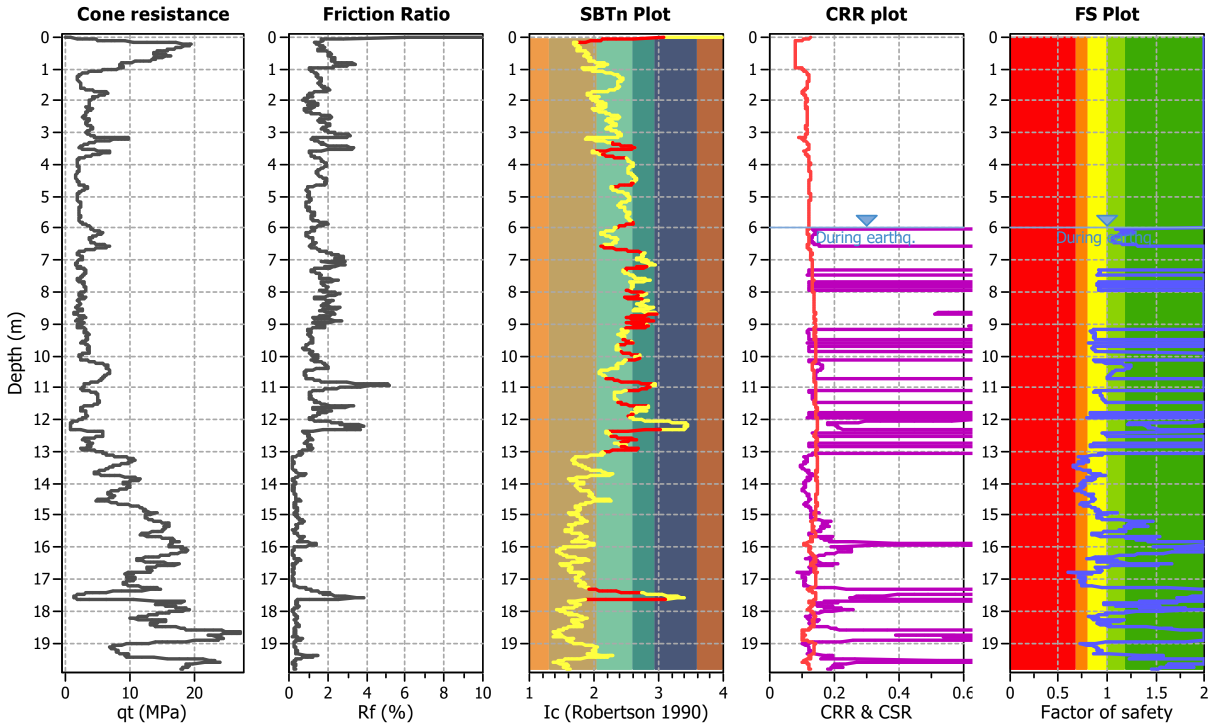
LIQUEFACTION ANALYSIS REPORT

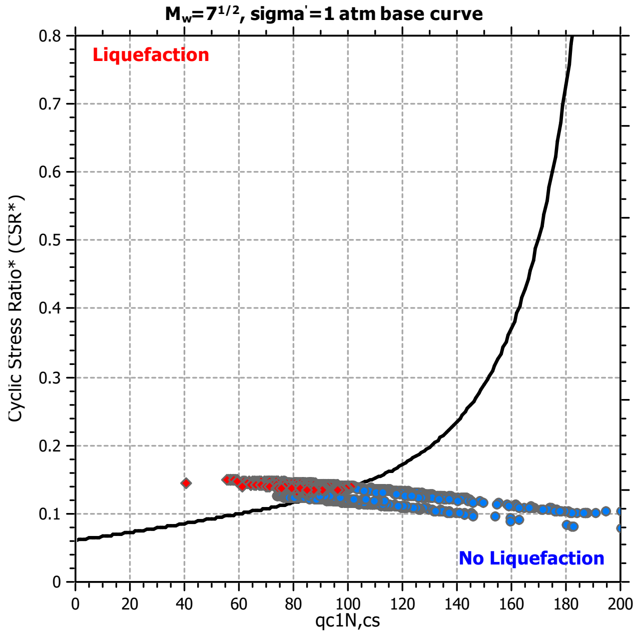
Project title : Outram Floodbank Investigation **Location : Outram, Otago**

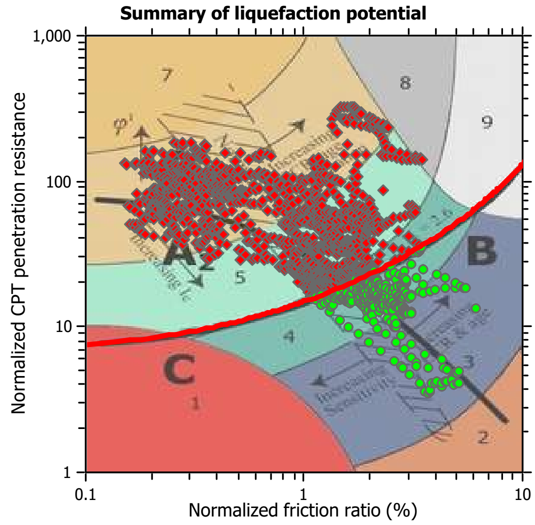
CPT file : CPT03

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	6.00 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	6.00 m	Fill height:	N/A	Limit depth applied:	No
Points to test:	Based on Ic value	Average results interval:	3	Fill weight:	N/A	Limit depth:	N/A
Earthquake magnitude M_w:	6.00	Ic cut-off value:	2.60	Trans. detect. applied:	Yes	MSF method:	Method based
Peak ground acceleration:	0.23	Unit weight calculation:	Based on SBT	K_σ applied:	Yes		

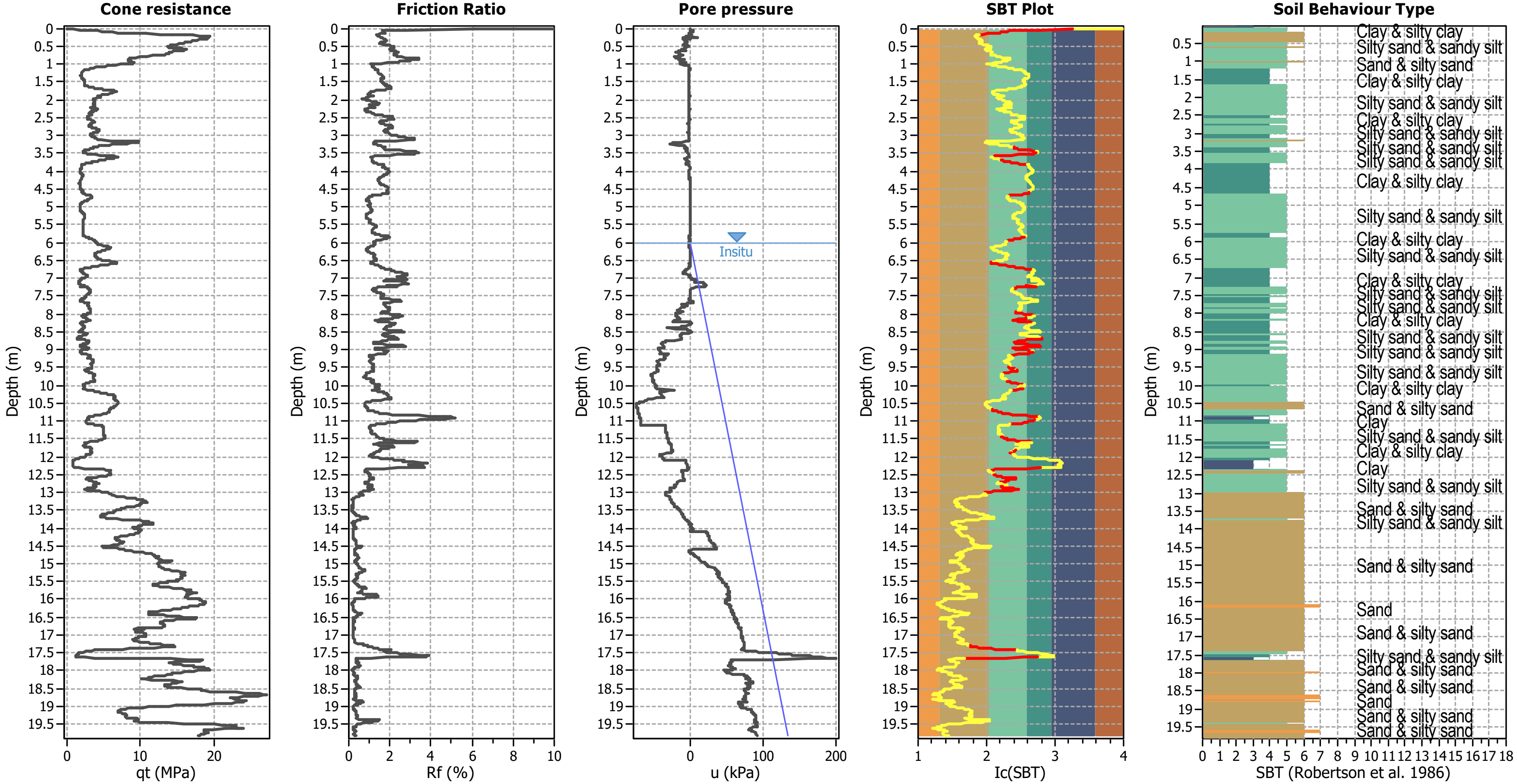






Zone A_1: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A_2: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and strength loss possible depending on soil plasticity, brittleness/sensitivity, strain to peak undrained strength and ground geometry

CPT basic interpretation plots



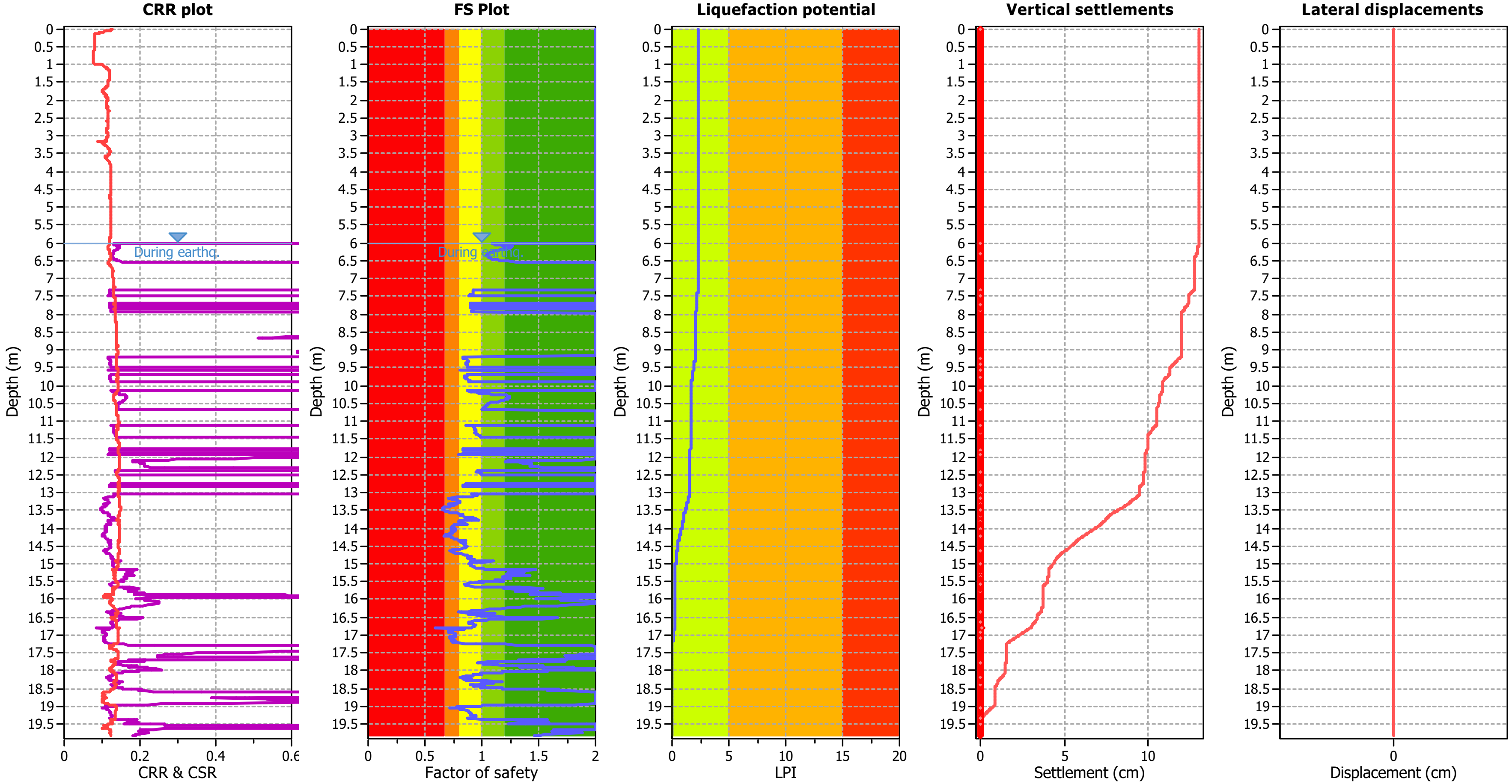
Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.00 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_{σ} applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.23	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.00 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

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.00 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.23	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.00 m	Fill height:	N/A	Limit depth:	N/A

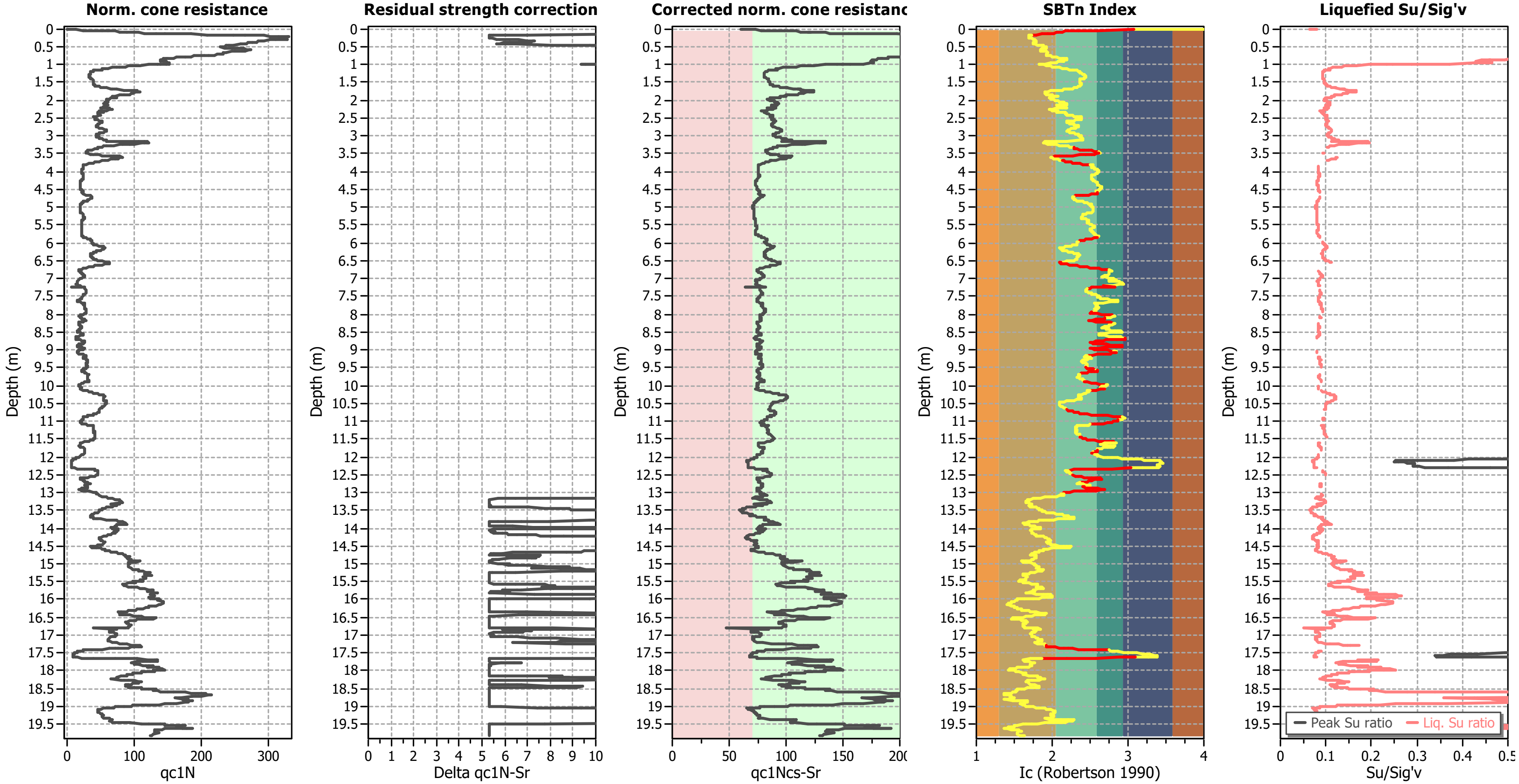
F.S. color scheme

- Almost certain it will liquefy
- Very likely to liquefy
- Liquefaction and no liq. are equally likely
- Unlike to liquefy
- Almost certain it will not liquefy

LPI color scheme

- Very high risk
- High risk
- Low risk

Check for strength loss plots (Idriss & Boulanger (2008))



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.00 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.23	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.00 m	Fill height:	N/A	Limit depth:	N/A

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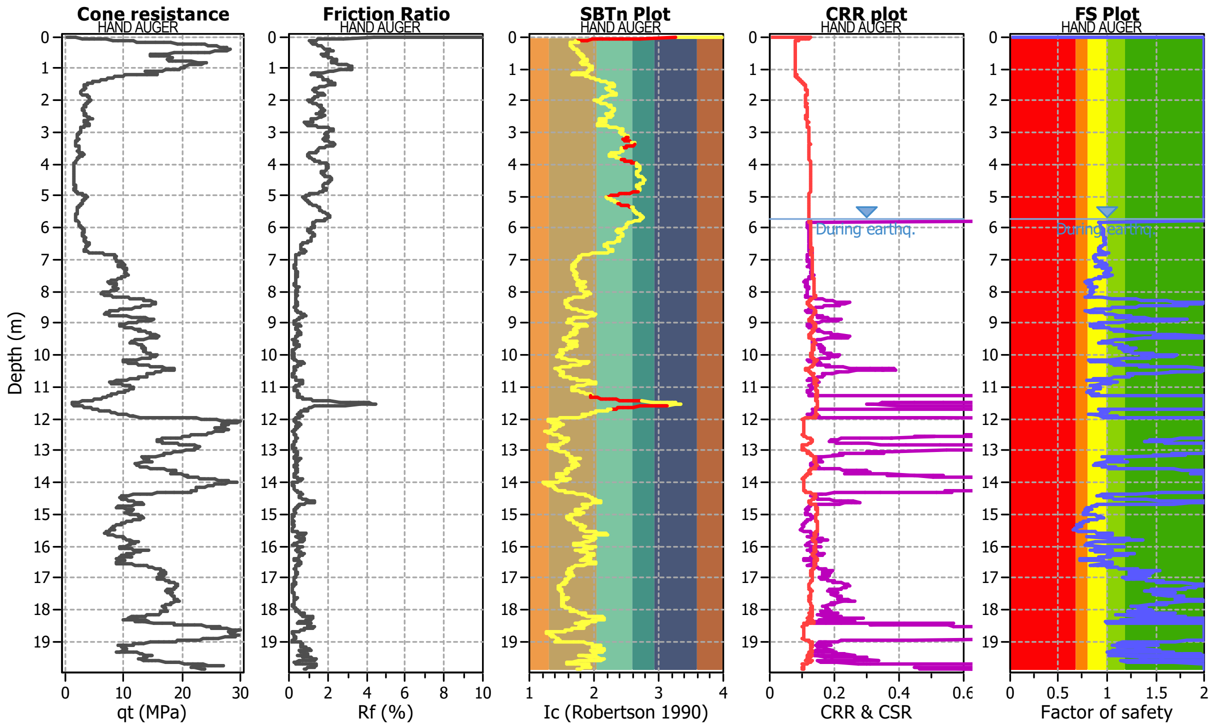
LIQUEFACTION ANALYSIS REPORT

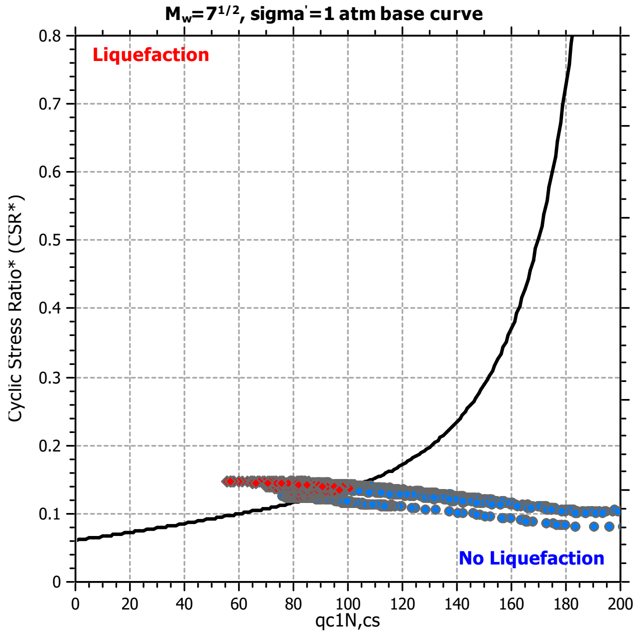
Project title : Outram Floodbank Investigation **Location : Outram, Otago**

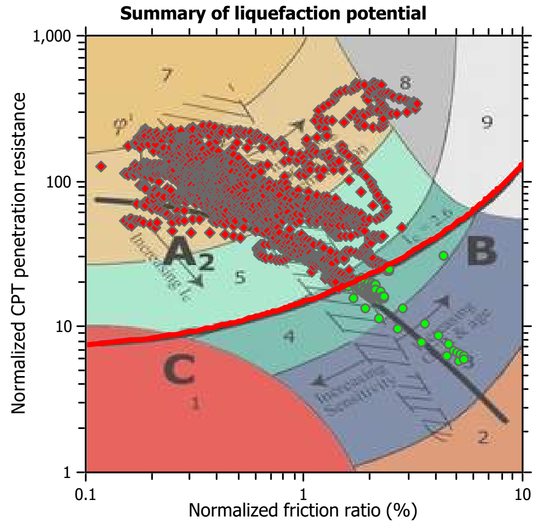
CPT file : CPT04

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	5.70 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	5.70 m	Fill height:	N/A		
Points to test:	Based on Ic value	Average results interval:	3	Fill weight:	N/A	Limit depth applied:	No
Earthquake magnitude M_w:	6.00	Ic cut-off value:	2.60	Trans. detect. applied:	Yes	Limit depth:	N/A
Peak ground acceleration:	0.23	Unit weight calculation:	Based on SBT	K_σ applied:	Yes	MSF method:	Method based

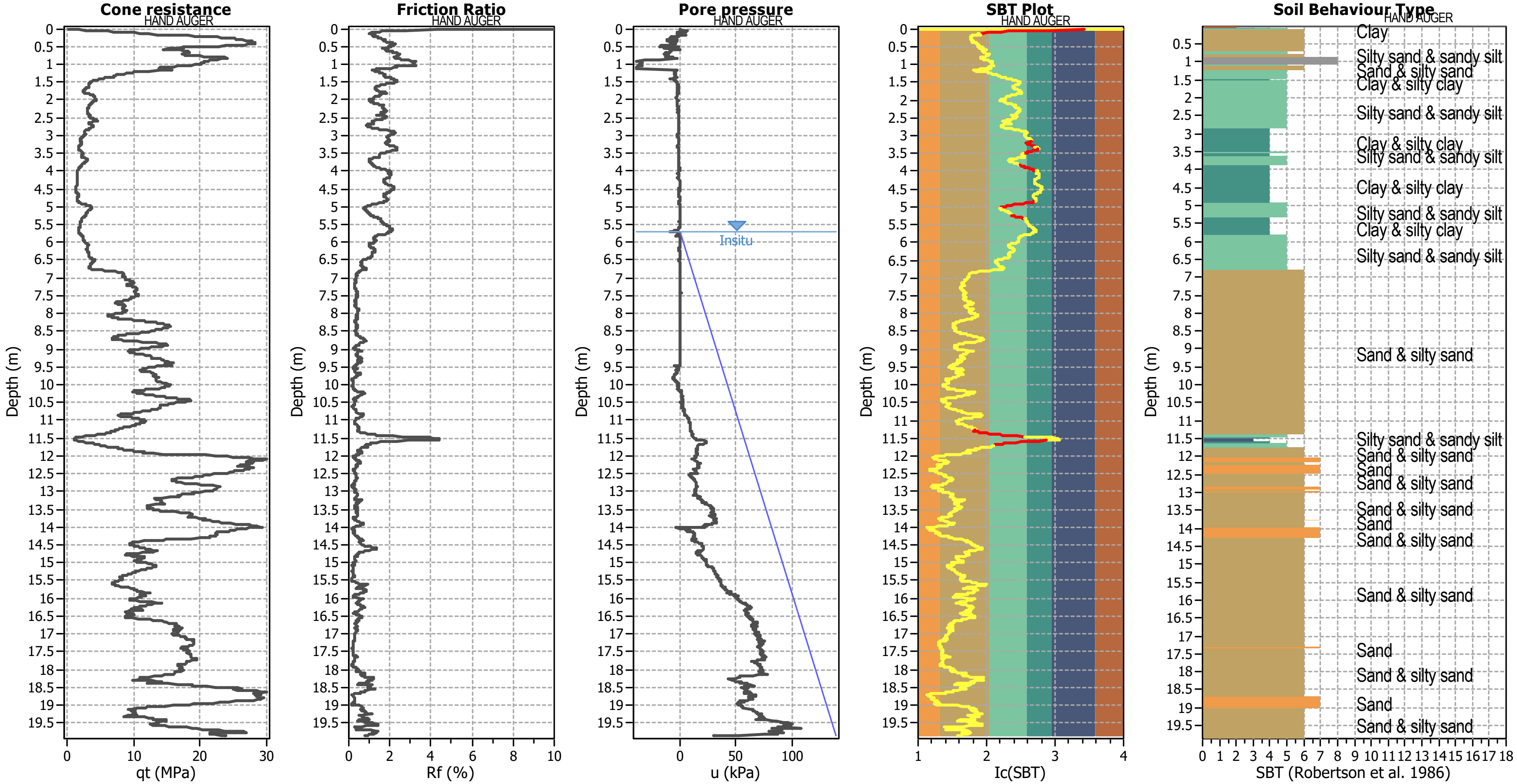






Zone A_1: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A_2: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and strength loss possible depending on soil plasticity, brittleness/sensitivity, strain to peak undrained strength and ground geometry

CPT basic interpretation plots



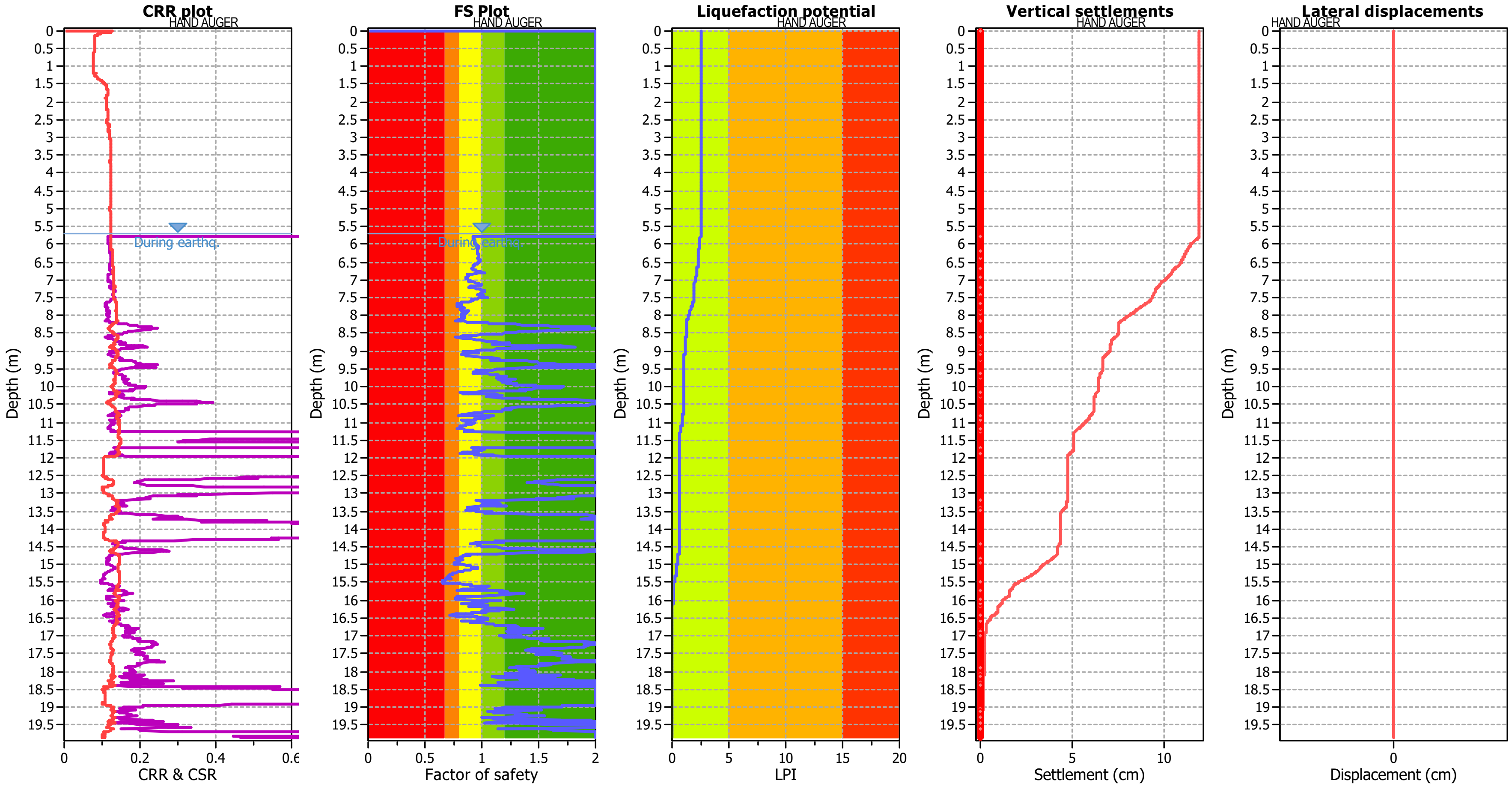
Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	5.70 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.23	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	5.70 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

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	5.70 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.23	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	5.70 m	Fill height:	N/A	Limit depth:	N/A

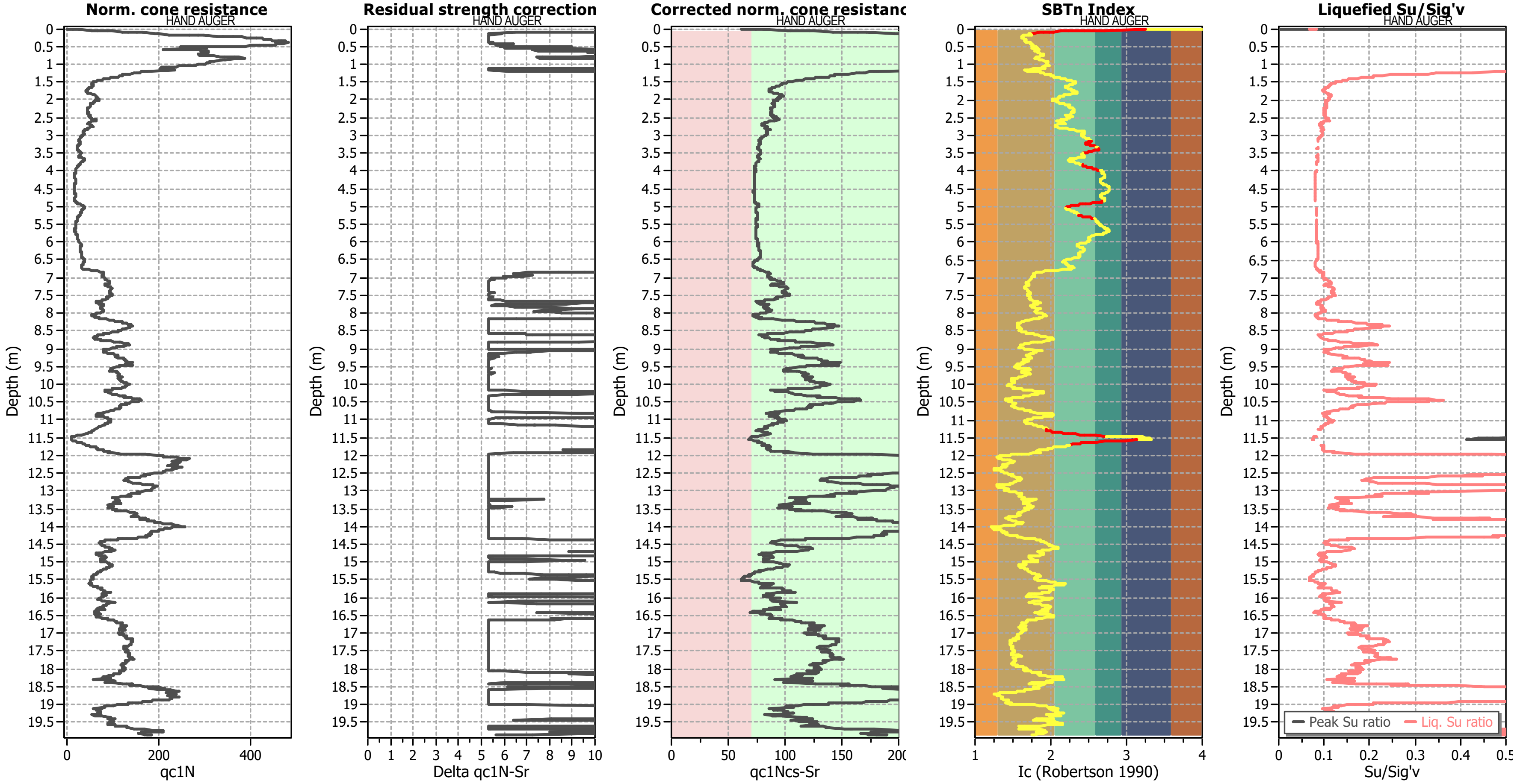
F.S. color scheme

- Almost certain it will liquefy
- Very likely to liquefy
- Liquefaction and no liq. are equally likely
- Unlike to liquefy
- Almost certain it will not liquefy

LPI color scheme

- Very high risk
- High risk
- Low risk

Check for strength loss plots (Idriss & Boulanger (2008))



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	5.70 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.23	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	5.70 m	Fill height:	N/A	Limit depth:	N/A

