Dudley Creek Flood Remediation
Downstream Options Report
Rev 2, 12/6/15
Appendix E

Report

Dudley Creek Flood Remediation

Downstream Options - Concept Geotechnical Assessment Report

Prepared for Christchurch City Council

Prepared by Beca Ltd (Beca) and Opus International Consultants Ltd (Opus)

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Revision History

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1	Marcus Gibson	Concept Issue	12/06/15
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Prepared by	Marcus Gibson		12/06/2015
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on behalf of	Beca Ltd and Opus Ltd		

Executive Summary

Geotechnical Assessment

Geotechnical assessment has been carried out of the concept design options for the Dudley Creek Downstream Options which involve modifications of existing waterways and bypass piping to improve the passage of stormwater from residential suburbs of Mairehau, Shirley, Street Albans and Richmond, though Dudley Creek and associated waterways into the Avon River. Three options have been considered south of the intersection of Stapletons Road and Warden Street. The options incorporate a range of potential engineering solutions including; pipelines, pump stations and modification of the existing Dudley Creek channel along sections of Stapletons Road and Banks Avenue.

The geotechnical assessment has been carried out to identify project risks, consider anticipated resilience associated with static and seismic performance, and to recommend potential mitigation measures for incorporation into the concept option cost assessment.

Typical soil profiles were developed from interpretation of geotechnical investigations sourced from the Canterbury Geotechnical Database. Springston Formation deposits of dominant sandy sit, sand and silt of 4 to 9m thickness (variability in layer thickness and material type), overlie up to 9m thick medium dense gravel layer, with Christchurch Formation sands beneath.

Strong ground motion during the Canterbury Earthquake Sequence (CES) triggered extensive liquefaction within the project area, resulting in ground cracks >200mm wide and moderate to major lateral spreading of the margins of Dudley Creek extending 50 to 80m beyond the creek, combined with ground settlements in the order of 100mm up to 1000mm. Significant lateral spreading was observed in a zone of about 150m adjacent to the Avon River, which consequently has been zoned as CERA residential red zone. Back analysis of observations measured seismic performance during the CES was used to verify empirical equations and stability models used for assessment of seismic performance of the concept design.

The geotechnical assessment of the performance of the margins of the Dudley Creek and the pipe conduits considered the static design case and a range of seismic design cases. Seismic cases ranged between a serviceability limit state (SLS) earthquake, being a minor earthquake having an annual exceedance probability (AEP) of 1/25 years (peak ground acceleration (PGA) 0.13g), through to significant ultimate limit state (ULS) earthquake having an AEP of 1/500 years (PGA 0.35g).

Design loading for structures is determined based on selected Importance Level (NZS1170). Seismic design criteria varies with design life and Importance Level as defined in NZS1170, which corresponds to assessed risk to life safety and importance of post disaster functionality. Project structures are assessed as Importance Level 2 with PGA's of 0.35g to 0.44g depending on design life (50-100 years). Sensitivity assessment considering Importance Level 3 has been performed for critical pump station structures (PGA 0.61g).

Assessment of liquefaction triggering by the methods of Boulanger and Idriss (2014) identified that isolated soil lenses are anticipated to liquefy in a SLS earthquake, though lateral spread is not anticipated, and differential settlements of <50mm are expected along the alignment.

Extensive liquefaction triggering and increased potential for lateral spread deformation will likely occur where ground accelerations exceed approximately 0.15g to 0.20g.

The ULS design earthquake will result in liquefaction triggering, seismic settlement and lateral spreading with similar or marginally greater extent and severity than that observed following the 22 February 2011 Christchurch Earthquake.

Geotechnical Hazards, Risks with Potential Engineering Solutions

The geotechnical assessment of seismic performance, mitigation options, associated residual risks and comments on the merits and difficulties in terms of constructability and relative cost is summarised in the attached Table A. The main outcomes of the assessment are further outlined in the following sections.

Pump Stations

If a pumped option is chosen, the concept pump station design incorporates a shallow foundation solution with a laterally extended base to resist buoyant uplift. Pipe connections should be detailed to maximise flexibility to accommodate differential settlements and lateral stretch.

In areas of lateral spreading, treatment to improve the ground beneath and surrounding pump stations could be considered to limit the influence of lateral spread on post disaster functionality, where this can be carried out cost effectively. Alternatively, a lightweight modular pump station could be adopted which is cheap and easy to replace, providing the risk of seismic damage is accepted by the Council. This strategy has been adopted by SCIRT for pump stations in similar difficult ground.

Pipe Conduits

Pipelines will be subject to the effects of static and seismic settlement, and lateral stretch during moderate to severe earthquakes if located in lateral spread zones. Pumped solutions will exhibit higher resilience compared to gravity systems, as they are less susceptible to sags and humps in the pipeline caused by differential settlement. Continuous and ductile pipe materials such as polyethylene will exhibit the highest level of performance and post disaster functionality. Segmented systems such as precast concrete box culverts are vulnerable to dislocation from lateral stretch with potential abrupt vertical deformations associated with ground settlement. Tying segments together could increase structural integrity but differential settlements also increase loading and need to be considered in design. Geotextile wrapping of joints as adopted for SCIRT repairs will reduce adverse effects associated with deformations, limiting ingress of fines into backfill from the native soil.

Conduits are subject to the influence of buoyant uplift, specific design will be required to limit uplift potential for uplift during earthquakes.

Conduits formed by trenchless technologies exhibit elevated levels of construction risk, and require detailed assessment during detailed design. Ground conditions are relatively adverse for this form of construction with high ground water levels, and limited, possibly unacceptable, cover being available over the pipe for construction above the highly permeable gravels at 4.5 to 6m depth.

Seismic resilience should be improved, where feasible, by cost effective measures such, soil raft foundations and extending the base of foundations for culverts and adding mass to conduits to resist uplift, and structural restraint or geotextile wrapping of joints that could become dislocated. Consideration should be given to adopting the costly but more resilient pumped solution in areas with high differential settlement potential.

Waterway Modification

Options A and C involve widening sections of Dudley Creek by excavating benches in the waterway banks above the normal waterline, to improve flow capacity. No significant lowering of the creek bed is proposed that would remove competent (ie firm) material. The widening has been assessed to have minor and not observable effect on the seismic deformation performance of adjacent private property located greater than 15m from a modified creek bank. The assessed change in ground performance is significantly smaller than the bounds of uncertainty in quantifying this deformation.

However if bank widening is proposed within 15m of private property or structures, or if any lowering of the creek bed (removing competent material) is proposed, then further site-specific assessment needs to be carried out during the detailed design phase, If this assessment indicates the works cause a material increase in risk of ground deformation, this could be mitigated using mass stabilisation shear walls, buried sheet pile walls or solder pile walls.

Bridge Structures

A number of culverts and bridges across Dudley Creek will need to be replaced. Assuming these bridges have relatively large spans (>10m) they will likely require deep piled foundations. Bridge design will consider the lateral loading applied to the abutments and piles from the laterally spreading non-liquefied crust. Founding depth of greater than 15m limits influence of liquefaction on pile performance, and provides competent founding strata.

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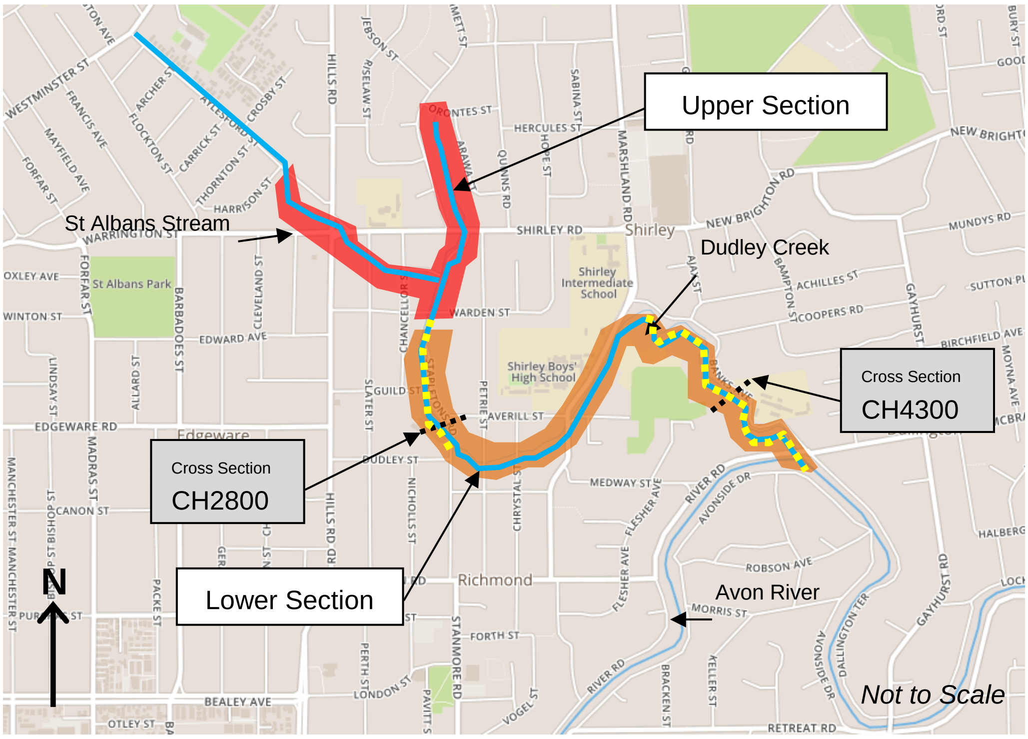
Slope Stability Modelling

1 Introduction

Beca Ltd (Beca) and Opus International Consultants (OPC) Limited (Opus) have been commissioned by the Christchurch City Council (the Council) to provide engineering design services for flood mitigation of Dudley Creek, in the northeast of Christchurch. Dudley Creek drains the residential suburbs of Mairehau, Shirley, Saint Albans, Richmond, and other catchments further upstream (refer to Figure 1-1). Following the recent Canterbury Earthquake Sequence (CES), liquefaction, lateral spreading and settlement have contributed to reduced drainage capability and increased flooding potential in the basin.

Figure 1-1 Dudley Creek Location Plan



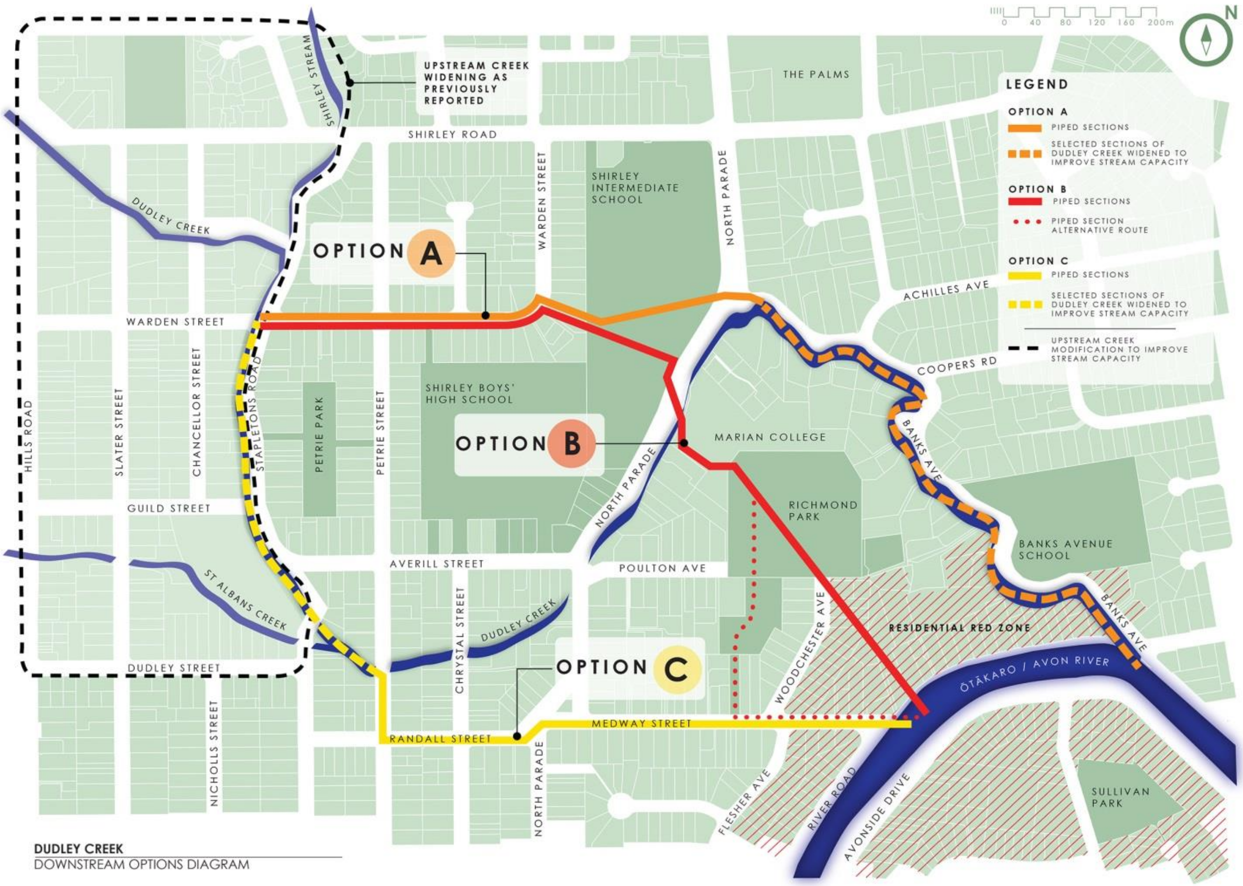
Within the project area Dudley Creek has been split into two sections being the “upper section” located above Warden Street, and the “lower section” between this point and the Avon River.

This report discusses geotechnical influences and interactions with three proposed piped alignment options (Refer Section 2 for details), waterway modifications, and associated structures. Ground conditions adjacent to Dudley Creek are assessed, and back analysis is preformed to compare conceptual ground models with observed seismic performance during the CES. The back analysed models are used to inform conceptual assessment of the influence of proposed modification to the naturalised waterway channel profile on the seismic performance of the adjacent land. Project geotechnical risks are discussed along with concept design recommendations.

2 Lower Dudley Creek – Concept Design Options

Three options are being considered during the concept design phase, all starting at the point where Warden Street crosses Dudley Creek. The alignments are presented on Figure 2-1. Within these alignments a combination of engineering solutions are proposed including use of existing waterway channels, modifying existing channels and use of gravity or pumped pipelines.

Figure 2-1 Lower Dudley Creek – Concept Options



A conceptualised summary of the three alignment options being assessed during the concept geotechnical assessment are provided below:

- **Option A:** Box culvert or pipeline from an intake structure at the intersection of Dudley Creek and Warden Street, to an outfall structure discharging back into Dudley Creek at the north end of Banks Avenue. Gravity or pumped system, with pump station located at Warden Street. Modification of the creek profile along Banks Ave by localised cutting to accommodate increased flow, while maintaining a naturalised profile.

- **Option B:** Intake structure at the intersection of Dudley Creek and Warden Street, linked by a box culvert or pipeline to an outfall structure discharging into the Avon River. Gravity or pumped system, with pump station located at Warden Street. Includes a pipe thrust beneath North Parade and Dudley Creek.

- **Option C:** Modification of the Dudley Creek channel profile along Stapletons Road though localised cutting to accommodate increased flow, while maintaining a naturalised profile. Box culvert or pipeline linking an intake structure at the intersection of Dudley Creek and Petrie Street, to an outfall structure discharging into the Avon River. Gravity or pumped system, with pump station located at Petrie Street.

3 Geology

The published geology of Christchurch (Brown & Weeber, 1992) maps show the ground in the Dudley Creek area to be dominantly alluvial sand and silt over bank deposits of the Springston Formation, underlined by Christchurch Formation sand of fixed and semi-fixed dune and beaches. Pockets of Christchurch Formation are mapped to outcrop on the west bank of Dudley Creek.

4 Soil Profile

4.1 Generalised Soil Profile

A generalised ground profile has been developed for the project area within the lower section of Dudley Creek. The soil profile considered a selection of geotechnical investigations in the area sourced from the Canterbury Geotechnical Database (CGD). Table 4-1 presents the generalised soil profile. Note, that the near surface ground conditions (within 5m of the ground surface) can vary significantly over short distances, a range of depths and thickness and descriptions are provided to demonstrate this variability.

Table 4-1 Generalised soil profile within lower Dudley Creek

Unit	Description	Depth to top of unit (m bgl)	Thickness (m)
1, 2, 3	Soft to medium dense sandy SILT, SILT, Silty SAND, SAND	0 – 1	4 - 9
4	Medium dense to very dense gravelly SAND, sandy fine to coarse GRAVEL, with silt lenses.	4 - 10	0 - 9
5	Dense to very dense fine to medium SAND, minor silt, trace organics	7 - 12	<8 -12

4.2 Dudley Creek Cross Sections

Specific ground profiles have been developed for assessing stability and lateral spread hazard where channel modification is proposed. Proposed cross sections showing existing and proposed modified stream channel profile were reviewed, considering ground conditions, seismic performance of the land during the CES and proximity to private land. Two moderately conservative cross sections were identified:

- CH2800 (Option C) located on a straight section of Dudley Creek between Warden and Averill Streets and represents a 300m stretch of Dudley Creek which is orientated North to South. Stapleton Road is located on the east bank of this stretch of creek. Residential property boundaries are offset approximately 20 to 26m from the edge of the creek bank to the east, and are immediately adjacent to the west with some houses offset by less than 10m.

- CH4300 (Option A) is located along Banks Avenue and is representative of the 600 to 700m stretch of Dudley Creek to its confluence with the Avon River. The alignment of Dudley Creek is torturous, winding around vegetated banks. Banks Avenue is located on the east bank of this stretch of creek and residential property boundaries offset approximately 20 to 25m from the creek. Residential properties are offset 5 to 10m from the west bank and are accessed at bridges across Dudley Creek.

The locations of the cross sections are provided in Figure 1-1.

The soil profiles for CH2800 and CH4300 were derived considering on ground investigation data comprising borehole and CPT data and laboratory testing obtained from the CGD.

Table 4-2 Ground Model CH2800 (Stapletons Road), East Bank

Unit	Description	Depth to top of unit (m bgl)	Thickness (m)	SPT N Range (Typical)	CPT q_c Range (Typical)
1A	Soft to firm sandy SILT and SILT. Lens of fine SAND	0.0	1.8	5 -19 (15)	1.5 – 12 (2)
2	Firm SILT, LP	1.8	0.4	3 – 8 (4)	0.5 – 2 (0.5)
3A	Soft to firm sandy SILT and SILT. Lens of fine SAND	2.2	2.3	5 – 34 (15)	0.5 -7.0
4	Medium dense to very dense sandy fine to coarse GRAVEL	4.5	8.0	17->50 (45)	12 – 50+ (30)
5	Dense to very dense fine to medium SAND, minor silt, trace organics	12.5	>2.5	25 - >50 (35)	15 – 25 (20)

Table 4-3 Ground Model CH2800 (Chancellor Street), West Bank

Unit	Description	Depth to top of unit (m bgl)	Thickness (m)	SPT N Range (Typical)	CPT q_c Range (Typical)
1B	Loose to dense SAND, some silt	0.0	4.0	10 -43 (20)	5 – 20 (15)
2	Firm SILT, LP	4.0	1.0	3 – 8 (4)	0.5 -1.5 (1)
3B	Medium dense to dense SAND, some silt	5.0	3.0	10 – 23 (15)	8 – 20 (12)
4	Medium dense to very dense sandy fine to coarse GRAVEL	8.0	6.5	-	12 – 50+ (30)
5	Dense to very dense fine to medium SAND, minor silt, trace organics	14.5	>0.5	-	15 – 25 (20)

Table 4-4 Ground Model at CH4300 (Banks Avenue), West Bank

Unit	Description	Depth to top of unit (m bgl)	Thickness (m)	SPT N Range (Typical)	CPT q_c Range (Typical)
1	Stiff to very stiff SILT, some sand.	0.0	4.0	5 – 15 (10)	0.5 – 8 (3)
2	Loose to medium dense fine to coarse SAND	4.0	2.0	4 – 25 (10)	6 – 18 (12)
3	Medium dense sandy fine to coarse GRAVEL	6.0	8.0 – West 2.0 - East	10 – 40 (20)	10 – 30 (18)
4	Medium dense to dense fine to coarse SAND	14.0	>1.0	17 (17)	18 – 30 (20)

4.3 Groundwater

Groundwater levels were estimated from borehole static groundwater, CPTs and EQC monitoring wells and staging of Dudley Creek sourced from the CGD. The median value groundwater level was applied for seismic design and are summarised in Table 4-5. Typically groundwater was 1.0 to1.5m below adjacent ground level.

Table 4-5. Groundwater levels will vary seasonally and annually and a median value was assumed for the analysis.

Location	Design Ground Water Level (m RL) [1]	
	Ground Profile	Dudley Creek
CH2800	11.8	11.3
CH4300	10.3	9.6

[1] Christchurch City Council Drainage Datum

5 Seismic Performance during the Canterbury Earthquake Sequence

5.1 General Site Observations

Recent seismic activity within Christchurch and around Canterbury induced strong ground motion with significant peak ground accelerations (PGA), which triggered liquefaction, inducing seismic settlement and lateral spreading in many areas. Table 5-1 provides a summary of observations along the lower section of Dudley Creek, with key observations described below.

- A review of aerial photos with liquefaction interpretation shows moderate to severe liquefaction along the section in the 22 February 2011 and 13 June 2011 earthquakes, with lesser amounts during the 4 September and 23 December 2011 events.

- Earthquake Commission (EQC) records of observed and measured cracking of the ground surface (Figure 5-1) provide observed cracking inferring lateral spread displacements along the margins of the lower reaches of Dudley Creek. Following the 22 February 2011 earthquake, ground cracking with apertures greater than 50mm was observed along Stapletons Road (40 to 60m from Dudley Creek on both the West and East banks) and along Banks Avenue (50 to 70m on the west bank and 50 to 60m on the east bank).

- Approximate seismic settlement inferred by LiDAR DEM movements between earthquake events shows surface settlement greater than 300mm over a width of 20m on the west bank and 30m on the west bank of Dudley Creek.

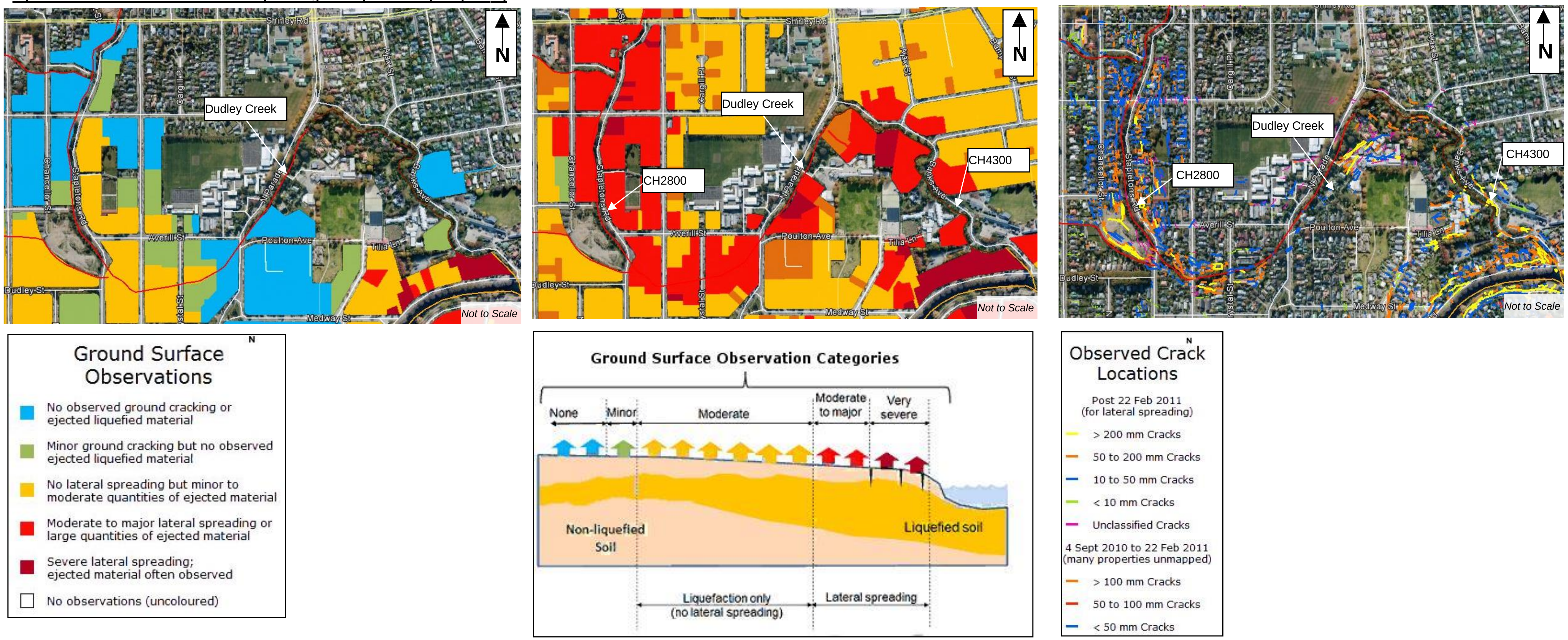
- Figure 5-2 provides total settlements, corrected for tectonic movement, between LiDAR data pre the 4 September 2010 earthquake and post the 13 June 2011 earthquake.