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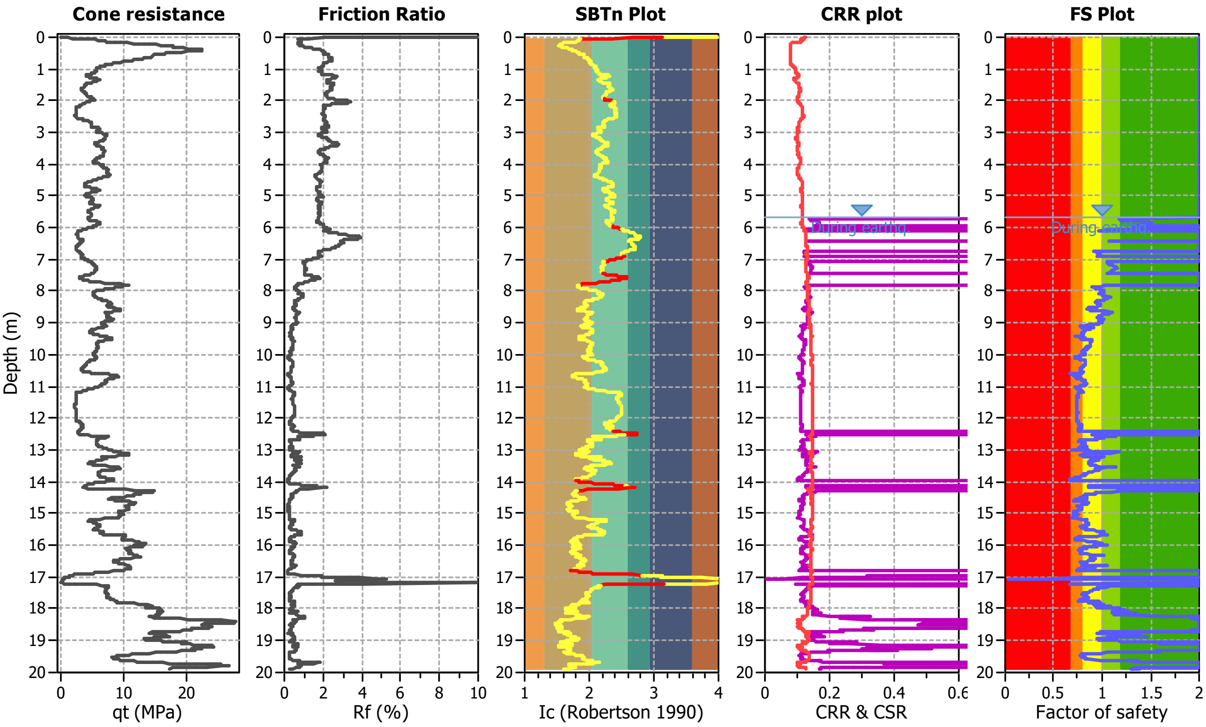
LIQUEFACTION ANALYSIS REPORT

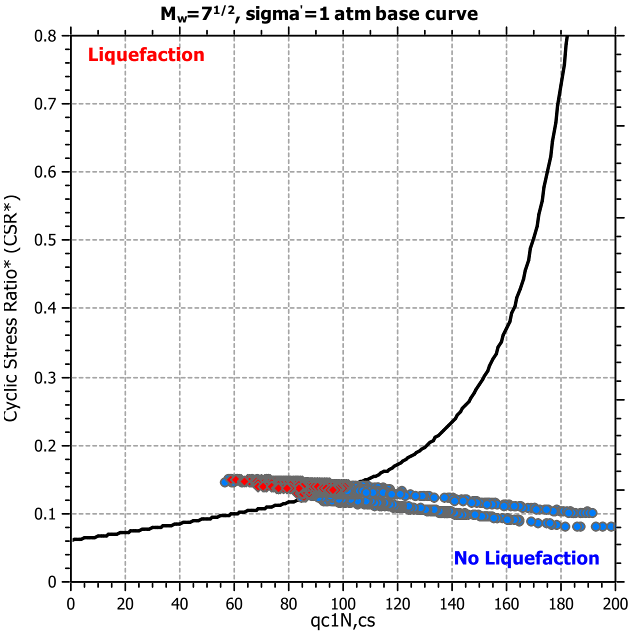
Project title : Outram Floodbank Investigation **Location : Outram, Otago**

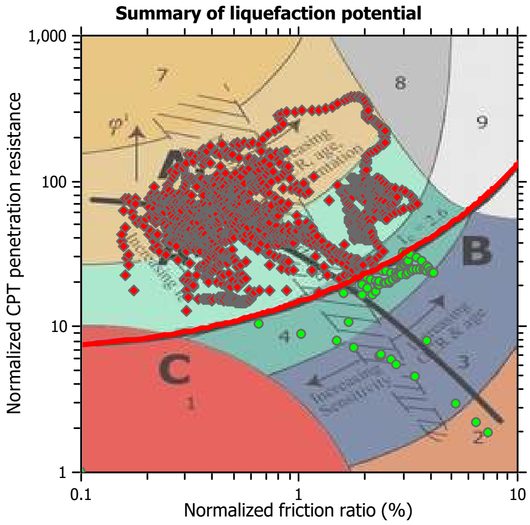
CPT file : CPT05

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	5.70 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	5.70 m	Fill height:	N/A	Limit depth applied:	No
Points to test:	Based on Ic value	Average results interval:	3	Fill weight:	N/A	Limit depth:	N/A
Earthquake magnitude M_w:	6.00	Ic cut-off value:	2.60	Trans. detect. applied:	Yes	MSF method:	Method based
Peak ground acceleration:	0.23	Unit weight calculation:	Based on SBT	K_σ applied:	Yes		

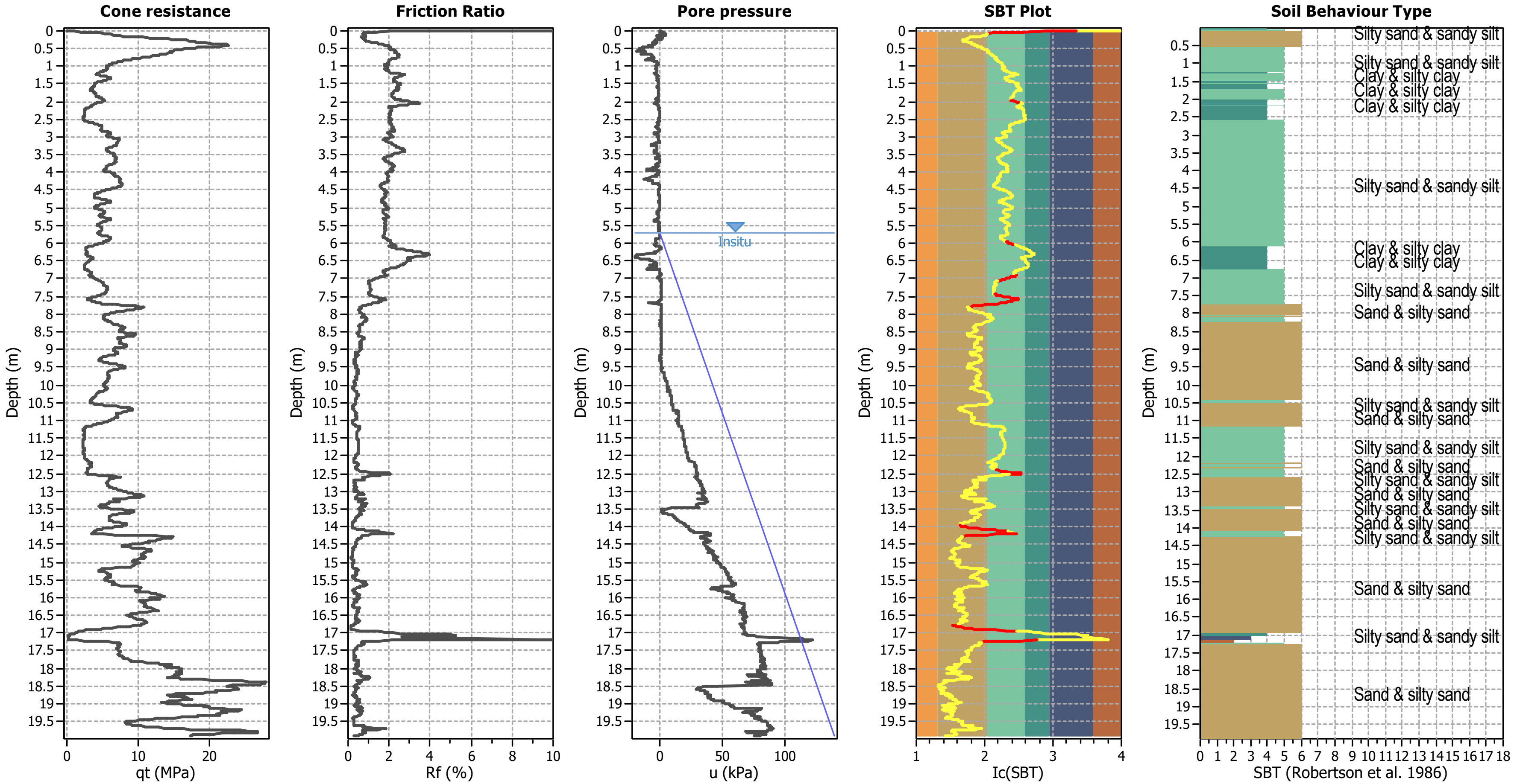






Zone A₁: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A₂: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and strength loss possible depending on soil plasticity, brittleness/sensitivity, strain to peak undrained strength and ground geometry

CPT basic interpretation plots



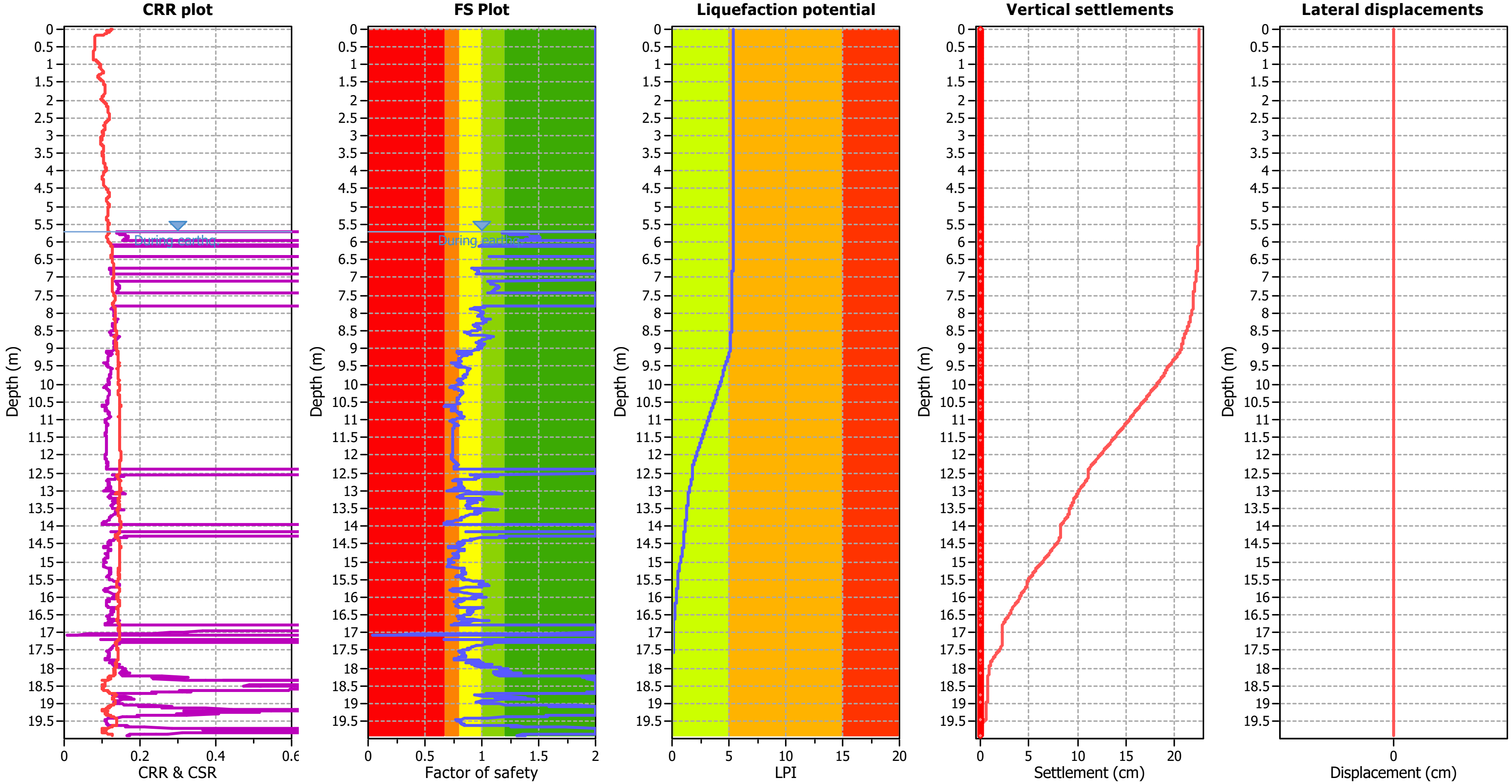
Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	5.70 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.23	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	5.70 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

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	5.70 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.23	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	5.70 m	Fill height:	N/A	Limit depth:	N/A

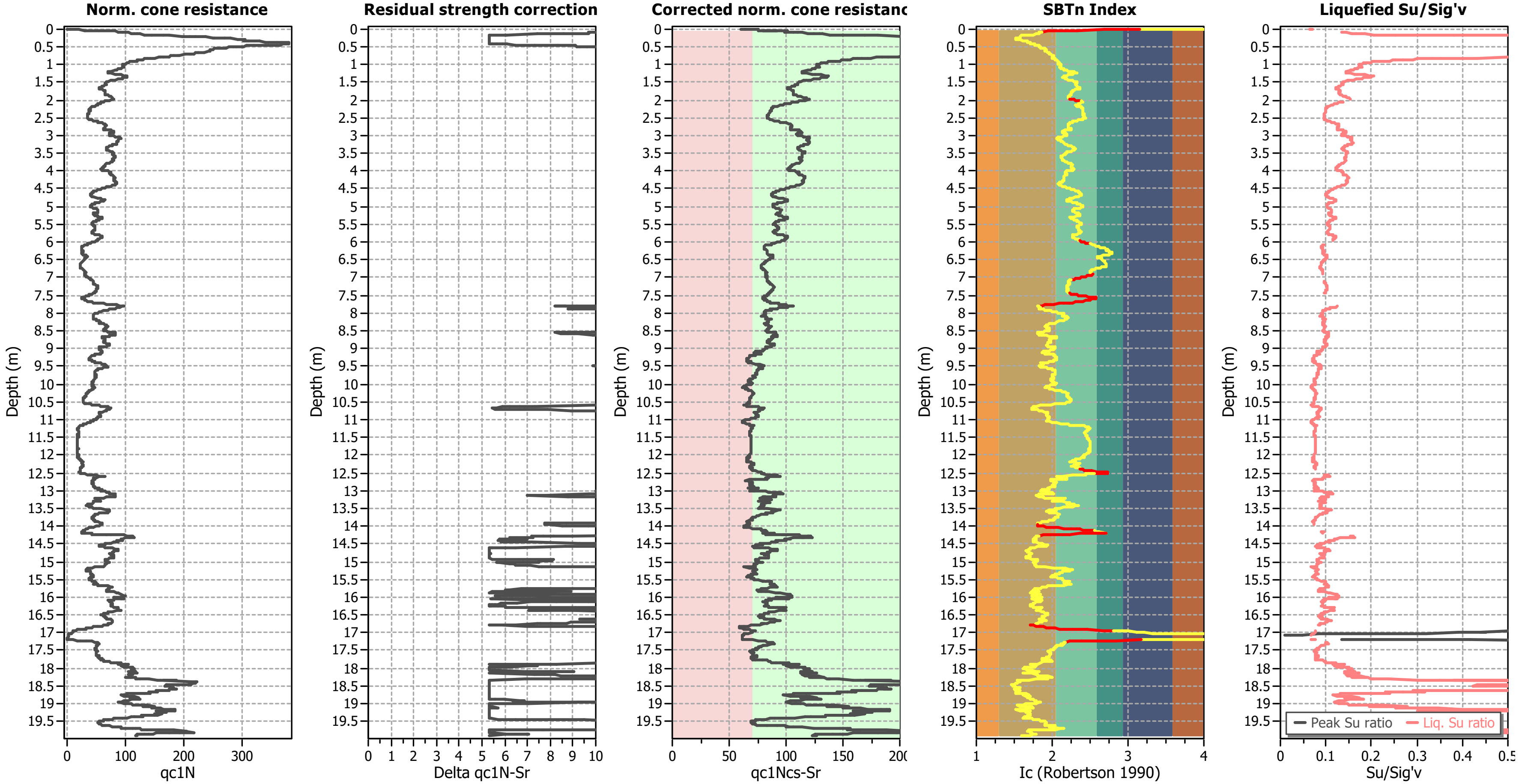
F.S. color scheme

- Almost certain it will liquefy
- Very likely to liquefy
- Liquefaction and no liq. are equally likely
- Unlike to liquefy
- Almost certain it will not liquefy

LPI color scheme

- Very high risk
- High risk
- Low risk

Check for strength loss plots (Idriss & Boulanger (2008))



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	5.70 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.23	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	5.70 m	Fill height:	N/A	Limit depth:	N/A

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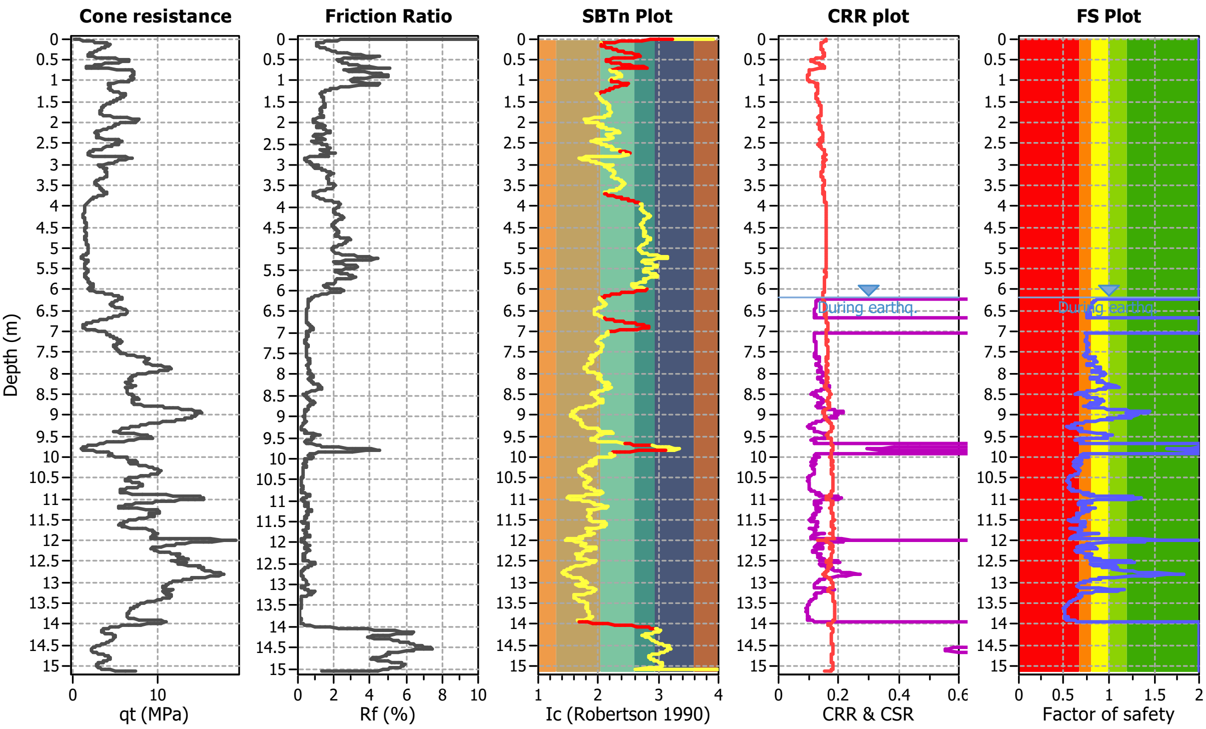
LIQUEFACTION ANALYSIS REPORT

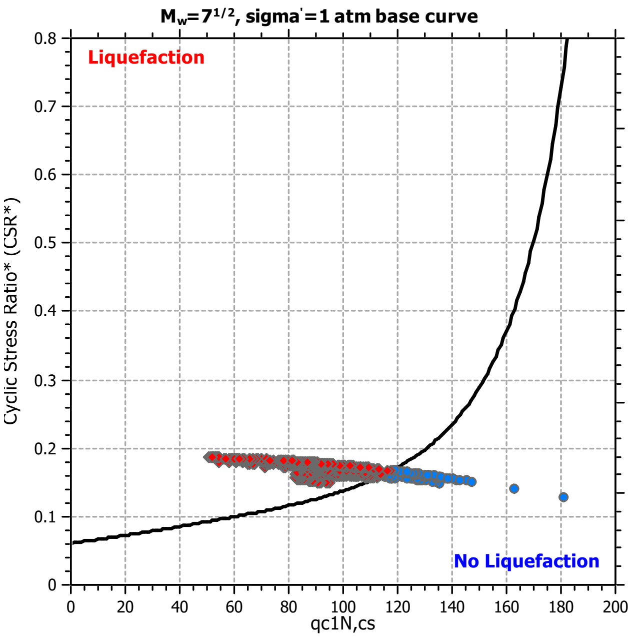
Project title : Outram Floodbank Investigation **Location : Outram, Otago**

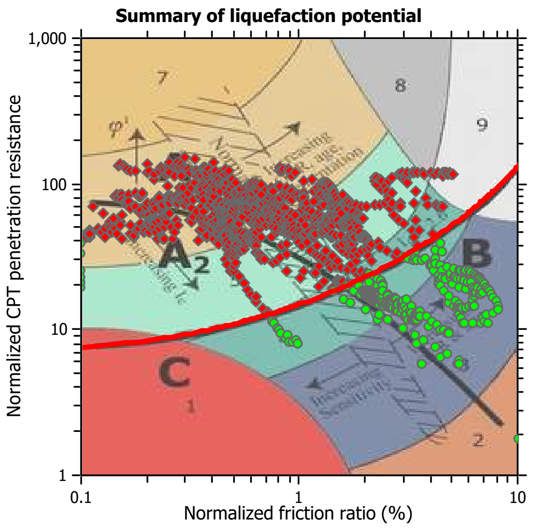
CPT file : CPT_185409

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	6.20 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	6.20 m	Fill height:	N/A	Limit depth applied:	No
Points to test:	Based on Ic value	Average results interval:	3	Fill weight:	N/A	Limit depth:	N/A
Earthquake magnitude M_w:	6.00	Ic cut-off value:	2.60	Trans. detect. applied:	Yes	MSF method:	Method based
Peak ground acceleration:	0.29	Unit weight calculation:	Based on SBT	K_σ applied:	Yes		

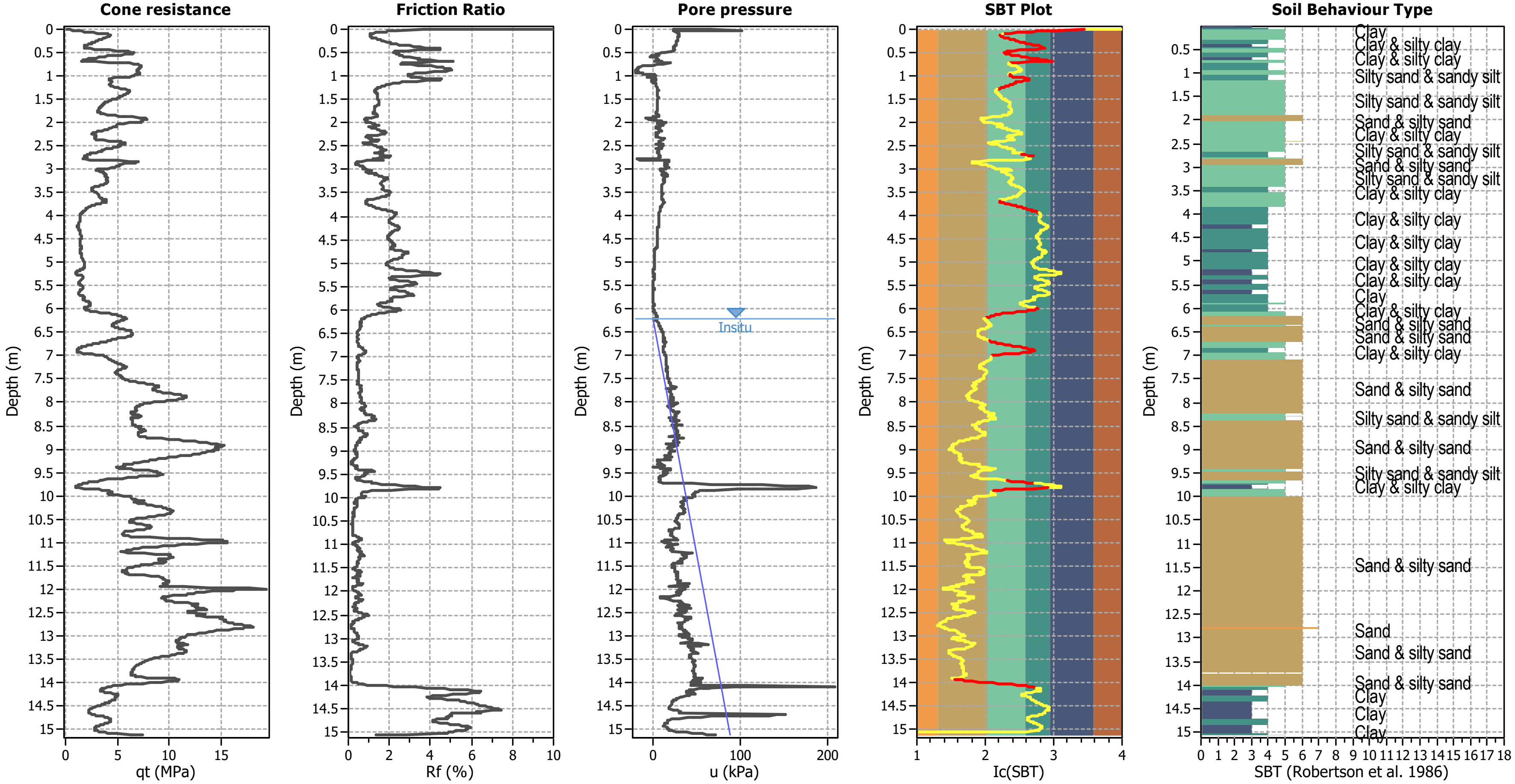






Zone A_1: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A_2: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and strength loss possible depending on soil plasticity, brittleness/sensitivity, strain to peak undrained strength and ground geometry

CPT basic interpretation plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.20 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.29	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.20 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

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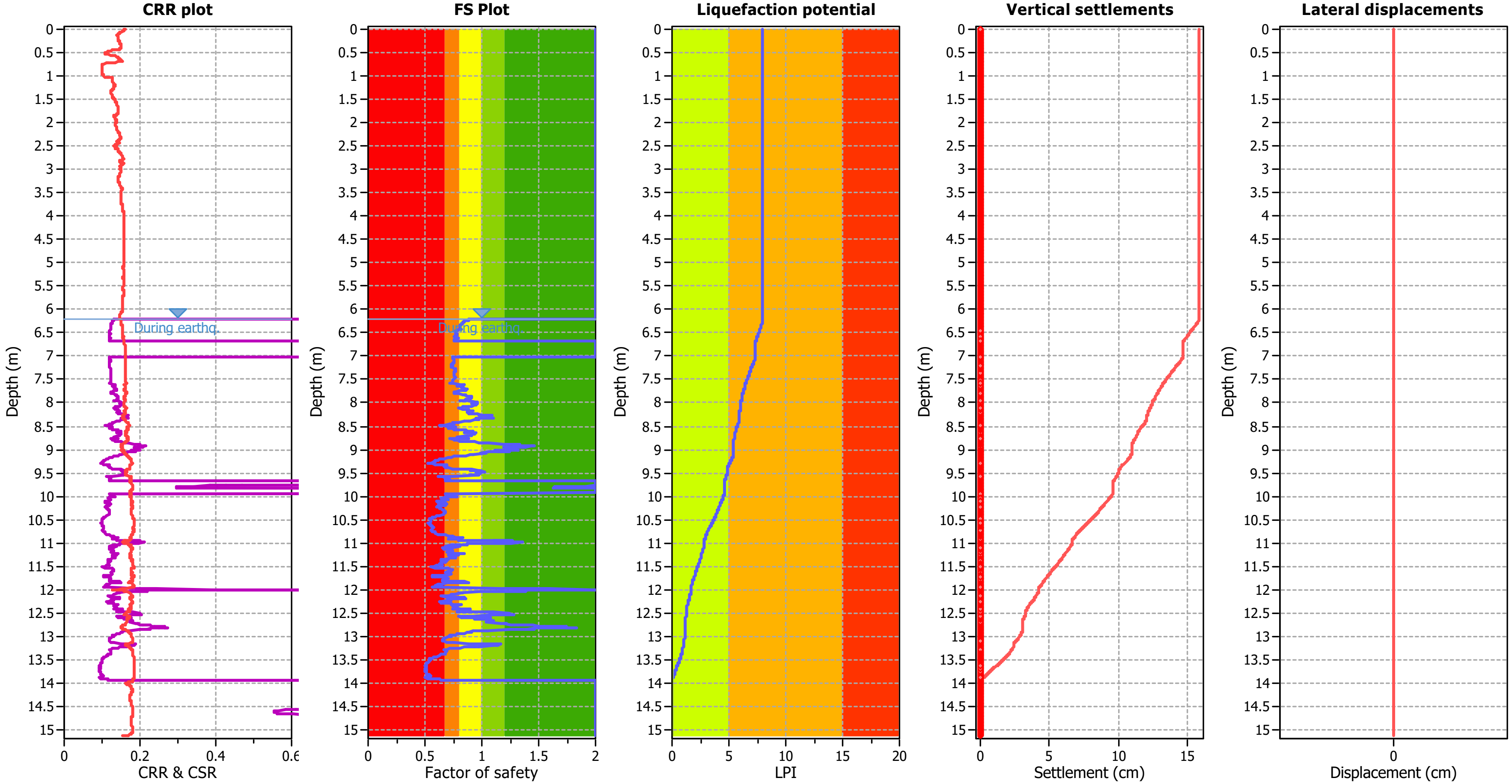
CPT name: CPT_185409

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.20 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.29	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.20 m	Fill height:	N/A	Limit depth:	N/A

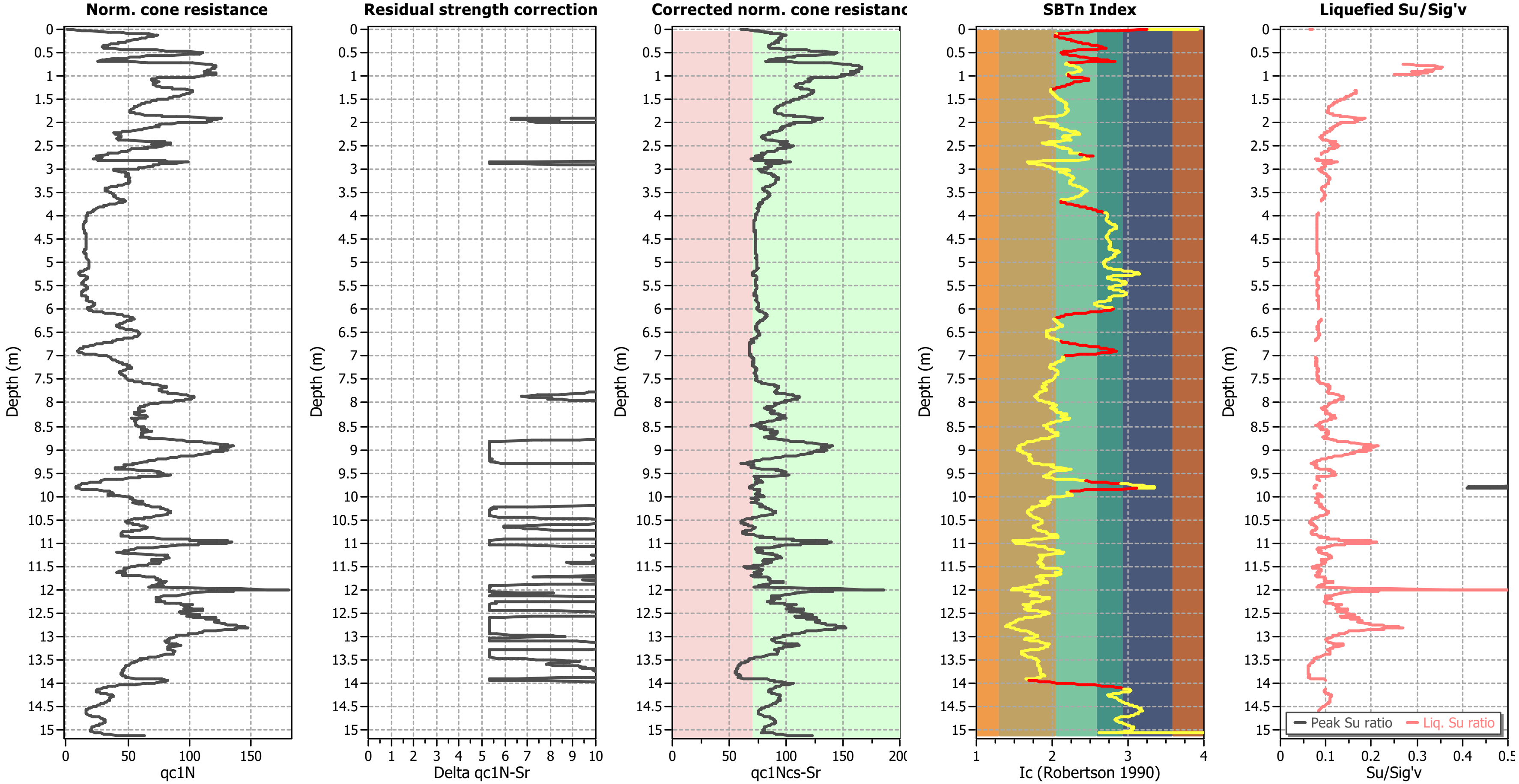
F.S. color scheme

- Almost certain it will liquefy
- Very likely to liquefy
- Liquefaction and no liq. are equally likely
- Unlike to liquefy
- Almost certain it will not liquefy

LPI color scheme

- Very high risk
- High risk
- Low risk

Check for strength loss plots (Idriss & Boulanger (2008))



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.20 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_{σ} applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.29	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.20 m	Fill height:	N/A	Limit depth:	N/A