Figure 5-1 - EQC Data Inferring Extent and Severity of Lateral Spread along Margins of Dudley Creek at Location of Proposed Changes in Creek Sections

EQC - Surface observations of Lateral spreading and liquefaction (4 Sep 2010)

EQC - Surface observations of Lateral spreading and liquefaction (22 Feb 2011)

EQC - Recorded Crack Locations and Widths (4 Sept 2010 to post Feb 2011



Created from maps and/or data extracted from the Canterbury Geotechnical Database (https://canterburygeotechnicaldatabase.projectorbit.com), which were prepared and/or compiled for the Earthquake Commission (EQC) to assist in assessing insurance claims made under the Earthquake Commission Act 1993. The source maps and data were not intended for any other purpose. EQC and its engineers, Tonkin & Taylor, have no liability for any use of the maps and data or for the consequences of any person relying on them in any way. This "Important notice" must be reproduced wherever this figure or any derivatives are reproduced.

Figure 5-2 - LiDAR vertical elevation change between July 2003 and February 2012 corrected for tectonic movement. Inferring magnitude of cumulative seismic settlement associated with the 2010/2011 Canterbury Earthquake Sequence.

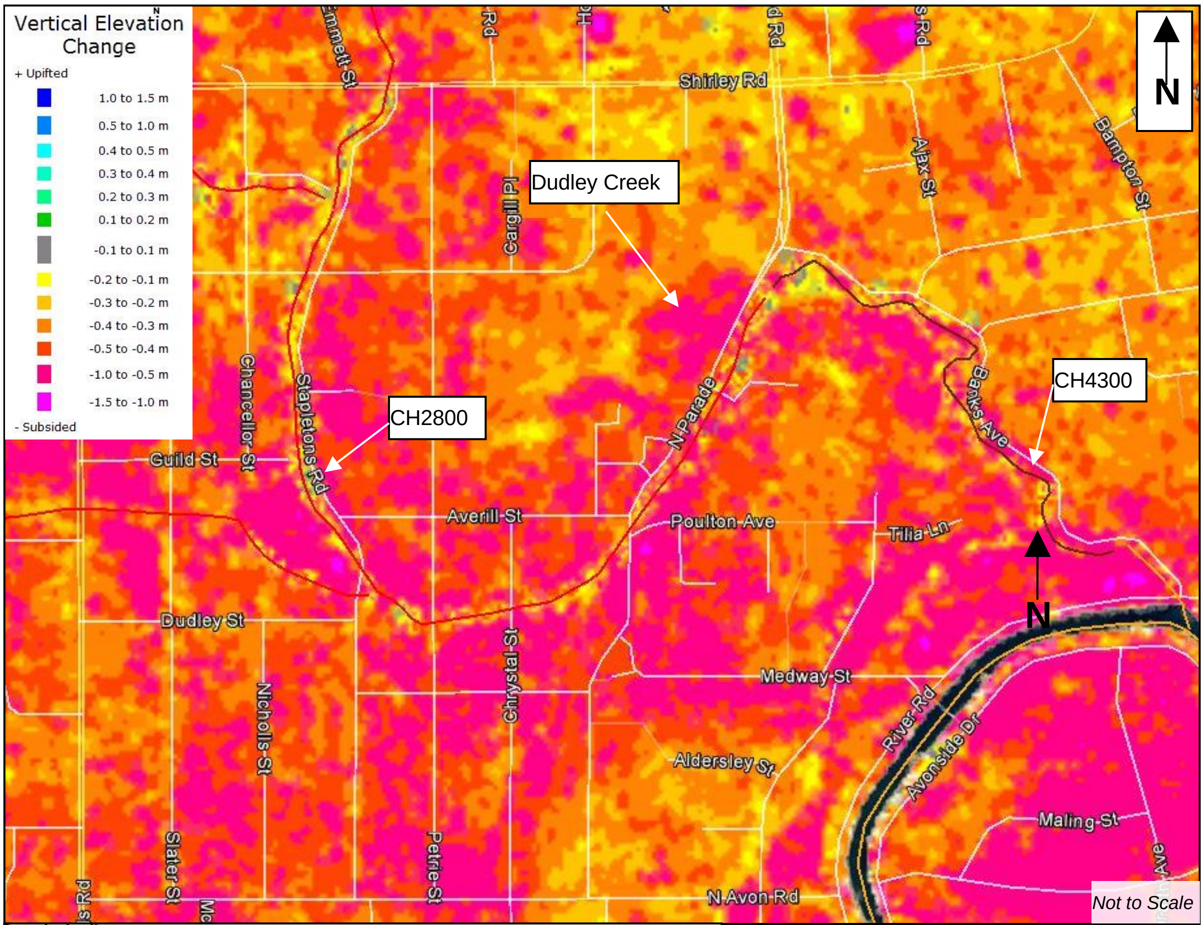


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Table 5-1 Summary of Recent Earthquake Characteristics, Resulting Liquefaction Observation and Measured Seismic Settlement along Dudley Creek

Earthquake Characteristics			Scaled Magnitude		Location	Observation		
Date	**Moment Magnitude (M_w)**	**PGA (g)** [1]	**Moment Magnitude (M_w)**	**PGA (g)**		**Visual Observation of Liquefaction**	**Observed Lateral Spreading**	**Approximate Magnitude earthquake Settlement (mm)** [2] **[LiDAR DEM Movement]**
4 September 2010	M_w7.1	0.20g	7.5	0.18	*CH2800*	Minor to moderate amounts of ejected materials	None observed.	100 - 1000
					CH4300	None observed. Minor ground cracking.	None observed.	100 - 1000
22 February 2011	M_w6.2	0.39 – 0.42	7.5	0.28 – 0.31	*CH2800*	Large to major amount of ejected materials	Moderate to major	0 - 200
					CH4300	Large to major amount of ejected materials	Moderate to major	200 -400
13 June 2011	M_w6.0	0.22 – 0.24	7.5	0.15 – 0.16	*CH2800*	Large amount of ejected materials	None observed.	0 - 200
					CH4300	Large to major amount of ejected materials	Moderate to major	0 - 200

1. Resultant Horizontal Peak Ground Acceleration (PGA)
2. LiDAR Digital Elevation Model (DEM) Movement accuracy +/- 200mm. Data source Canterbury Geotechnical Database.

6 Geotechnical Assessment of Dudley Creek Modification

6.1 Dudley Creek Works & Analysis

Options A and C require sections of Dudley Creek along Banks Avenue and Stapletons Road to be widened by excavating the creek bank. The concept design of modified channel profiles avoids lowering of the channel bed, with the excavation mainly comprising benching and widening of the channel banks above the normal water line. The effects of widening the existing channel have been assessed though engineering judgement supported by quantitative geotechnical assessment, to indicate the influence on the seismic performance of adjacent land.

6.2 Geotechnical Assessment Methodology and Inputs

6.2.1 Analysis Model and Assumptions

Limit equilibrium (LE) slope stability analyses were performed at the two moderately conservative and representative cross sections (CH2800 and CH4300) using Geostudio Slope/W software package.

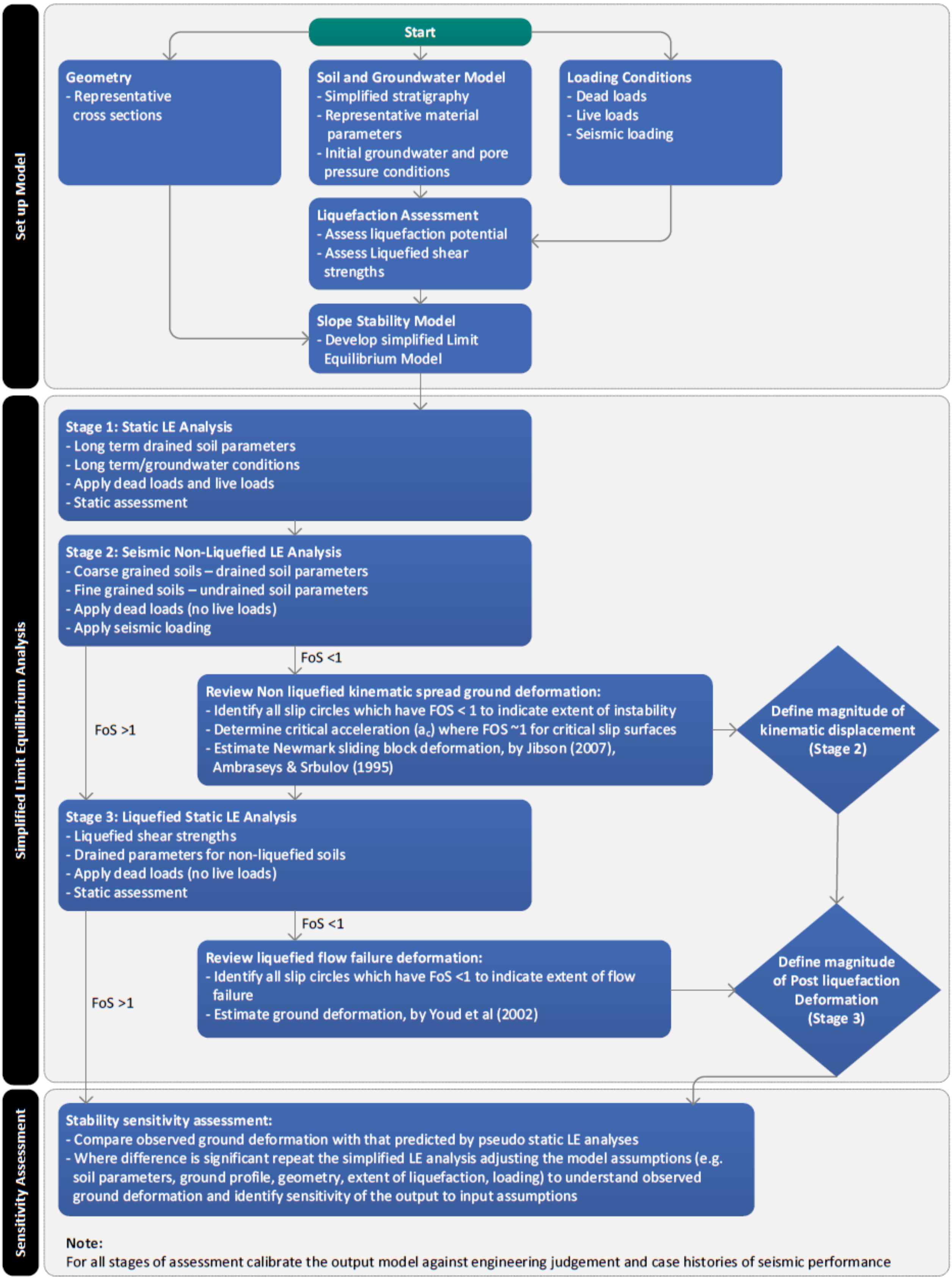
Back analysis was performed to compare the observed seismic performance of the land adjacent to Dudley Creek during the CES against theoretical performance. Figure 6-1 provides a summary of the assessment process which was followed, and Table 6-1 summarises the design loading cases assessed.

Table 6-1 - Dudley Creek Slope Stability Loading Cases

Design Case	Description
1 Static	▪ The static slope stability was determined using drained soil parameters
2 Seismic, full PGA, no liquefaction	▪ A pseudo-static seismic analysis was undertaken with the full design or historic PGA was applied to the ground profile simultaneously with the undrained strengths of the cohesive soil units, and drained parameters for cohesionless materials.
3 Seismic, with liquefaction residual strength	▪ Ground acceleration applied to the ground profile (using pseudo-static seismic analysis) in conjunction with the residual liquefied soil strength, or remoulded strength for soil units expected to liquefy or soften respectively.

Assessment focused on Design Case 2 and 3, namely anticipated Newmark sliding block lateral spread deformations for non-liquefied ground conditions with appropriate PGAs, and liquefied flow failure extent. The magnitude (i.e. extent) of flow failure deformation was estimated by the method of Youd et al (2002) and Zang et al (2004). Back analysis considered studies by Robinson et al (2013) and Bowen (2012) that identified that Youd's empirical equation over predicted lateral deformation in Christchurch during the CES by a factor of two compared to observed deformation.

Figure 6-1 Pseudo Static LE Back Analysis Methodology Assessment



6.3 Back Analysis of Seismic Performance of Land Adjacent to Dudley Creek

6.3.1 Field Observations

Field observations recorded on the Canterbury Geotechnical Database adjacent to Dudley Creek from the 2010/2011 Canterbury Earthquake Sequence were used in the back analysis of the modelled ground profile to calibrate soil parameters and understand the behaviour of design models. These observations include ground cracking and settlement as presented in Section 5. These back analysis refinements provide confidence in the theoretical models for the proposed concept design solutions.

6.3.2 Back Analysis Seismic Criteria

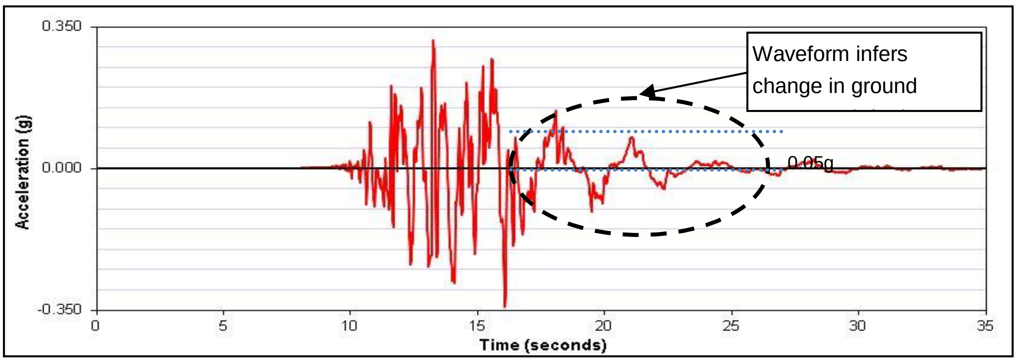
Bradley and Hughes (2012) produced a map of site specific conditional PGAs across Christchurch during the CES. Back analysis considered the 22 February 2011 Christchurch Earthquake. Magnitude scaling factors were applied to the February earthquake using Idriss and Boulanger 2008 so comparison could be made with the design PGAs specified in NZS1170.5 for Christchurch City (Refer to Table 6-6).

Table 6-2 22 February 2011 Earthquake Conditional PGAs for Back Analysis

Chainage	Observed		Equivalent 7.5 M_w PGA	
	Moment Magnitude (M_w)	Peak Ground Accelerations (PGA)	Moment Magnitude (M_w)	Peak Ground Accelerations (PGA)
CH2800	6.2	0.40g	7.5	0.28g
CH4300		0.41g		0.29g

Review of the 22 February 2011 acceleration data at the seismograph (SHLC, located approximately 900 & 700m to the North of CH2800 and CH4300 respectively) has suggests that liquefaction initiated beneath the seismograph after about 5 seconds of strong ground motion (refer Figure 6-2). Ground accelerations experienced following initiation of liquefaction less than 0.1g. In undertaking the back analysis, a sensitivity assessment was undertaken applying a nominal ground acceleration of 0.05g under liquefied conditions, considering conditions observed within main shock and aftershocks.

Figure 6-2 S50E Horizontal component of the SHLC seismograph, inferring initiation of liquefaction, 22 Feb 2011



6.3.3 Back Analysis Considerations

Back analysis of observed seismic performance of the slope stability and lateral spreading of the Dudley Creek margins following the 22 February 2011 earthquake has been undertaken applying the methodology outlined in Section 6.2.1. CES performance observations used for back analysis are provided in Section 5, and earthquake characteristics are provided in Section 6.3.2.

6.3.4 Liquefaction Triggering

The extent of liquefaction at CH2800 and CH4300 has been carried out following guidance given by the New Zealand Geotechnical Society (NZGS) and MBIE industrial building guidance (2014) and is summarised as follows:

- The liquefaction potential of ground materials has been assessed using the available CPT data sourced from the Canterbury Geotechnical Database (Refer Appendix B).
- The liquefaction assessment of the CPT data, has been carried out in general accordance with the NZGS Guidelines (2010) following the methods developed by Boulanger & Idriss (2014); assuming that soils with a Soil Behaviour Type Index (I_c) equal to or less than 2.6 have liquefaction potential. In this study soils with I_c greater than 2.6 are assumed not to have liquefaction potential.

The outputs from our liquefaction analyses are presented in the Appendix C, these results were incorporated in to the LE stability models.

6.3.5 Back Analysis Existing Channel – 22 February 2011 Earthquake

Stability of the land adjacent to Dudley Creek at the two representative cross sections (CH2800 and CH4300) was preformed though simplified LE analysis for the 22 February 2011 Christchurch Earthquake. Back analysis focused on Design Case 2 and 3 as described in Section 6.2.1, with results presented in Table 6-3.

Material properties adopted for analysis were selected based on published correlations for CPT, soil descriptions and Christchurch experience, modification of these parameters from initial values was limited, and only occurred where justification could be supported by the ground investigation data.

The back analysis LE model appears to marginally under estimate extent of flow failure when compared to EQC recorded crack mapping. The variable and often cohesive nature of the Springston Formation with interbeded sand and gravel layers significantly influences variability in stability. Sensitivity of the analysis to the observed variation of soils confirmed this observation; however the selected model material parameters are moderately conservative and generally representative. Ground accelerations exceeding the nominal 0.05g adopted for analysis post triggering of extensive liquefaction (aftershocks) are believed to be a major cause for divergences between recorded crack magnitudes and modelling estimates. Review of simplified LE analysis for assessment of lateral spreading deformations must incorporate qualitative assessment with engineering judgement.

Table 6-3 Summary of Back Analysis – CH 2800 and CH4300 – 22 February 2011 Earthquake

Dudley Creek Project Chainage	Slope Stability Model	Condition	PGA (g)	Factor of Safety (FoS)	Calculated Displacement [1] (mm)
CH 2800 Pre Earthquake ground Profile	East Bank Dudley Creek	Non-Liquefied	0.40	1.08	Not expected
		Liquefied	0	<1	Flow failure lateral spreading with displacements of ~120mm [3, 4] extending ~25m from creek bank.
		Liquefied	0.05	<1	Flow failure lateral spreading with displacements of ~120mm [3, 4] extending ~35m from creek bank. EQC observed cracking to extend ~ 50-80m.
	West Bank Dudley Creek	Non-Liquefied	0.40	0.68	Lateral spreading with displacements of approximately 50mm [2] extending ~25m from creek bank.
		Liquefied	0	<1	Flow failure lateral spreading with displacements of ~120mm [3, 4] extending ~25m from creek bank.
		Liquefied	0.05	<1	Flow failure lateral spreading with displacements of ~120mm [3, 4] extending ~40m from creek bank. EQC observed cracking to extend ~ 30-70m.
CH 4300 Pre Earthquake ground Profile	East Bank Dudley Creek	Non-Liquefied	0.40	1.22	Not expected
		Liquefied	0	<1	Flow failure lateral spreading with displacements of ~140mm [3, 4] extending ~25m from creek bank.
		Liquefied	0.05	<1	Flow failure lateral spreading with displacements of ~140mm [3, 4] extending ~45m from creek bank. EQC observed cracking to extend ~ 30-40m.
	West Bank Dudley Creek	Non-Liquefied	0.40	1.22	Not expected
		Liquefied	0	<1	Flow failure lateral spreading with displacements of ~140mm [3] extending ~25m from creek bank
		Liquefied	0.05	<1	Flow failure lateral spreading with displacements of ~140mm [3, 4] extending ~45m from creek bank. EQC observed cracking to extend ~ 40-60m.

[1] Based on a critical yield acceleration of 0.1g.

[2] Estimated using Jibson 2007, 50% confidence.

[3] Estimated using Youd et al (2002), with a magnitude reduction factor of 2 at 15m offset from creek bank.

[4] Estimated using Zang et al (2004), at 15m offset from creek bank.

6.3.6 Soil Parameters

Moderately conservative soil parameters optimised though back analysis are presented in Table 6-4 and Table 6-5, and are adopted for forward geotechnical assessment.

Table 6-4 Back Analysis Soil Parameters at CH2800

Unit	Description	Unit Weight (kN/m^3) Moist	Unit Weight (kN/m^3) Saturated	Friction Angle ϕ	Cohesion (kPa)	Undrained Shear Strength (kPa)	τ /σ_{vo}' Ratio or Soften Shear Strength (kPa)
1A	Soft to firm sandy SILT and SILT. Lens of fine SAND	17	19	28	3	30	0.08
1B	Medium dense to dense SAND, some silt	17	19	30	1	-	0.45
2	Firm SILT, LP	17	19	28	3	50	10 kPa
3A	Soft to firm sandy SILT and SILT. Lens of fine SAND	17	19	28	2	30	0.10
3B	Medium dense to dense SAND, some silt	17	19	30	0	-	0.10
4	Medium dense to very dense sandy fine to coarse GRAVEL	20	22	34	1	-	-
5	Dense to very dense fine to medium SAND, minor silt, trace organics	19	21	32	0	-	-

Table 6-5 Back Analysis Soil Parameters at CH4300

Unit	Description	Unit Weight (kN/m^3) Moist	Unit Weight (kN/m^3) Saturated	Friction Angle ϕ	Cohesion (kPa)	Undrained Shear Strength (kPa)	τ /σ_{vo}' Ratio or Soften Shear Strength (kPa)
1	Stiff to very stiff SILT, some sand.	17	19	30	5	50	0.10
2	Loose to medium dense fine to coarse SAND	18	20	30	1	-	0.12
3	Medium dense sandy fine to coarse GRAVEL	20	22	34	1	-	-
4	Medium dense fine to coarse SAND	19	21	32	0	-	0.12

6.4 Assessment of Effects of Modification of Channel Profile

6.4.1 Sections Analysed

Option A and Option C alignments require modification of the existing Dudley Creek channel profile along Banks Avenue and Stapletons Road. The proposed modification is to widen the channel though benching, limiting cutting of competent soils within the creek bed, such that the free face height is not increased.

Design slope sections at CH2800 and CH4300 of Dudley Creek were modelled with both the existing (2015) channel profile and the concept design modified channel profile (Concept Design, May 2015), to infer effects on bank stability, lateral spread extent and deformation.

6.4.2 Seismic Design Criteria

PGA for the slope stability design were computed in accordance with NZS 1170.5 (2004) and MBIE (2014) and are summarised in Table 6-6 below. Comparison with Table 5-1 shows that the ULS design earthquake is roughly equivalent to the 22 February 2011 earthquake (M_w6.2) and SLS design earthquake is smaller than the 13 June 2011 earthquake.

Table 6-6 - Seismic Design Criteria for Dudley Creek

Site Soil Sub class	Importance Level (NZS 1170.5:2004)	Magnitude (M_w)	Design Life (years)	Annual Probability of Exceedance (NZS 1170.5:2004, Table 3.5)		Peak Ground Acceleration (PGA) [3]	
				ULS[1]	SLS[2]	ULS[1]	SLS[2]
D	2	7.5	50	1/500	1/25	0.35	0.13

Notes:
[1] ULS – Ultimate Limit State
[2] SLS – Serviceability Limit State
[3] MBIE Canterbury Earthquake Industrial Rebuild Guidance (2014)

6.4.3 Liquefaction Triggering and Seismic Settlement

Liquefaction assessments were undertaken on available CPT data sourced from the CGD on and around CH2800 and CH4300 for the design earthquake PGA by the methods discussed in Section 6.3.4. Minor liquefaction is expected to occur in occasional isolated lenses during the SLS design earthquake, with extensive liquefaction for a ULS design earthquake. A gravel horizon encountered in channel sections is assessed to not liquefy during the design earthquake.

Free field liquefaction induced settlements in the order of 150 to 200mm are expected following a ULS design earthquake. However, settlement estimates were undertaken on CPTs with variable lengths, some of which refused at shallow depths due the presence of a hard impenetrable layer, potentially larger settlement could result. Furthermore, estimates make no account of settlement resulting from lateral spread which will contribute to vertical ground settlement.

Effects of modification of the channel profile on liquefaction triggering and free field seismic settlement are negligible not influencing adjacent property.

LE Stability Assessment

Forward analysis of static and seismic stability and potential for flow failure has been performed at the representative cross sections where concept design proposes modification of the existing channel profile. Two methods were adopted to estimate the influence of channel modification on adjacent private property for an SLS and ULS design earthquake, being:

- Assessment for potential for lateral spread utilising the back analysis calibrated LE models. Estimating the change in extent and magnitude of Newmark sliding block non-liquefied displacements and liquefied flow failure inferred by slip surfaces with a FOS<1.

- Estimation of the change in effective distance between private property and channel banks. Utilising empirical equation by Youd et al (2002) and Zang et al (2004) to estimate change in lateral spread displacement at adjacent private property boundaries.

Proposed channel modifications through cutting to form high level benches at both CH2800 and CH4300 reduce the distance to the centroid of the bank and adjacent private property by approximately 1m to 3m, with no change to the channel base elevation and associated free face height.

Analysis identified that the proposal channel widening has negligible influence on Newmark sliding block deformations, and only a very marginal decrease in FoS for flow failure with a minor increase in extent of flow failure of 3 to 5m. Though a minor decrease in seismic performance of the ground is inferred, it is expected that the additional effect on deformation magnitude within private property will be minor to very minor. The magnitude of change in performance is significantly smaller than the bounds of uncertainty in quantifying this deformation.

Table 6-7 Dudley Creek Seismic Stability Analysis – CH2800 and CH4300

Dudley Creek Project Chainage	Slope Stability Model	Condition	PGA (g)	Factor of Safety (FoS)		Commentary on Anticipated Performance Change on Private Property
				Existing Channel Profile	Modified Channel Profile	
CH 2800	East Bank	Non-Liquefied SLS	0.13	2.83	2.97	Deformation not expected
		Non-Liquefied ULS	0.35	1.14	1.51	Deformation not expected
		Liquefied	0	0.78	0.76	Flow failure lateral spreading extending ~19m into private property for existing scenario and 22m where modified. Anticipated displacements ~140mm [2, 3] within private property, with <50mm increase with channel modification.
	West Bank	Non-Liquefied SLS	0.13	0.94	1.01	Potential deformation <25mm [1].
		Non-Liquefied ULS	0.35	0.69	0.77	Lateral spreading with displacements of approximately 200mm [1] extending 20-25m from creek bank.
		Liquefied	0	0.56	0.56	Flow failure lateral spreading extending ~21m into private property for both scenarios. Anticipated displacements ~160mm [2, 3] within private property, with <50mm increase with channel modification.
CH 4300	East Bank	Non-Liquefied SLS	0.13	2.81	2.66	Deformation not expected
		Non-Liquefied ULS	0.35	2.05	4.00	Deformation not expected
		Liquefied	0	0.30	0.41	Flow failure lateral spreading extending ~20m into private property for existing scenario and 24m where modified. Anticipated displacements ~270mm [2, 3] within private property, with <50mm increase with channel modification.
	West Bank	Non-Liquefied SLS	0.13	2.77	2.82	Deformation not expected
		Non-Liquefied ULS	0.35	1.89	1.89	Deformation not expected
		Liquefied	0	0.27	0.27	Flow failure lateral spreading extending ~21m into private property for existing scenario and 20m where modified. Anticipated displacements ~270mm [2, 3] within private property, with <50mm increase with channel modification.

[1] Estimated using Jibson (2007), 85% confidence.
[2] Estimated using Youd et al (2002), at 15m offset from creek bank.
[3] Estimated using Zang et al (2004), at 15m offset from creek bank.

On the basis that competent soils are not being excavated to deepen Dudley creek, and modification comprising channel widening, analysis indicates that the change in seismic performance of the ground is anticipated to be minor, with no ground improvement or structural treatments proposed. The cost of treatment measures are relatively expensive and given the low impact of widening these treatments are considered unlikely to be warranted for long sections of the river bank. However, they may need to be considered if widening of a river bank is proposed within 15m of a house, or other structure, or if lowering of the channel bed is required.

Ground treatments which could be incorporated into design if required in specific areas include; insitu mass stabilisation to create shear walls, buried sheet pile wall, or steel H pile solider pile wall along the road edge.

These solutions would most likely offer a range of improvement in performance to a level which would be better than the existing situation (betterment for adjacent properties).

7 Pump Station Considerations

7.1 Failure Mechanisms

A number of potential earthquake ground responses and their typical consequences for buried pump stations are described in Table 7-1. These mechanisms are further considered in the following sections, along with an assessment of what effects the earthquake ground responses would have on the pump stations.

Table 7-1 Pump Station Failure Mechanisms

Earthquake Ground Response	Description	Typical Consequences for Pump Station
Lateral Spread	Pump stations located within a zone of lateral spread are subject to translation, and the shallow non-liquefied 'crust' soil can exert passive pressures on the structure. These effects are most commonly observed where pump stations are located close to a free face.	■ Total and differential settlement of structure. ■ Rotation of the structure. ■ Translation of structure towards the free face. ■ Damage to connecting pipe infrastructure. ■ Damage to the pump station structure.
Seismic Settlement	Variation in ground conditions beneath the pump station can result in differential seismic settlement.	■ Differential settlement and rotation of structures. ■ Damage to connecting pipe infrastructure.
	Pump station elements and connected infrastructure founded at different depths can experience differing magnitudes of seismic settlement.	■ Differential settlement between sections of the pump station structure founded at different depths causing rotation and/or structural damage. ■ Settlement of surrounding ground and infrastructure relative to the pump station structure, leading to damage to pipe connections.
	Gravity pipes within the catchment are laid shallower than the pump station wet well, which can lead to differential seismic settlement between the gravity catchment and the pump station.	■ Reduced or reverse pipe grades on connecting gravity pipes, possibly resulting in flooding upstream.
Buoyancy	Seismic induced elevated pore water pressures within liquefied soils exert uplift pressures.	■ Uplift of the structure. Magnitude dependent on the factor of safety resisting uplift, the thickness of the surface crust, and the duration of ground shaking. ■ Rotation of the structure. ■ Damage to connecting pipe infrastructure. ■ Damage to the pump station structure.
Bearing Failure	Reduced bearing capacity of liquefied soils beneath the foundations, and associated reduction in soil stiffness, leading to bearing failure.	■ Total and differential settlement of the structure. ■ Rotation of the structure. ■ Damage to connecting pipe infrastructure. ■ Damage to connecting structures.
Dynamic Structural Damage	Differences in seismic response between pump station structural elements and pipes.	■ Damage to connecting pipe infrastructure and adjacent structures.

7.2 Design Options

For each route option (A, B and C) either gravity or pumped bypasses are being considered. If the pumped option is chosen, an intake and stormwater pump station would be built on Warden Street for Options A & B, and at 65 Petrie Street for Option C. The concept design for the pump station includes a below ground structure with plan dimensions in the order of 7 by 9m and depth of 5 to 6m.

If a pump station is constructed at these locations, options for mitigation of the potential failure mechanisms can be prioritised and are summarised in Table 7-2.

Table 7-2 Mitigation Hierarchy of Potential Failure Mechanisms

Ranking	Failure Mechanism
1	Limit the influence of lateral deformation and assorted lateral stretch of connecting pipes and potential translation and rotation of the pump station structure.
2	Limit buoyancy uplift of the pump station structure under both hydrostatic and seismic conditions.
3	Provide compatibility between total settlement of the wet well structure and connecting infrastructure to limit damage and reduce potential differential settlement across the structure.
4	Limit differential settlement of the wet well structure and associated rotation, to reduce damage to connecting infrastructure and reduce the cost of the post-earthquake repair or replacement.

7.3 Geotechnical Assessment

7.3.1 Static Performance

Static bearing capacity of the soil is not expected to be exceeded due to the weight of the soil being removed being greater than the weight of the pump station. The pump station will require an extended base to utilise the effective mass of backfill material or piles to resist buoyant uplift. Further analyses should be undertaken during detailed design.

7.3.2 Seismic Performance

The size of the proposed pump stations and capital expenditure will likely result in adoption of a moderate to high level of resilience applied to the foundation system in order to ensure satisfactory post disaster functionality and limit potential remedial works. The assessment of seismic performance of pump stations, possible mitigation and residual risks is included in Table A.

a. Influence of liquefied soils

The pump stations will be founded largely within liquefiable silty sands and sandy silt (Soil Unit 2). A non-liquefiable gravel layer (Unit 3 at around 4.5 to 6m depth) is expected at the pump station sites, removal of liquefiable soils above this gravel and replacement with granular hardfill (extending 1 to 2m beyond footprint) should be incorporated to control differential settlements.

Excess porewater pressures will develop beneath the pump station structures associated with strong ground motion and the upward migration of excess pore pressure from liquefiable soil layers at depth. This uplift force may increase the risk of rotation or tilting of the pump station and should be considered further during detailed design. If uplift occurs, eccentric loading on the pump station could lead to rotation of the structure. Bearing failure may occur during and directly after a seismic event, when the strength of the subgrade beneath the pump stations is reduced. Local bearing pressures could exceed ultimate bearing capacity for the liquefied soils, resulting in bearing failure beneath the pump station.

Pump stations should be designed to mitigate the potential for uplift from generation of excess pore pressure and bearing failure of the structure. Extending the base of the pump station foundation laterally outside the footprint of the station is recommended as a cost effective measure of mitigation against uplift. The effective weight of backfill is used to resist net uplift. Use of piles, though technically feasible, and robust may prove to be costly due to the depth and size of piles required to found in non-liquefiable material and sufficiently stiff to carry any negative skin friction loads and resist lateral loading on the pump station and the piles themselves.

b. Lateral Spreading

Lateral spreading flow failure is anticipated at the pump station sites upon development of extensive liquefaction (PGA in the order of 0.15g - 0.20g) during a significant earthquake. The non-liquefied crust within spreading ground will apply passive soil pressure to the pump station promoting translation and rotation. Recommended mitigation comprises use of ground improvement surrounding and beneath the pump station to reduce lateral spread deformation. Potentially feasible solutions include:

- Excavate and replace liquefiable soil beneath and surrounding the pump station.
- Ground improvement with stone columns around and beneath the pump station, but may not be effective for silts and clays
- Insitu cement stabilisation of soil under and around the pump station by mass stabilisation, or deep soil mix columns.

The suitability of improvements would need to be verified though site specific geotechnical investigations,

Use of flexible connections on all connecting pipes and utilities is recommended to accommodate lateral deformation and differential settlement, to limiting potential for damage.

c. Dynamic Structural Damage

The pump station structure and connecting pipe network will experience different seismic responses during ground shaking. The effect of this has not been analysed as part of this assessment. However it is important to highlight this as a potential cause of damage that may render the pump stations unserviceable, due to pipe and/or connection and structural breakage.

The attributes and features of the possible mitigation options and residual risks is included in Table A.

8 Pipe Conduits

8.1 Pipe Materials

All options include construction of a piped bypass comprised either of individual pipe units (e.g. reinforced concrete box culvert) or a more continuous and flexible polyethylene (PE) pipe. Other pipe materials will be considered at the detailed design stage.

8.2 Static Performance

Construction of the pipelines would be in accordance with the Christchurch City Council Construction Specifications. Sections of the alignment will likely encounter “soft” ground conditions requiring incorporation of a geotextile wrapped CCC GC 65-40 raft foundation. Review of anticipated static consolidation settlements and potential for development of pipe dips should be considered during detailed design.

8.3 Seismic Performance

The project area is subject to extensive liquefaction during a significant earthquake, and associated moderate to severe total and differential settlement and lateral stretch.

Segmented Pipes

Reinforced concrete culvert units (such as might be used for the gravity pipelines) exhibit a low level of seismic resilience, with potential costs for remedial works or replacement following a significant earthquake being substantial. This risk needs to be considered in the context of the capital cost (which may be lower than other conduit options) when the design option is chosen.

Wrapping segmented pipe or box culvert joints with a high strength geotextile is recommended where moderate to severe lateral stretch is anticipated. Geotextile limits migration of fines from the surrounding soil into the pipeline upon dislocation, allowing continued but reduced functionality and reduced potential for expression of the failure at the ground surface. This is recommended within 200m of Dudley Creek and the Avon River, but would provide benefit (by limiting the risk of fines entering through dislocated joints) over the full pipeline length.Differential settlements in the order of 100mm are anticipated along pipeline alignments, inducing undulations in vertical alignment of the pipe and potential steps between culvert units. Restraining precast concrete box culvert units, say with post tensioning is not recommended without consideration of additional structural loading and potential damage due to differential settlement. Incorporation of a geogrid reinforced raft or a mass or reinforced concrete foundation under the pipe could assist with reducing the rate of differential settlement, but not the magnitude. Ground improvement beneath the pipelines to limit differential settlements is not practical and is anticipated to be of low economic value.

The box culvert units will require an extended foundation to improve resistance to buoyant uplift. Large diameter pipes will require detailed review of potential for buoyant uplift during detailed design.

Polyethylene (PE) Pipes

End restrained continuous PE pipes (such as might be used for the pumped options) are anticipated to exhibit a good level of performance.

Initial calculations indicate buoyancy uplift can be mitigated through trench and backfill detailing.

9 Trenchless Technologies

The pipeline route for Option B may require installation of an approx. 2.5m diameter pipe beneath North Parade and Dudley Creek (refer Figure 2-1). This might be installed using trenchless technologies. Detailed site and technology specific assessment has not been performed at this conceptual stage of the project. Design and construction risk considerations are summarised below:

- The ground conditions are anticipated to vary over short distances, comprising of silty sand, sandy silt, silt, sand and gravel. Minor to trace organics are expected. The conceptual pipeline alignment is likely to encounter a medium dense to dense gravel layer (in part or full). Running sands could be encountered below the groundwater table. Obstructions such as boulders and tree stumps could also be encountered perhaps only rarely but would have significant cost consequences for construction.

- Dewatering groundwater flows will vary depending on strata intersected, it is likely that significant flows will be encountered in the gravel, sand lenses and adjacent to Dudley Creek. Groundwater inflows will promote hole collapse and development of sinkholes and expressions of settlement at the ground surface. Extensive dewatering will be required for the launching and receiving pits. Pressure balance trenchless construction methods are likely to be required.

- Adequate overburden thickness is required to mitigate potential for ground heave, piping failure from Dudley Creek and fracking of drilling fluids to the ground surface. The gravels at 4.5m to 6m depth are likely to require shallower pipe excavation and this will limit the amount of overburden cover available affecting the feasibility of excavation of a single large pipe without piping failures.

Detailed assessment of ground conditions along the pipe route, and identification of appropriate trenchless technologies to mitigate construction, quality and cost risks would be required for detailed design.

The seismic performance of such a pipeline installed by trenchless construction would be similar to that of a trenched pipeline except mitigation would tend to be more difficult and expensive. Possible options include ground improvement with stone columns, deep soil mixed columns or possibly jet grouting.

Trenchless construction is unlikely to prove advantageous for long sections of pipeline due to the relative acceptability of trenched pipeline construction on local roads along the route. However it may have merit for short sections under busier roads, intersections or to avoid services.

10 Construction Considerations

Constructability issues should be considered when selecting a preferred conceptual design, and during development of preferred option during detailed design and construction documentation.

The geotechnical aspects of the culvert and pipelines and modification of Dudley Creek may be adequately constructed by an experienced contractor. However pump station construction and implementation of trenchless technologies will require a specialist contractor.

All the conceptual options require temporary works to support excavations and dewatering. Dewatering construction risks include:

- If inadequate groundwater drawdown is achieved with dewatering then potential for soil heave at base of excavation and potential for settlement is increased
- Soil volume loss due to inadequate dewatering design resulting in potential settlement of structure during construction and increasing the liquefaction potential of soils
- The larger the dewatering area then associated dewatering construction costs increase non-linearly. Consideration should be given to cost benefit associated with small excavated areas.
- Uncertainty associated with feasibility and cost for trenchless technologies, associated with variable and adverse soil and groundwater conditions.

The risks associated with dewatering may be minimised by reducing the area requiring dewatering and ensuring that the constructor has appropriately designed, implemented and minimised the duration for dewatering.

11 Conclusion and Recommendations

Concept design has considered modifications of the waterway networks to improve the passage of stormwater from residential suburbs of Mairehau, Shirley, St Albans and Richmond, though Dudley Creek and associated waterways into the Avon River. Three alignment options (Option A, B & C) have been considered within the lower section of Dudley Creek. Options incorporate a range of engineering solutions including; pipelines, pump stations and modification of the existing creek channel profile.

The geotechnical assessment has been carried out to identify project risks, consider anticipated resilience associated with static and seismic performance, and recommend potential mitigation measures for incorporation into the concept option cost assessment. Table A summaries this assessment. The main outcomes of the assessment are further outlined in the following sections.

Pump Stations

The concept pump station structure incorporates a shallow foundation solution with a laterally extended base to resist buoyant uplift. Pipe connections should be detailed to maximise flexibility to accommodate differential settlements and lateral stretch.

In areas of lateral spreading, treatment to improve the ground beneath and surrounding pump stations could be considered to limit the influence of lateral spread on post disaster functionality, where this can be carried out cost effectively. Alternatively, a lightweight modular pump station could be adopted which is cheap and easy to replace, providing the risk of seismic damage is accepted by the Council. This strategy has been adopted by SCIRT for pump stations in similar difficult ground.

Pipe Conduits

Pipelines will be subject to the effects of static and seismic settlement, and lateral stretch during moderate to severe earthquakes if located in lateral spread zones. Pumped solutions with a continuous welded polyethylene pressure pipeline will exhibit higher resilience compared to gravity systems constructed of segmented pipe, as they are less susceptible to sags and humps in the pipeline caused by differential settlement.

Continuous and ductile pipe materials such as polyethylene will exhibit the highest level of performance and post disaster functionality. Segmented systems such as precast concrete box culverts are vulnerable to dislocation from lateral stretch with potential abrupt vertical deformations associated with ground settlement. Tying segments together could increase structural integrity but differential settlements also increase loading and need to be considered in design. Geotextile wrapping of backfills as adopted for SCIRT repairs will reduce adverse effects associated with deformations, limiting ingress of fines into backfill from the native soil.

Conduits are subject to the influence of buoyant uplift, specific design will be required to limit uplift potential for uplift during earthquakes.

The relative capital costs and seismic resilience of the various conduit options should be considered as part of the option selection and design process. Seismic resilience should be improved, where feasible, by cost effective measures such as soil raft foundations and extending the base of foundations for culverts and adding mass to conduits to resist uplift, and structural restraint or geotextile wrapping of joints that could become dislocated.

Conduits formed by trenchless technologies exhibit elevated levels of construction risk, and require detailed assessment during detailed design. Ground conditions are relative adverse for this form of construction with high ground water levels, and limited, possibly unacceptable, cover being available over the pipe for construction above the highly permeable gravels at 4.5 to 6m depth.

Waterway Modification

The proposed increase in channel width (created through excavating benches in the banks along sections of Dudley Creek above the normal water line) have been assessed to have a minor and not observable additional effect on the seismic deformation performance of adjacent private property that is located greater than 15m from a modified creek bank. The change in performance is significantly smaller than the bounds of uncertainty in quantifying this deformation.

If however widening is carried out where buildings and other structures are located within 15m of creek widening, or if channel bed lowering (removing competent material) is being considered, incorporation of engineered stabilising solutions may be required. Feasible solutions include mass stabilisation shear walls, buried sheet pile walls and solder pile walls may be required.

Bridge Structures

Where bridges are to be replaced, and assuming the spans exceed 10m, these will need to include deep piled foundations. Bridge design will consider the lateral loading applied to the abutments and piles from the laterally spreading non-liquefied crust. Founding depth of greater than 15m limits influence of liquefaction on pile performance, and provides competent founding strata.

Applicability

This report has been prepared by Beca Ltd and Opus International Consultants Ltd on the specific instructions of our 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 Ltd and Opus International Consultants Ltd Beca has not given their prior written consent, is at that person's own risk.

This report includes factual data of field investigations. The field investigations have been undertaken at discrete locations and no inferences about the nature and continuity of ground conditions away from the investigation locations are made. Furthermore logs are provided presenting description of the soils and geology based on our observation of the samples recovered in the fieldwork and may not be truly representative of the actual underlying conditions.

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.