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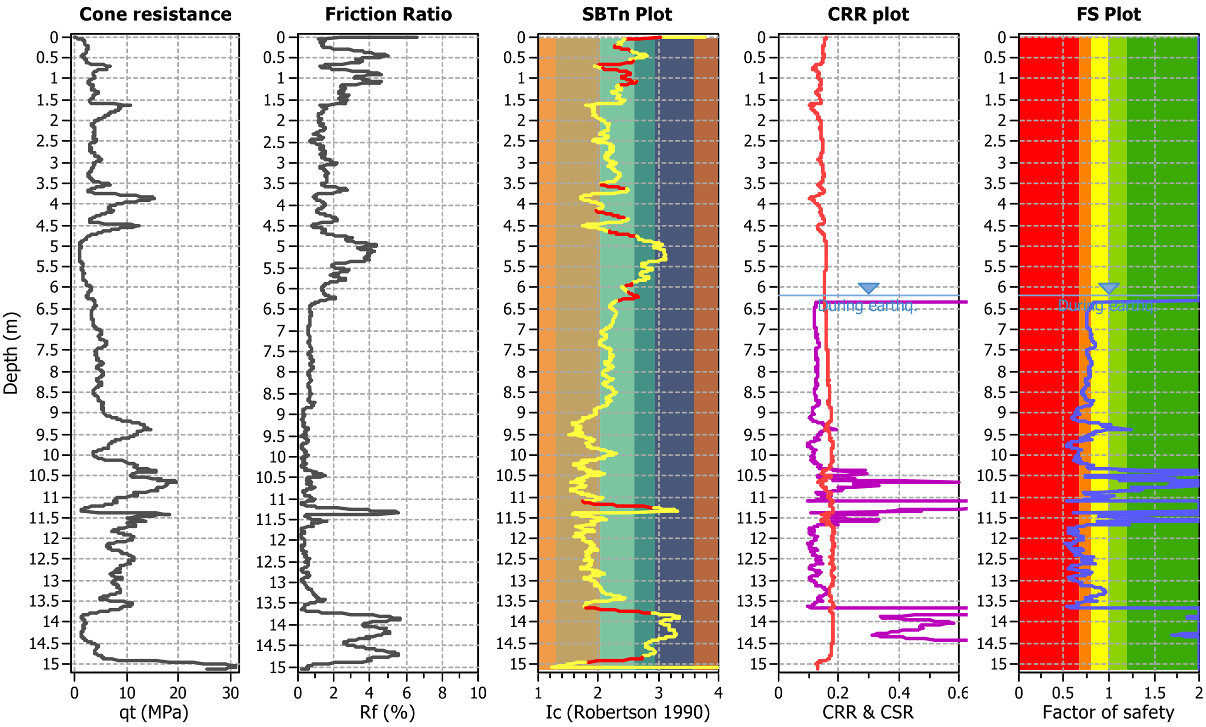
LIQUEFACTION ANALYSIS REPORT

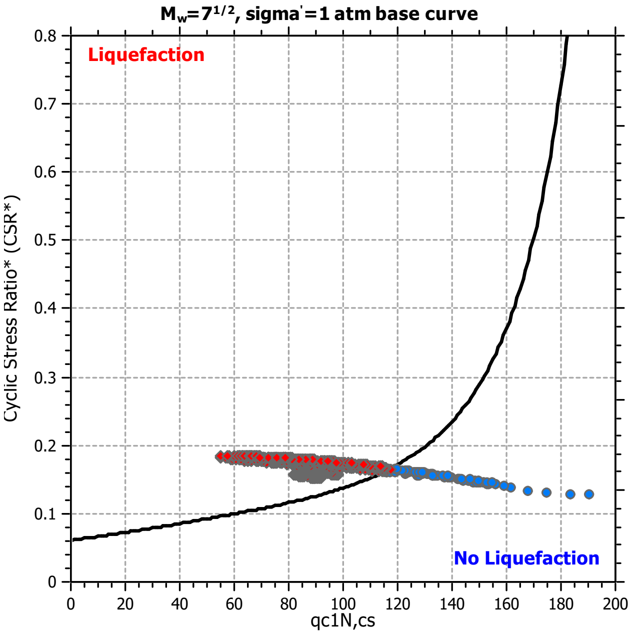
Project title : Outram Floodbank Investigation **Location : Outram, Otago**

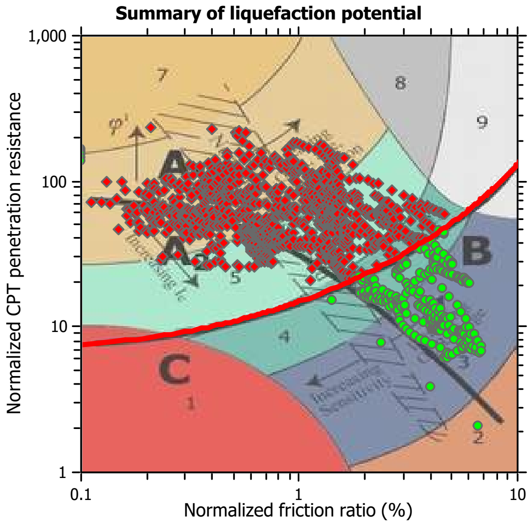
CPT file : CPT_185413

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	6.20 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	6.20 m	Fill height:	N/A		
Points to test:	Based on Ic value	Average results interval:	3	Fill weight:	N/A	Limit depth applied:	No
Earthquake magnitude M_w:	6.00	Ic cut-off value:	2.60	Trans. detect. applied:	Yes	Limit depth:	N/A
Peak ground acceleration:	0.29	Unit weight calculation:	Based on SBT	K_σ applied:	Yes	MSF method:	Method based

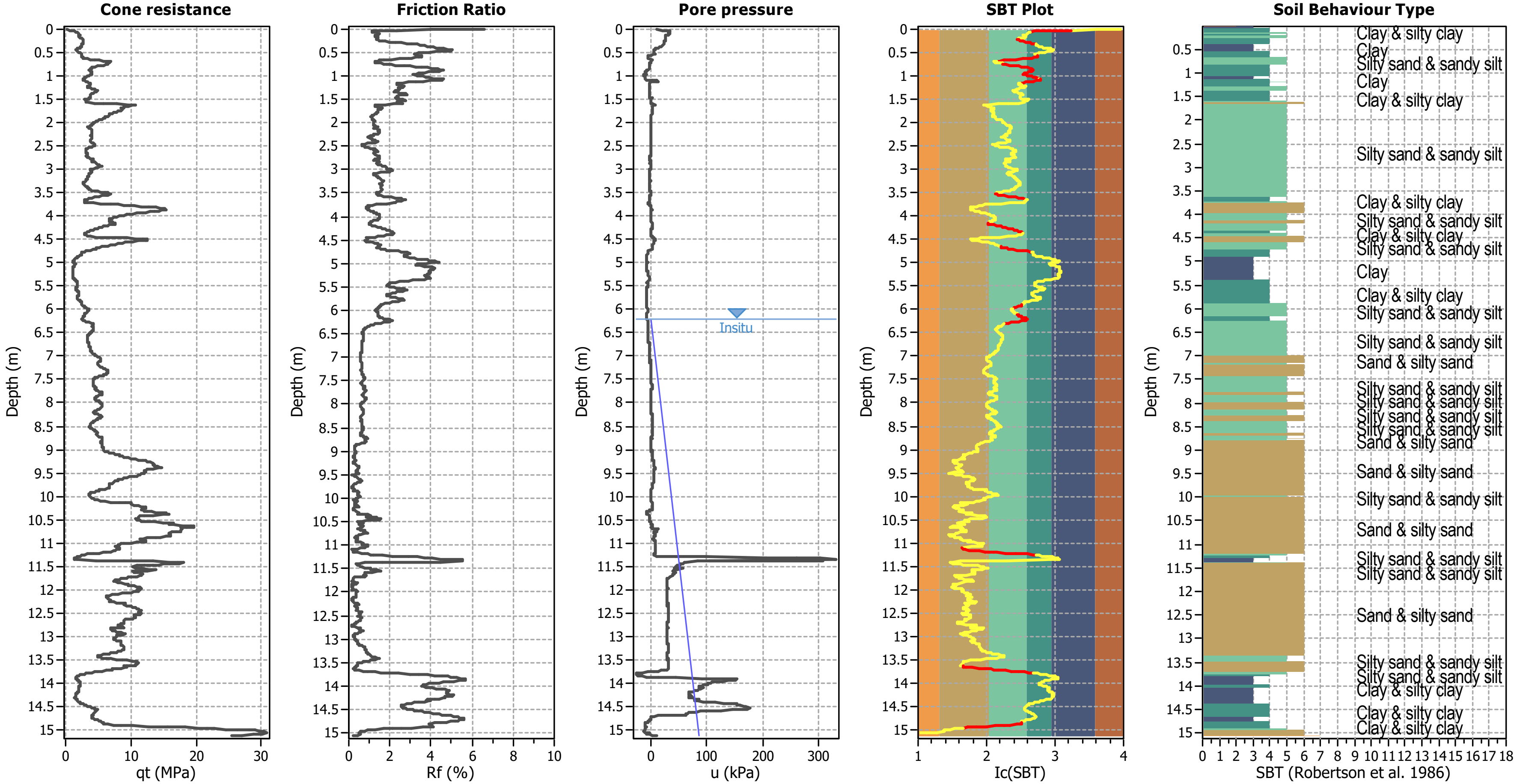






Zone A_1: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A_2: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and strength loss possible depending on soil plasticity, brittleness/sensitivity, strain to peak undrained strength and ground geometry

CPT basic interpretation plots



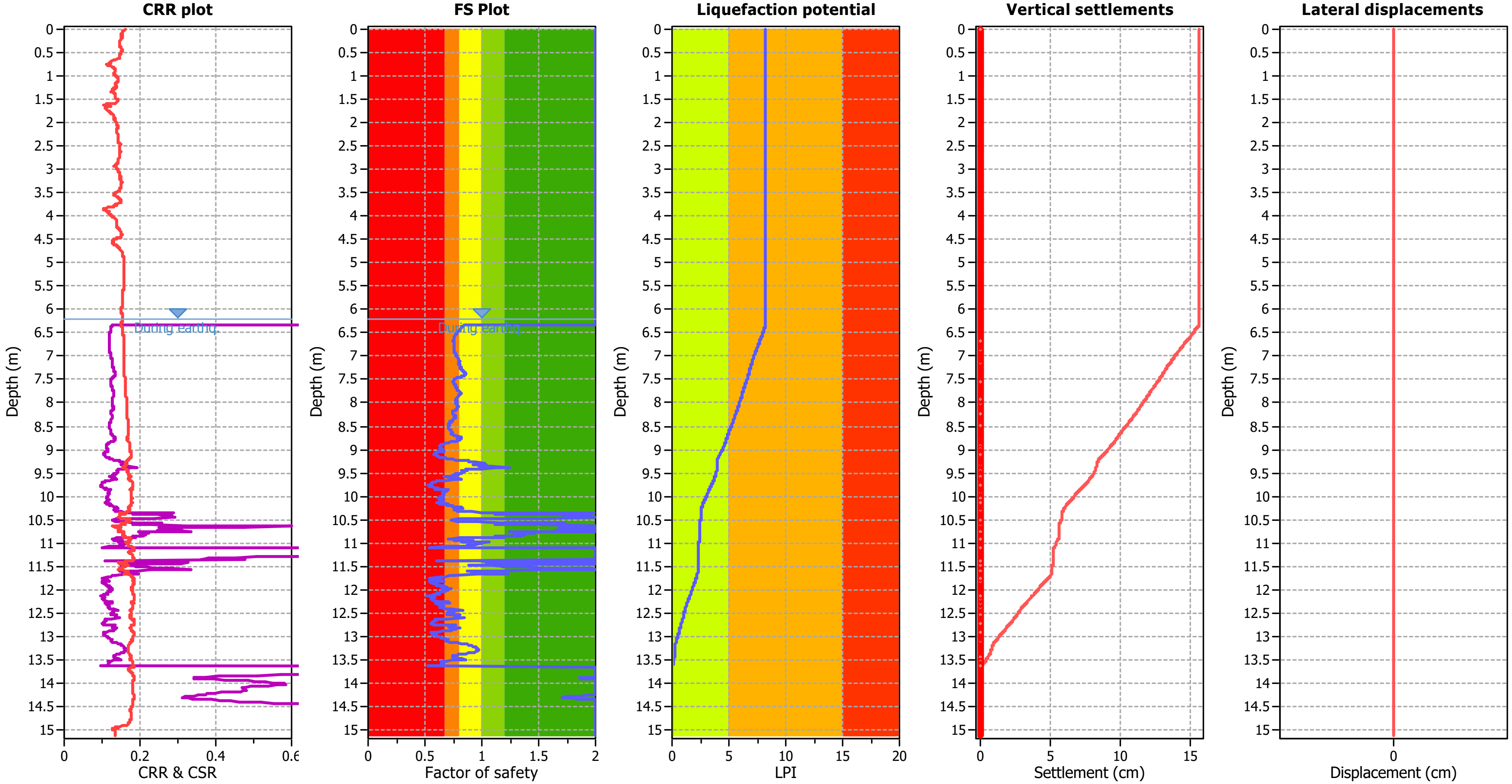
Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.20 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.29	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.20 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

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.20 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.29	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.20 m	Fill height:	N/A	Limit depth:	N/A

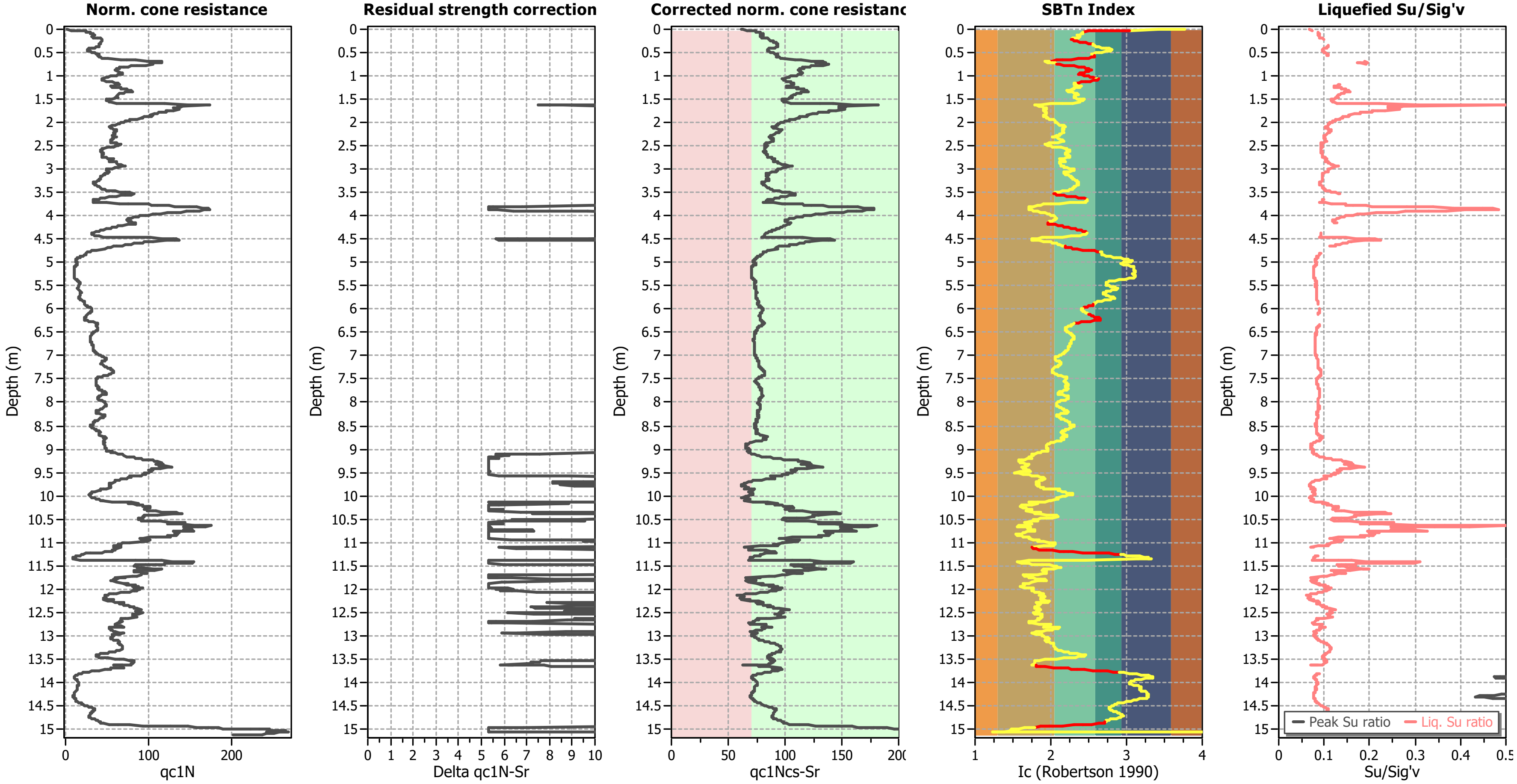
F.S. color scheme

- Almost certain it will liquefy
- Very likely to liquefy
- Liquefaction and no liq. are equally likely
- Unlike to liquefy
- Almost certain it will not liquefy

LPI color scheme

- Very high risk
- High risk
- Low risk

Check for strength loss plots (Idriss & Boulanger (2008))



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.20 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.29	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.20 m	Fill height:	N/A	Limit depth:	N/A

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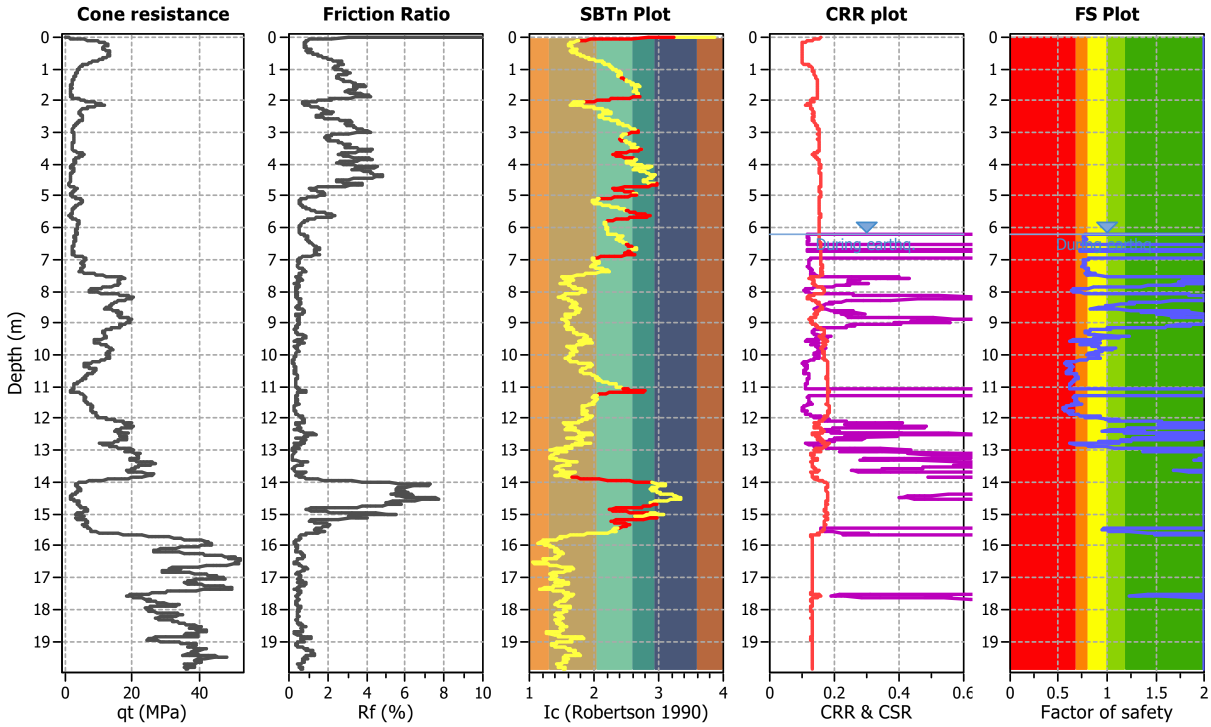
LIQUEFACTION ANALYSIS REPORT

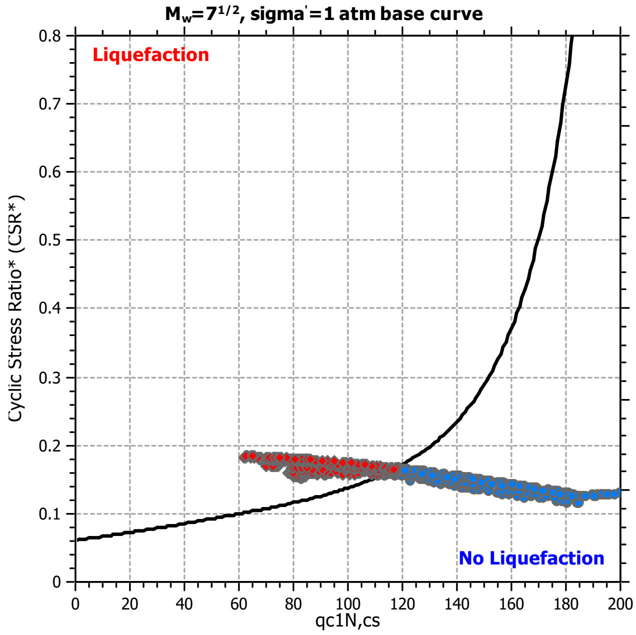
Project title : Outram Floodbank Investigation **Location : Outram, Otago**

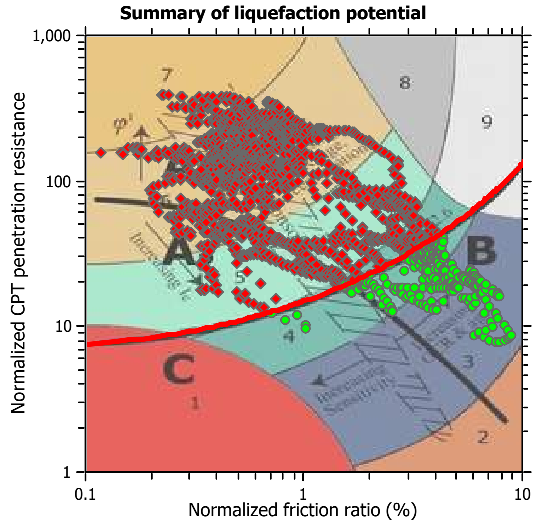
CPT file : CPT01

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	6.20 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	6.20 m	Fill height:	N/A	Limit depth applied:	No
Points to test:	Based on Ic value	Average results interval:	3	Fill weight:	N/A	Limit depth:	N/A
Earthquake magnitude M_w:	6.00	Ic cut-off value:	2.60	Trans. detect. applied:	Yes	MSF method:	Method based
Peak ground acceleration:	0.29	Unit weight calculation:	Based on SBT	K_σ applied:	Yes		

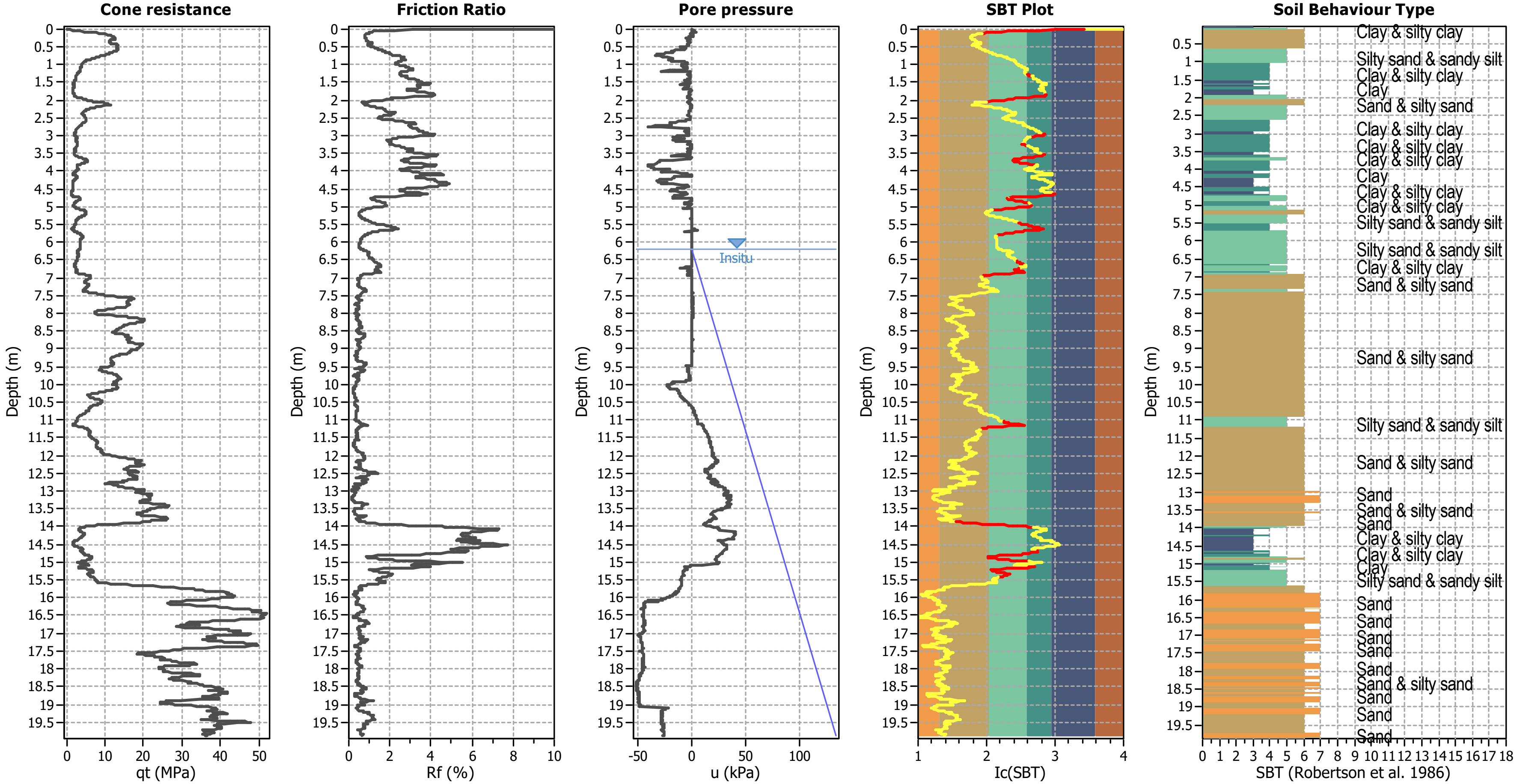






Zone A_1: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A_2: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and strength loss possible depending on soil plasticity, brittleness/sensitivity, strain to peak undrained strength and ground geometry

CPT basic interpretation plots



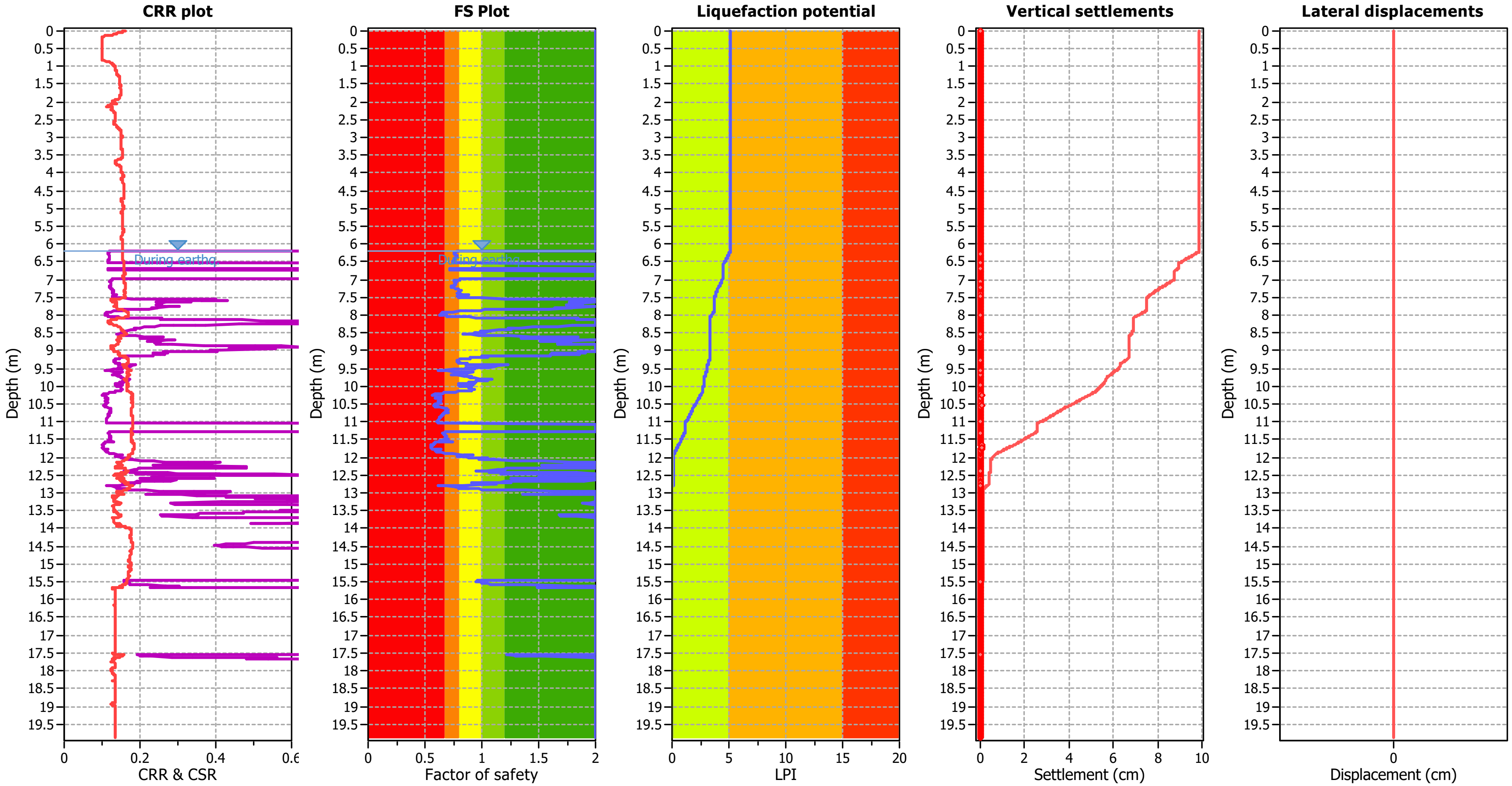
Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.20 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.29	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.20 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

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.20 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.29	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.20 m	Fill height:	N/A	Limit depth:	N/A

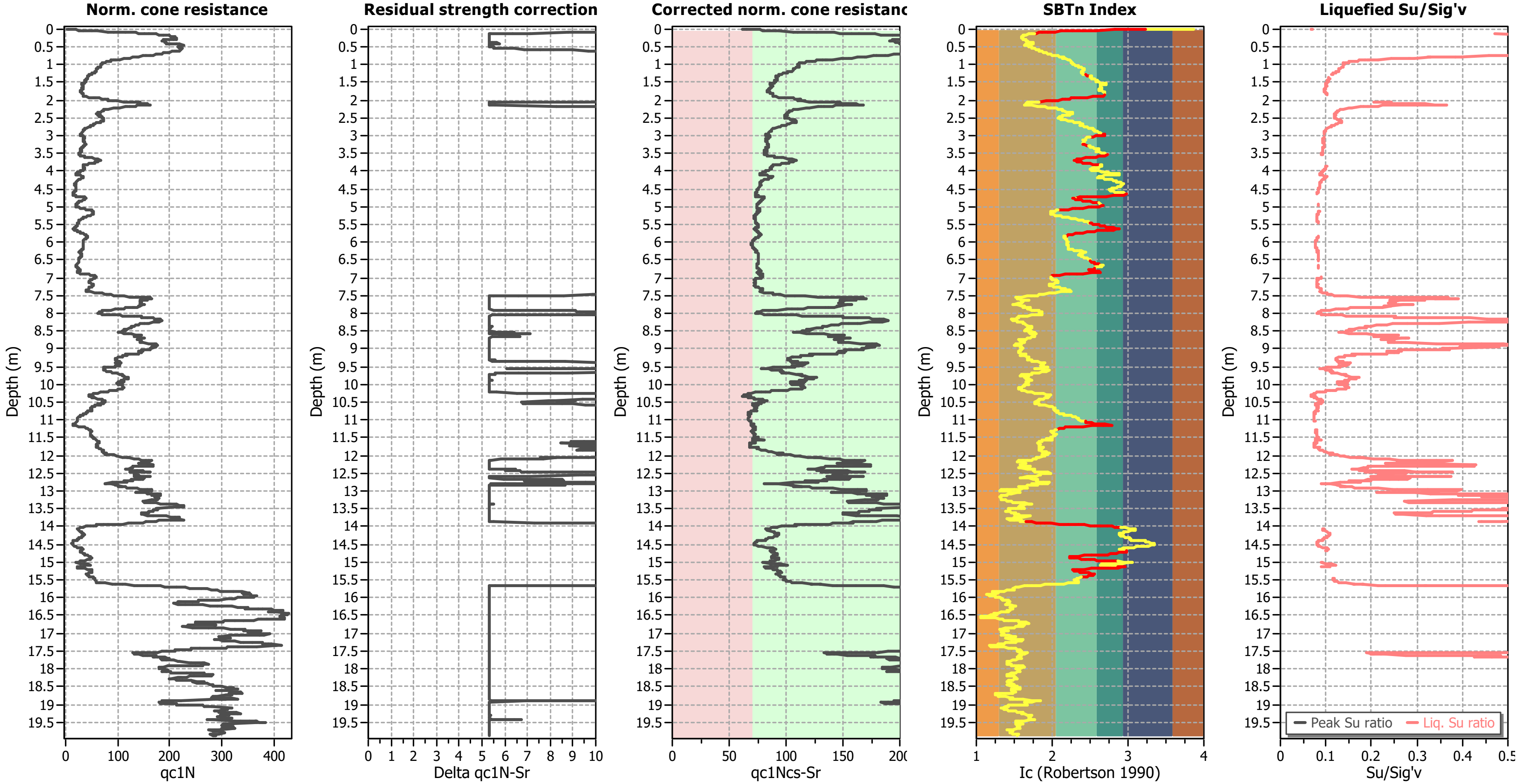
F.S. color scheme

- Almost certain it will liquefy
- Very likely to liquefy
- Liquefaction and no liq. are equally likely
- Unlike to liquefy
- Almost certain it will not liquefy

LPI color scheme

- Very high risk
- High risk
- Low risk

Check for strength loss plots (Idriss & Boulanger (2008))



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.20 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_{σ} applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.29	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.20 m	Fill height:	N/A	Limit depth:	N/A

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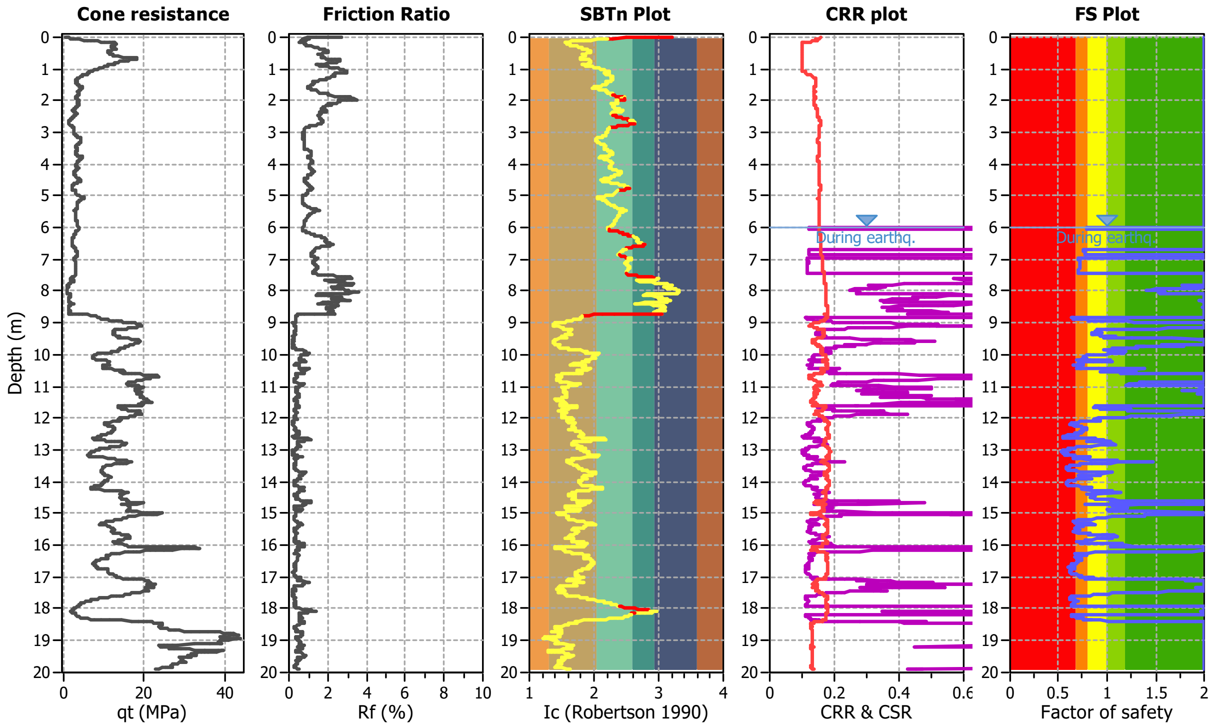
LIQUEFACTION ANALYSIS REPORT