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Appendix A

Summary Geotechnical Hazards, Risks, with Potential Engineering Solutions and Residual Risks

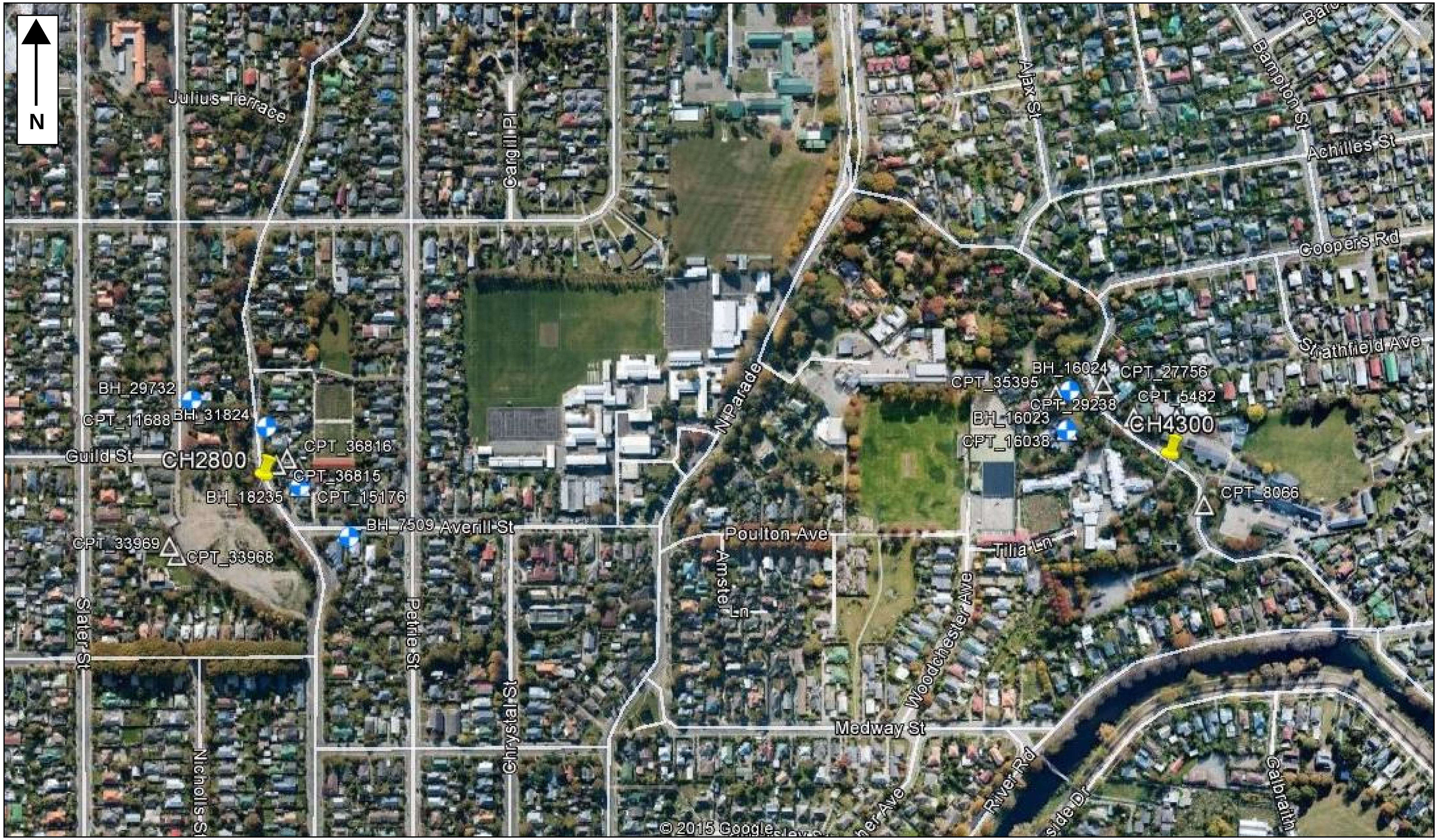
Table A – Lower Dudley Creek Geotechnical Assessment - Summary Geotechnical Hazards, Risks, with Potential Engineering Solutions and Residual Risks

Design Component	Hazards Affecting Performance	Engineering Solutions to Improve Performance	Residual Risks	Advantages	Disadvantages
Pump Station and Inlet Structures	▪ Lateral spread ▪ Settlement ▪ Buoyant uplift ▪ Bearing failure ▪ Dynamic damage	<u>Accept deformation</u> Design detailing of connecting infrastructure to maximize potential for post disaster functionality.	▪ Deformations may exceed ability of detailing to accommodate deformation, resulting in functional failure ▪ Post disaster remedial or replacement required	▪ Low capital costs ▪ Can accommodate minimum functionality	▪ Potential functional failure following significant earthquake ▪ High repair costs
		<u>Small light modular pump stations</u> Cheap modular pump stations that can easily and cost efficiently reinstated following an earthquake. Detail to limit potential for lateral stretch to result in functional failure (continuous PE pipe or wrap joints in geotextile).	▪ Post disaster functionality maintained, however at a reduced capacity ▪ Accept post-earthquake remedial required	▪ Fast and economic reinstatement ▪ Modular construction allows incremental repair ▪ Low capital cost	▪ Space constraints ▪ Technical challenges associated with connecting single inlet structure and outlet pipe to multiple pump stations
		<u>Ground improvement</u> Ground improvement to a depth of 6-10m, to mitigate lateral spread and control settlement. Methods include; excavate and replace, vibro-replacement, deep soil mixing and mass stabilisation.	▪ Ground improvement specified may be insufficient to adequately mitigate deformation for a significant earthquake ▪ Level of improvement required is not achieved during construction due to soils having high fines content ▪ Settlement of connecting infrastructure relative to the pump station, potentially compromising functionality	▪ Limits liquefaction and ground deformation ▪ Can be transitioned to control rate of differential settlement	▪ High capital cost ▪ Challenging ground conditions affecting level of improvement achieved ▪ Space constraints
		<u>Piles</u> Piles sized to resist lateral soil and settlement. Founded in competent soil below 15m depth.	▪ Differential settlement and associated damage to connecting infrastructure limiting resilience ▪ Settlement of the connecting pipes relative to pump station reducing hydraulic efficiency	▪ Limits settlement and translation of pump station	▪ High capital cost ▪ Low resilience if not designed to accommodate lateral loads ▪ Promotes damage to connecting infrastructure
		<u>Resist buoyant uplift</u> Extended base with non-liquefiable backfill. Alternative solutions include; tension piles, additional mass, high permeability drainage.	▪ Performance is dependent on accurate assessment of uplift pressures, providing adequate resistance and construction quality	▪ Low to moderate cost	▪ Effectiveness dependent on the pump station geometrics and foundation conditions
		<u>Limit eccentric loading</u> Limit rotation from eccentric loading locally exceeding bearing capacity.	▪ Vulnerable to influence of lateral spread and uplift pressure ▪ May not be economic or feasible to optimise	▪ Low capital cost	▪ Limited ability to limit influence of lateral loads
Conduits (pipes and box culverts)	▪ Lateral stretch ▪ Buoyant uplift ▪ Settlement ▪ Structural damage	<u>Resilient material selection</u> Performance is dominantly influenced by pipe selection.	▪ Seismic performance of conduits. Ductile continuous PE pipes are ground deformation tolerant while maintaining a level of functionality (albeit reduced). Segmented and/or brittle pipes and box culverts are subject to dislocation and structural damage ▪ Post disaster remedial or replacement required, or reduction in residual asset life (varies with pipe selection) ▪ Failure could result inconsequential damage to adjacent and above ground infrastructure ▪ Vulnerable to damage in lateral stretch zones and significant differential settlement	▪ Pipe materials that exhibit elevated resilience provide improve post disaster asset functionality	▪ High capital cost for resilient pipe materials ▪ Feasibility of resilient pipe materials limited by proposed large diameters
		<u>Pumped solution</u> Pumped solutions tolerant of differential settlement compared to gravity solutions. Potential to upgrade pumps provides improved flexibility for increased future flows.	▪ Performance of pumped solutions poor following dislocation (pressure leakage, erosion and scour) ▪ Residual vulnerability of the pump station structure, infrastructure and service connections	▪ Highest resilience ▪ Flexibility in operation ▪ Upgradable	▪ High capital cost for resilient pipe materials and pump station structure ▪ Operational costs
		<u>Geotextile wrapping conduit</u> Reduce effects of dislocation in zones of lateral stretch. Limit potential for backfill and native soil to collapse into conduit.	▪ Effectiveness of mitigation reduced through potential for geotextile damage ▪ Temporary mitigation, residual asset life significantly reduced following pipe dislocation ▪ Remediation expensive, and possibly not technically feasible	▪ Low cost solution ▪ Improves ability to programme post disaster remedial	▪ Performance not reliable ▪ Temporary mitigation
		<u>Soft raft foundation</u> Removal of unsuitable soils where insufficient bearing capacity is encountered or incorporate geogrid reinforcement in lateral stretch zones.	▪ Over-excavation and filling with granular materials can promote static settlement ▪ Geogrid reinforcement does not prevent lateral stretch; but it provides a level of control and distribution. Not reliable mitigation	▪ Assists with constructability ▪ Marginal improvements in static and seismic performance	▪ Additional cost ▪ Surcharge from fill materials promoting settlement
		<u>Resist buoyant uplift</u> Extended base to box culverts, and add mass to large diameter pipes as required.	▪ Potential for design measures to complicate future maintenance or remediation ▪ Effectiveness dependent on construction quality	▪ Practical solutions to mitigate uplift	▪ Additional cost
		<u>Structural restraint systems</u> Structural restraint systems to limit pipe separation and/or vertical step changes.	▪ Restraint systems can focus strain promoting damage (elevated for stiff and/or brittle pipe materials)	▪ Reduced potential for pipe dislocation and steps between pipe units	▪ Elevated risk for structural damage to pipes ▪ Capital cost
		<u>Ground improvement or piles</u> Incorporate ground improvement or piles beneath pipes to limit potential for static of seismic settlement.	▪ Differential settlement at transitions with improvement ▪ Insufficient treatment to limit lateral spread or liquefied buoyant uplift pressures	▪ Reduced pipe settlements	▪ High capital cost ▪ Low value solution

Design Component	Hazards Affecting Performance	Engineering Solutions to Improve Performance	Residual Risks	Advantages	Disadvantages
Trenchless Technologies	■ Groundwater inflow ■ Obstructions ■ Presence of trace organics	Vertical alignment Optimal vertical alignment for the proposed technologies considering ground conditions.	■ Ground conditions are relatively adverse for use of trenchless technologies, presence of a highly permeable medium dense to dense gravel ■ Shallow installation could result in heave, sink holes and frack out due to insufficient cover ■ Shallow alignments are vulnerable to the effects of lateral spreading at creek margins ■ Obstructions and unforeseen ground conditions	■ Minimised construction risk and optimised performance	■ High risk construction methodology considering site constraints and ground conditions
		Trenchless technology selection Selection of trenchless technology. Ideally with passive support and pressure balance to minimise the influence of the challenging ground conditions.	■ Reliance on specialist contractors adopting optimised technical decisions in the field ■ Programme risk ■ Variability of ground conditions adversely influencing feasibility, cost and programme	■ Reduced disruption to road operation and environmental effects within waterways.	■ High risk activity ■ High capital cost
Modification of naturalized creek channel	■ Change in lateral spread deformation ■ Creek bed heave	Limit excavation of competent sediments from creek bed Limit excavation of competent soils from the creek bed to mitigate increase of free face height.	■ Over excavation during construction could remove or disturb competent soils in creek bed ■ Increase in magnitude of potential lateral spread deformation	■ Minor increase in lateral spread deformation	
		Minimise width of channel modification Minimise the width of channel modification to minimum required for hydraulic design.	■ Uncertainty associated with design assumptions for material properties, and variability of soil and groundwater conditions across the site. Back analysis of CES performance used to verify model assumptions	■ Assessment considered by multiple simplified methods assessing relative change in performance	■ Residual uncertainty associated with assessment of magnitude of lateral spread deformation
		Engineered solutions to reduce deformation Engineered solutions to improve the seismic performance of the waterway. Feasible solutions include; mass stabilization shear walls, buried sheet pile walls and soldier pile walls.	■ Remediate following a significant earthquake ■ Design performance risk	■ Confidence in mitigation of potential effects	■ High capital cost
Bridge structures	■ Lateral spread ■ Settlement ■ Dynamic damage	Deep foundations Designed to accommodate lateral spread loading from non-liquefied crust, and mitigate settlement.	■ Compatibility between lateral deformation of abutment and bridge design ■ Damage may be sustained if excessive lateral loading occurs in significant earthquakes exceeding SLS	■ Limits effects of liquefaction and lateral spread on bridge performance	■ Moderate capital cost
		Ground improvement Incorporate ground improvement at bridge abutments.	■ Some potential for deformation may remain in significant earthquakes.	■ Better resilience of bridges	■ High capital cost disproportionate with cost of replacement of small bridges

Appendix B

Canterbury Geotechnical Database Investigations



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PDF ONLY
NO DWG FILE

No.	Revision	By	Chk	Appd	Date
A	ISSUED FOR INFORMATION	BE	MG	MG	29/05/15

Drawing Originator: Beca

Not to Scale

Design	BE	29/05/15	Approved For Construction*
Drawn	BE	29/05/15	
Dsg Verifier	MG	29/05/15	
Dwg Check	MG	29/05/15	Date

* Refer to Revision 1 for Original Signature

Client: Christchurch City Council

Project: Dudley Creek Flood Remediation

Title: Canterbury Geotechnical Database Investigations Adjacent to CH2800 and CH4300

Discipline: GEOTECHNICAL

Drawing No. 3384543-G002

Rev. A

BLUEBEAM

DO NOT SCALE

IF IN DOUBT ASK.

Appendix C

Liquefaction Assessment

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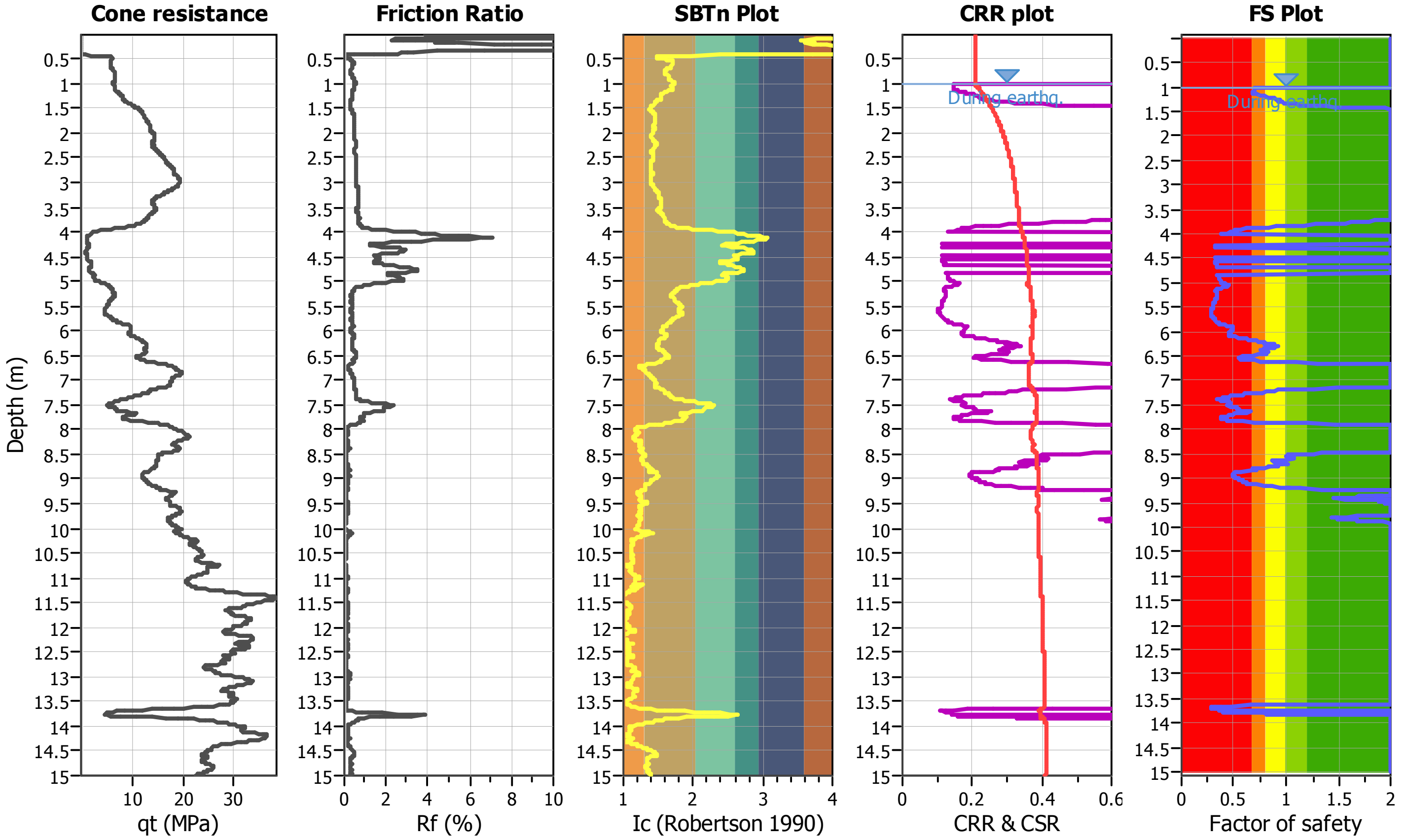
LIQUEFACTION ANALYSIS REPORT

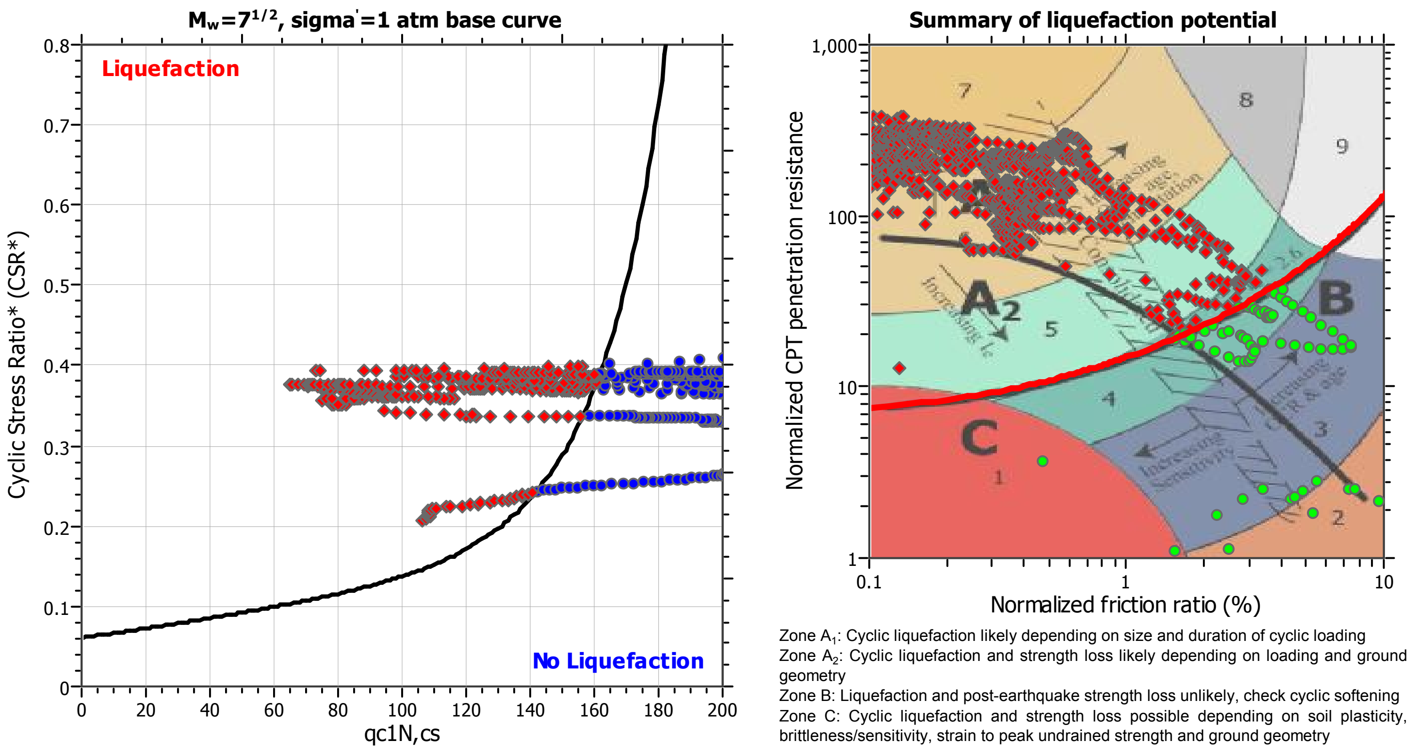
Project title : Dudley Creek **Location : CH2800**

CPT file : CPT_11688

Input parameters and analysis data

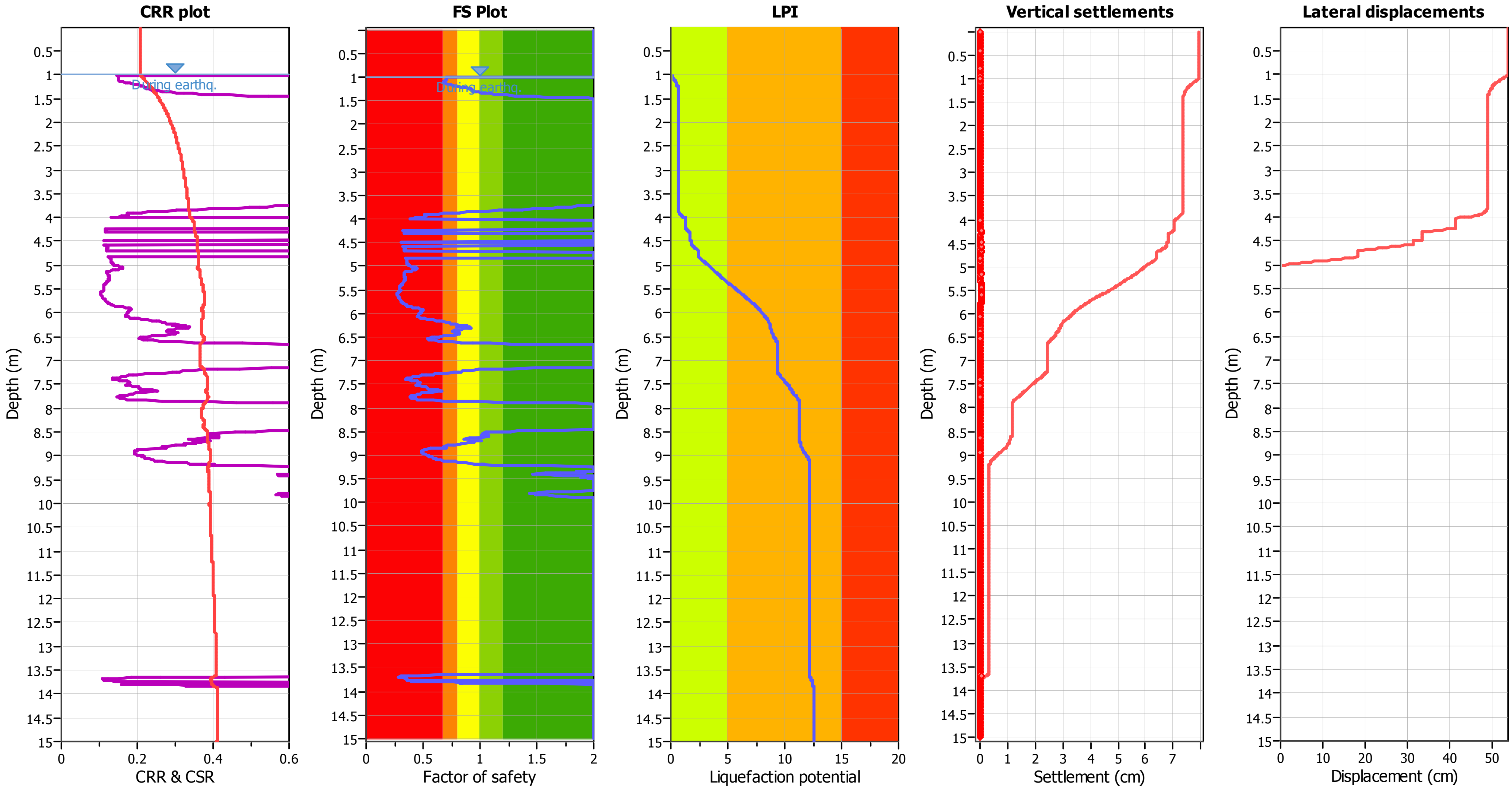
Analysis method:	B&I (2014)	G.W.T. (in-situ):	1.00 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	1.00 m	Fill height:	N/A	Limit depth applied:	No
Points to test:	Based on Ic value	Average results interval:	3	Fill weight:	N/A	Limit depth:	N/A
Earthquake magnitude M_w:	7.50	Ic cut-off value:	2.60	Trans. detect. applied:	No	MSF method:	Method based
Peak ground acceleration:	0.35	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

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.50	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.35	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 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

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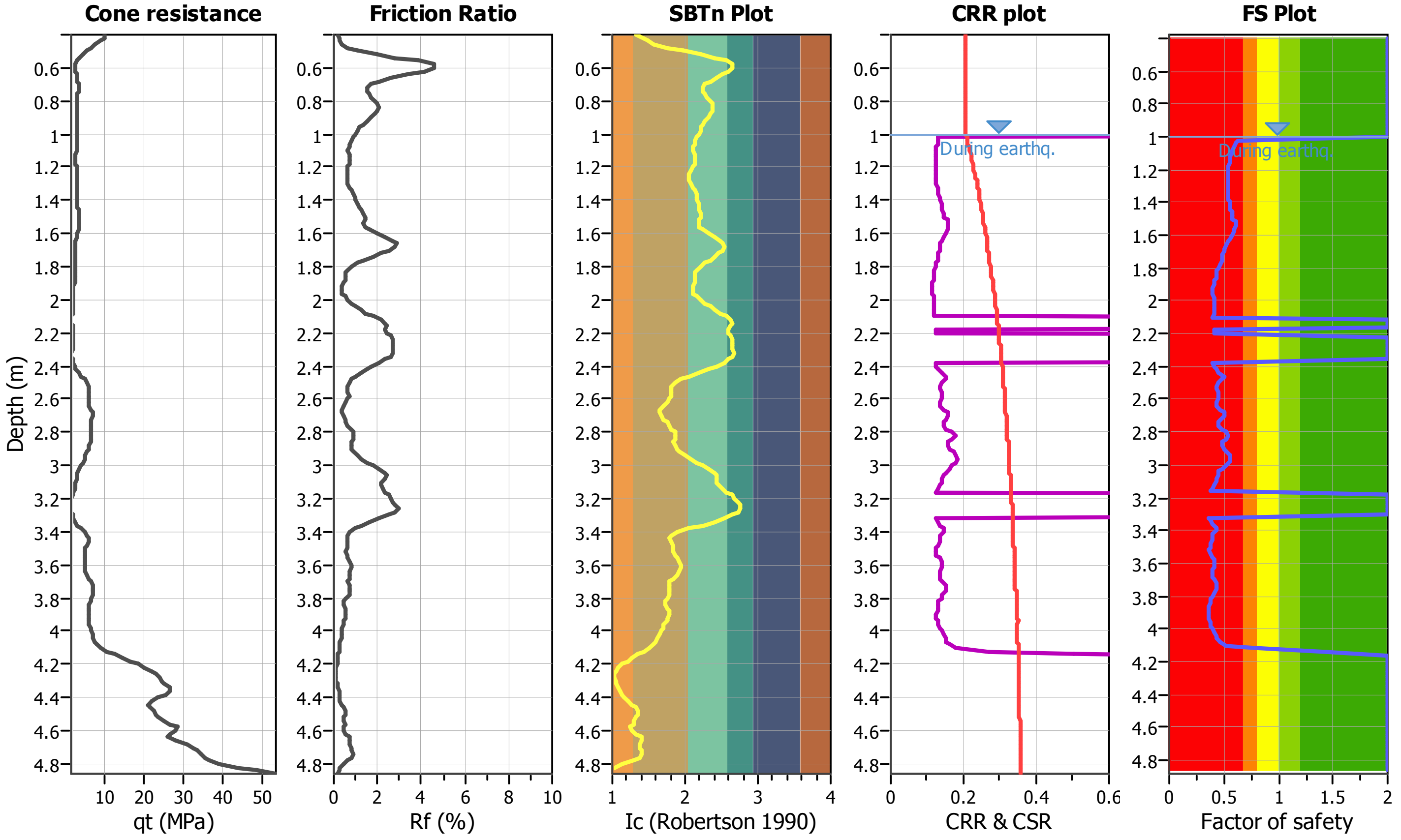
LIQUEFACTION ANALYSIS REPORT

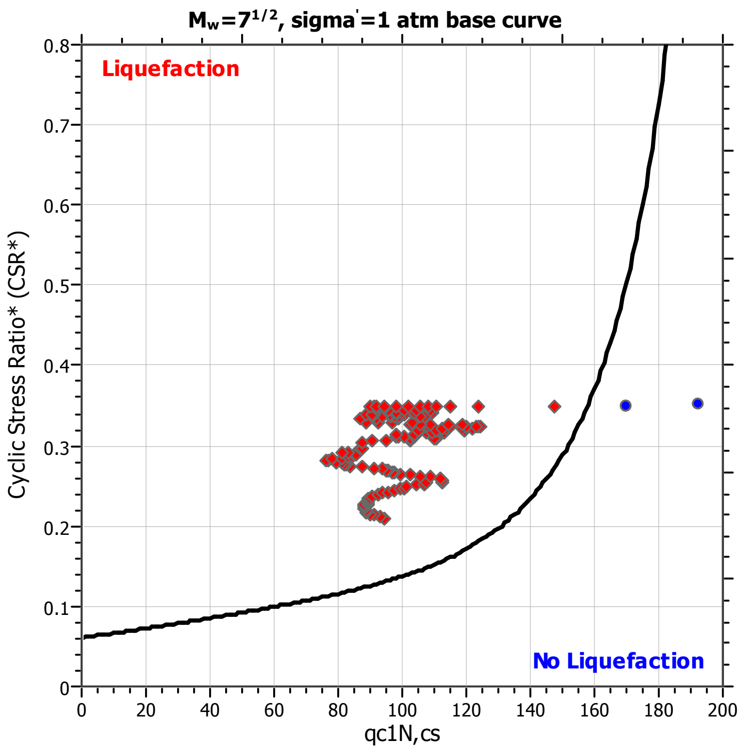
Project title : Dudley Creek **Location : CH2800**

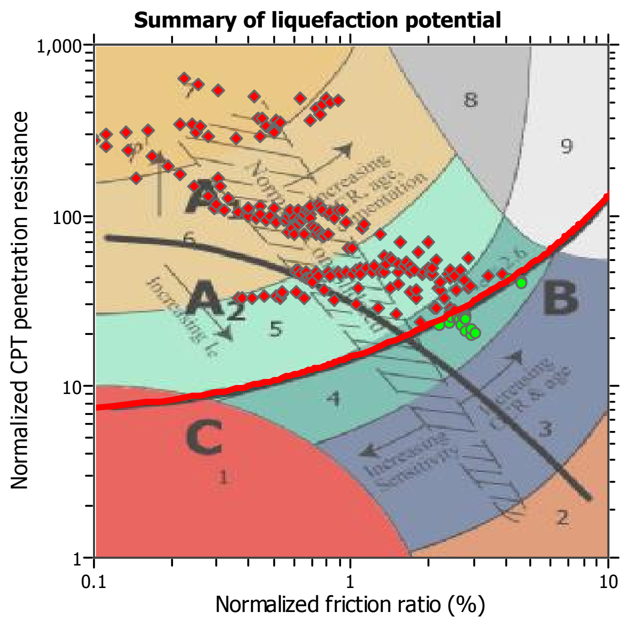
CPT file : CPT_15176

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	1.00 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	1.00 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:	7.50	Ic cut-off value:	2.60	Trans. detect. applied:	No	MSF method:	Method based
Peak ground acceleration:	0.35	Unit weight calculation:	Based on SBT	K_σ applied:	Yes		

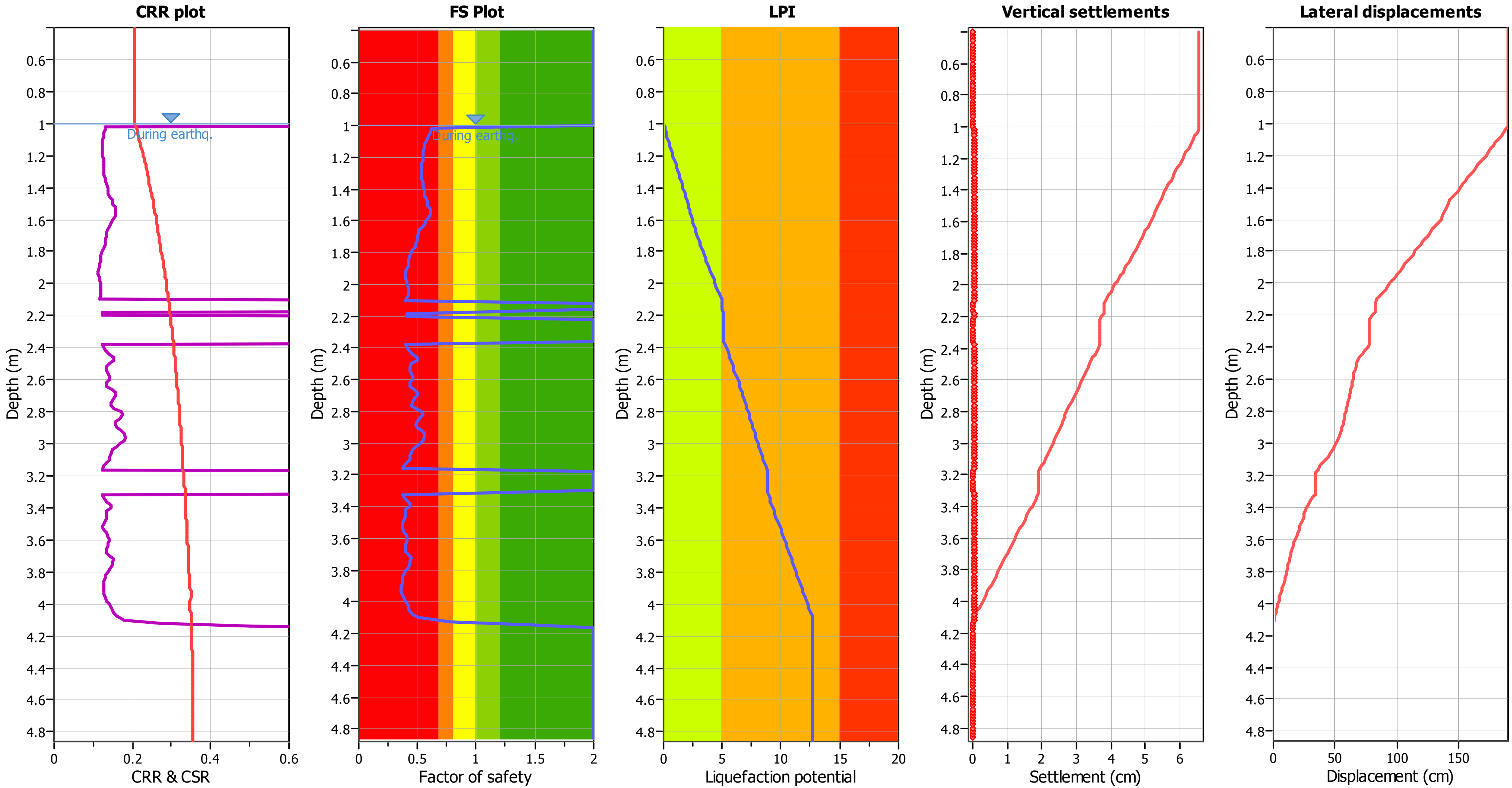






Zone A_1: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A_2: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and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

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.50	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.35	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 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

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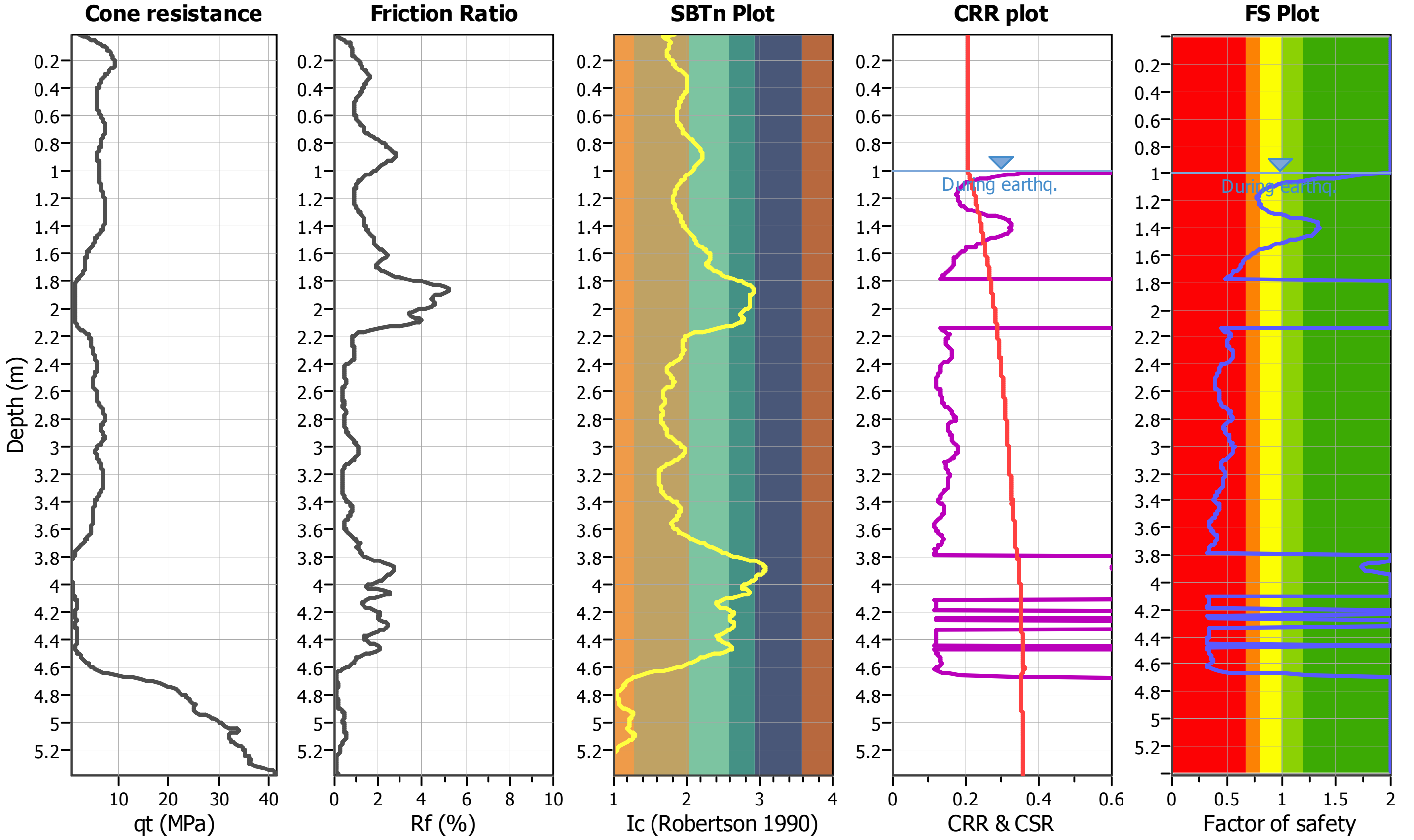
LIQUEFACTION ANALYSIS REPORT

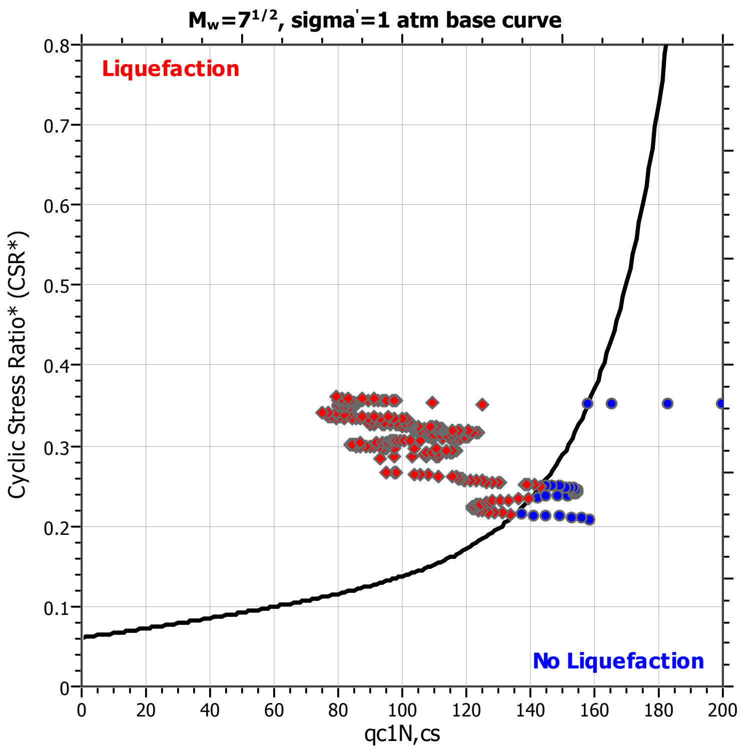
Project title : Dudley Creek **Location : CH2800**

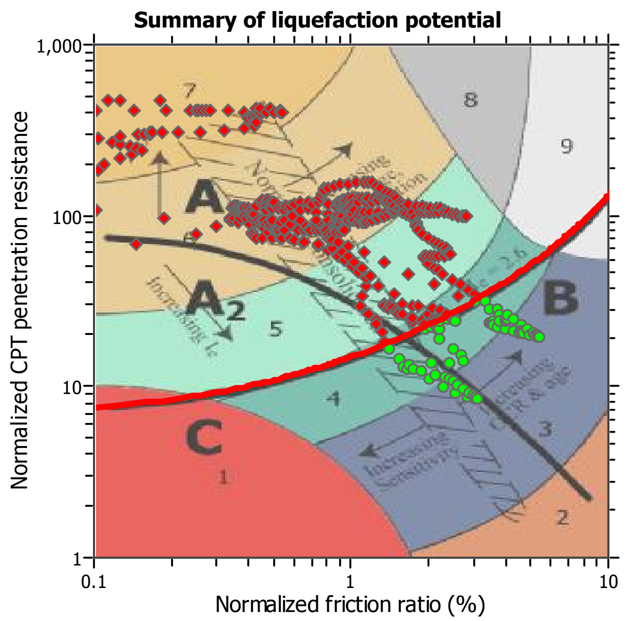
CPT file : CPT_36815

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	1.00 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	1.00 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:	7.50	Ic cut-off value:	2.60	Trans. detect. applied:	No	MSF method:	Method based
Peak ground acceleration:	0.35	Unit weight calculation:	Based on SBT	K_σ applied:	Yes		

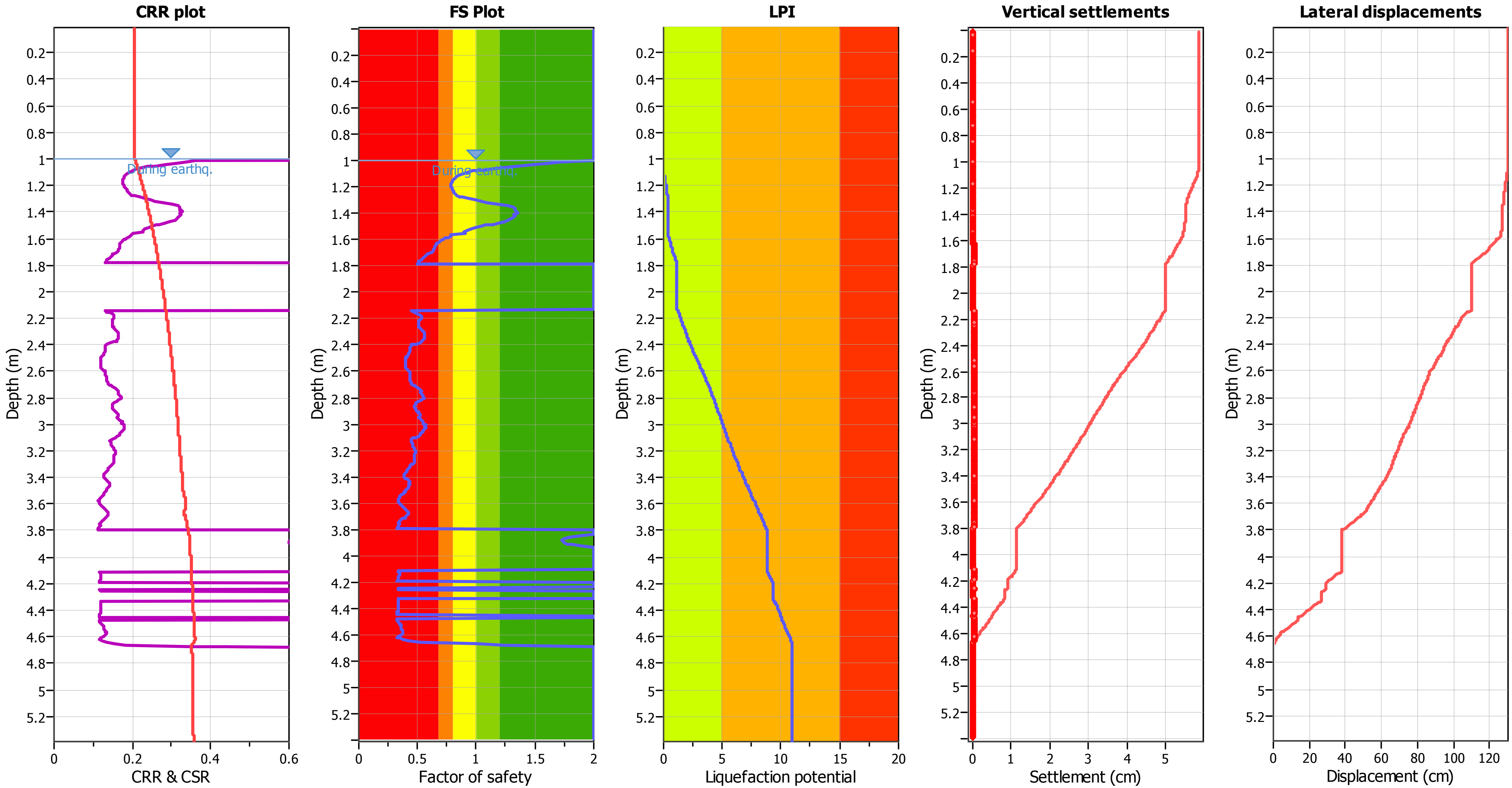






Zone A_1: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A_2: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and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

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.50	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.35	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 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

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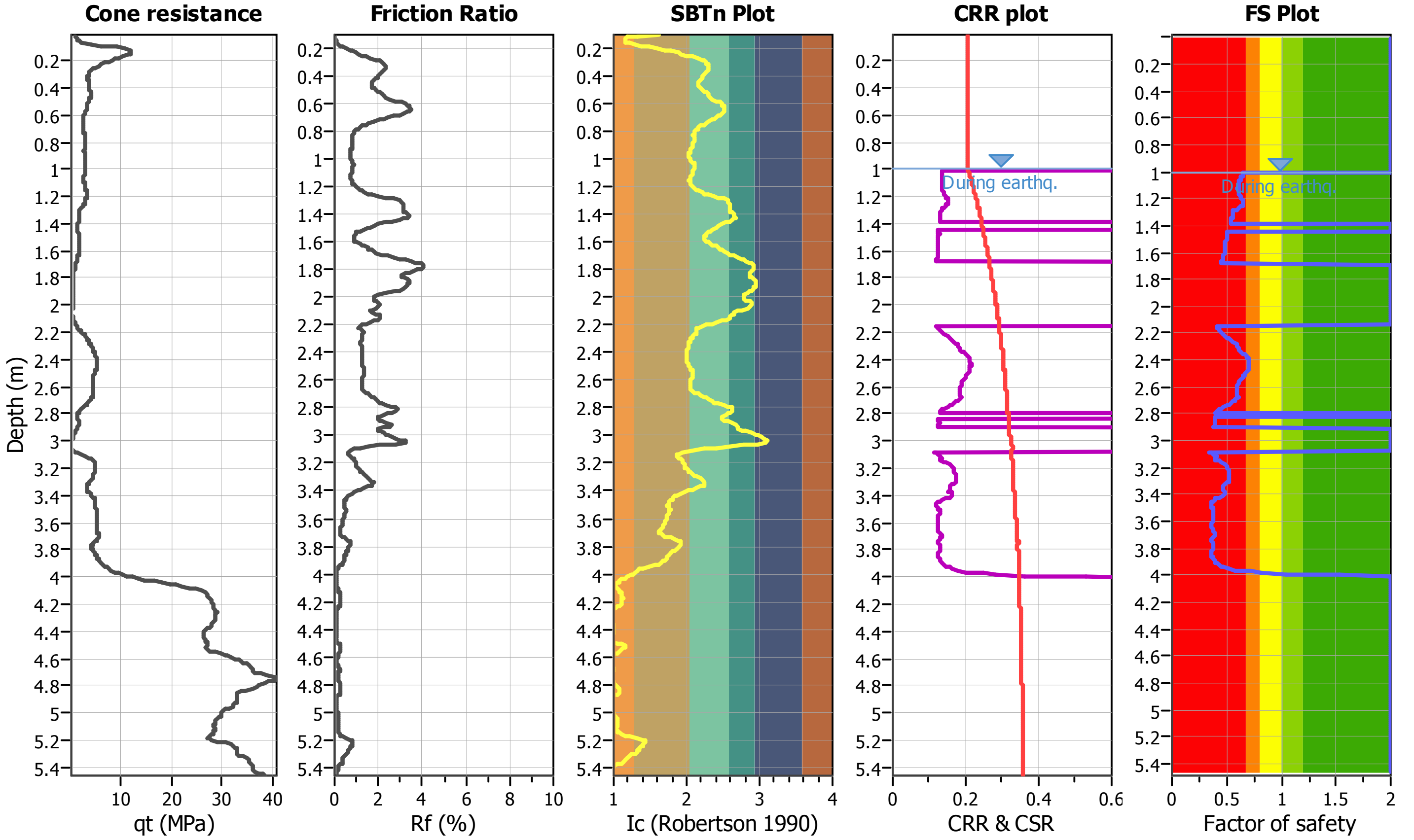
LIQUEFACTION ANALYSIS REPORT