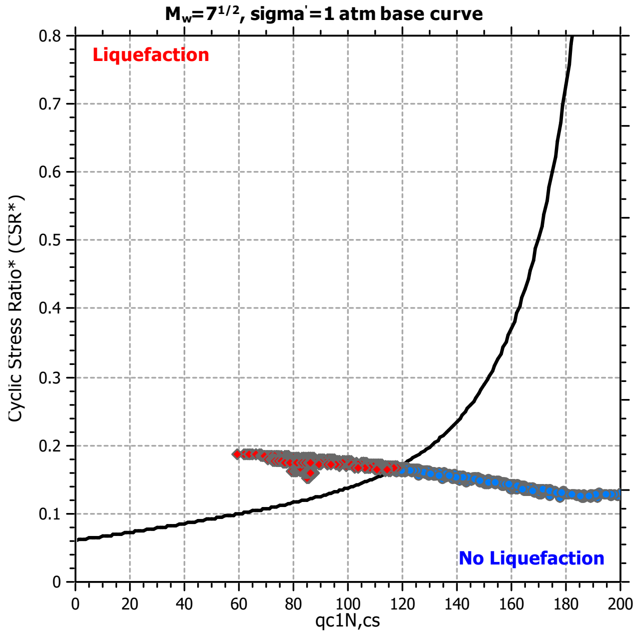
Project title : Outram Floodbank Investigation **Location : Outram, Otago**

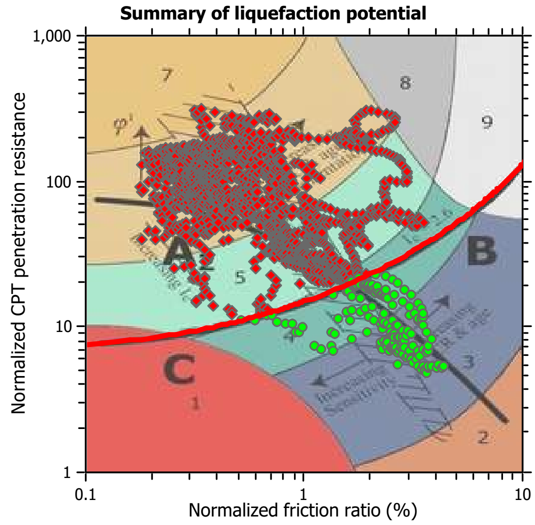
CPT file : CPT02

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	6.00 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	6.00 m	Fill height:	N/A	Limit depth applied:	No
Points to test:	Based on Ic value	Average results interval:	3	Fill weight:	N/A	Limit depth:	N/A
Earthquake magnitude M_w:	6.00	Ic cut-off value:	2.60	Trans. detect. applied:	Yes	MSF method:	Method based
Peak ground acceleration:	0.29	Unit weight calculation:	Based on SBT	K_σ applied:	Yes		

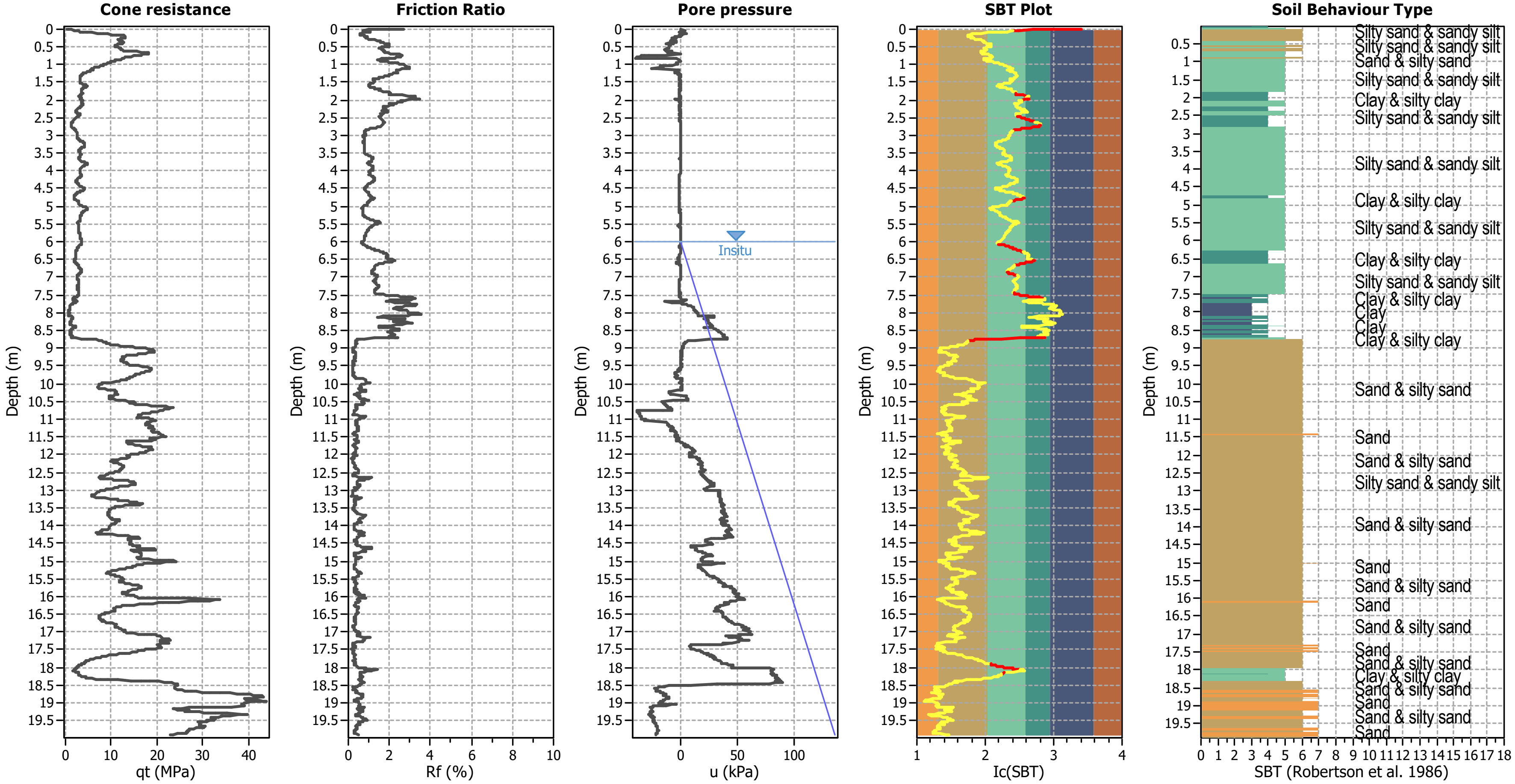






Zone A_1: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A_2: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and strength loss possible depending on soil plasticity, brittleness/sensitivity, strain to peak undrained strength and ground geometry

CPT basic interpretation plots



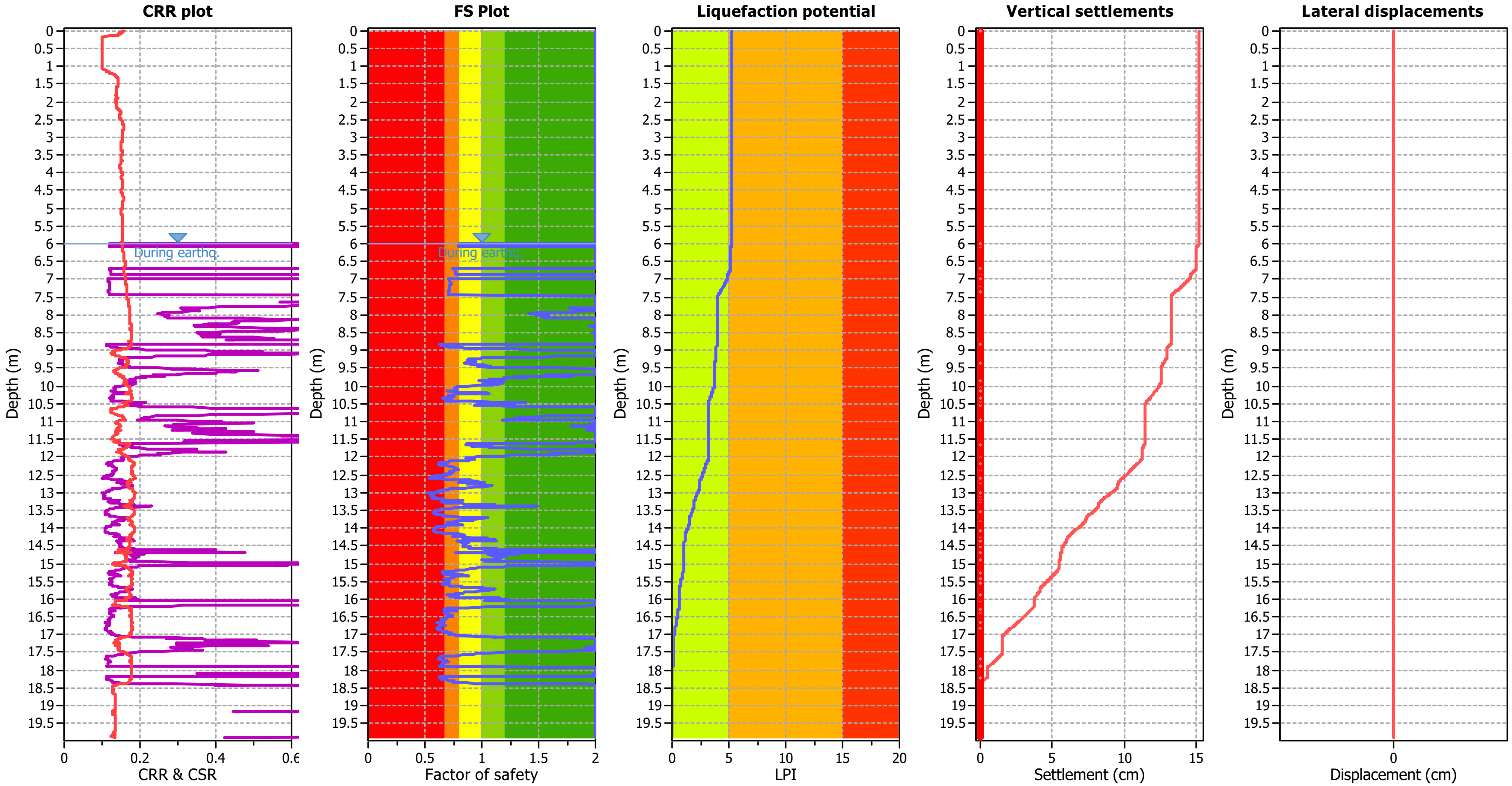
Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.00 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.29	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.00 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

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.00 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.29	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.00 m	Fill height:	N/A	Limit depth:	N/A

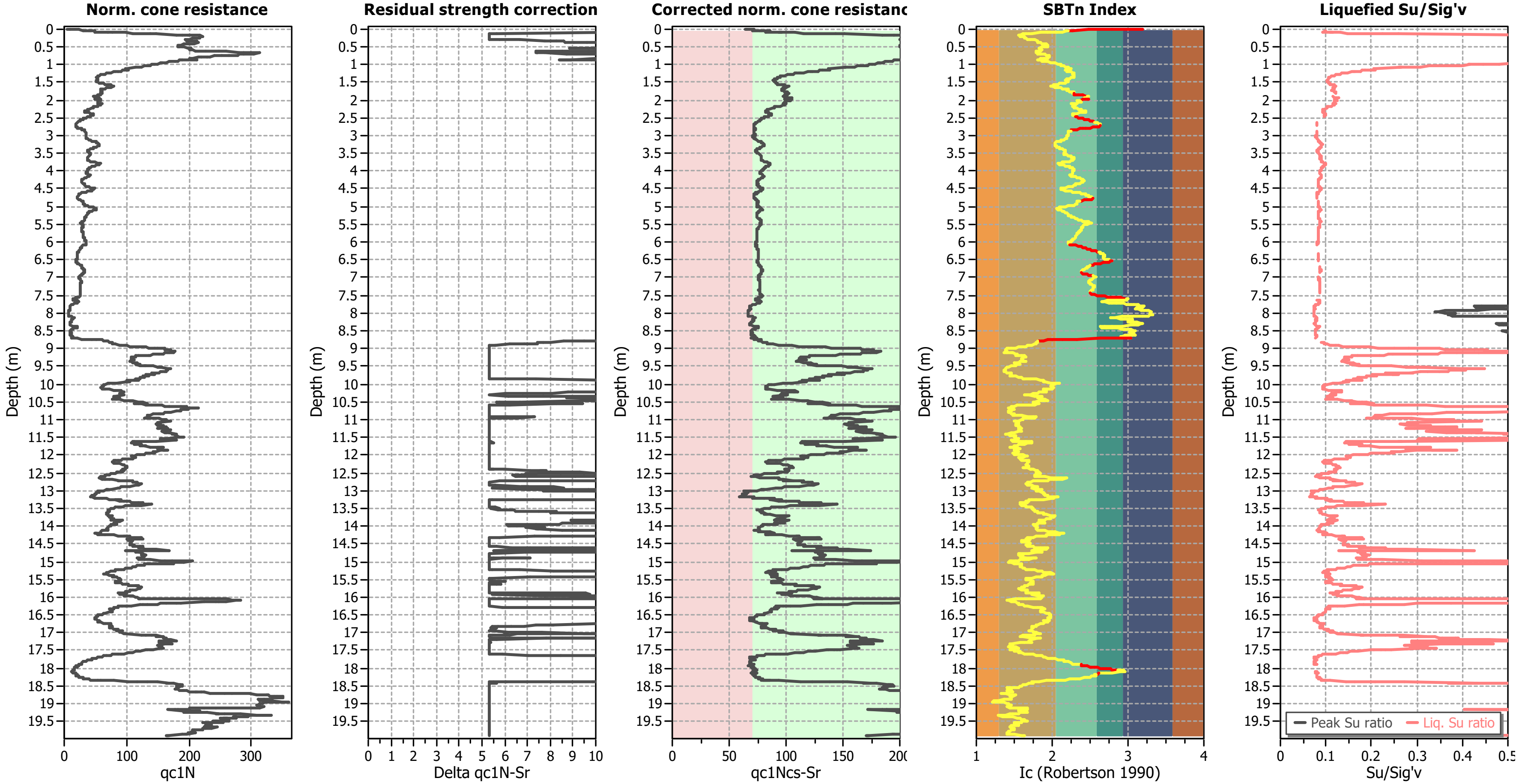
F.S. color scheme

- Almost certain it will liquefy
- Very likely to liquefy
- Liquefaction and no liq. are equally likely
- Unlike to liquefy
- Almost certain it will not liquefy

LPI color scheme

- Very high risk
- High risk
- Low risk

Check for strength loss plots (Idriss & Boulanger (2008))



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.00 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.29	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.00 m	Fill height:	N/A	Limit depth:	N/A

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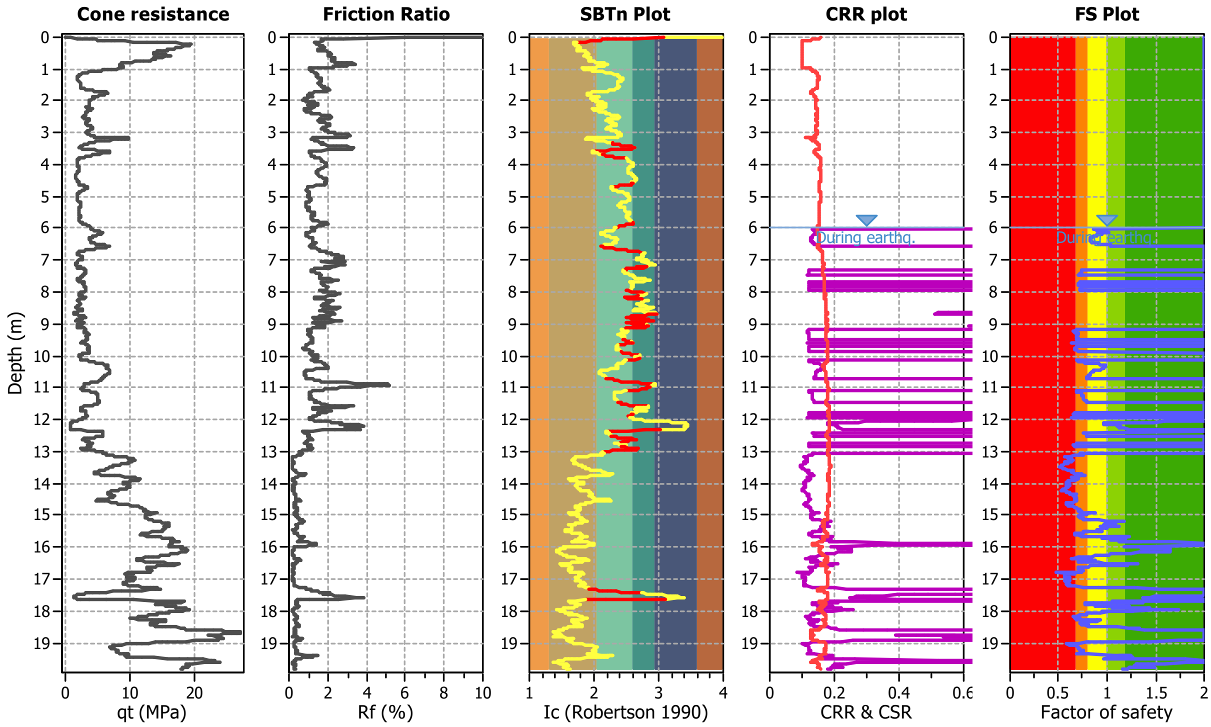
LIQUEFACTION ANALYSIS REPORT

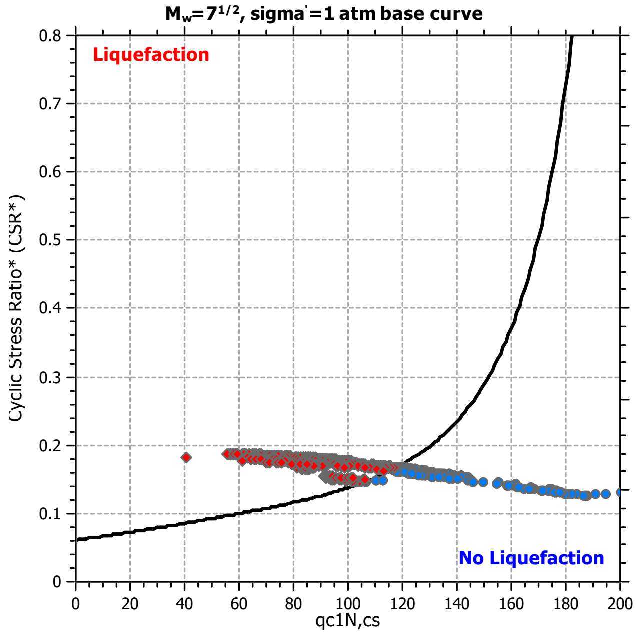
Project title : Outram Floodbank Investigation **Location : Outram, Otago**

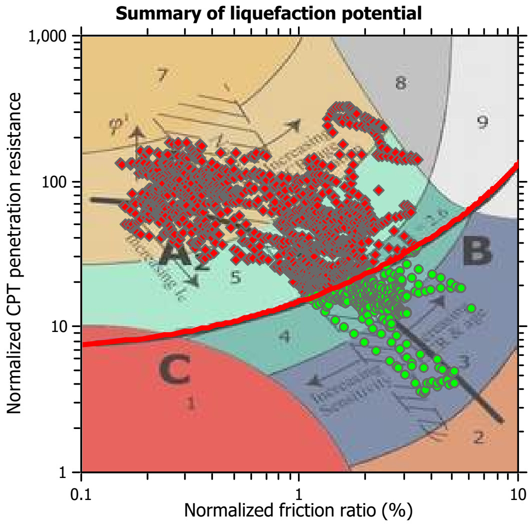
CPT file : CPT03

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	6.00 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	6.00 m	Fill height:	N/A	Limit depth applied:	No
Points to test:	Based on Ic value	Average results interval:	3	Fill weight:	N/A	Limit depth:	N/A
Earthquake magnitude M_w:	6.00	Ic cut-off value:	2.60	Trans. detect. applied:	Yes	MSF method:	Method based
Peak ground acceleration:	0.29	Unit weight calculation:	Based on SBT	K_σ applied:	Yes		

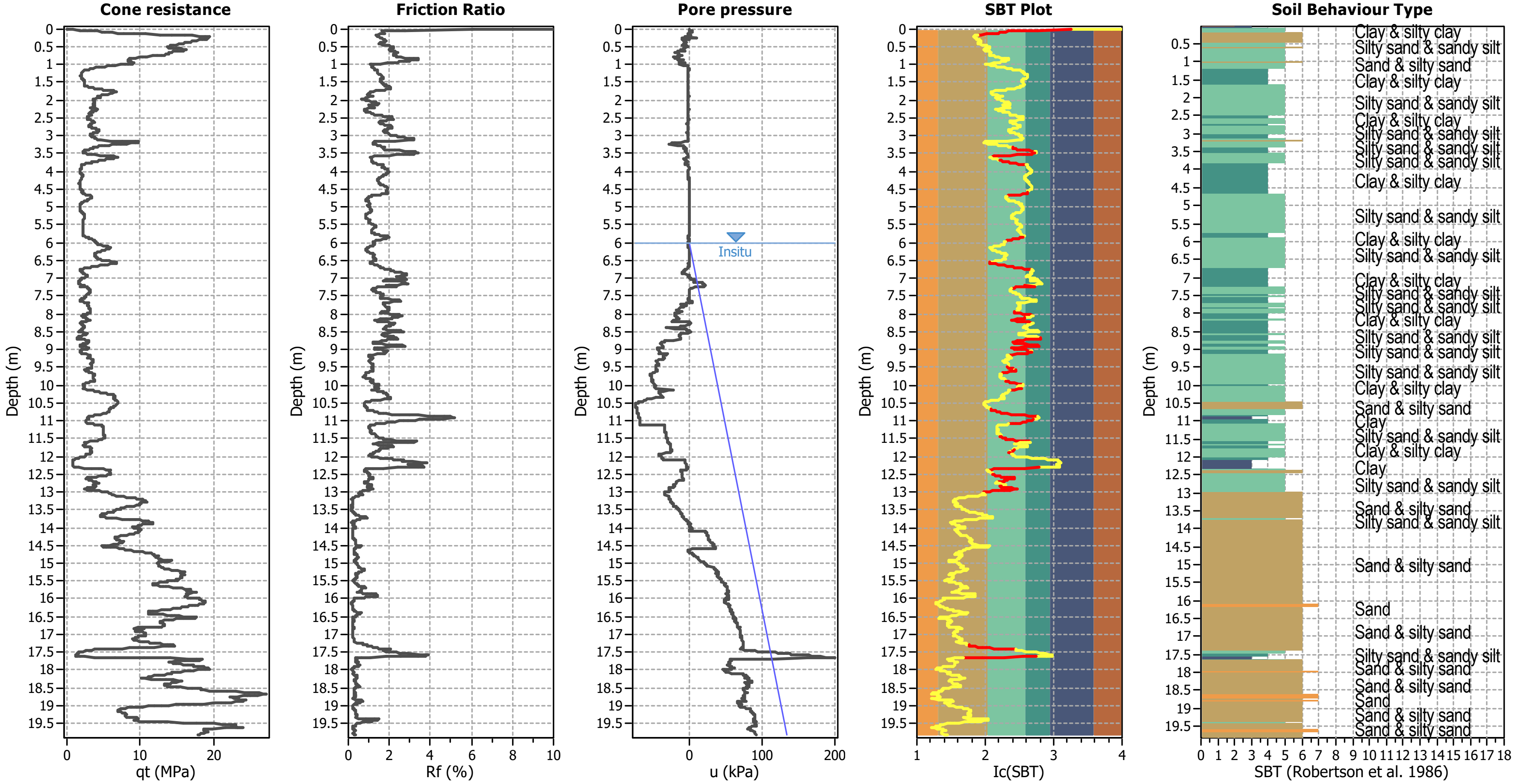






Zone A_1: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A_2: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and strength loss possible depending on soil plasticity, brittleness/sensitivity, strain to peak undrained strength and ground geometry

CPT basic interpretation plots



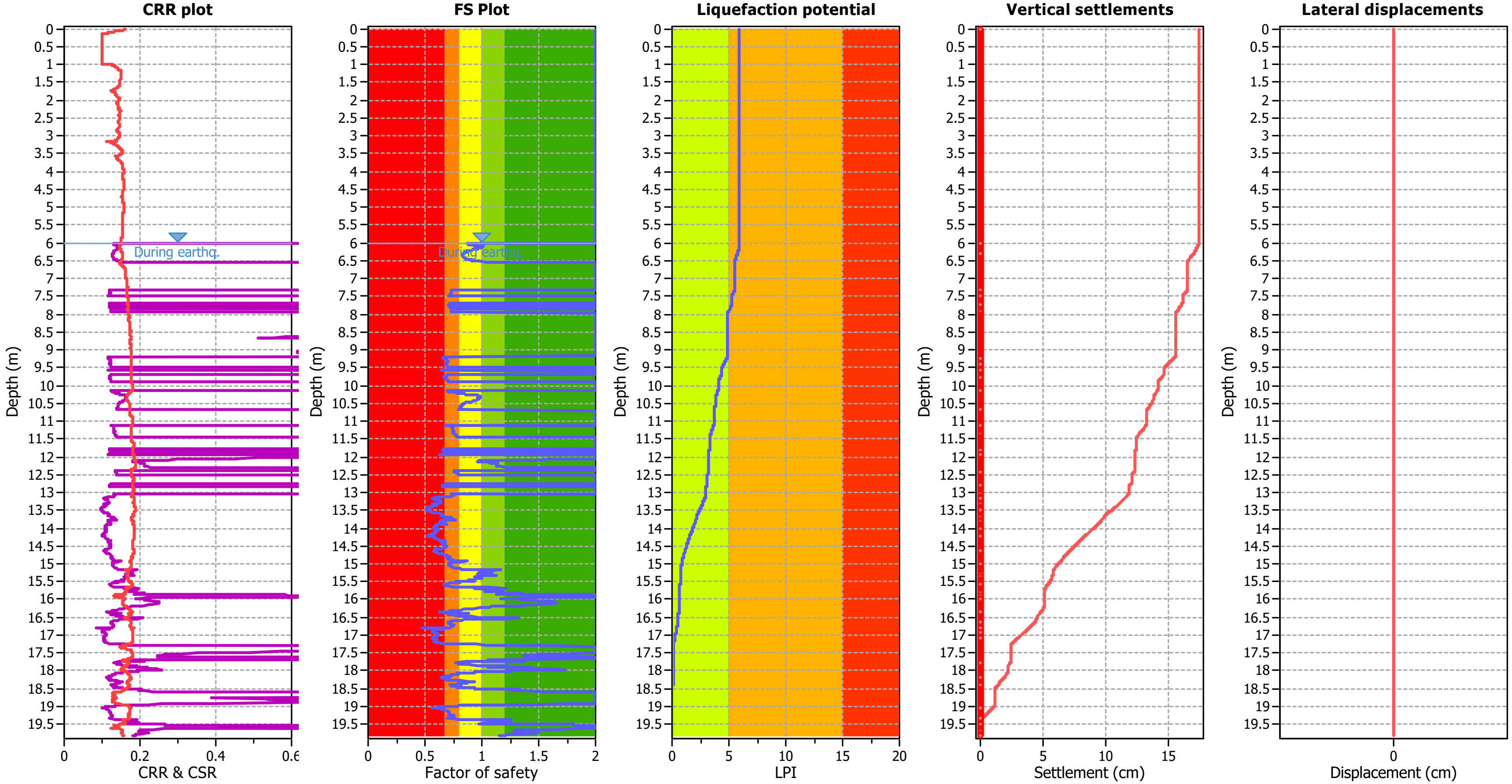
Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.00 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.29	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.00 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

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.00 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.29	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.00 m	Fill height:	N/A	Limit depth:	N/A

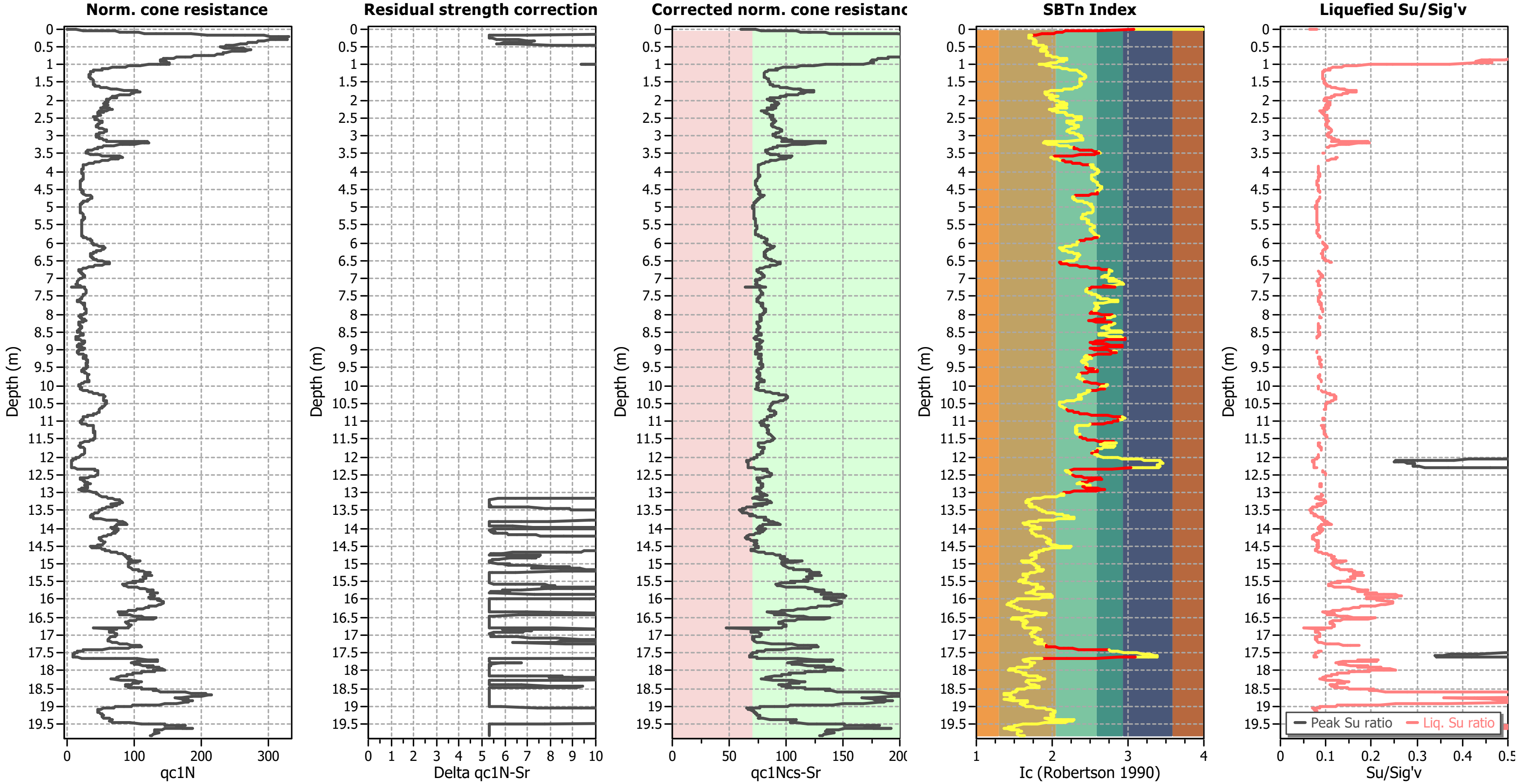
F.S. color scheme

- Almost certain it will liquefy
- Very likely to liquefy
- Liquefaction and no liq. are equally likely
- Unlike to liquefy
- Almost certain it will not liquefy

LPI color scheme

- Very high risk
- High risk
- Low risk

Check for strength loss plots (Idriss & Boulanger (2008))



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	6.00 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.29	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	6.00 m	Fill height:	N/A	Limit depth:	N/A

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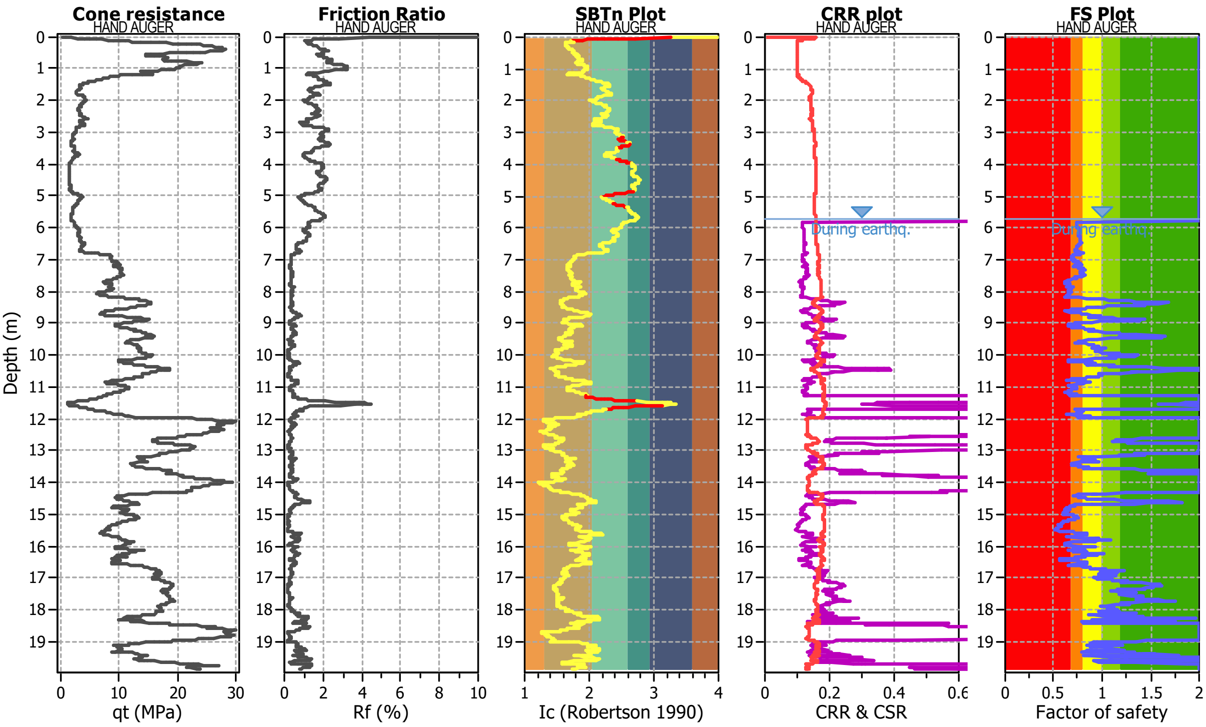
LIQUEFACTION ANALYSIS REPORT

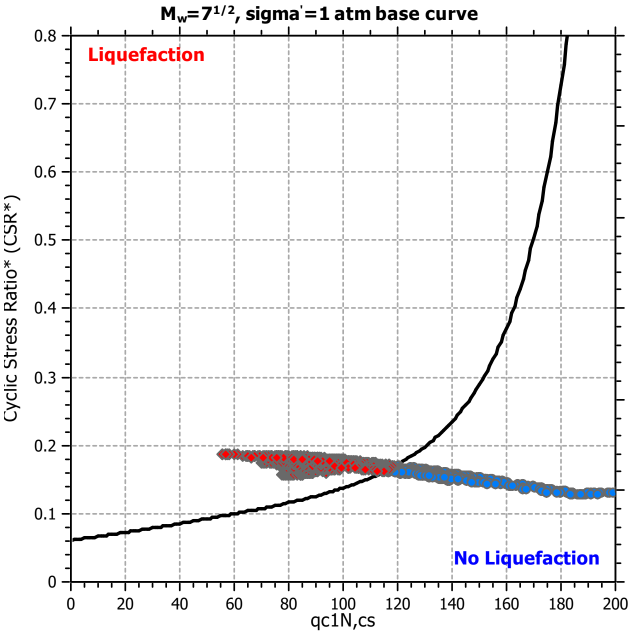
Project title : Outram Floodbank Investigation **Location : Outram, Otago**

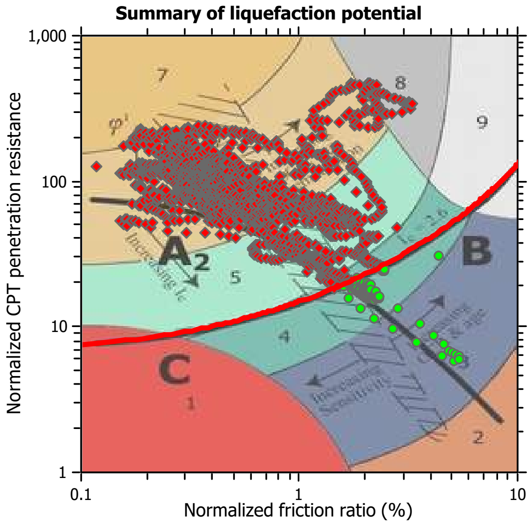
CPT file : CPT04

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	5.70 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	5.70 m	Fill height:	N/A		
Points to test:	Based on Ic value	Average results interval:	3	Fill weight:	N/A	Limit depth applied:	No
Earthquake magnitude M_w:	6.00	Ic cut-off value:	2.60	Trans. detect. applied:	Yes	Limit depth:	N/A
Peak ground acceleration:	0.29	Unit weight calculation:	Based on SBT	K_σ applied:	Yes	MSF method:	Method based

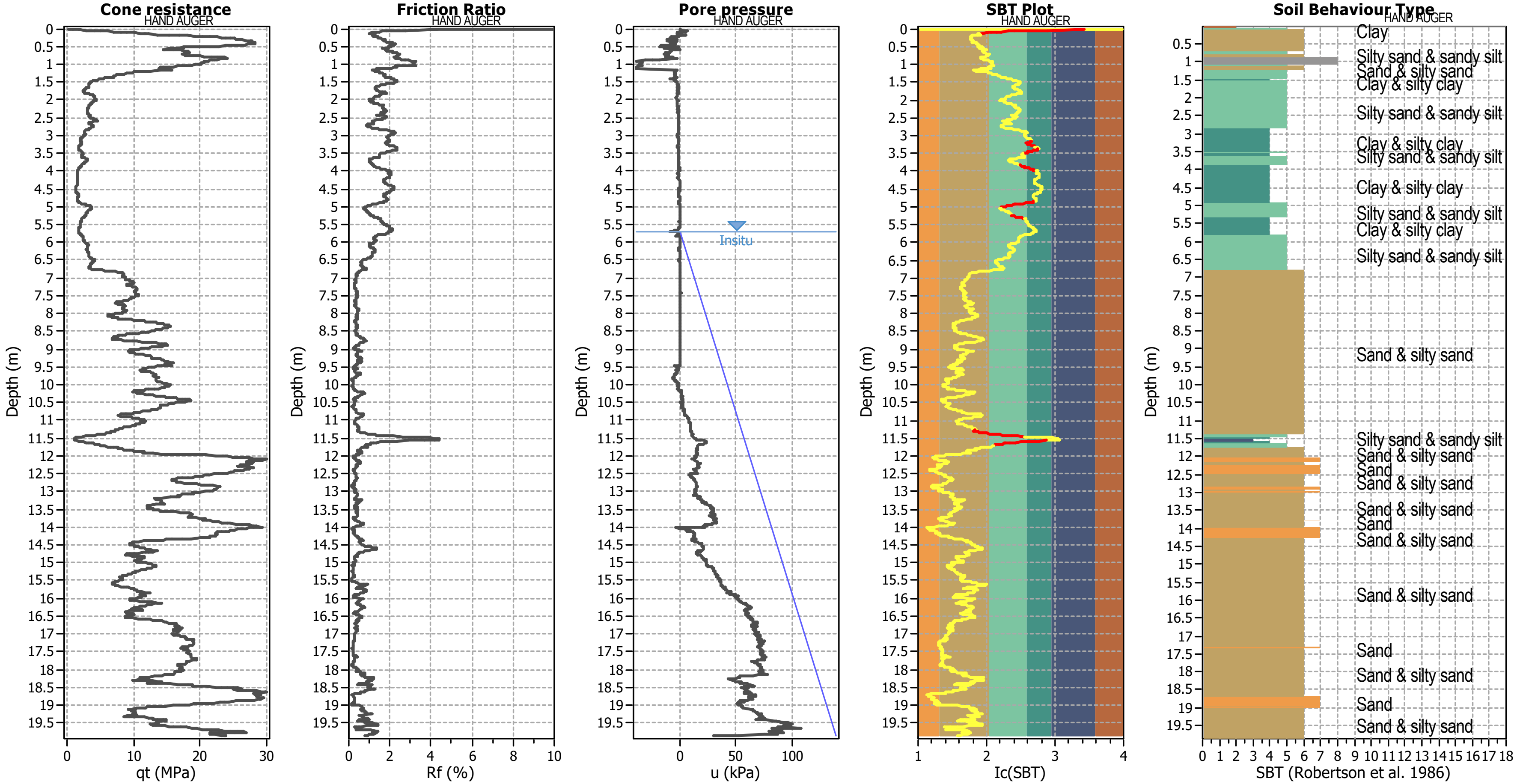






Zone A_1: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A_2: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and strength loss possible depending on soil plasticity, brittleness/sensitivity, strain to peak undrained strength and ground geometry

CPT basic interpretation plots



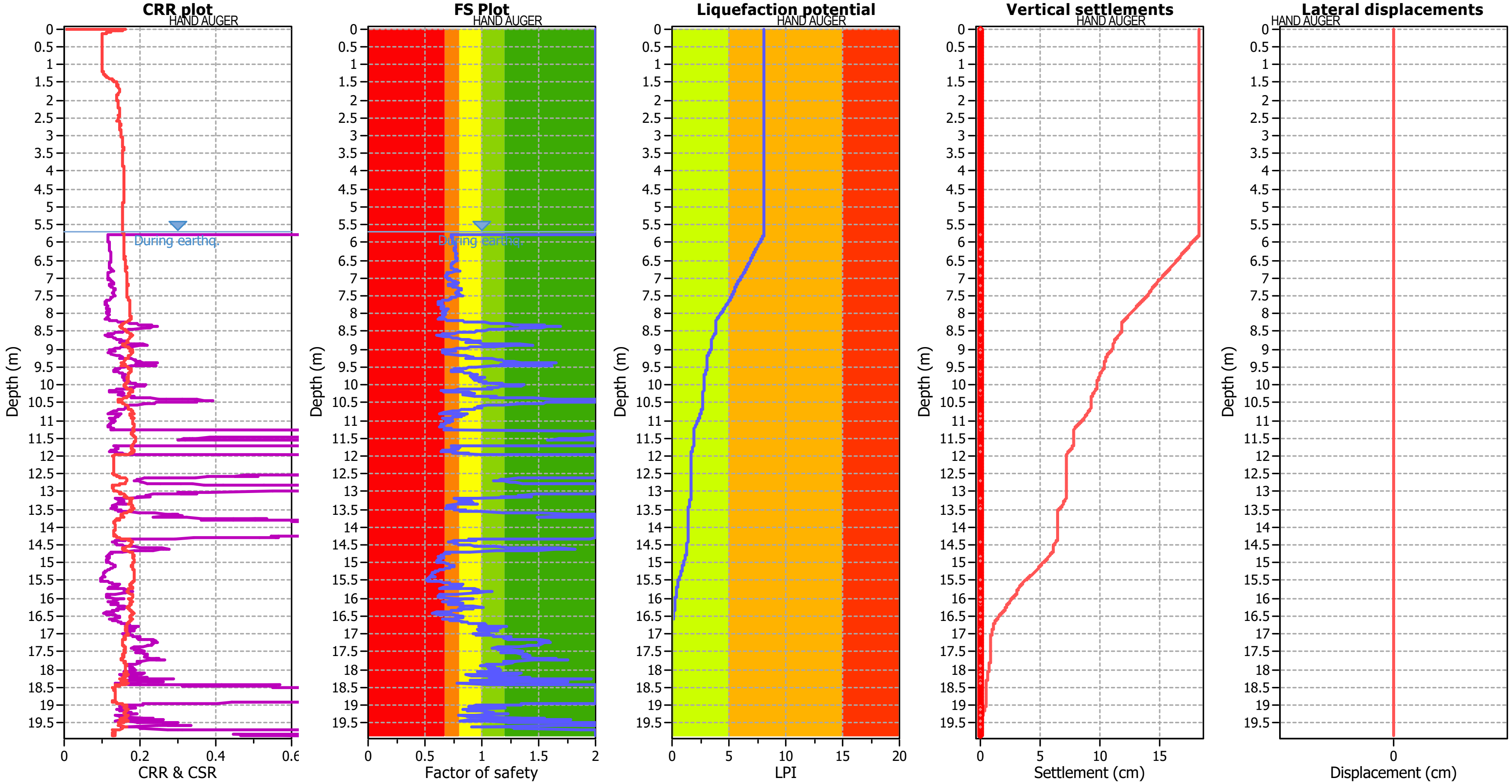
Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	5.70 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.29	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	5.70 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

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	5.70 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.29	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	5.70 m	Fill height:	N/A	Limit depth:	N/A

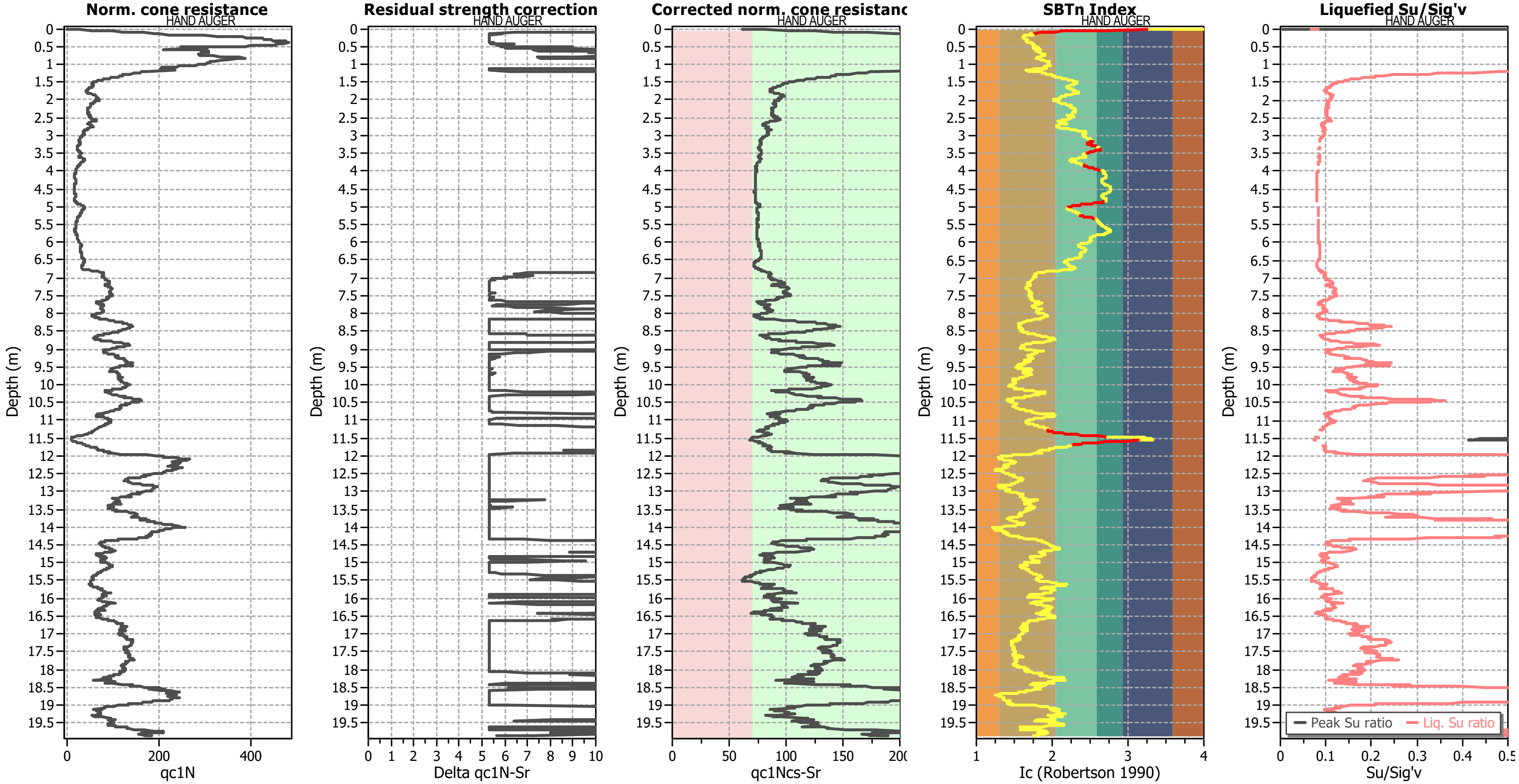
F.S. color scheme

- Almost certain it will liquefy
- Very likely to liquefy
- Liquefaction and no liq. are equally likely
- Unlike to liquefy
- Almost certain it will not liquefy

LPI color scheme

- Very high risk
- High risk
- Low risk

Check for strength loss plots (Idriss & Boulanger (2008))



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	5.70 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.29	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	5.70 m	Fill height:	N/A	Limit depth:	N/A

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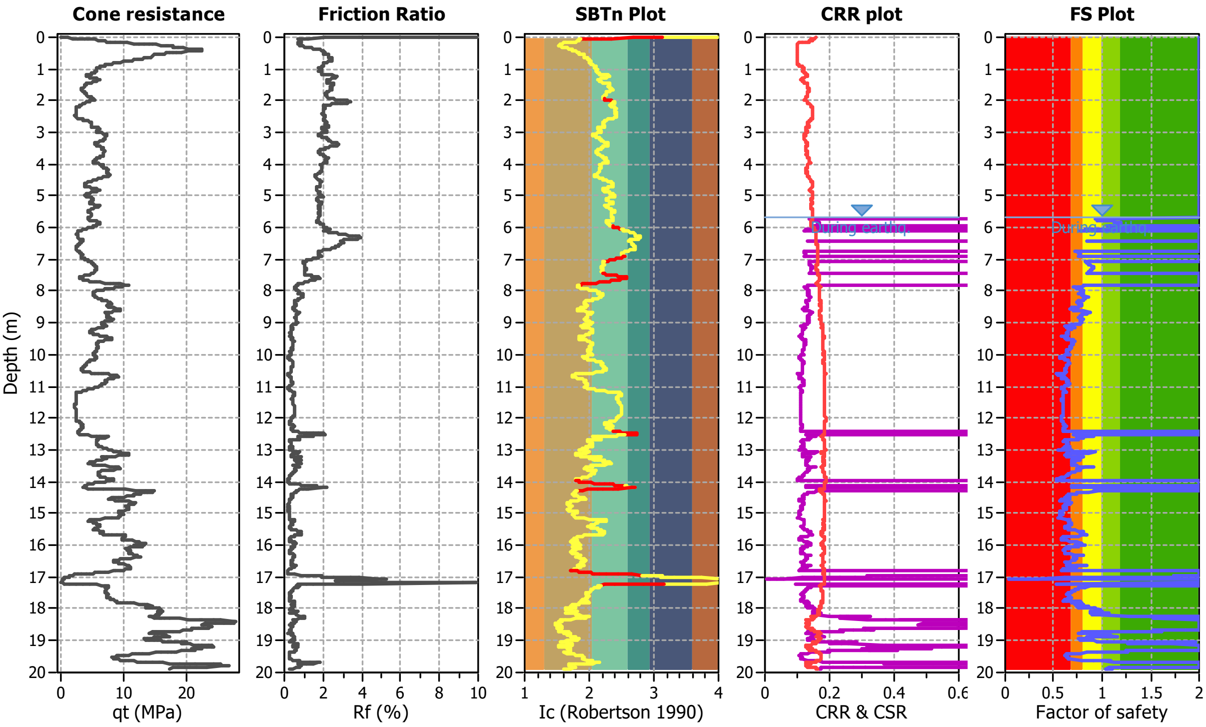
LIQUEFACTION ANALYSIS REPORT

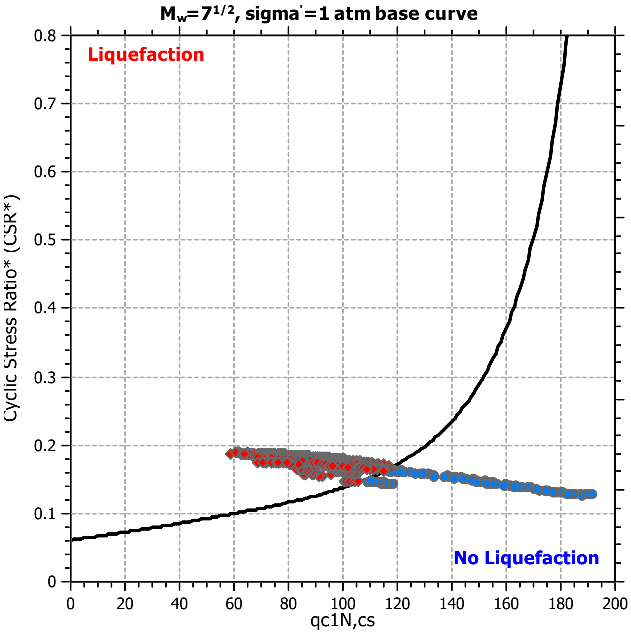
Project title : Outram Floodbank Investigation **Location : Outram, Otago**

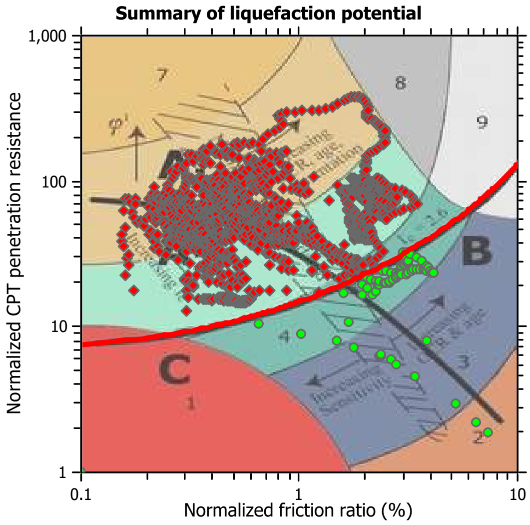
CPT file : CPT05

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	5.70 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	5.70 m	Fill height:	N/A	Limit depth applied:	No
Points to test:	Based on Ic value	Average results interval:	3	Fill weight:	N/A	Limit depth:	N/A
Earthquake magnitude M_w:	6.00	Ic cut-off value:	2.60	Trans. detect. applied:	Yes	MSF method:	Method based
Peak ground acceleration:	0.29	Unit weight calculation:	Based on SBT	K_σ applied:	Yes		

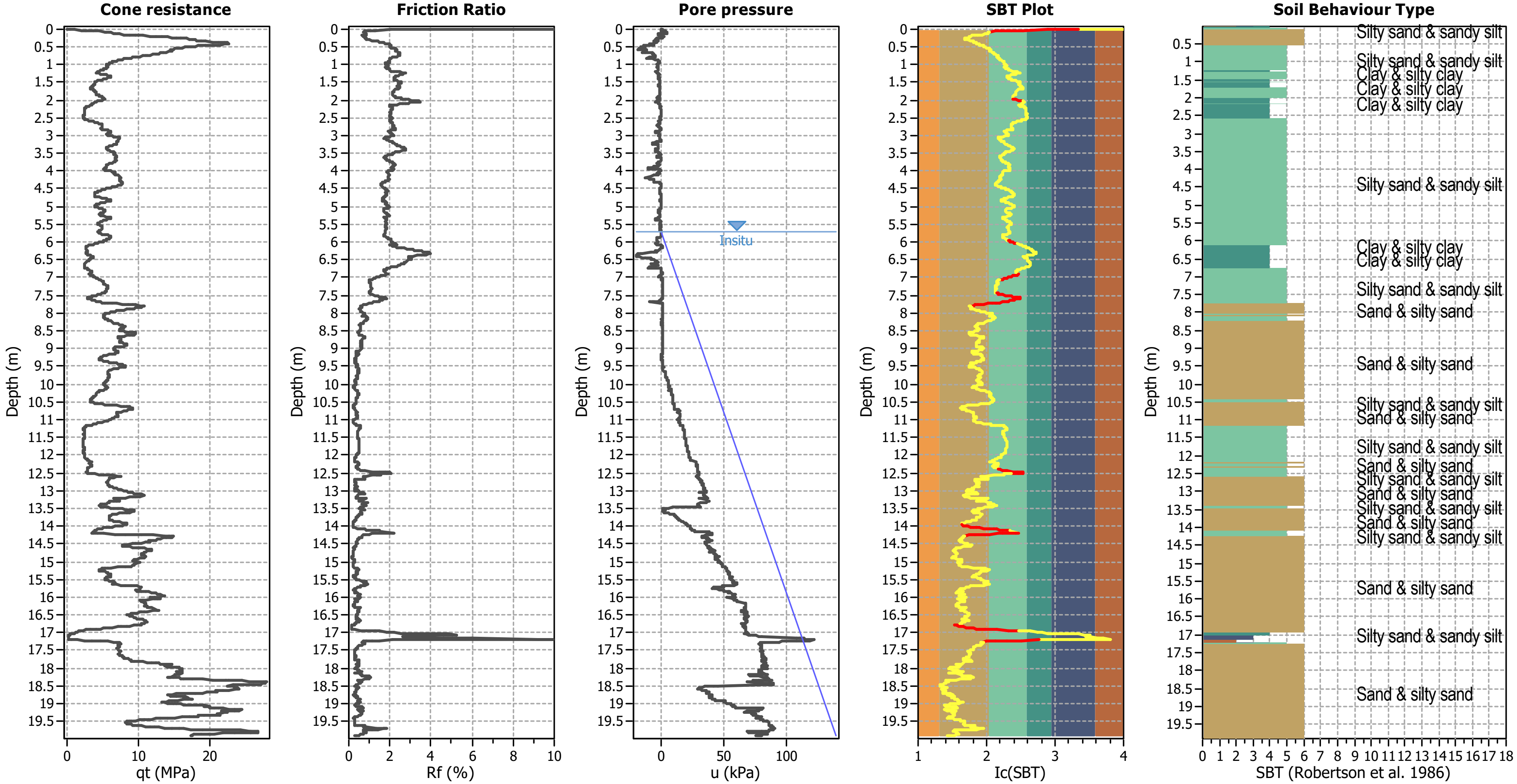






Zone A_1: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A_2: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and strength loss possible depending on soil plasticity, brittleness/sensitivity, strain to peak undrained strength and ground geometry

CPT basic interpretation plots



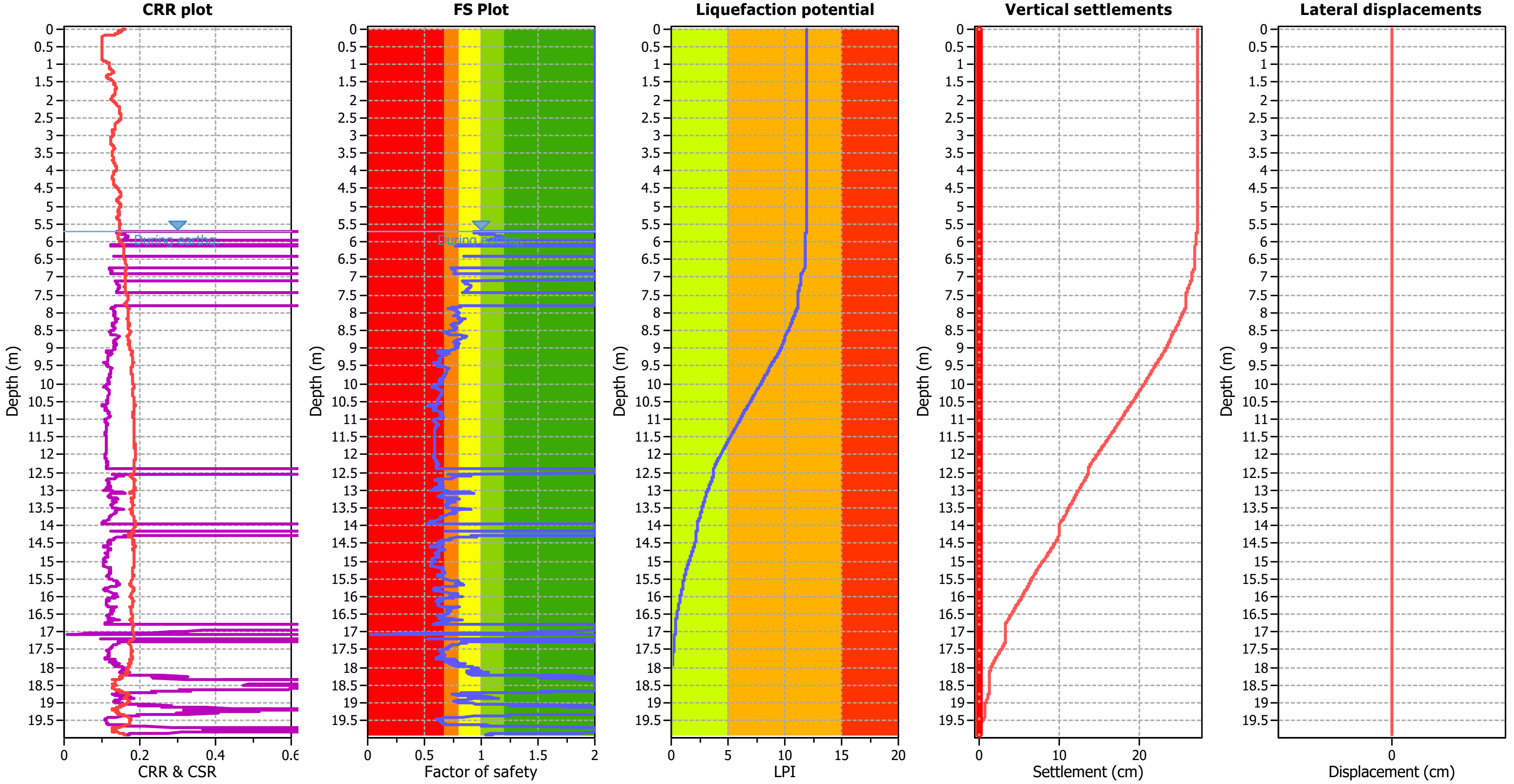
Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	5.70 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.29	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	5.70 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

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	5.70 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.29	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	5.70 m	Fill height:	N/A	Limit depth:	N/A

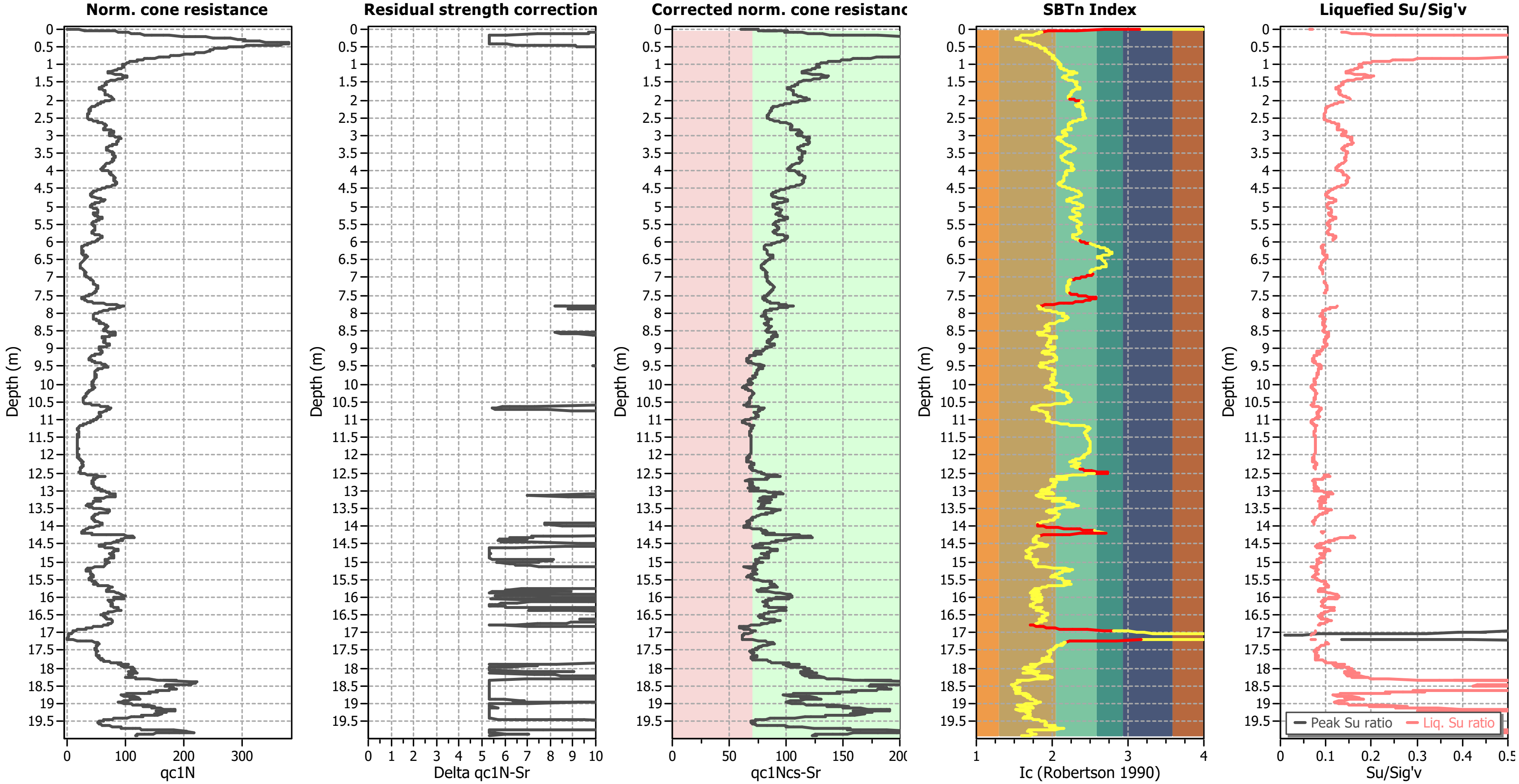
F.S. color scheme

- Almost certain it will liquefy
- Very likely to liquefy
- Liquefaction and no liq. are equally likely
- Unlike to liquefy
- Almost certain it will not liquefy

LPI color scheme

- Very high risk
- High risk
- Low risk

Check for strength loss plots (Idriss & Boulanger (2008))



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	5.70 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	Yes
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	6.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.29	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	5.70 m	Fill height:	N/A	Limit depth:	N/A

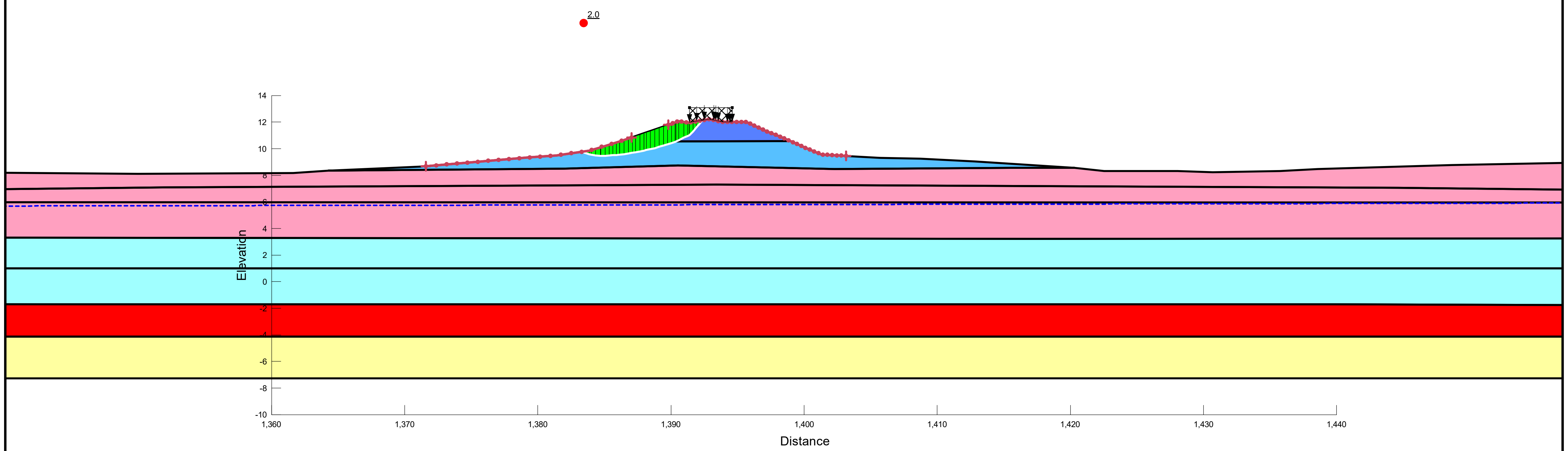
E

Appendix E – Slope Stability Assessment

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
(yellow)	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20	0	38	0
(blue)	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18	3	30	0
(light blue)	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17	0	28	0
(pink)	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17	0	30	0
(cyan)	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18	0	32	0
(red)	Stiff SILT	Mohr-Coulomb	18	2	28	0