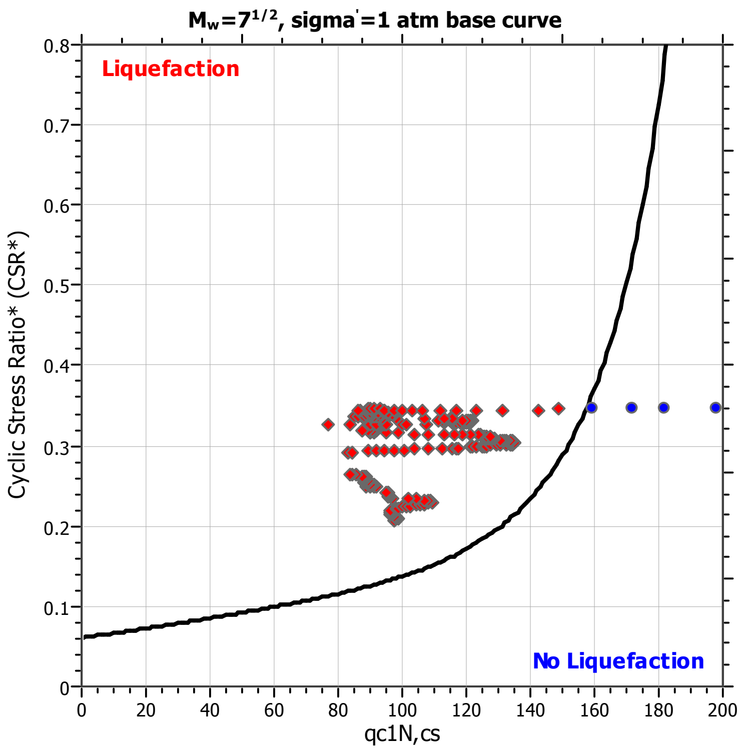
Project title : Dudley Creek **Location : CH2800**

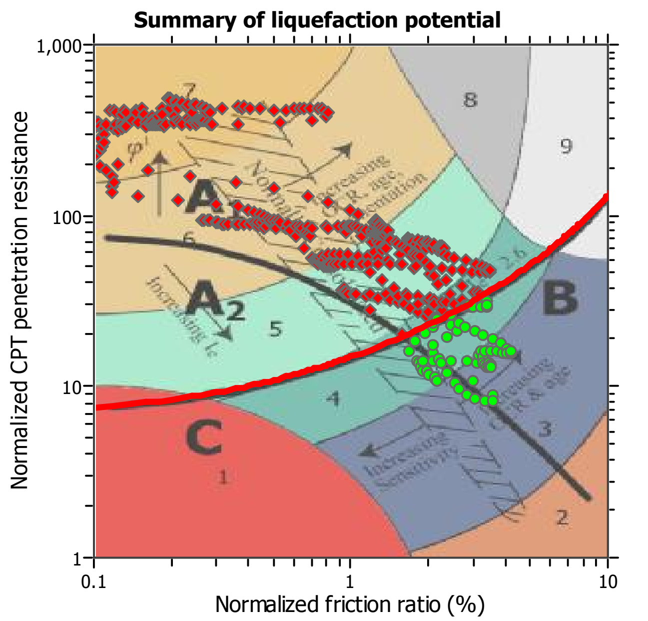
CPT file : CPT_36816

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	1.00 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	1.00 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:	7.50	Ic cut-off value:	2.60	Trans. detect. applied:	No	Limit depth:	N/A
Peak ground acceleration:	0.35	Unit weight calculation:	Based on SBT	K_σ applied:	Yes	MSF method:	Method based

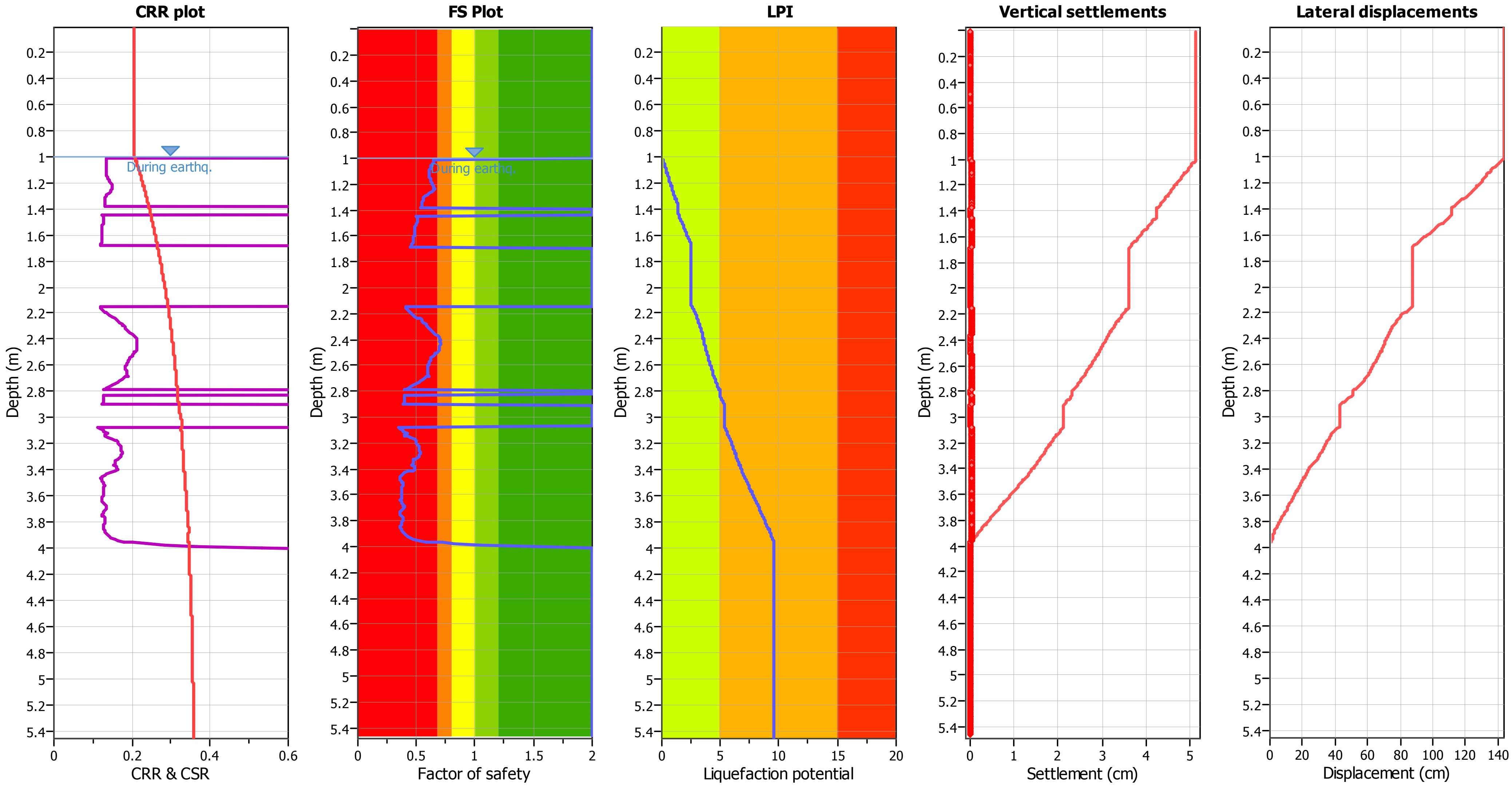






Zone A_1: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A_2: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and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

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.50	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.35	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 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

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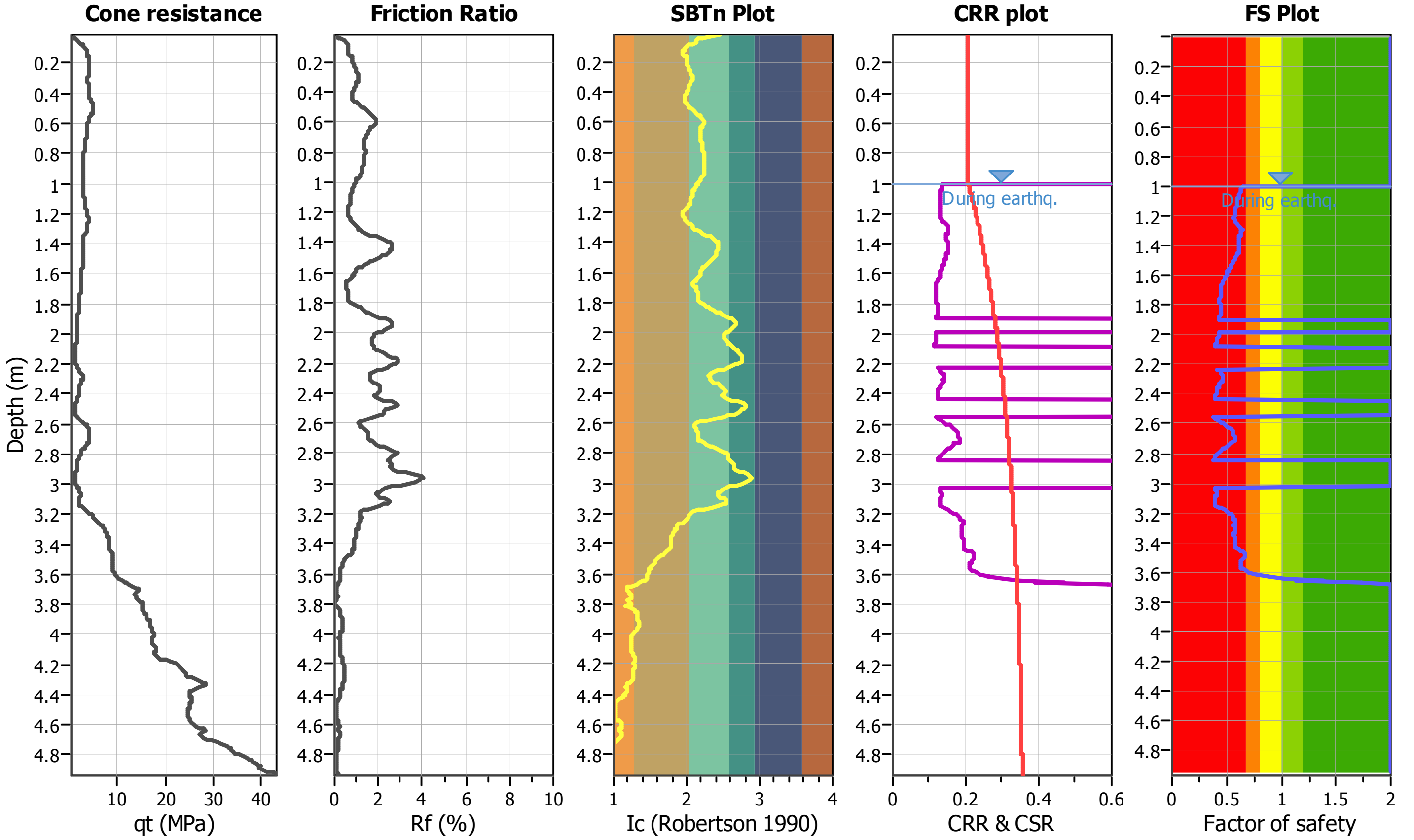
LIQUEFACTION ANALYSIS REPORT

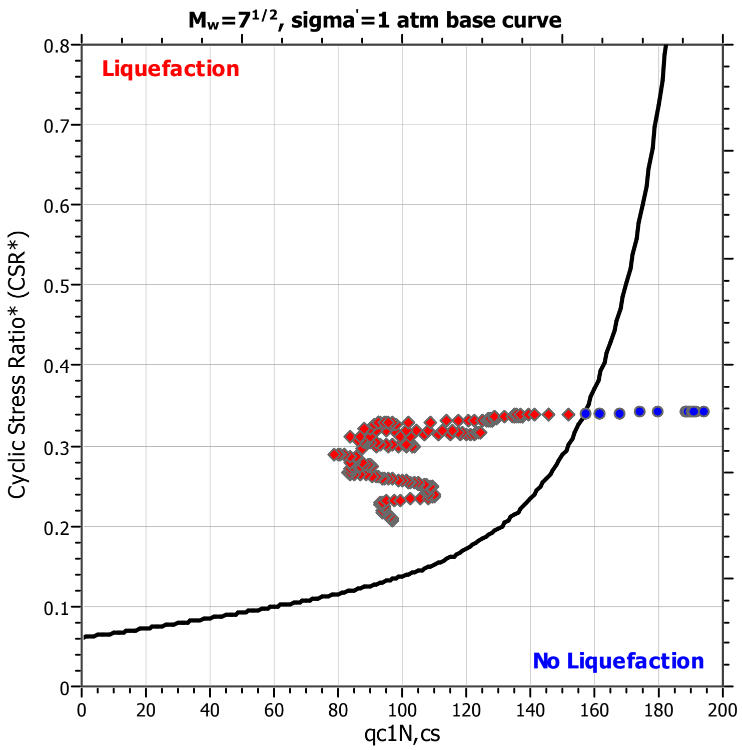
Project title : Dudley Creek **Location : CH2800**

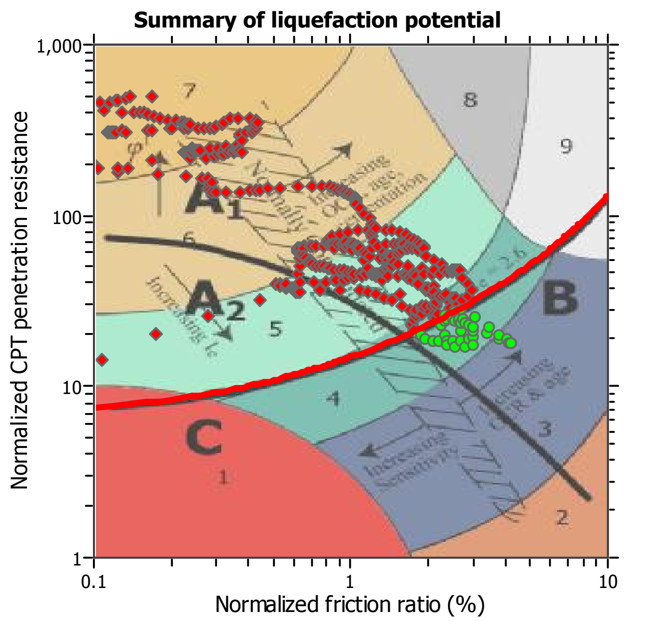
CPT file : CPT_36817

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	1.00 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	1.00 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:	7.50	Ic cut-off value:	2.60	Trans. detect. applied:	No	MSF method:	Method based
Peak ground acceleration:	0.35	Unit weight calculation:	Based on SBT	K_σ applied:	Yes		

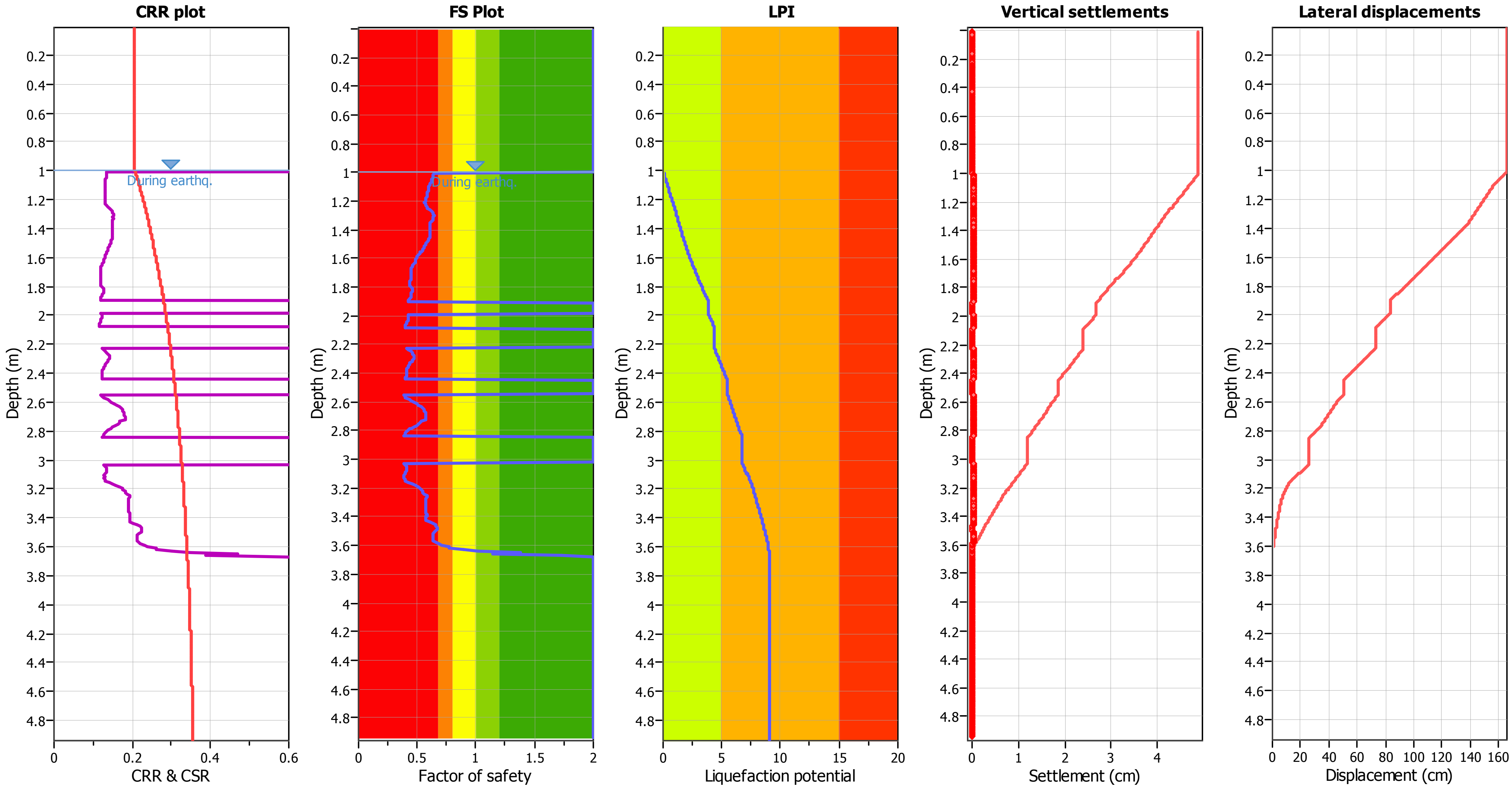






Zone A_1: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A_2: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and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

Liquefaction analysis overall plots



Input parameters and analysis data

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Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.50	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.35	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 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

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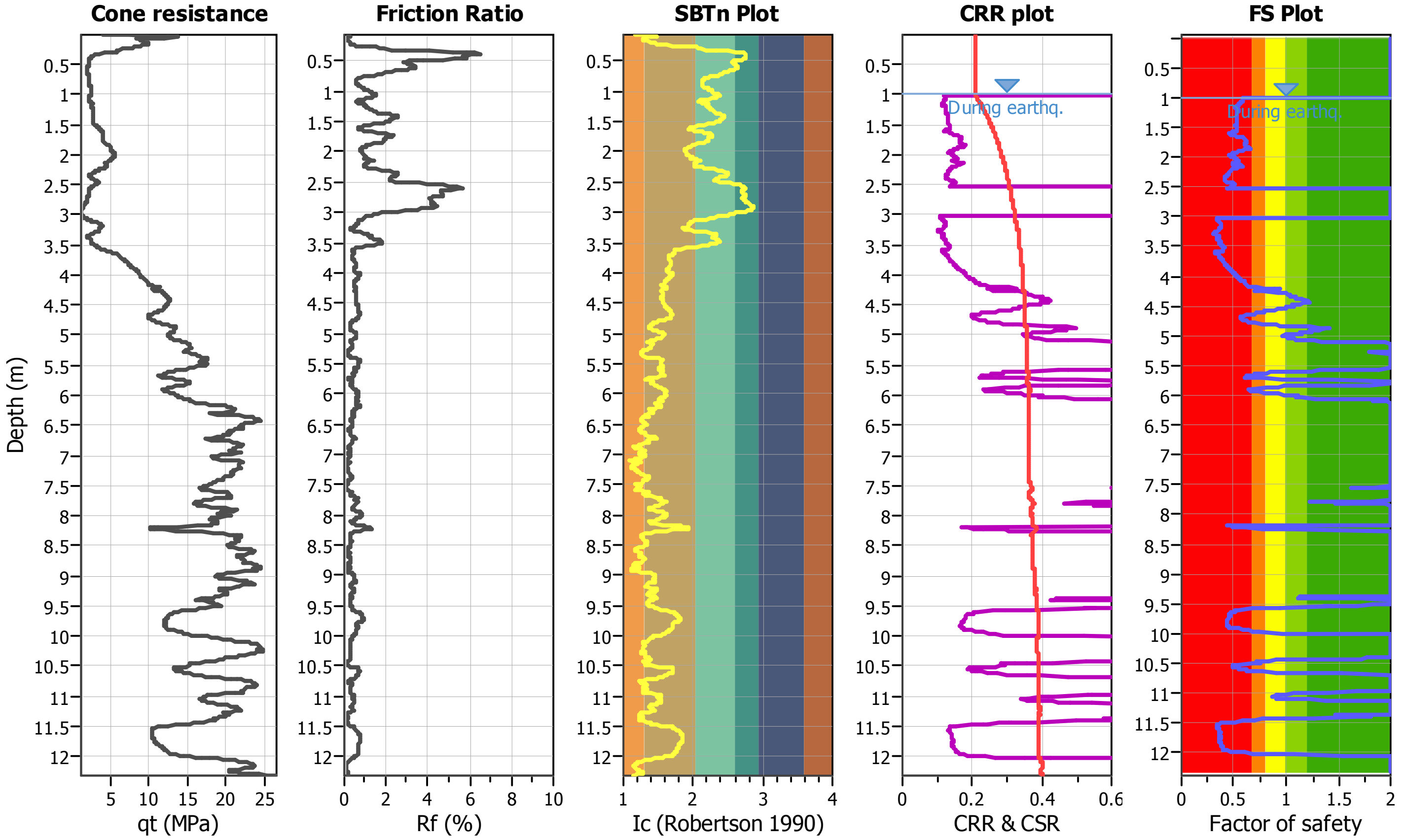
LIQUEFACTION ANALYSIS REPORT