Factor of Safety

- ≤ 1.0 - 1.1
- 1.1 - 1.2
- 1.2 - 1.3
- 1.3 - 1.4
- ≥ 1.4



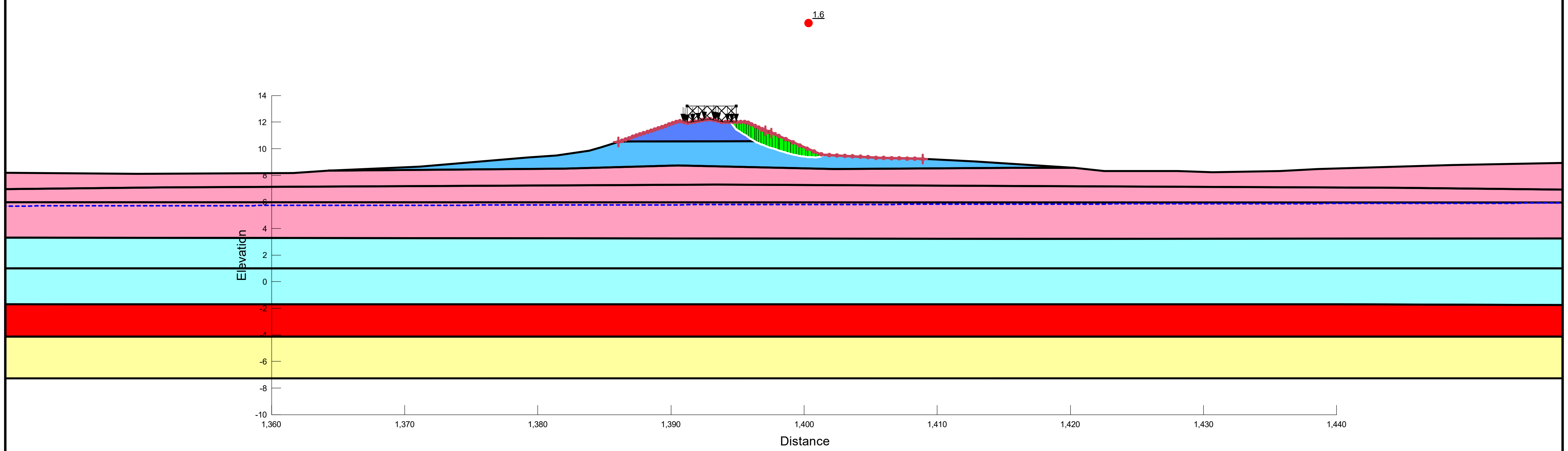
Surcharge (Unit Weight): 12 kN/m³

01 Static long term landside A-A'	
Outram_SEEP-W Model_Average Conditions.gsz	
16/08/2024	1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
(light yellow)	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20	0	38	0
(blue)	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18	3	30	0
(light blue)	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17	0	28	0
(pink)	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17	0	30	0
(cyan)	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18	0	32	0
(red)	Stiff SILT	Mohr-Coulomb	18	2	28	0

Factor of Safety

- ≤ 1.0 - 1.1
- 1.1 - 1.2
- 1.2 - 1.3
- 1.3 - 1.4
- ≥ 1.4



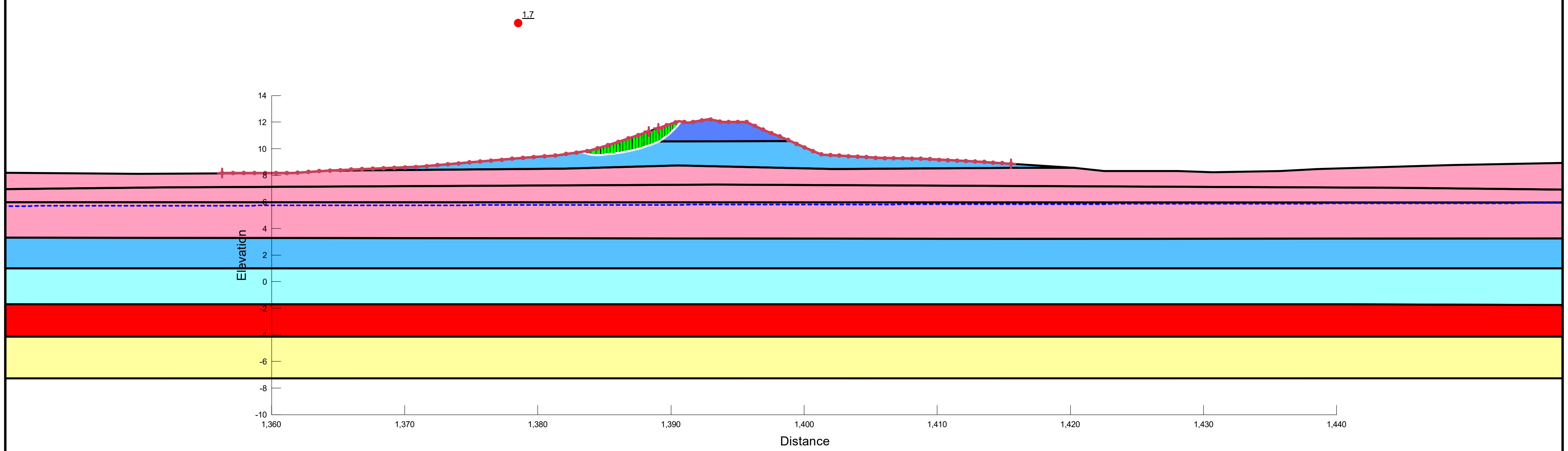
Surcharge (Unit Weight): 12 kN/m³

02 Static long term riverside A-A'	
Outram_SEEP-W Model_Average Conditions.gsz	
16/08/2024	1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
(pale yellow)	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20	0	38	0
(blue)	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18	3	30	0
(light blue)	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17	0	28	0
(pink)	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17	0	30	0
(cyan)	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18	0	32	0
(red)	Stiff SILT	Mohr-Coulomb	18	2	28	0

Factor of Safety

- ≤ 1.0 - 1.1
- 1.1 - 1.2
- 1.2 - 1.3
- 1.3 - 1.4
- ≥ 1.4

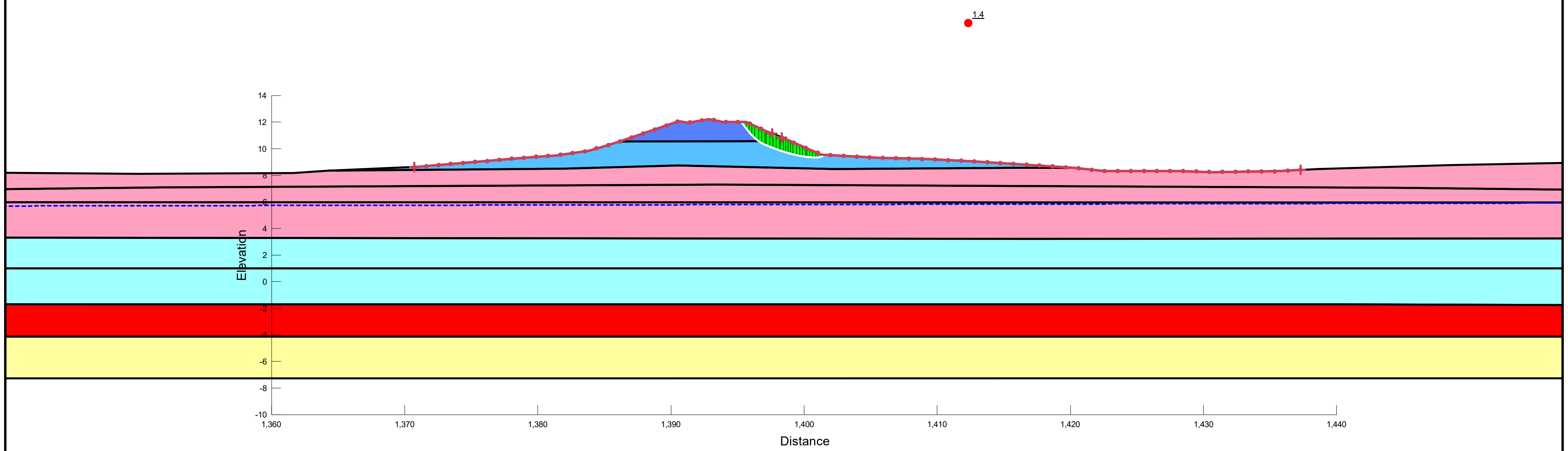


05 Seismic SLS landside A-A'	
Outram_SEEP-W Model_Average Conditions.gsz	
16/08/2024	1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
(pale yellow)	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20	0	38	0
(blue)	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18	3	30	0
(light blue)	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17	0	28	0
(pink)	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17	0	30	0
(cyan)	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18	0	32	0
(red)	Stiff SILT	Mohr-Coulomb	18	2	28	0

Factor of Safety

- ≤ 1.0 - 1.1
- 1.1 - 1.2
- 1.2 - 1.3
- 1.3 - 1.4
- ≥ 1.4



06 Seismic SLS riverside A-A'

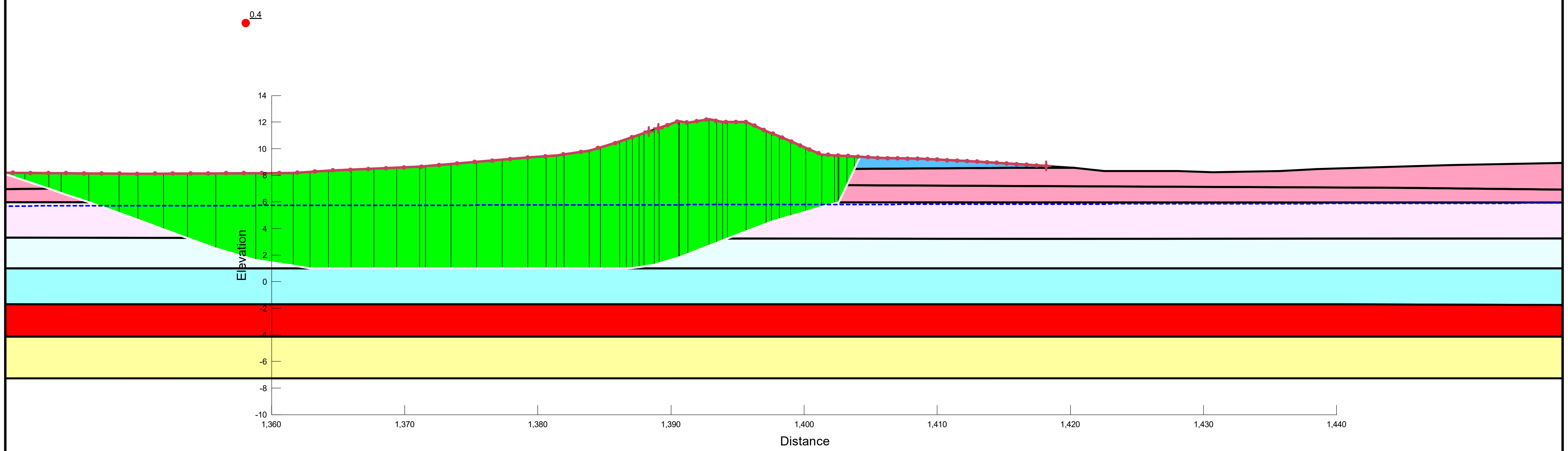
Outram_SEEP-W Model_Average Conditions.gsz

16/08/2024 1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Minimum Shear Strength (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20			0	38	0
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18			3	30	0
	Liqefiable sandy ILT	SHANSEP	17	0.09	0			
	Liquefiable medium-dense gravelly SAND	SHANSEP	18	0.09	0			
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17			0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17			0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18			0	32	0
	Stiff SILT	Mohr-Coulomb	18			2	28	0

Factor of Safety

- ≤ 1.0 - 1.1
- 1.1 - 1.2
- 1.2 - 1.3
- 1.3 - 1.4
- ≥ 1.4



07 Seismic ULS IL2 landside A-A'

Outram_SEEP-W Model_Average Conditions.gsz

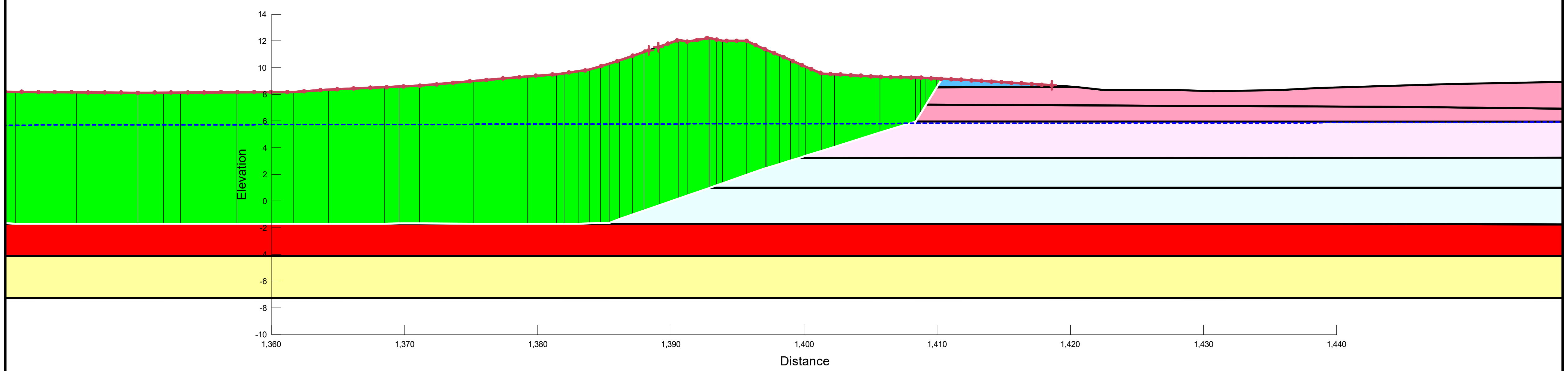
01/08/2024 1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Minimum Shear Strength (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20			0	38	0
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18			3	30	0
	Liqefiable sandy ILT	SHANSEP	17	0.09	0			
	Liquefiable medium-dense gravelly SAND	SHANSEP	18	0.09	0			
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17			0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17			0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18			0	32	0
	Stiff SILT	Mohr-Coulomb	18			2	28	0

08 Seismic ULS IL2 riverside A-A'	
Outram_SEEP-W Model_Average Conditions.gsz	
01/08/2024	1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Minimum Shear Strength (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20			0	38	0
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18			3	30	0
	Liqefiable sandy ILT	SHANSEP	17	0.09	0			
	Liquefiable medium-dense gravelly SAND	SHANSEP	18	0.09	0			
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17			0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17			0	30	0
	Stiff SILT	Mohr-Coulomb	18			2	28	0

actor of Safety
≤ 1.0 - 1.1
1.1 - 1.2
1.2 - 1.3
1.3 - 1.4
≥ 1.4



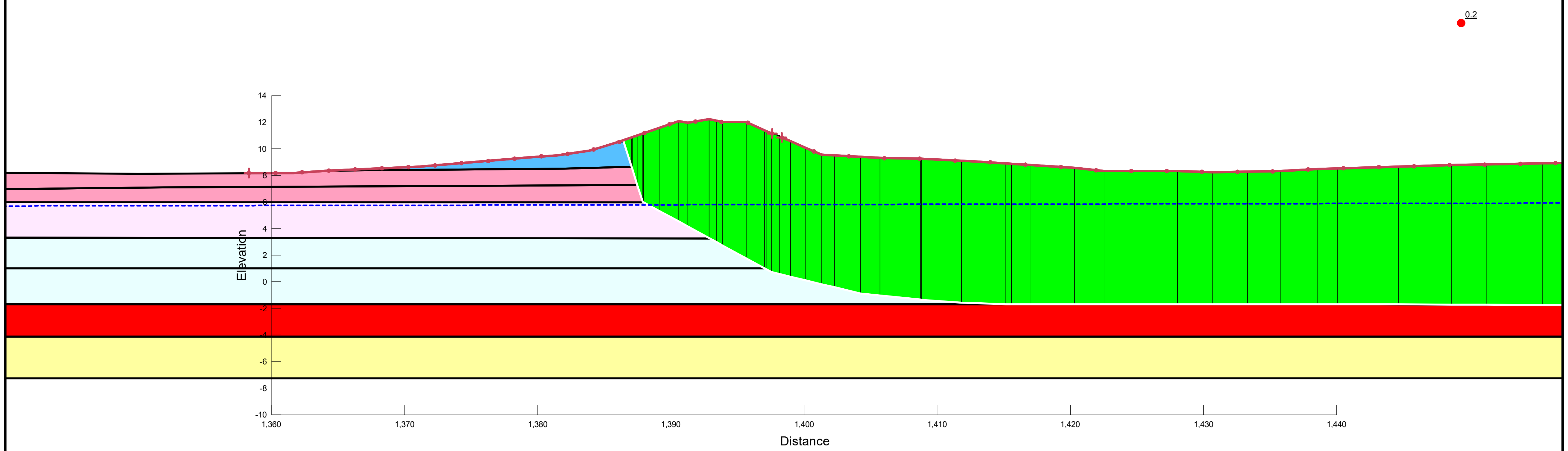
09 Seismic ULS IL3 landside A-A'

Outram_SEEP-W Model_Average Conditions.gsz

01/08/2024 1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Minimum Shear Strength (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20			0	38	0
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18			3	30	0
	Liqefiable sandy ILT	SHANSEP	17	0.09	0			
	Liquefiable medium-dense gravelly SAND	SHANSEP	18	0.09	0			
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17			0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17			0	30	0
	Stiff SILT	Mohr-Coulomb	18			2	28	0

actor of Safety
≤ 1.0 - 1.1
1.1 - 1.2
1.2 - 1.3
1.3 - 1.4
≥ 1.4



10 Seismic ULS IL3 riverside A-A'	
Outram_SEEP-W Model_Average Conditions.gsz	
01/08/2024	1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Minimum Shear Strength (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20			0	38	0
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18			3	30	0
	Liqefiable sandy ILT	SHANSEP	17	0.09	0			
	Liquefiable medium-dense gravelly SAND	SHANSEP	18	0.09	0			
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17			0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17			0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18			0	32	0
	Stiff SILT	Mohr-Coulomb	18			2	28	0

Factor of Safety

- ≤ 1.0 - 1.1
- 1.1 - 1.2
- 1.2 - 1.3
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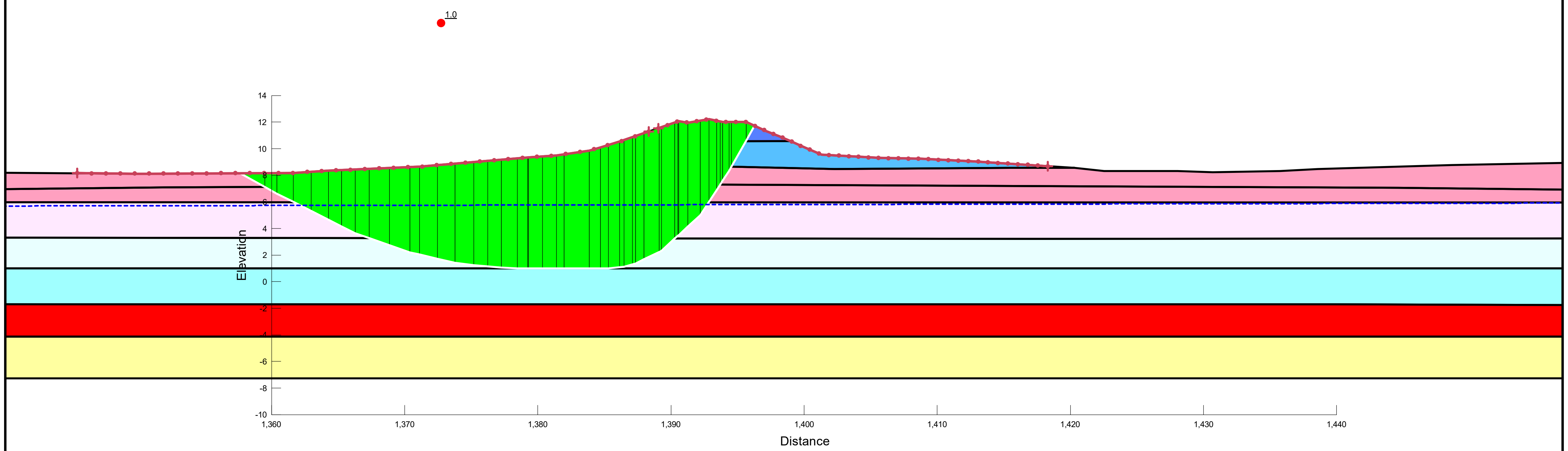
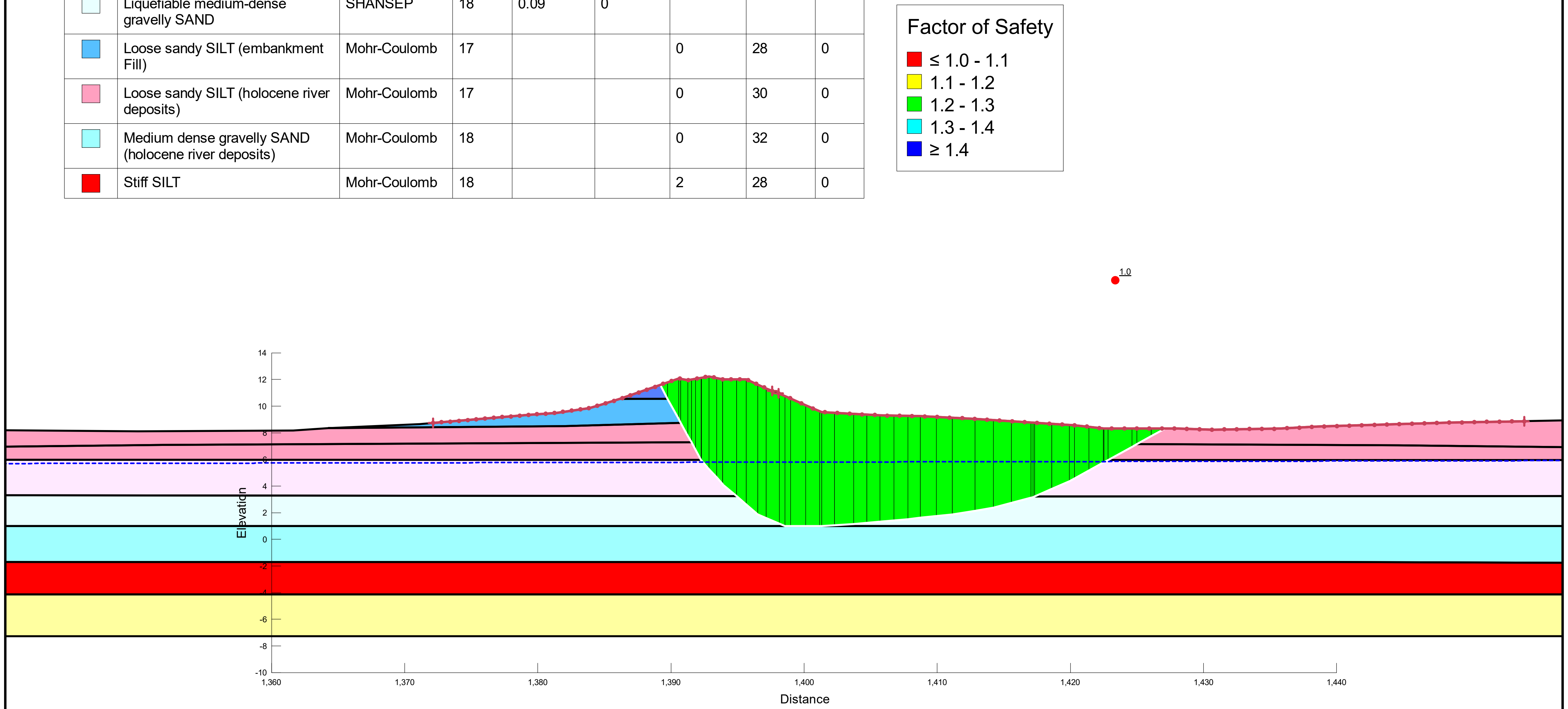


11 Seismic - Yield Acceleration - landside A-A'	
Outram_SEEP-W Model_Average Conditions.gsz	
01/08/2024	1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Minimum Shear Strength (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20			0	38	0
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18			3	30	0
	Liqefiable sandy ILT	SHANSEP	17	0.09	0			
	Liquefiable medium-dense gravelly SAND	SHANSEP	18	0.09	0			
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17			0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17			0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18			0	32	0
	Stiff SILT	Mohr-Coulomb	18			2	28	0

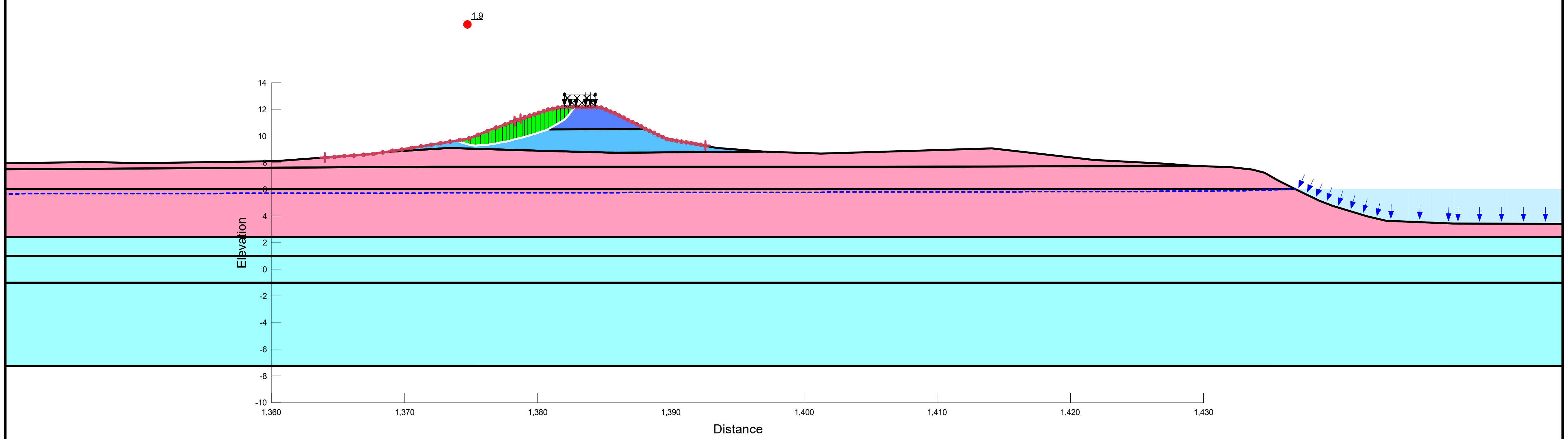


12 Seismic - Yield Acceleration - riverside A-A'	
Outram_SEEP-W Model_Average Conditions.gsz	
01/08/2024	1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
(blue)	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18	3	30	0
(light blue)	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17	0	28	0
(pink)	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17	0	30	0
(cyan)	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18	0	32	0

Factor of Safety

- ≤ 1.0 - 1.1
- 1.1 - 1.2
- 1.2 - 1.3
- 1.3 - 1.4
- ≥ 1.4



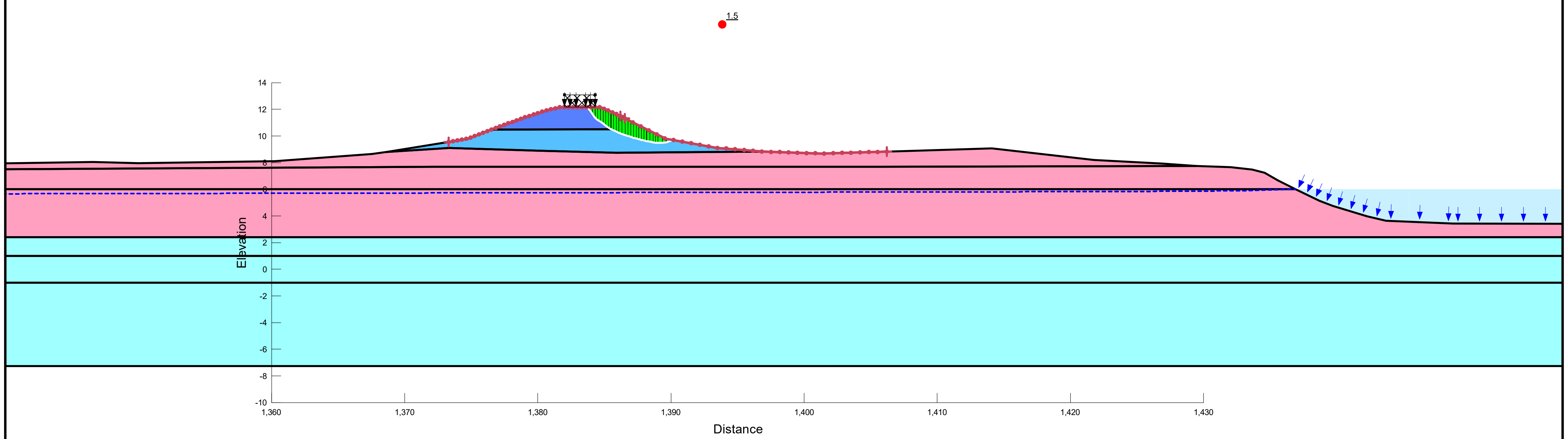
Surcharge (Unit Weight): 12 kN/m³

01 Static long term landside B'B'	
Outram_SEEP-W Model_Average Conditions.gsz	
16/08/2024	1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18	3	30	0
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17	0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17	0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18	0	32	0

Factor of Safety

- ≤ 1.0 - 1.1
- 1.1 - 1.2
- 1.2 - 1.3
- 1.3 - 1.4
- ≥ 1.4



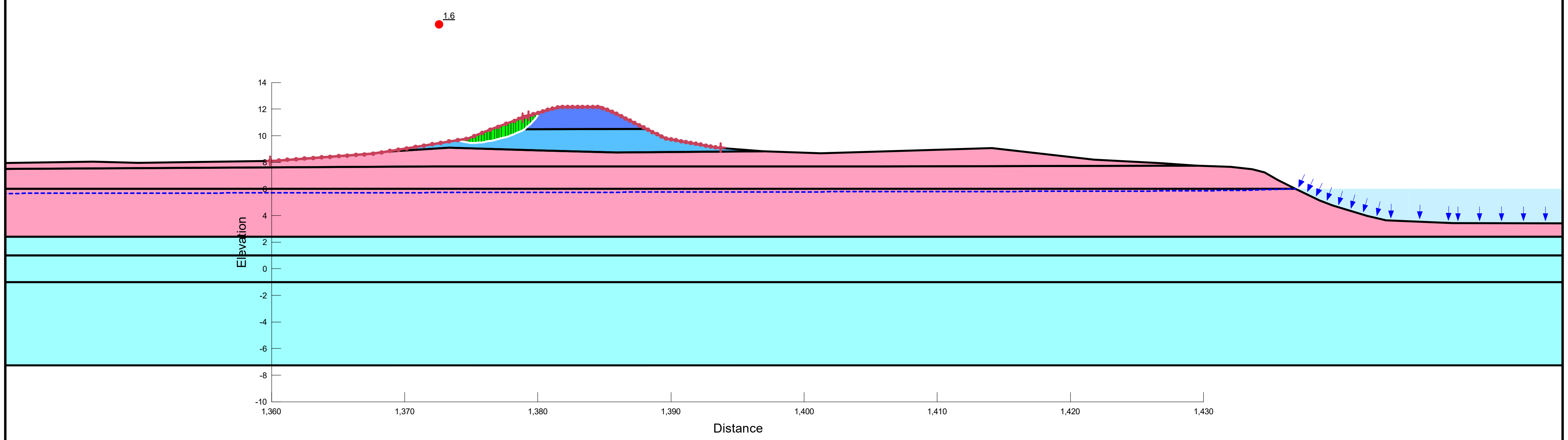
Surcharge (Unit Weight): 12 kN/m³

02 Static long term riverside B'B'	
Outram_SEEP-W Model_Average Conditions.gsz	
16/08/2024	1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18	3	30	0
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17	0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17	0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18	0	32	0

Factor of Safety

- ≤ 1.0 - 1.1
- 1.1 - 1.2
- 1.2 - 1.3
- 1.3 - 1.4
- ≥ 1.4

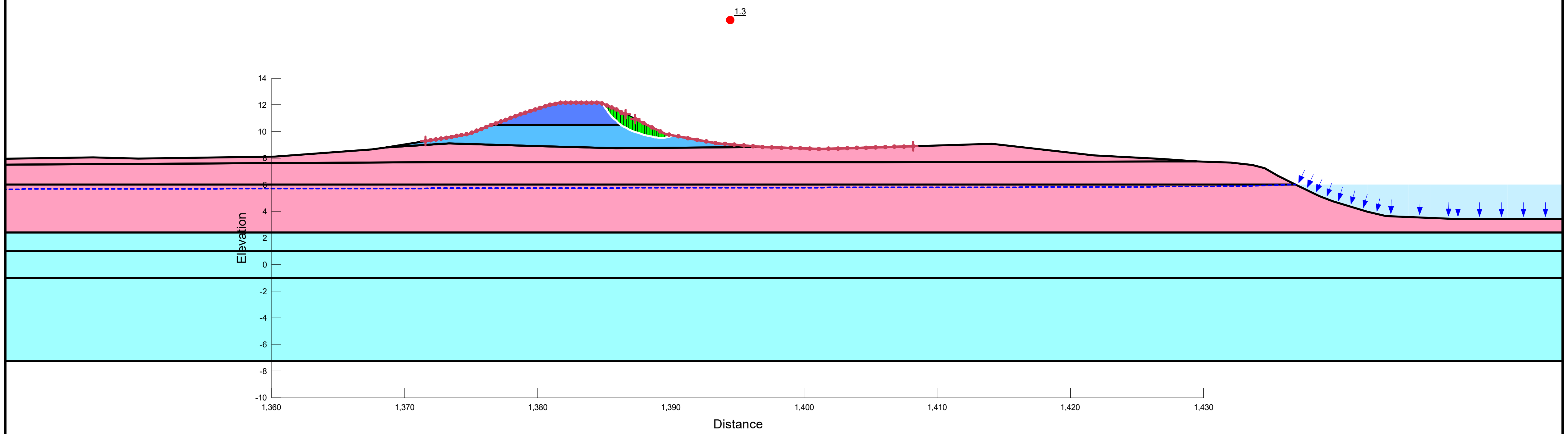


05 Seismic SLS landside B'B'	
Outram_SEEP-W Model_Average Conditions.gsz	
16/08/2024	1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18	3	30	0
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17	0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17	0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18	0	32	0

Factor of Safety

- ≤ 1.0 - 1.1
- 1.1 - 1.2
- 1.2 - 1.3
- 1.3 - 1.4
- ≥ 1.4



06 Seismic SLS riverside B'B'

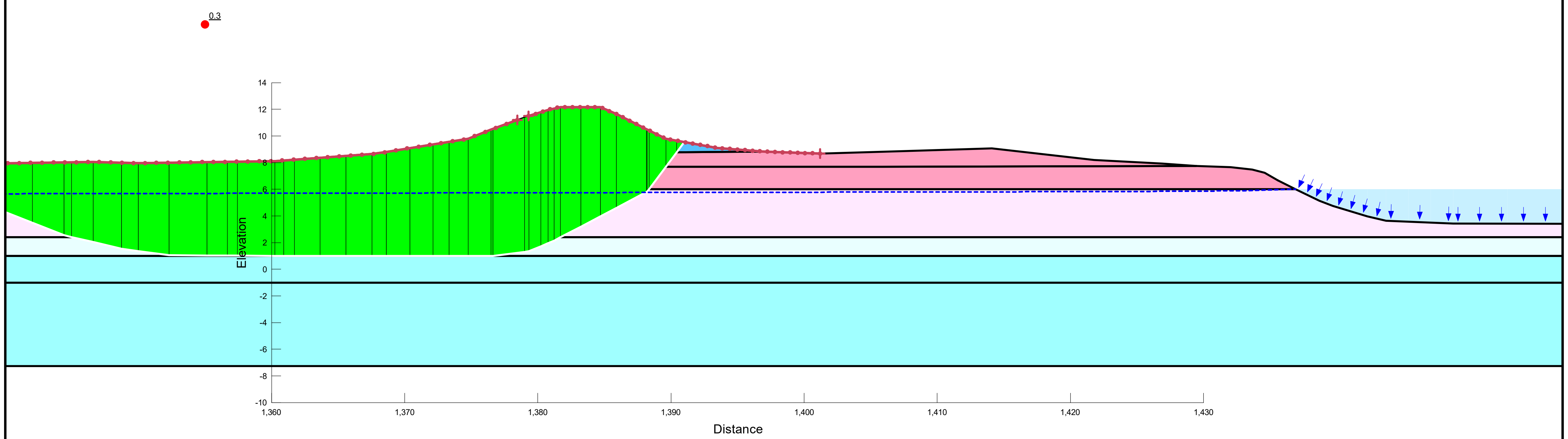
Outram_SEEP-W Model_Average Conditions.gsz