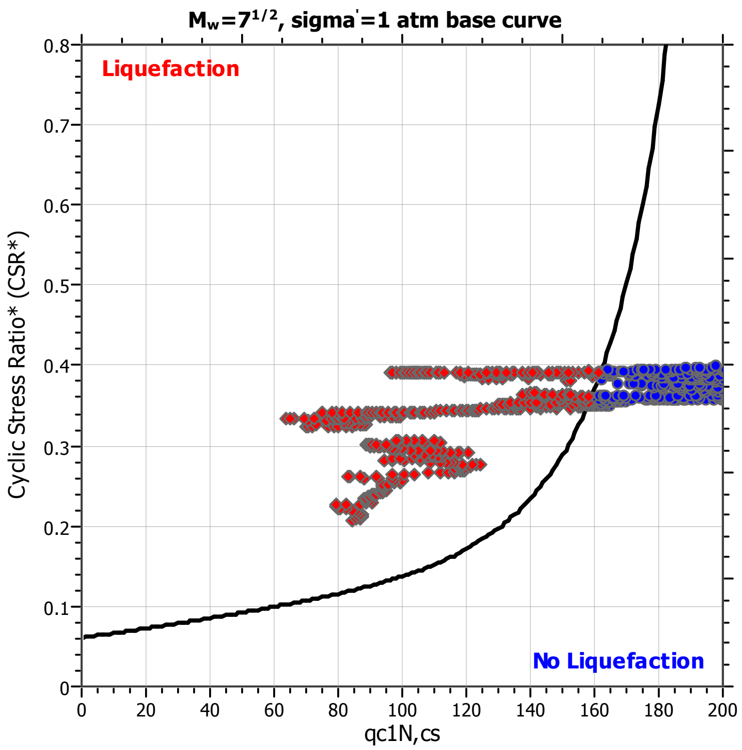
Project title : Dudley Creek **Location : CH4300**

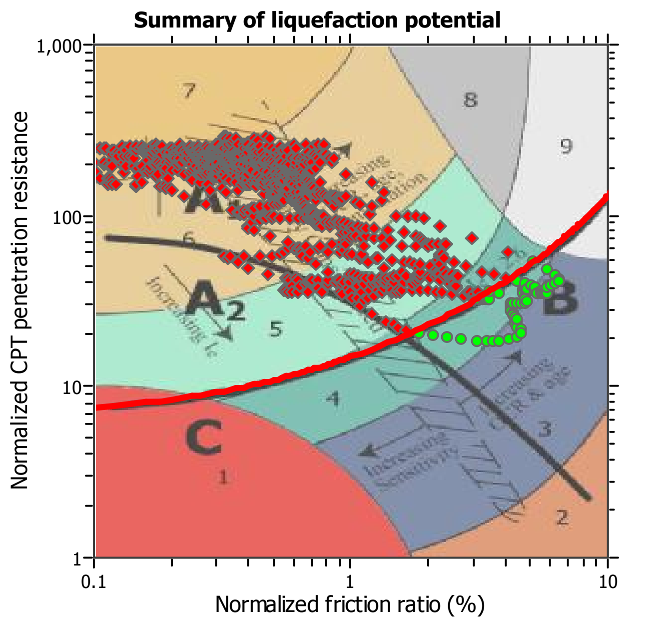
CPT file : CPT_16038

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	1.00 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	1.00 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:	7.50	Ic cut-off value:	2.60	Trans. detect. applied:	No	MSF method:	Method based
Peak ground acceleration:	0.35	Unit weight calculation:	Based on SBT	K_σ applied:	Yes		

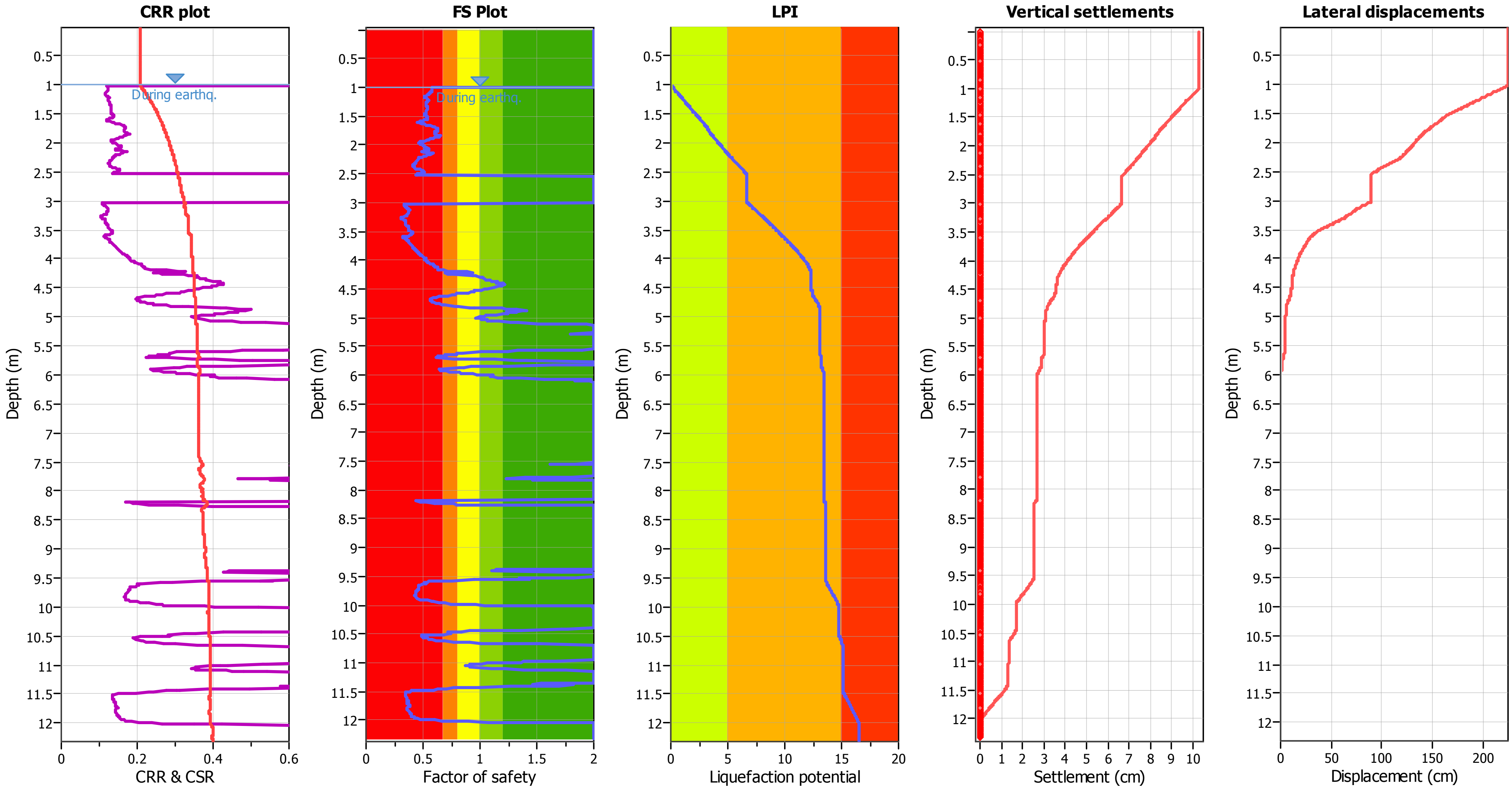






Zone A_1: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A_2: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and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

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.50	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.35	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 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

310 Colombo St
Christchurch
http://www.Beca.com

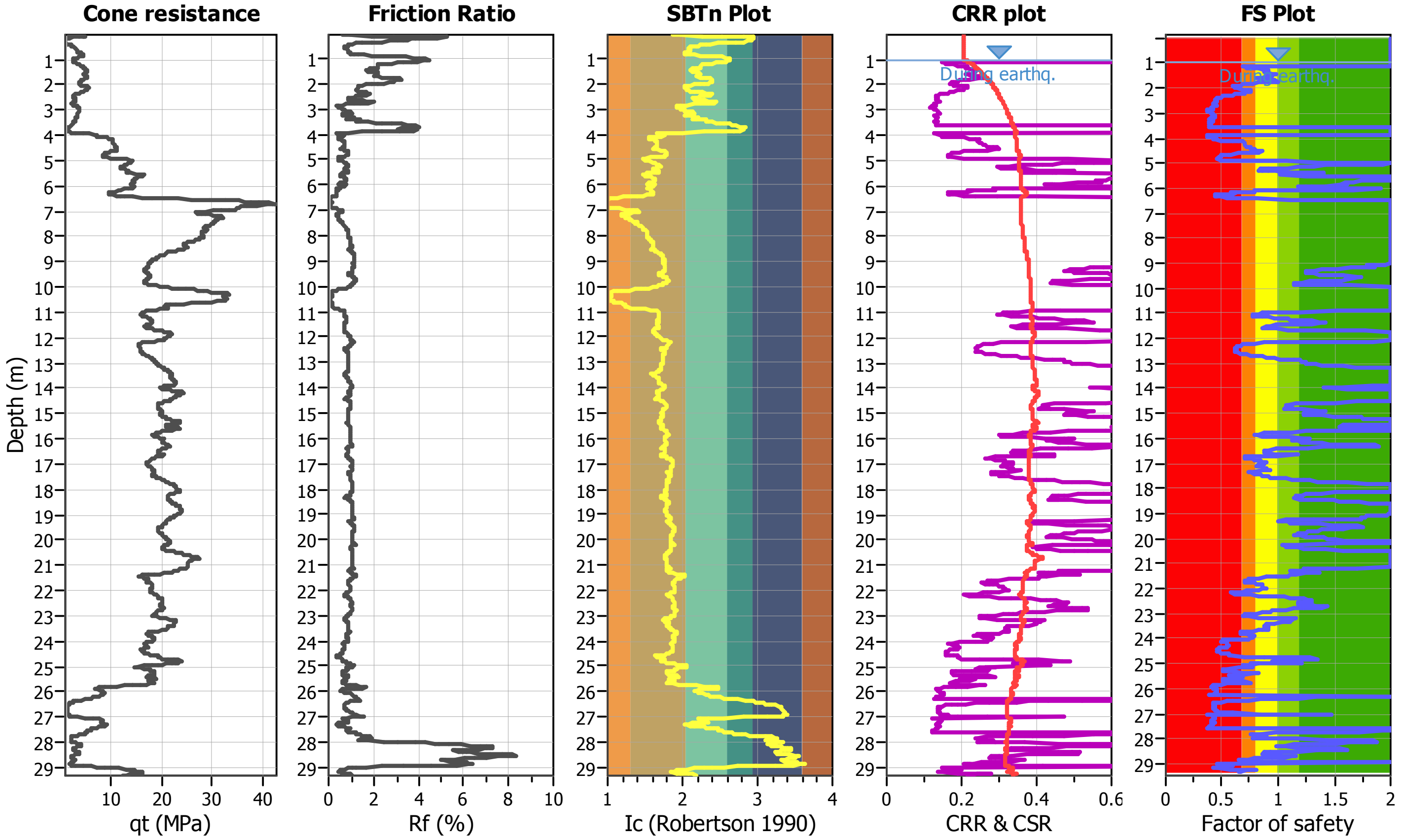
LIQUEFACTION ANALYSIS REPORT

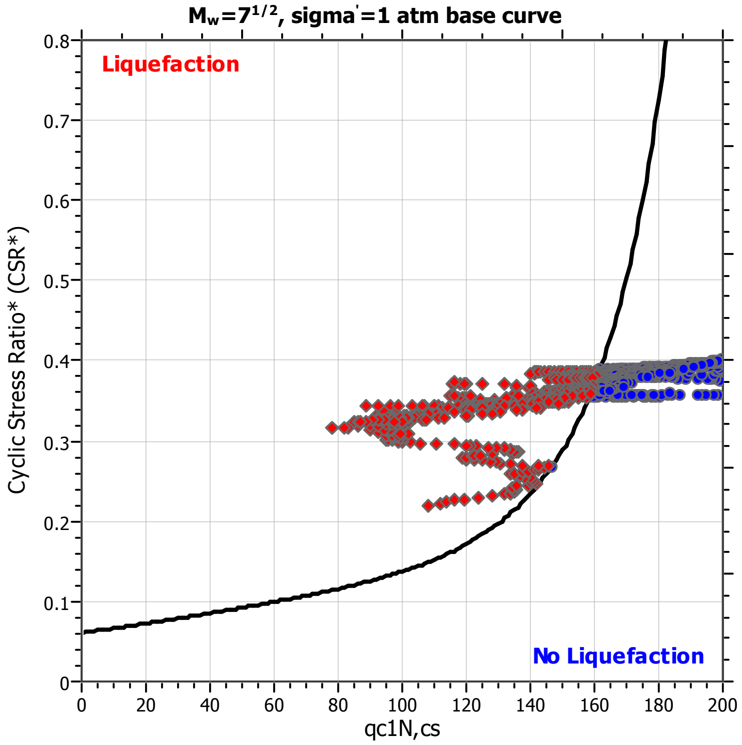
Project title : Dudley Creek **Location : CH4300**

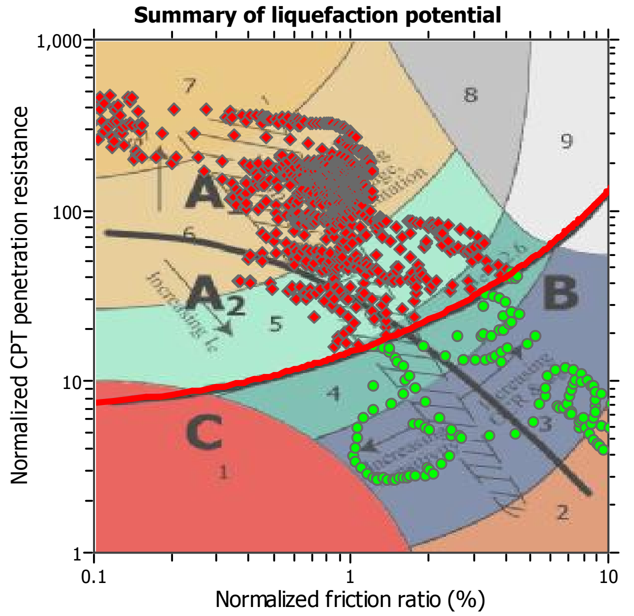
CPT file : CPT_29238

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	1.00 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	1.00 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:	7.50	Ic cut-off value:	2.60	Trans. detect. applied:	No	MSF method:	Method based
Peak ground acceleration:	0.35	Unit weight calculation:	Based on SBT	K_σ applied:	Yes		

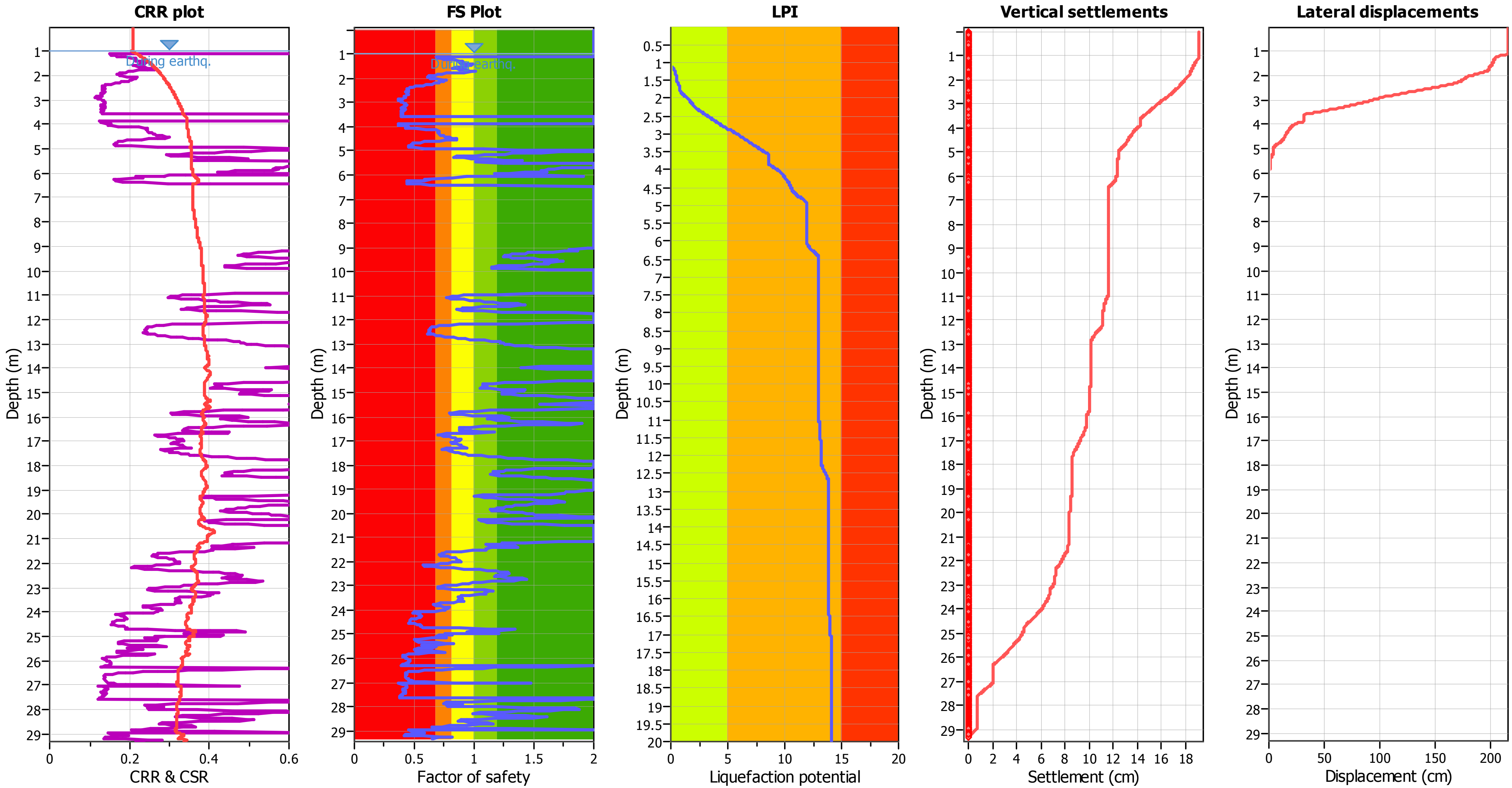






Zone A_1: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A_2: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and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

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.50	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.35	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 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

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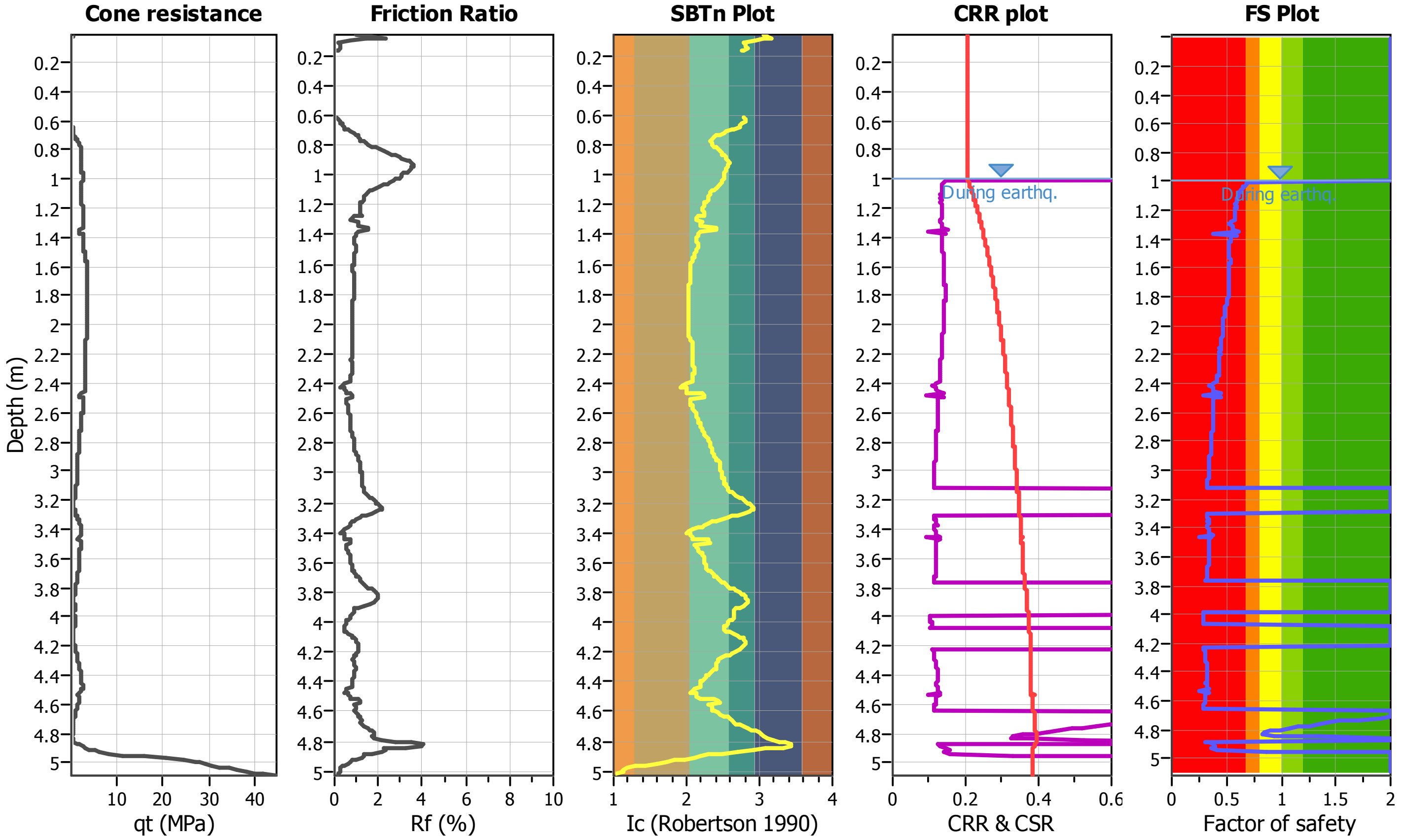
LIQUEFACTION ANALYSIS REPORT

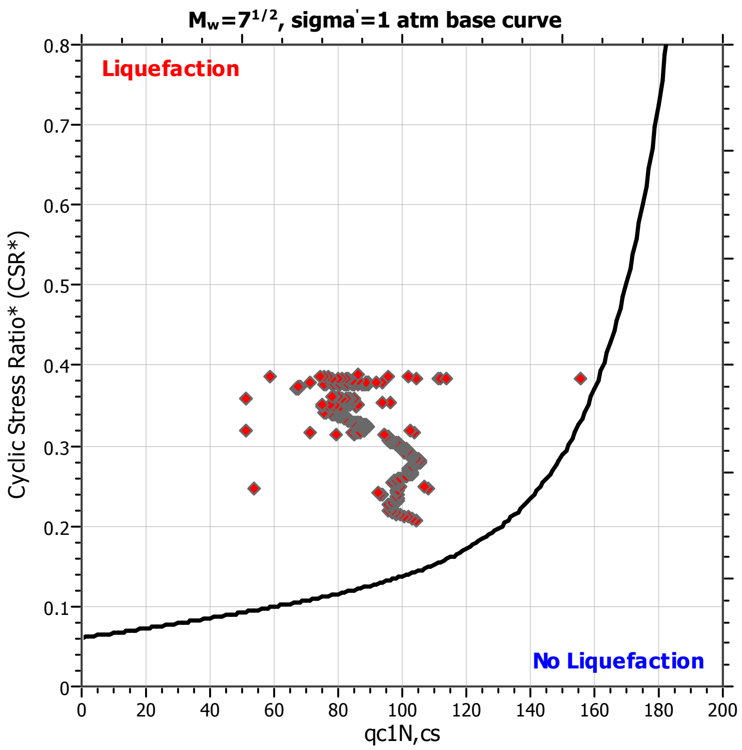
Project title : Dudley Creek **Location : CH4300**