16/08/2024 1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Minimum Shear Strength (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18			3	30	0
	Liqefiable sandy ILT	SHANSEP	17	0.09	0			
	Liquefiable medium-dense gravelly SAND	SHANSEP	18	0.09	0			
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17			0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17			0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18			0	32	0

Factor of Safety

- ≤ 1.0 - 1.1
- 1.1 - 1.2
- 1.2 - 1.3
- 1.3 - 1.4
- ≥ 1.4

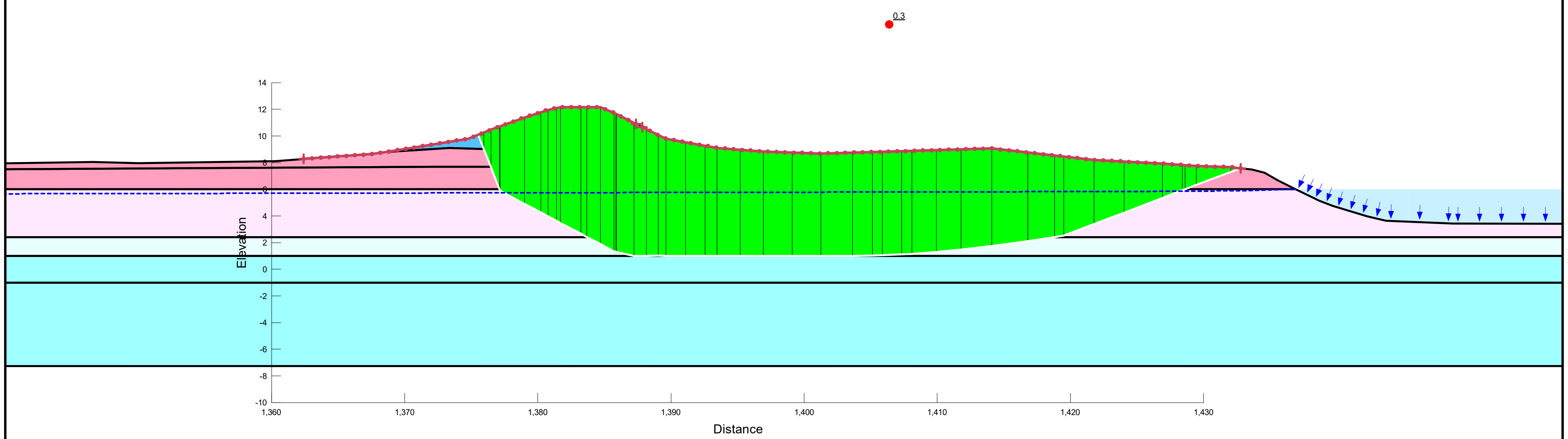


07 Seismic ULS IL2 landside B'B'
Outram_SEEP-W Model_Average Conditions.gsz
01/08/2024 1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Minimum Shear Strength (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18			3	30	0
	Liqefiable sandy ILT	SHANSEP	17	0.09	0			
	Liquefiable medium-dense gravelly SAND	SHANSEP	18	0.09	0			
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17			0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17			0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18			0	32	0

Factor of Safety

- ≤ 1.0 - 1.1
- 1.1 - 1.2
- 1.2 - 1.3
- 1.3 - 1.4
- ≥ 1.4

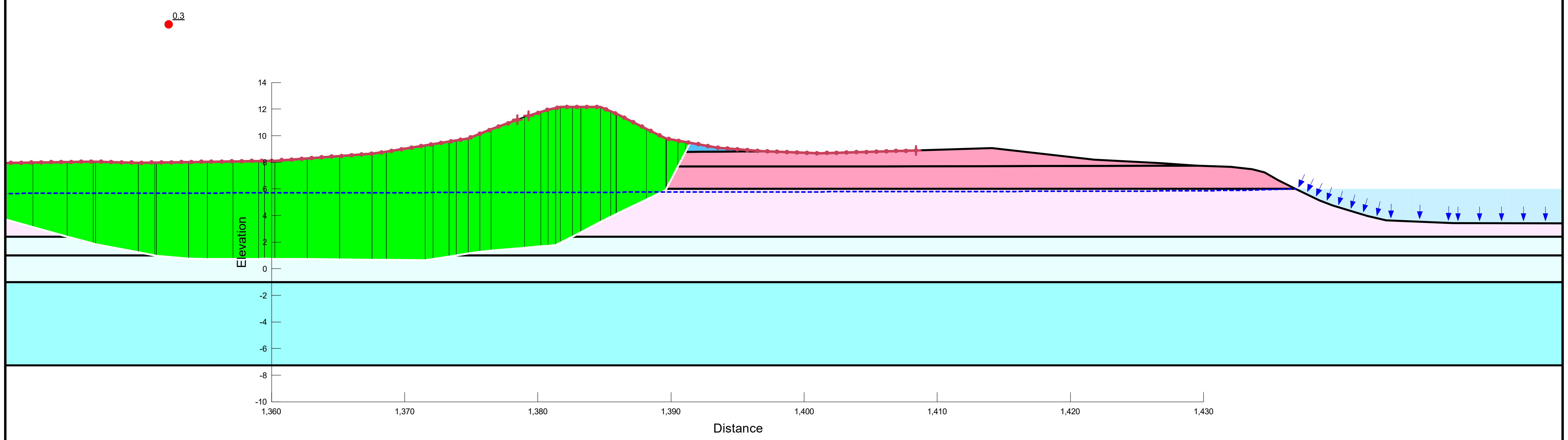


08 Seismic ULS IL2 riverside B'B'
Outram_SEEP-W Model_Average Conditions.gsz
01/08/2024 1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Minimum Shear Strength (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18			3	30	0
	Liqefiable sandy ILT	SHANSEP	17	0.09	0			
	Liquefiable medium-dense gravelly SAND	SHANSEP	18	0.09	0			
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17			0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17			0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18			0	32	0

Factor of Safety

- ≤ 1.0 - 1.1
- 1.1 - 1.2
- 1.2 - 1.3
- 1.3 - 1.4
- ≥ 1.4

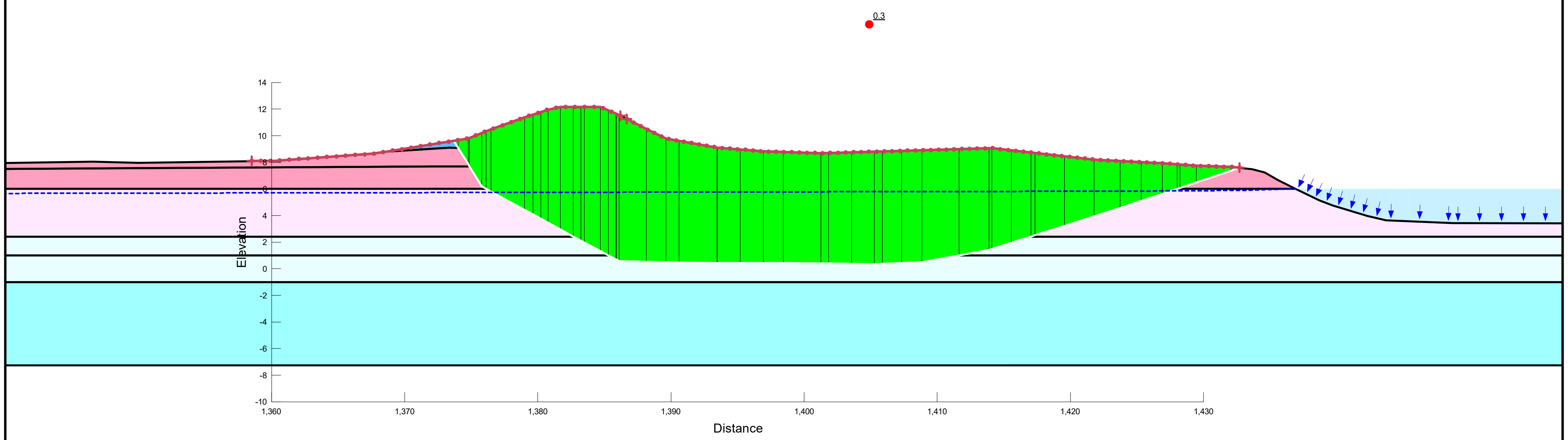


09 Seismic ULS IL3 landside B'B'	
Outram_SEEP-W Model_Average Conditions.gsz	
01/08/2024	1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Minimum Shear Strength (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18			3	30	0
	Liqefiable sandy ILT	SHANSEP	17	0.09	0			
	Liquefiable medium-dense gravelly SAND	SHANSEP	18	0.09	0			
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17			0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17			0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18			0	32	0

Factor of Safety

- ≤ 1.0 - 1.1
- 1.1 - 1.2
- 1.2 - 1.3
- 1.3 - 1.4
- ≥ 1.4



10 Seismic ULS IL3 riverside B'B'

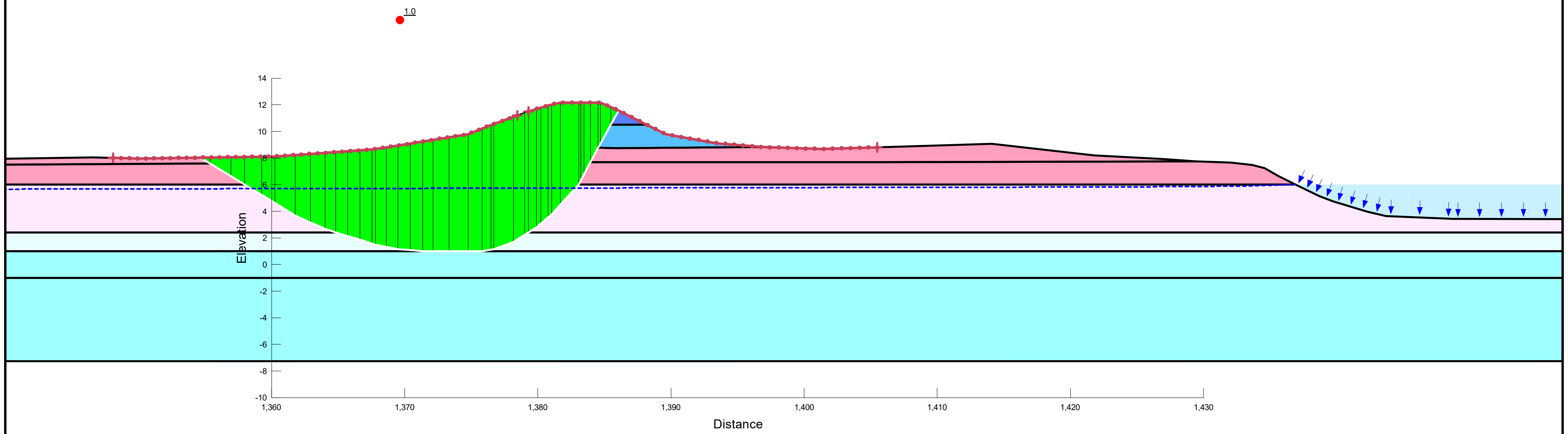
Outram_SEEP-W Model_Average Conditions.gsz

01/08/2024 1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Minimum Shear Strength (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18			3	30	0
	Liqefiable sandy ILT	SHANSEP	17	0.09	0			
	Liquefiable medium-dense gravelly SAND	SHANSEP	18	0.09	0			
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17			0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17			0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18			0	32	0

Factor of Safety

- ≤ 1.0 - 1.1
- 1.1 - 1.2
- 1.2 - 1.3
- 1.3 - 1.4
- ≥ 1.4

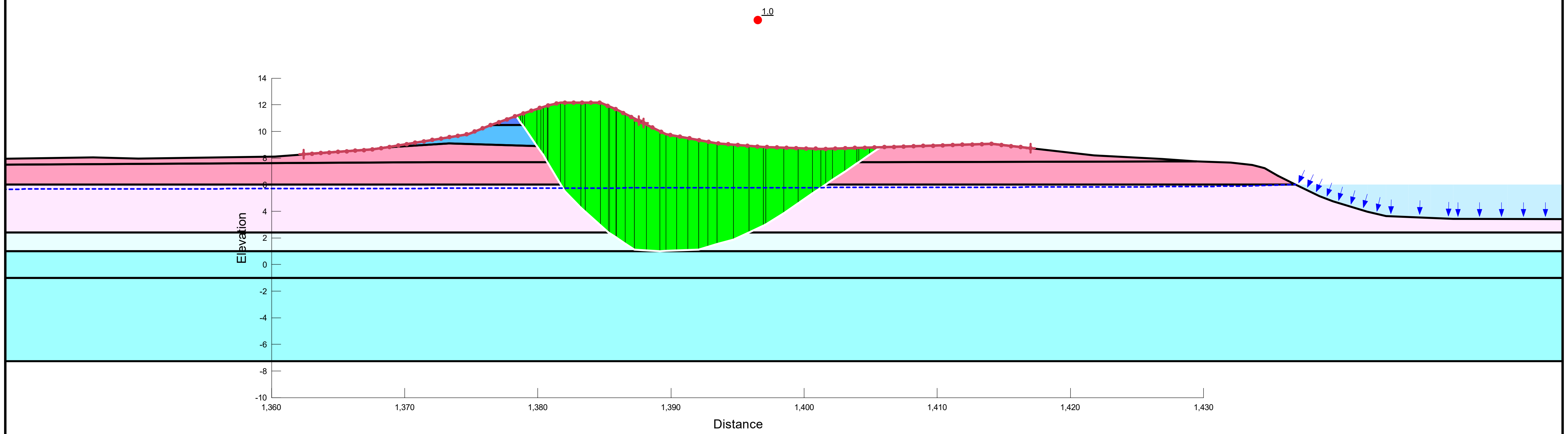


11 Seismic - Yield Acceleration landside B'B'	
Outram_SEEP-W Model_Average Conditions.gsz	
01/08/2024	1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Minimum Shear Strength (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18			3	30	0
	Liqefiable sandy ILT	SHANSEP	17	0.09	0			
	Liquefiable medium-dense gravelly SAND	SHANSEP	18	0.09	0			
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17			0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17			0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18			0	32	0

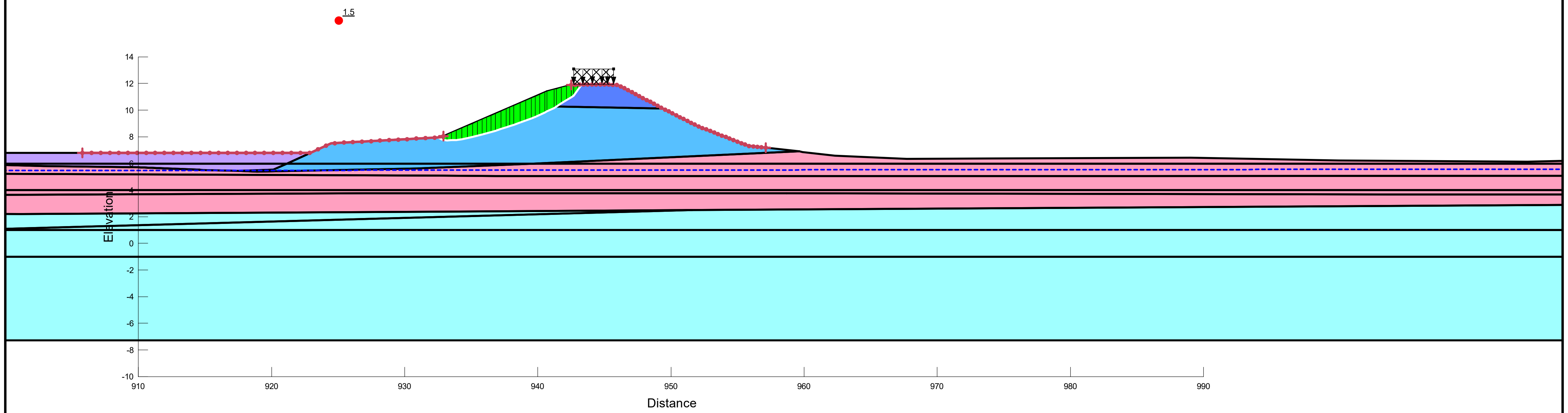
Factor of Safety

- ≤ 1.0 - 1.1
- 1.1 - 1.2
- 1.2 - 1.3
- 1.3 - 1.4
- ≥ 1.4



12 Seismic - Yield Acceleration - riverside B'B'	
Outram_SEEP-W Model_Average Conditions.gsz	
01/08/2024	1:300

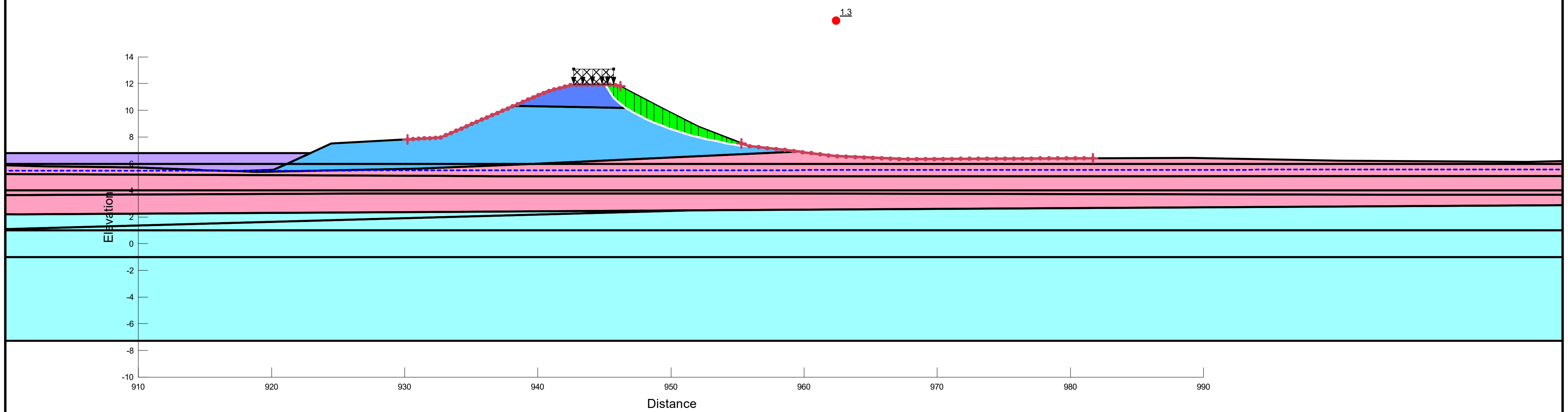
Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20	0	38	0
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18	3	30	0
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17	0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17	0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18	0	32	0
	Stiff SILT	Mohr-Coulomb	18	2	28	0
	Weighted Blanket - Alluvial SILT	Mohr-Coulomb	17	1	28	0



Surcharge (Unit Weight): 12 kN/m³

01 Static long term landside C-C'	
Outram_SEEP-W Model_Average Conditions.gsz	
16/08/2024	1:300

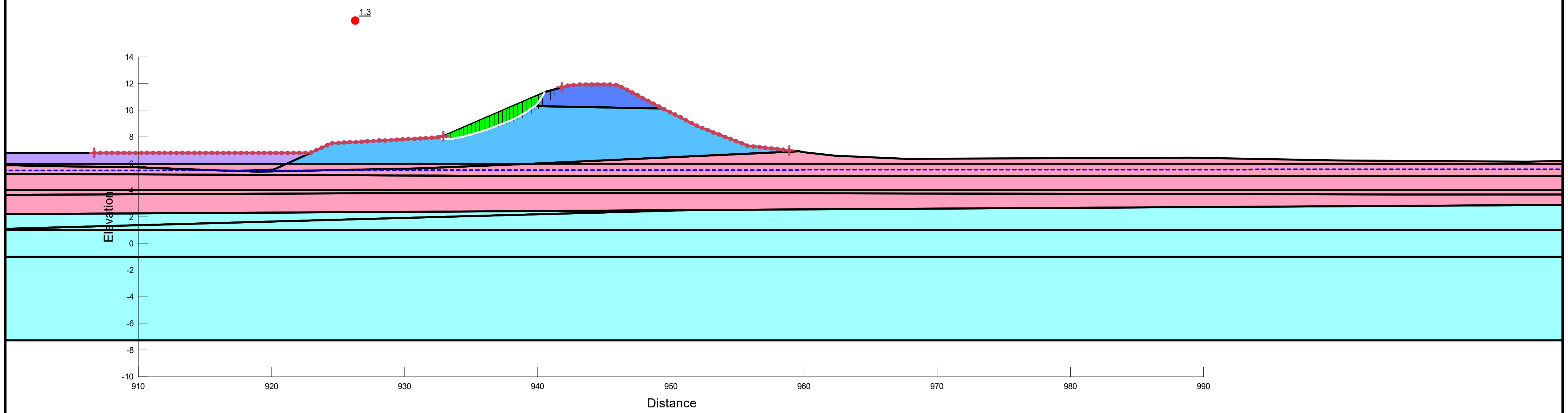
Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20	0	38	0
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18	3	30	0
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17	0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17	0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18	0	32	0
	Stiff SILT	Mohr-Coulomb	18	2	28	0
	Weighted Blanket - Alluvial SILT	Mohr-Coulomb	17	1	28	0



Surcharge (Unit Weight): 12 kN/m³

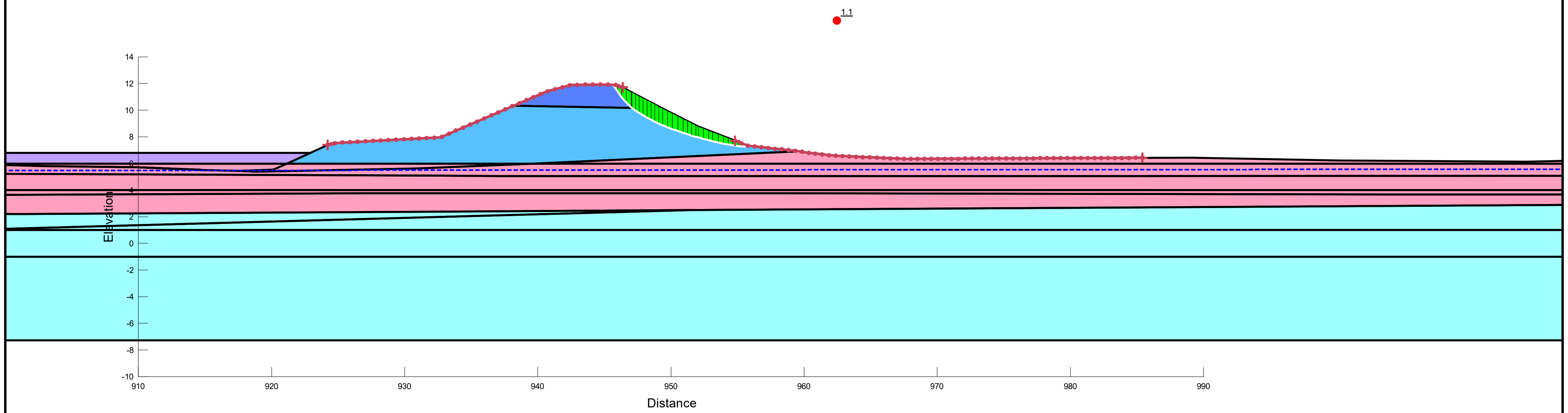
02 static long term riverside C-C'	
Outram_SEEP-W Model_Average Conditions.gsz	
16/08/2024	1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Minimum Shear Strength (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20			0	38	0
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18			3	30	0
	Liqefiable sandy ILT	SHANSEP	17	0.09	0			
	Liquefiable medium-dense gravelly SAND	SHANSEP	18	0.09	0			
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17			0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17			0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18			0	32	0
	Stiff SILT	Mohr-Coulomb	18			2	28	0
	Weighted Blanket - Alluvial SILT	Mohr-Coulomb	17			1	28	0



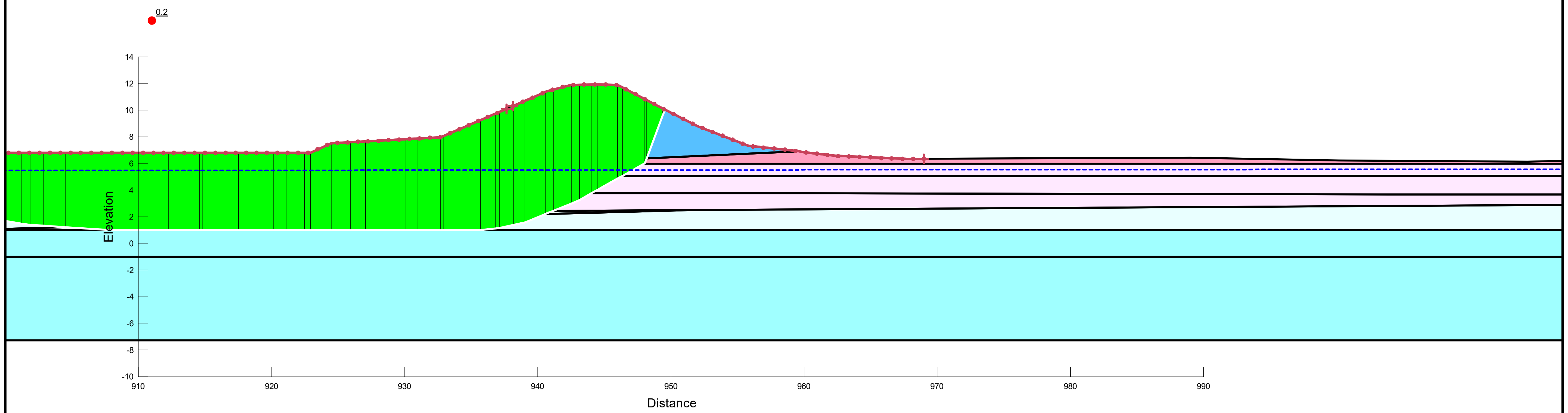
05 Seismic SLS landside C-C'	
Outram_SEEP-W Model_Average Conditions.gsz	
16/08/2024	1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Minimum Shear Strength (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20			0	38	0
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18			3	30	0
	Liqefiable sandy ILT	SHANSEP	17	0.09	0			
	Liquefiable medium-dense gravelly SAND	SHANSEP	18	0.09	0			
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17			0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17			0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18			0	32	0
	Stiff SILT	Mohr-Coulomb	18			2	28	0
	Weighted Blanket - Alluvial SILT	Mohr-Coulomb	17			1	28	0



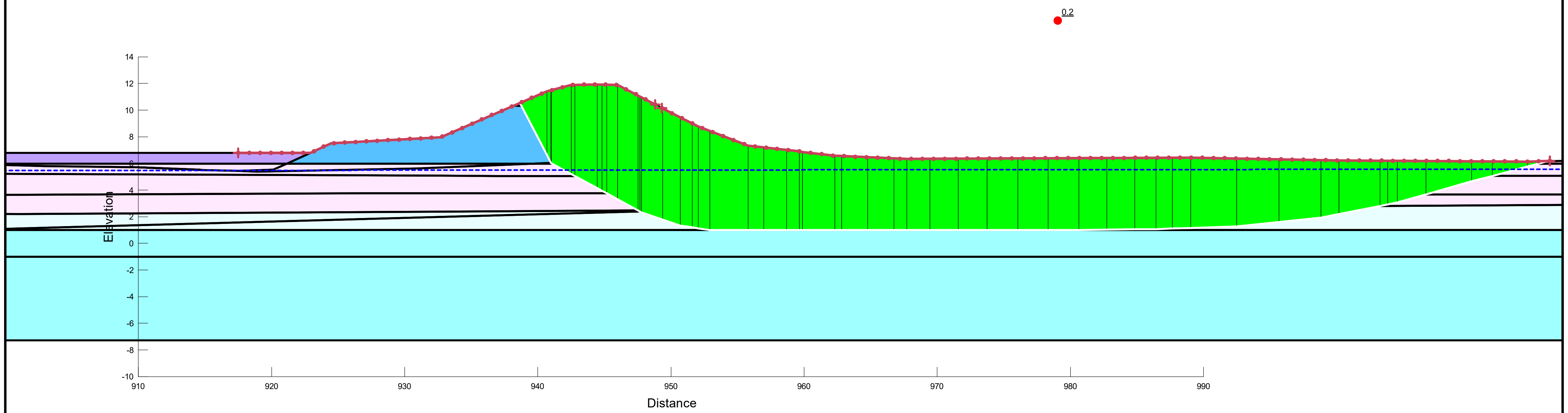
06 Seismic SLS riverside C-C'	
Outram_SEEP-W Model_Average Conditions.gsz	
16/08/2024	1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Minimum Shear Strength (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20			0	38	0
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18			3	30	0
	Liqefiable sandy ILT	SHANSEP	17	0.09	0			
	Liquefiable medium-dense gravelly SAND	SHANSEP	18	0.09	0			
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17			0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17			0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18			0	32	0
	Stiff SILT	Mohr-Coulomb	18			2	28	0
	Weighted Blanket - Alluvial SILT	Mohr-Coulomb	17			1	28	0



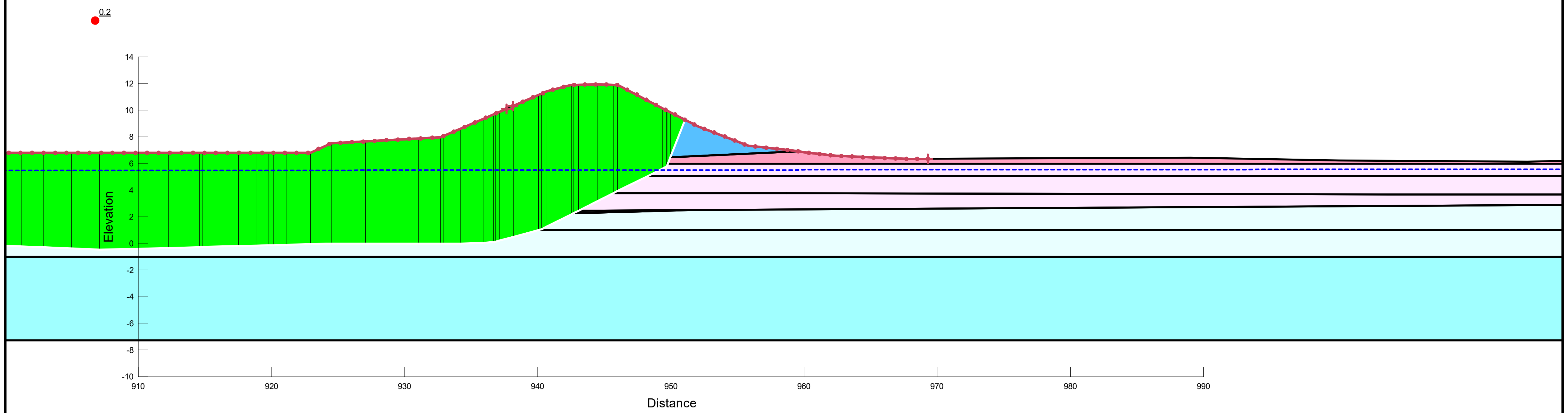
07 Seismic ULS IL2 landside C-C'	
Outram_SEEP-W Model_Average Conditions.gsz	
01/08/2024	1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Minimum Shear Strength (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20			0	38	0
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18			3	30	0
	Liqefiable sandy ILT	SHANSEP	17	0.09	0			
	Liquefiable medium-dense gravelly SAND	SHANSEP	18	0.09	0			
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17			0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17			0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18			0	32	0
	Stiff SILT	Mohr-Coulomb	18			2	28	0
	Weighted Blanket - Alluvial SILT	Mohr-Coulomb	17			1	28	0



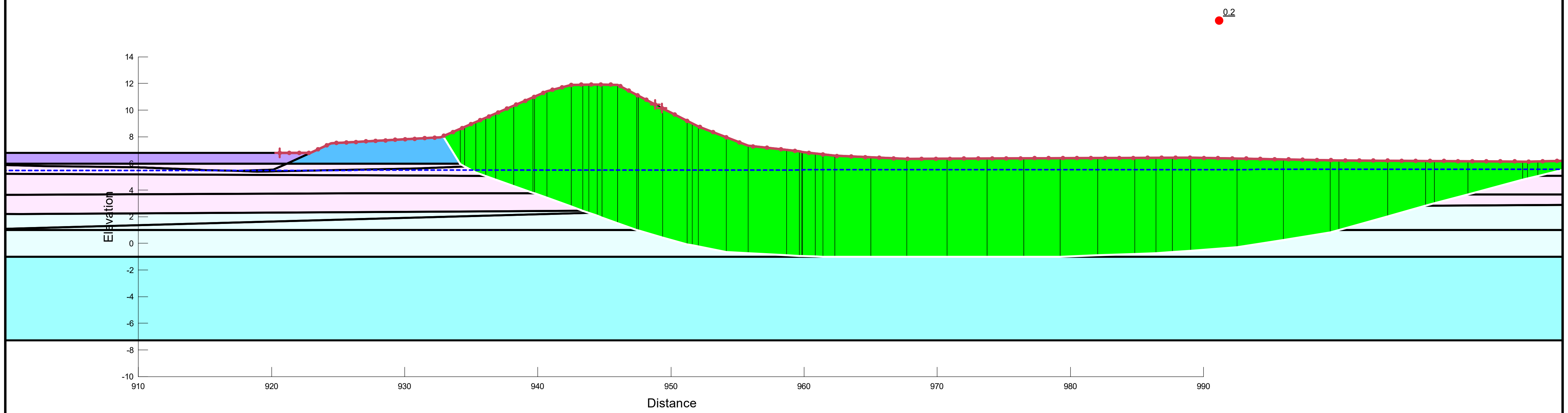
08 Seismic ULS IL2 riverside C-C'
Outram_SEEP-W Model_Average Conditions.gsz
01/08/2024 1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Minimum Shear Strength (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20			0	38	0
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18			3	30	0
	Liqefiable sandy ILT	SHANSEP	17	0.09	0			
	Liquefiable medium-dense gravelly SAND	SHANSEP	18	0.09	0			
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17			0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17			0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18			0	32	0
	Stiff SILT	Mohr-Coulomb	18			2	28	0
	Weighted Blanket - Alluvial SILT	Mohr-Coulomb	17			1	28	0



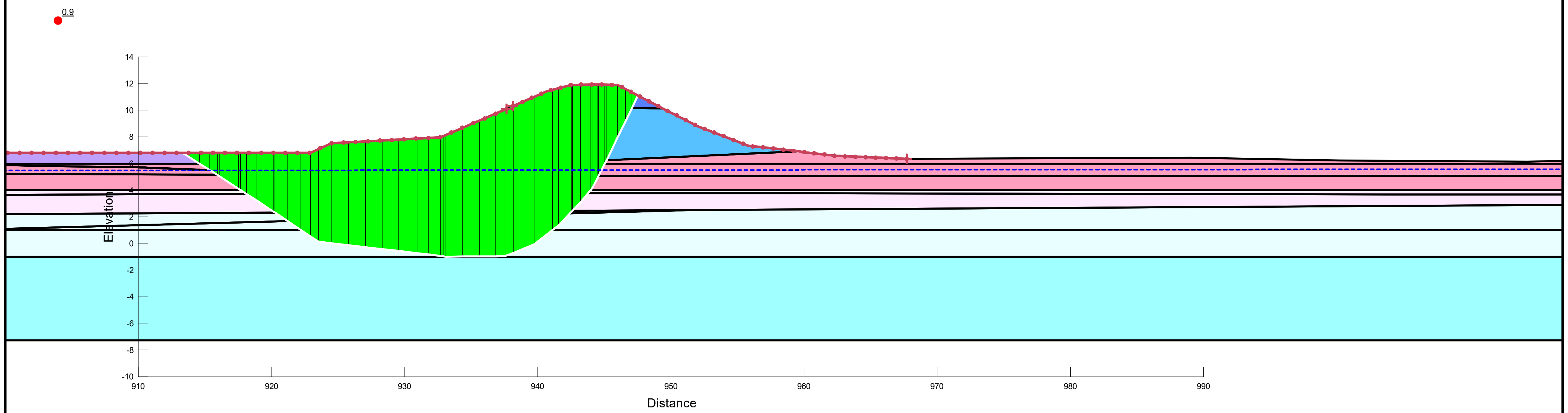
09 Seismic ULS IL3 landside C-C'	
Outram_SEEP-W Model_Average Conditions.gsz	
01/08/2024	1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Minimum Shear Strength (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20			0	38	0
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18			3	30	0
	Liqefiable sandy ILT	SHANSEP	17	0.09	0			
	Liquefiable medium-dense gravelly SAND	SHANSEP	18	0.09	0			
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17			0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17			0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18			0	32	0
	Stiff SILT	Mohr-Coulomb	18			2	28	0
	Weighted Blanket - Alluvial SILT	Mohr-Coulomb	17			1	28	0



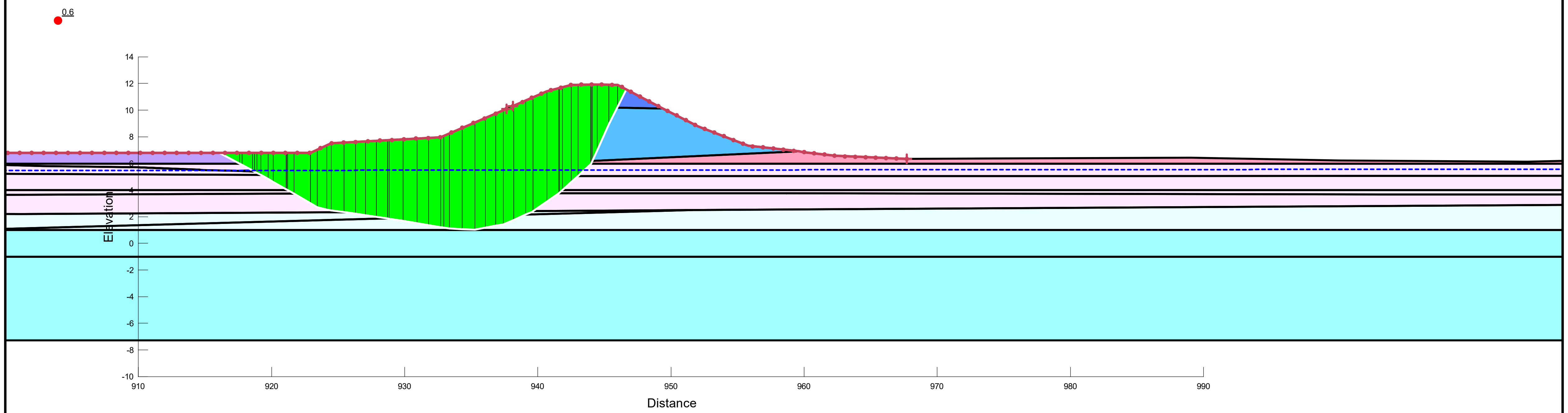
10 Seismic ULS IL3 riverside C-C'	
Outram_SEEP-W Model_Average Conditions.gsz	
01/08/2024	1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Minimum Shear Strength (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20			0	38	0
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18			3	30	0
	Liqefiable sandy ILT	SHANSEP	17	0.09	0			
	Liquefiable medium-dense gravelly SAND	SHANSEP	18	0.09	0			
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17			0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17			0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18			0	32	0
	Stiff SILT	Mohr-Coulomb	18			2	28	0
	Weighted Blanket - Alluvial SILT	Mohr-Coulomb	17			1	28	0



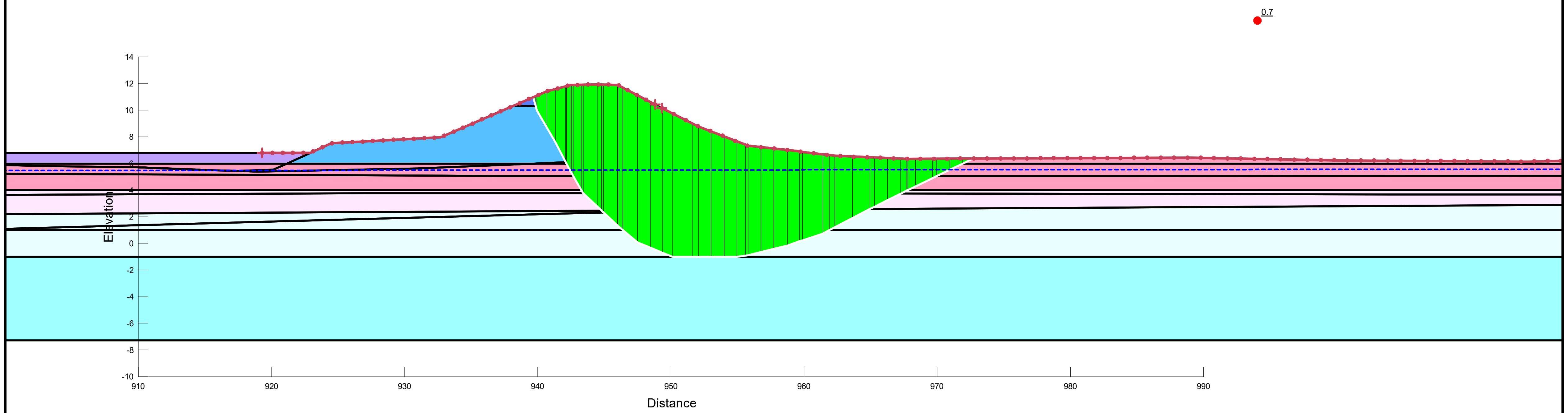
11 Seismic - Yield Acceleration landside 2m crust C-C'	
Outram_SEEP-W Model_Average Conditions.gsz	
01/08/2024	1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Minimum Shear Strength (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20			0	38	0
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18			3	30	0
	Liqefiable sandy ILT	SHANSEP	17	0.09	0			
	Liquefiable medium-dense gravelly SAND	SHANSEP	18	0.09	0			
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17			0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17			0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18			0	32	0
	Stiff SILT	Mohr-Coulomb	18			2	28	0
	Weighted Blanket - Alluvial SILT	Mohr-Coulomb	17			1	28	0



11 Seismic - Yield Acceleration landside C-C'	
Outram_SEEP-W Model_Average Conditions.gsz	
01/08/2024	1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Minimum Shear Strength (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20			0	38	0
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18			3	30	0
	Liqefiable sandy ILT	SHANSEP	17	0.09	0			
	Liquefiable medium-dense gravelly SAND	SHANSEP	18	0.09	0			
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17			0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17			0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18			0	32	0
	Stiff SILT	Mohr-Coulomb	18			2	28	0
	Weighted Blanket - Alluvial SILT	Mohr-Coulomb	17			1	28	0

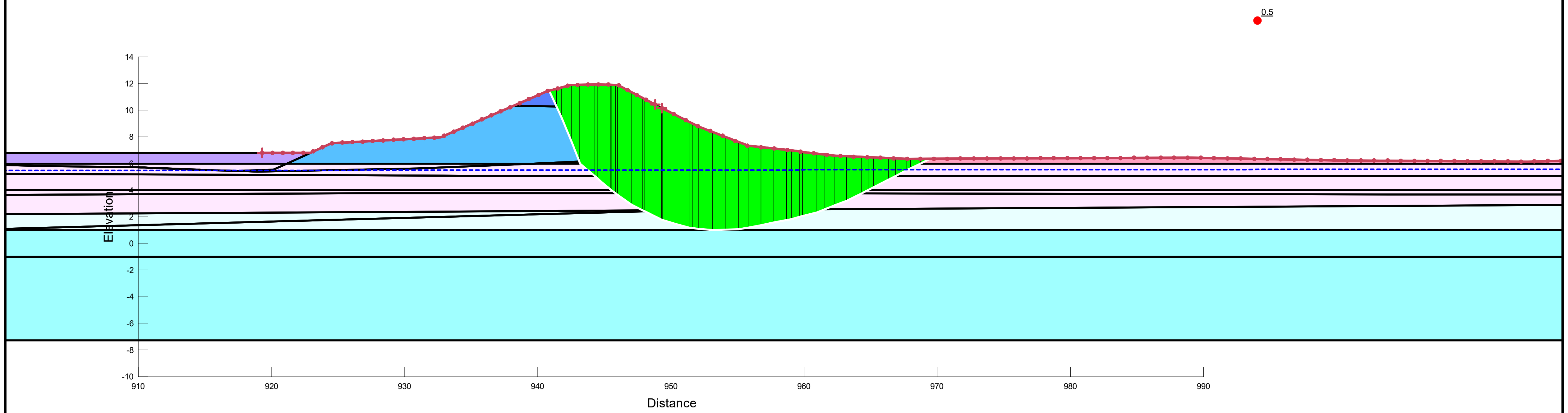


12 Seismic - Yield Acceleration riverside 2 m crust C-C'

Outram_SEEP-W Model_Average Conditions.gsz

01/08/2024 1:300

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Minimum Shear Strength (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL	Mohr-Coulomb	20			0	38	0
	Hard SILT, some clay (embankment fill)	Mohr-Coulomb	18			3	30	0
	Liqefiable sandy ILT	SHANSEP	17	0.09	0			
	Liquefiable medium-dense gravelly SAND	SHANSEP	18	0.09	0			
	Loose sandy SILT (embankment Fill)	Mohr-Coulomb	17			0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17			0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18			0	32	0
	Stiff SILT	Mohr-Coulomb	18			2	28	0
	Weighted Blanket - Alluvial SILT	Mohr-Coulomb	17			1	28	0



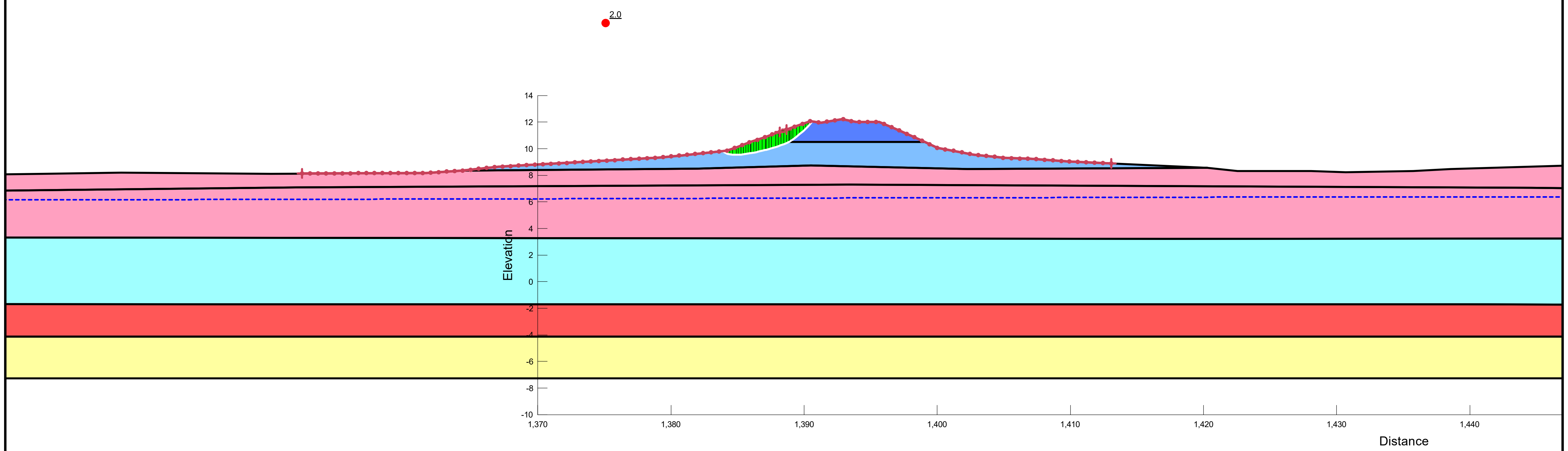
12 Seismic - Yield Acceleration riverside C-C'

Outram_SEEP-W Model_Average Conditions.gsz

01/08/2024 1:300

Elapsed Time: 1.5 d

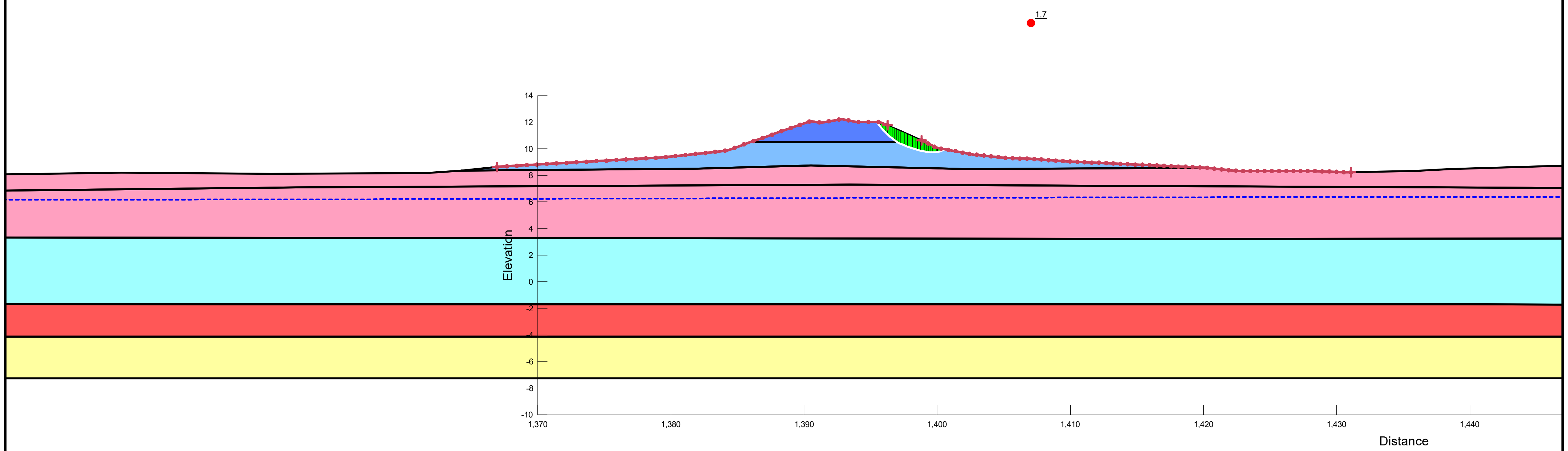
Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL (holocene river deposits)	Mohr-Coulomb	20	0	38	0
	hard SILT, some clay (embankment fill)	Mohr-Coulomb	18	3	30	0
	Loose sandy SILT (embankment fill)	Mohr-Coulomb	17	0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17	0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18	0	32	0
	Stiff SILT	Mohr-Coulomb	18	2	28	0



03 Rapid drawdown landside A-A'	
Outram_SEEP-W scenario rapid ddn_2hr.gsz	
08/08/2024	1:300

Elapsed Time: 1.5 d

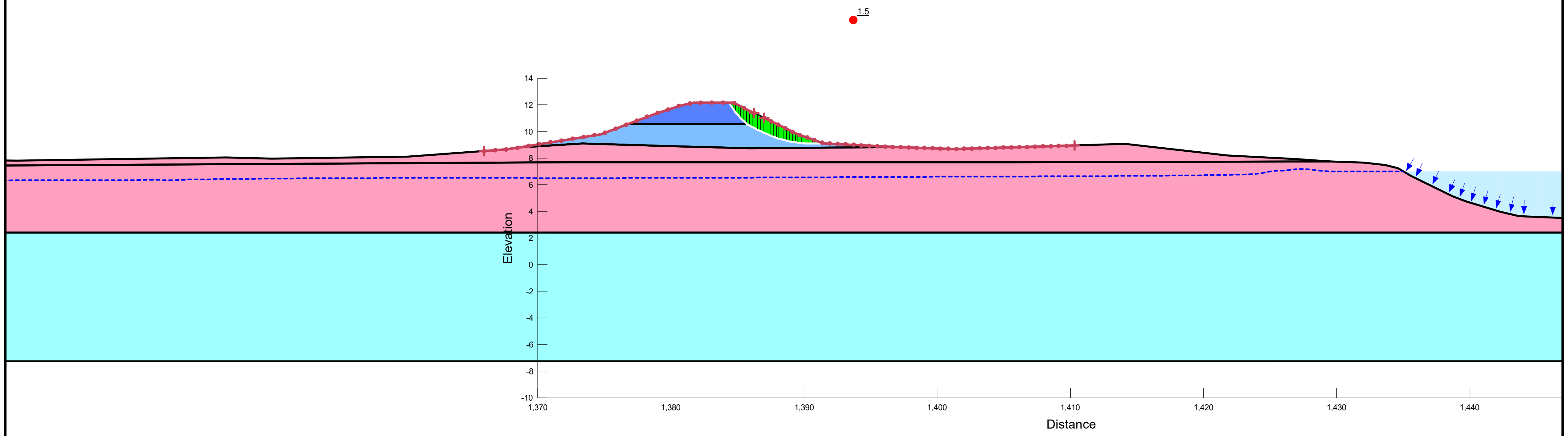
Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL (holocene river deposits)	Mohr-Coulomb	20	0	38	0
	hard SILT, some clay (embankment fill)	Mohr-Coulomb	18	3	30	0
	Loose sandy SILT (embankment fill)	Mohr-Coulomb	17	0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17	0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18	0	32	0
	Stiff SILT	Mohr-Coulomb	18	2	28	0



04 Rapid drawdown riverside A-A'	
Outram_SEEP-W scenario rapid ddn_2hr.gsz	
08/08/2024	1:300

Elapsed Time: 1.5 d

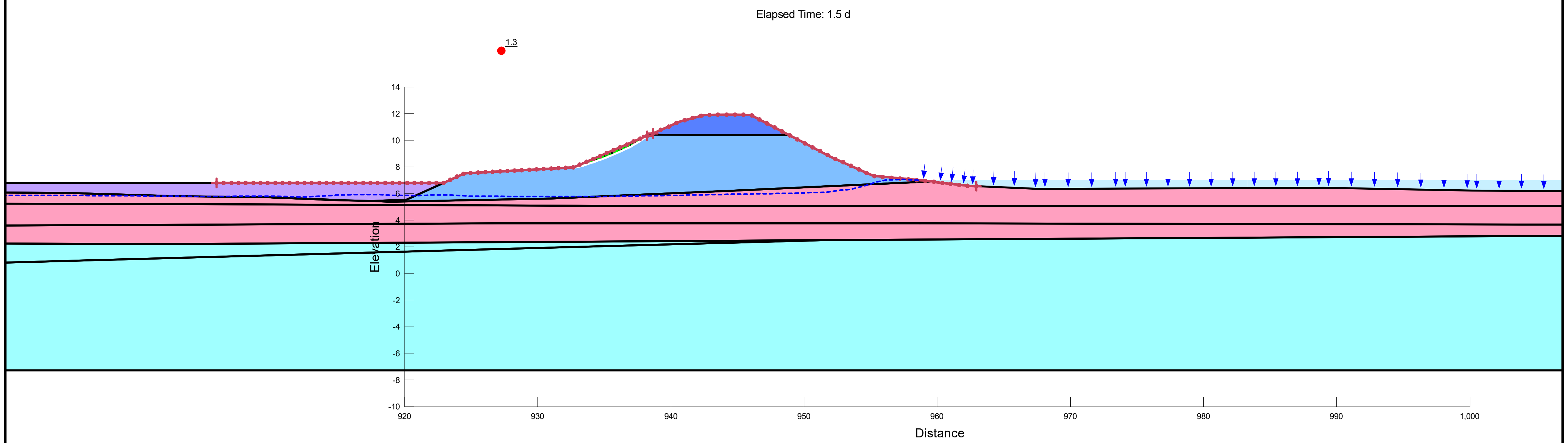
Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	hard SILT, some clay (embankment fill)	Mohr-Coulomb	18	3	30	0
	Loose sandy SILT (embankment fill)	Mohr-Coulomb	17	0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17	0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18	0	32	0



04 Rapid drawdown riverside B-B'	
Outram_SEEP-W scenario rapid ddn_2hr.gsz	
08/08/2024	1:300

Elapsed Time: 1.5 d

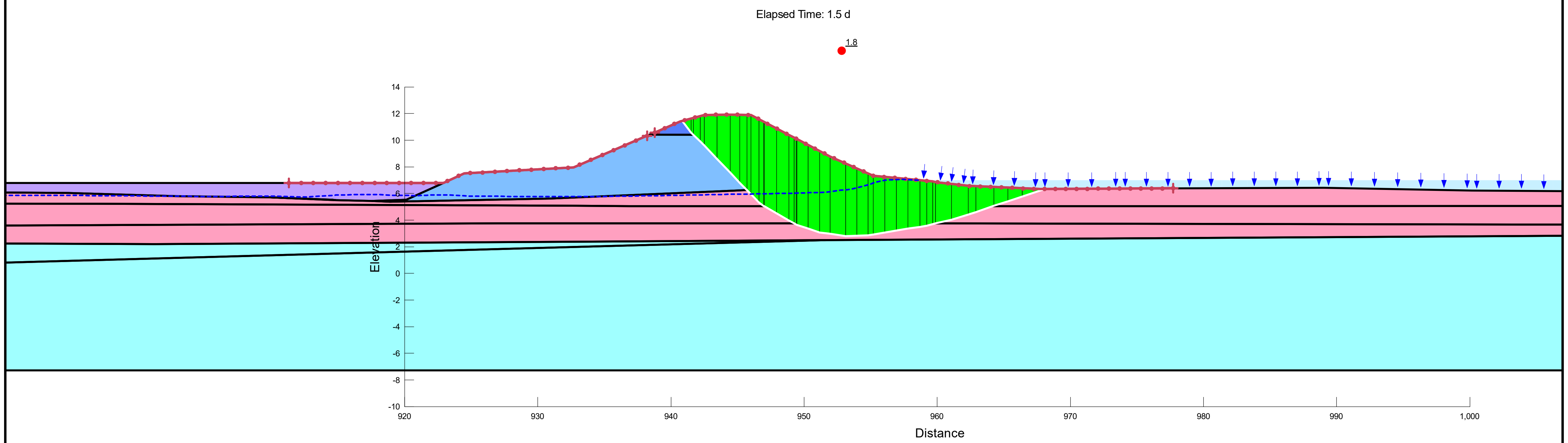
Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL (holocene river deposits)	Mohr-Coulomb	20	0	38	0
	hard SILT, some clay (embankment fill)	Mohr-Coulomb	18	3	30	0
	Loose sandy SILT (embankment fill)	Mohr-Coulomb	17	0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17	0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18	0	32	0
	Weighted Blanket - Alluvial SILT	Mohr-Coulomb	17	0	30	0



03 Rapid drawdown landside C-C'	
Outram_SEEP-W scenario rapid ddn_2hr.gsz	
08/08/2024	1:300

Elapsed Time: 1.5 d

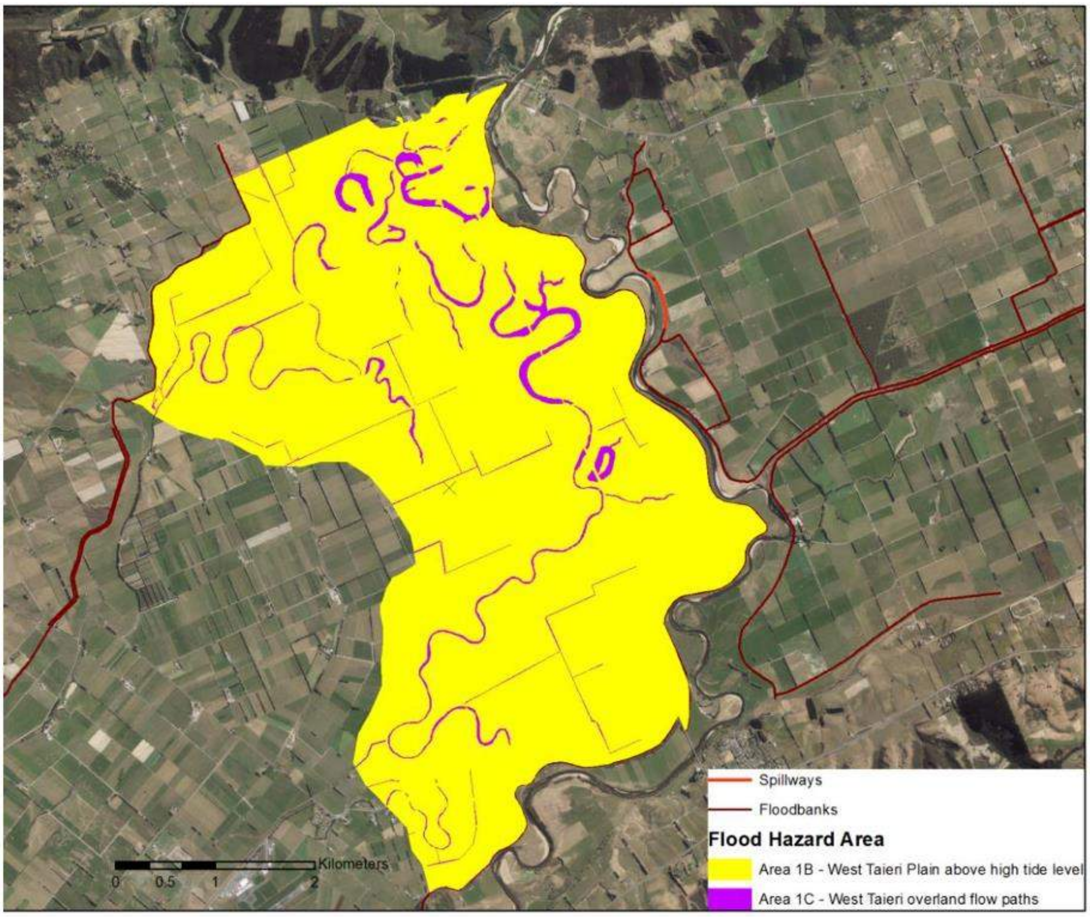
Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	Dense to very dense sandy GRAVEL (holocene river deposits)	Mohr-Coulomb	20	0	38	0
	hard SILT, some clay (embankment fill)	Mohr-Coulomb	18	3	30	0
	Loose sandy SILT (embankment fill)	Mohr-Coulomb	17	0	28	0
	Loose sandy SILT (holocene river deposits)	Mohr-Coulomb	17	0	30	0
	Medium dense gravelly SAND (holocene river deposits)	Mohr-Coulomb	18	0	32	0
	Weighted Blanket - Alluvial SILT	Mohr-Coulomb	17	0	30	0



04 Rapid drawdown riverside C-C'
Outram_SEEP-W scenario rapid ddn_2hr.gsz
08/08/2024 1:300

F

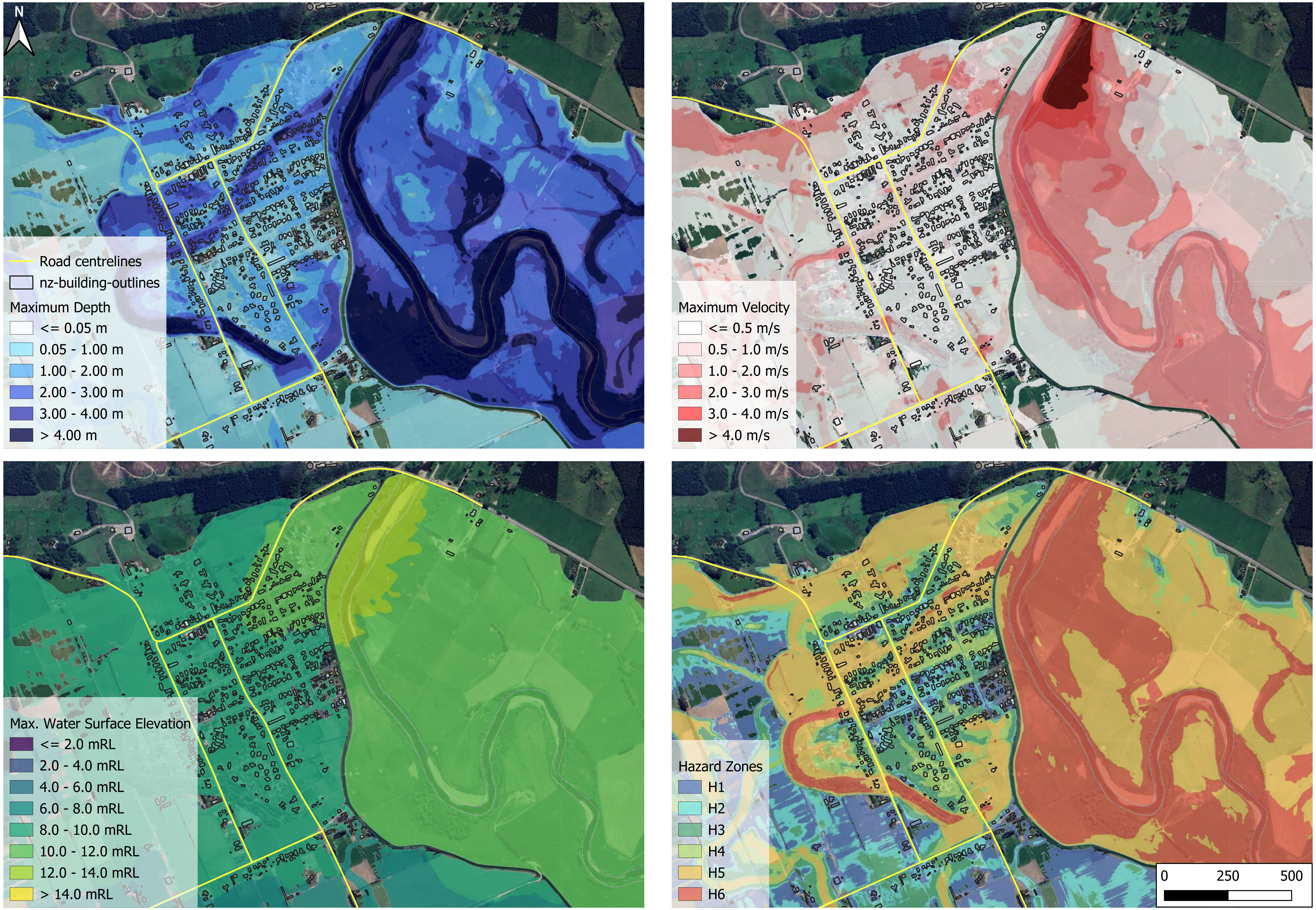
Appendix F – Paleochannels/ Overland Flow Paths in and below Outram



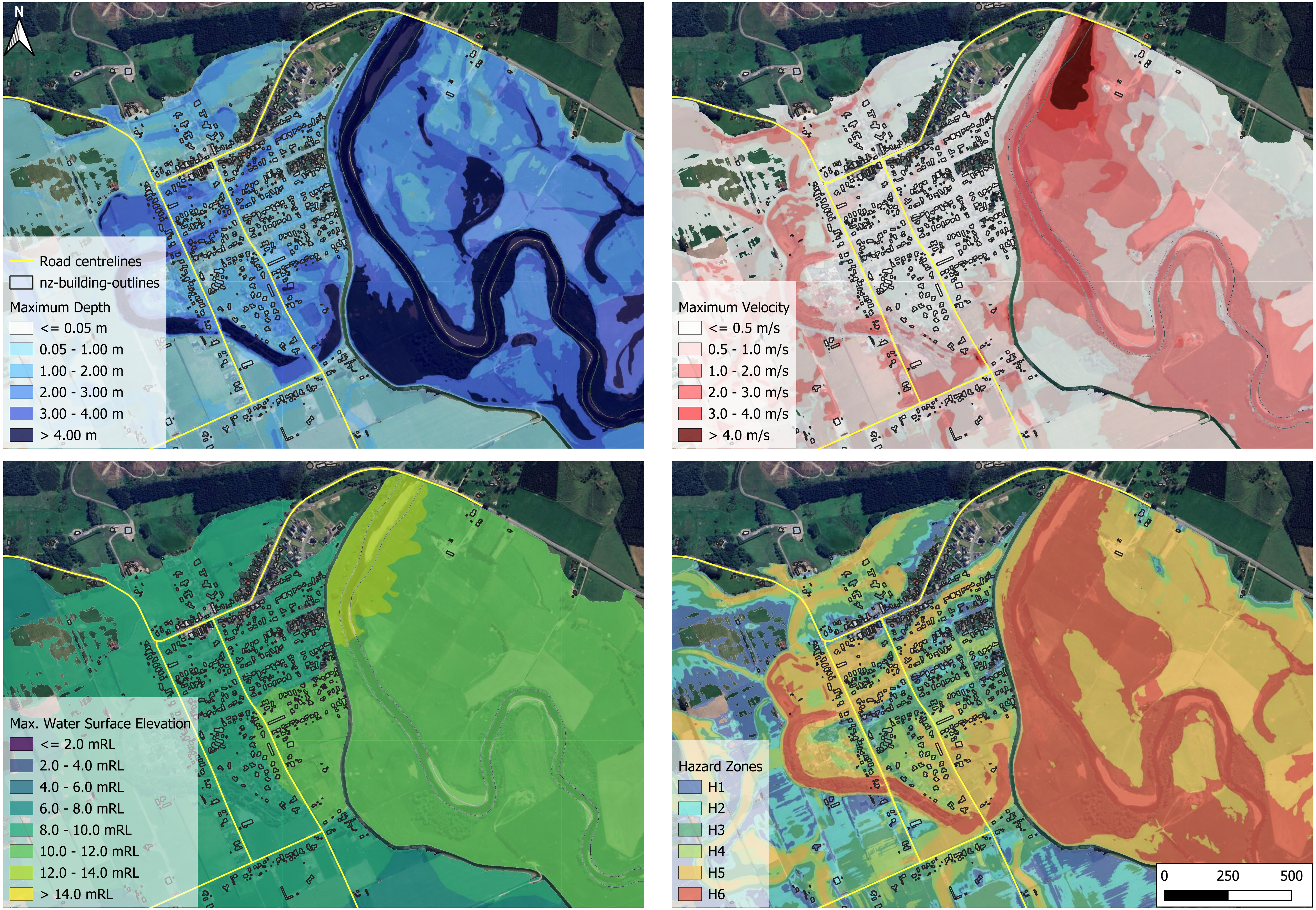
Flood Hazard Map Showing Paleochannels/ Overland Flow Paths in Pink. Source: ORC, 2015.

G

Appendix G – Breach Modelling Results Maps



200-year ARI Breach 390CH Scenario



200-year ARI Breach 1250CH Scenario