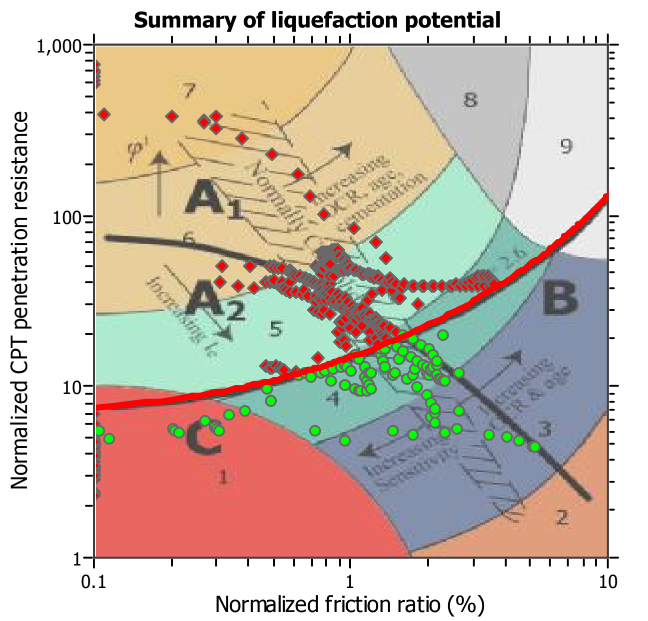
CPT file : CPT_523AGS01

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	1.00 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	1.00 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:	7.50	Ic cut-off value:	2.60	Trans. detect. applied:	No	Limit depth:	N/A
Peak ground acceleration:	0.35	Unit weight calculation:	Based on SBT	K_σ applied:	Yes	MSF method:	Method based

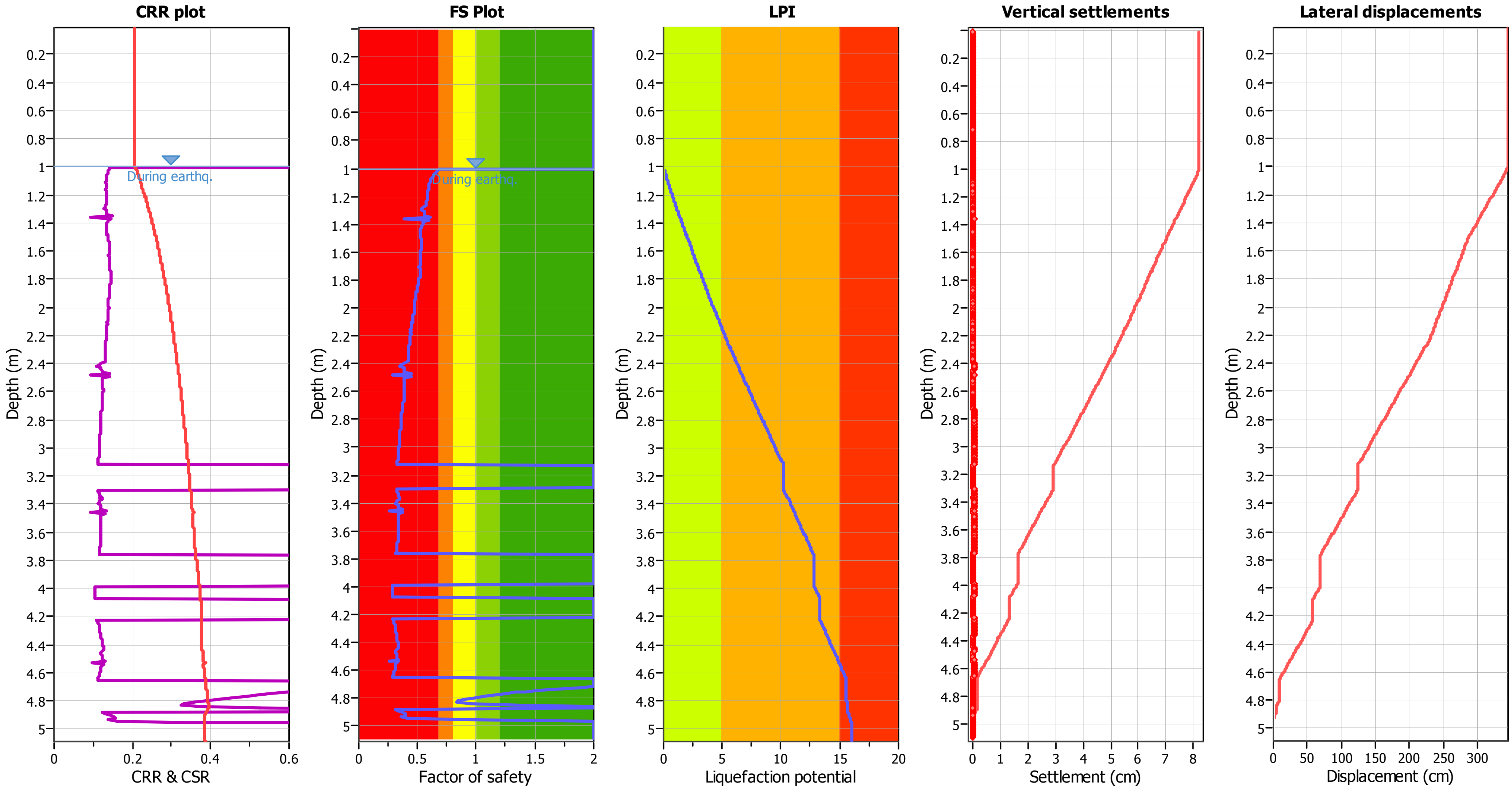






Zone A_1: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A_2: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and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

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.50	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.35	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 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

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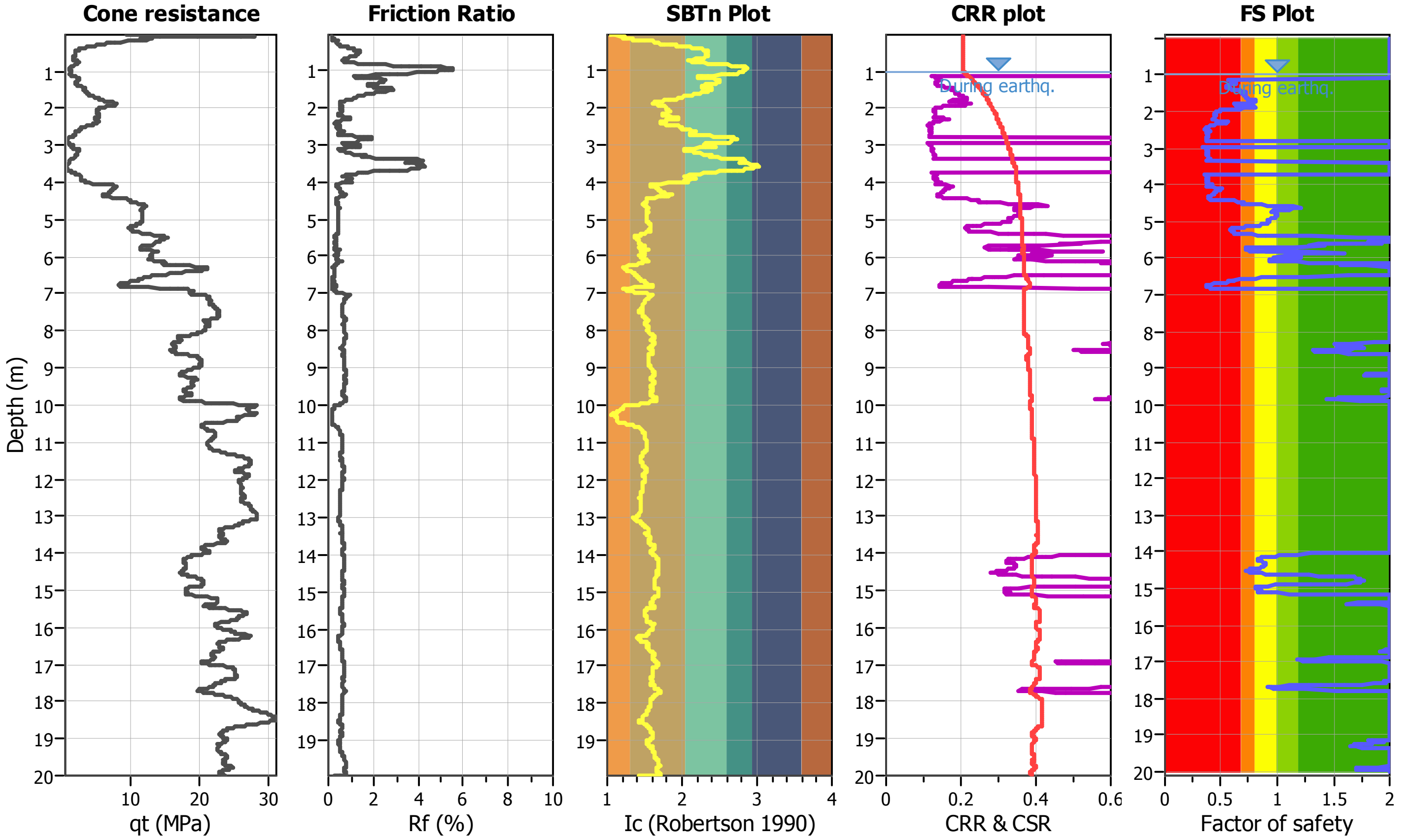
LIQUEFACTION ANALYSIS REPORT

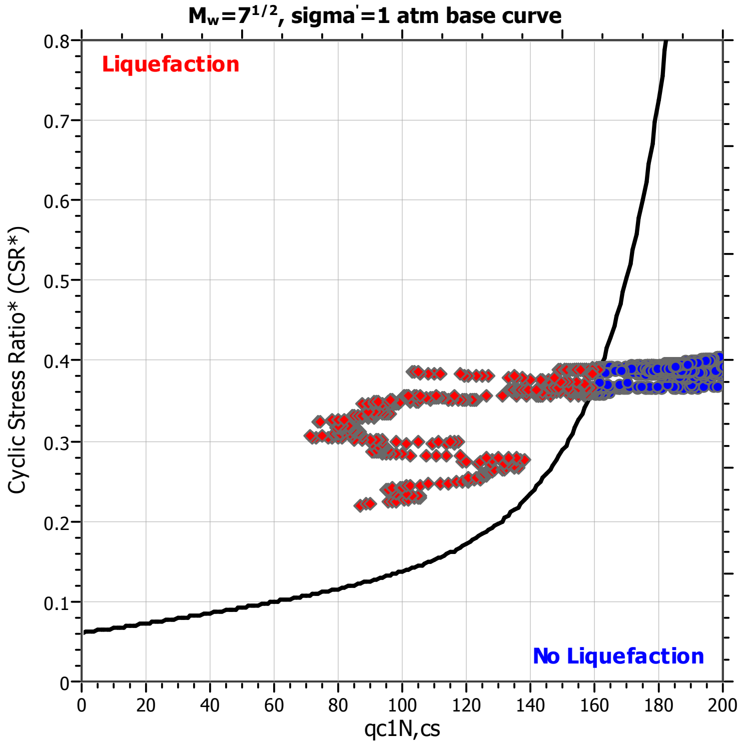
Project title : Dudley Creek **Location : CH4300**

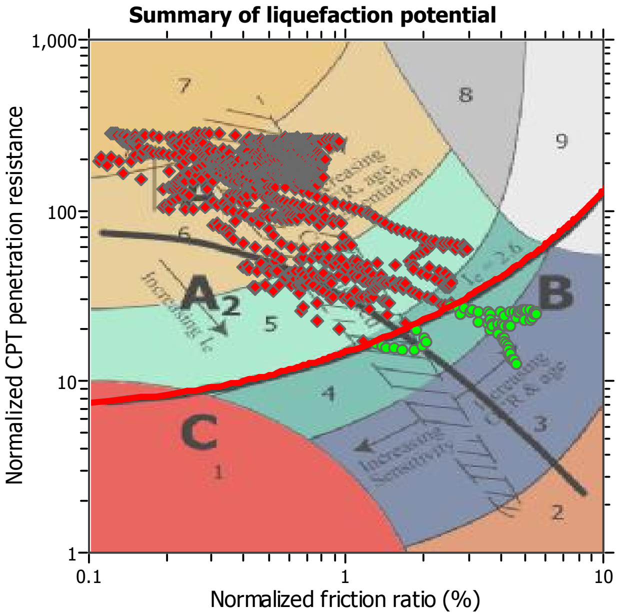
CPT file : CPT_5482_AGS01

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	1.00 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	1.00 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:	7.50	Ic cut-off value:	2.60	Trans. detect. applied:	No	MSF method:	Method based
Peak ground acceleration:	0.35	Unit weight calculation:	Based on SBT	K_σ applied:	Yes		

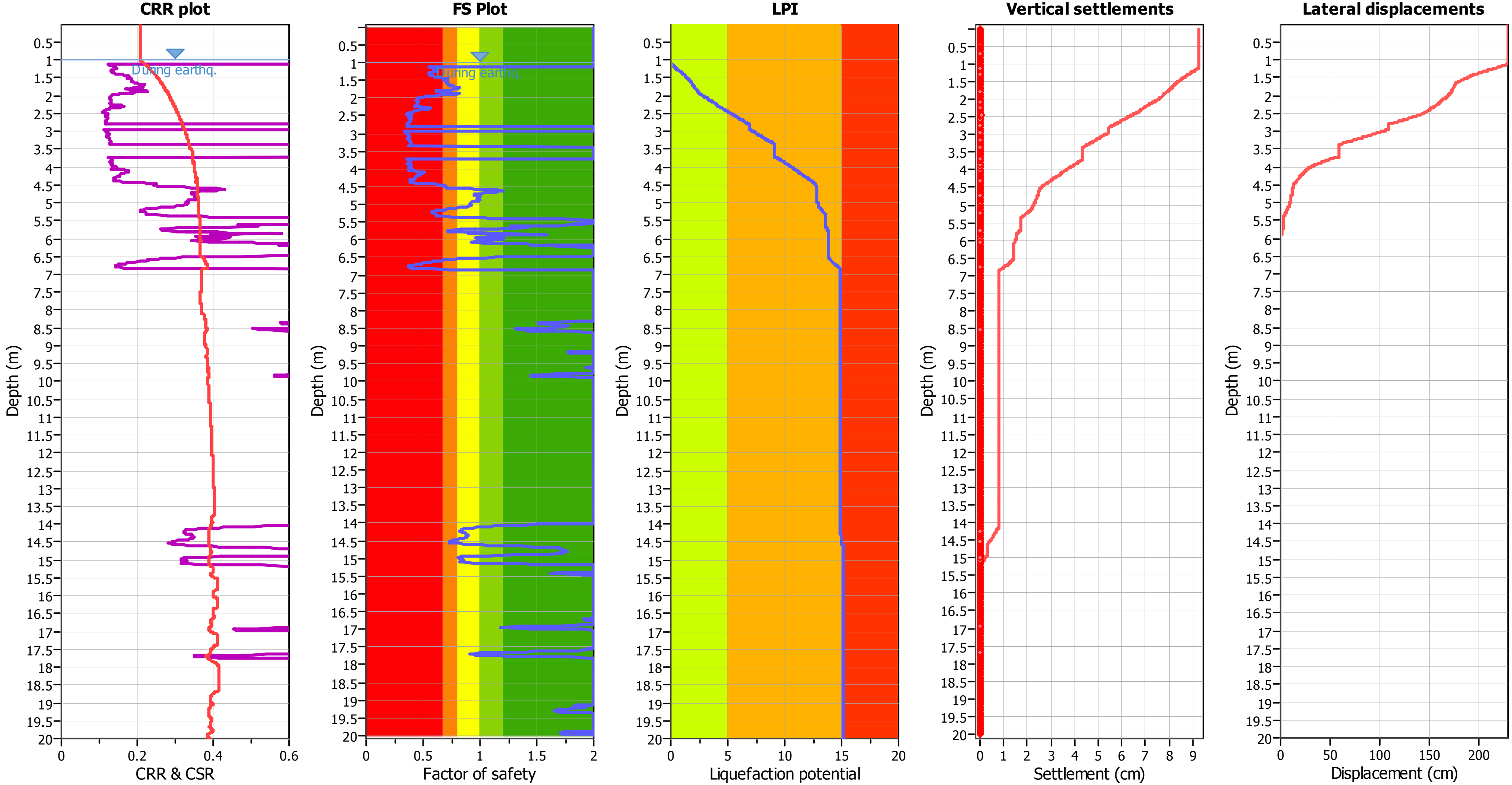






Zone A_1: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A_2: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and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

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.50	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.35	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 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

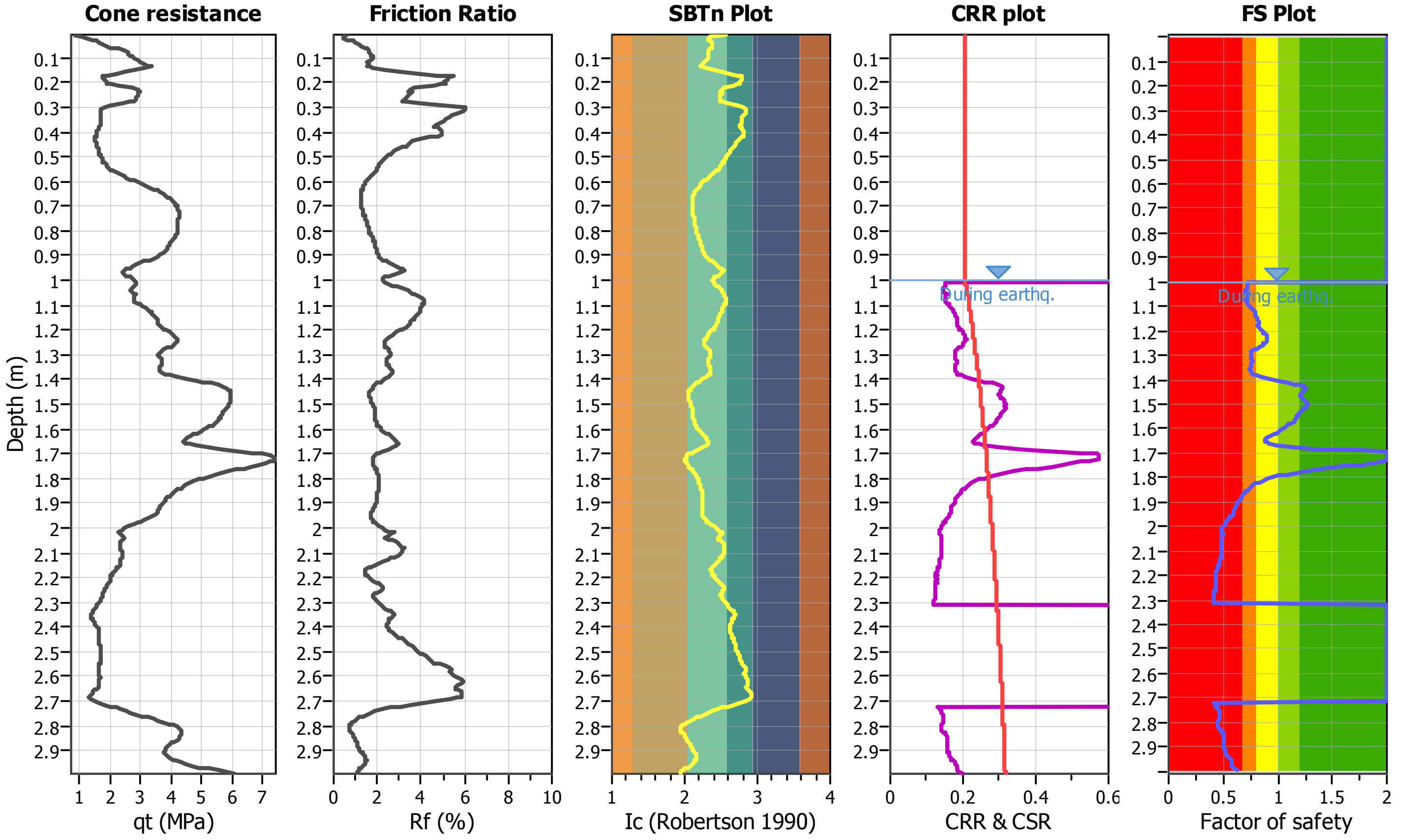
LIQUEFACTION ANALYSIS REPORT

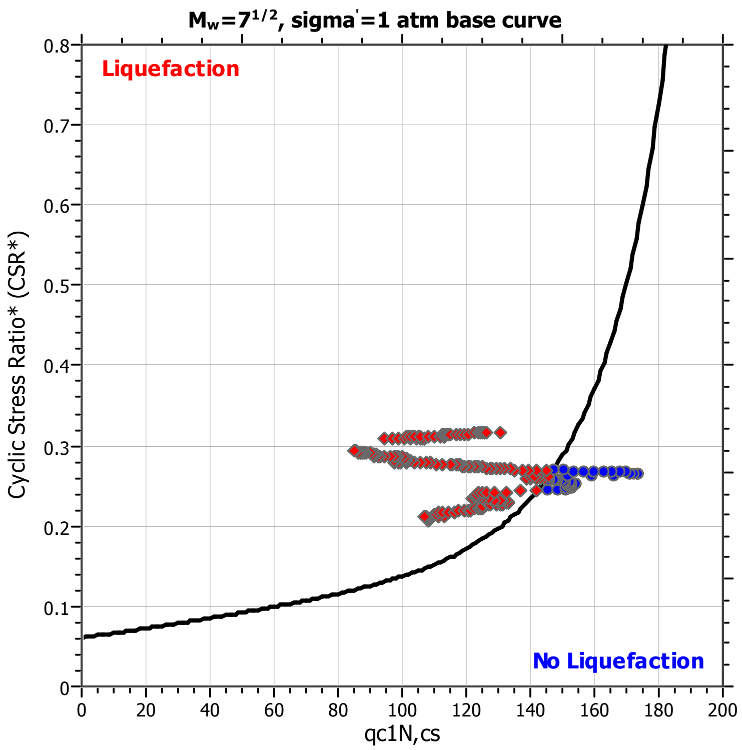
Project title : Dudley Creek **Location : CH4300**

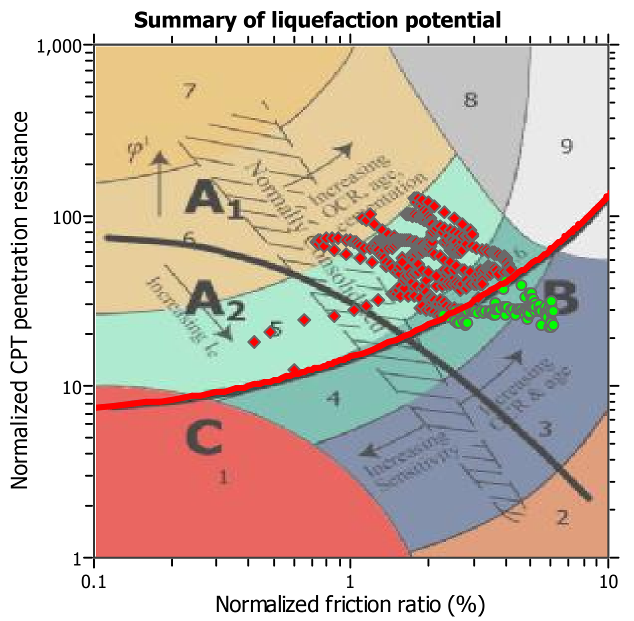
CPT file : CPT_8066_Raw01

Input parameters and analysis data

Analysis method:	B&I (2014)	G.W.T. (in-situ):	1.00 m	Use fill:	No	Clay like behavior applied:	Sand & Clay
Fines correction method:	B&I (2014)	G.W.T. (earthq.):	1.00 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:	7.50	Ic cut-off value:	2.60	Trans. detect. applied:	No	MSF method:	Method based
Peak ground acceleration:	0.35	Unit weight calculation:	Based on SBT	K_σ applied:	Yes		

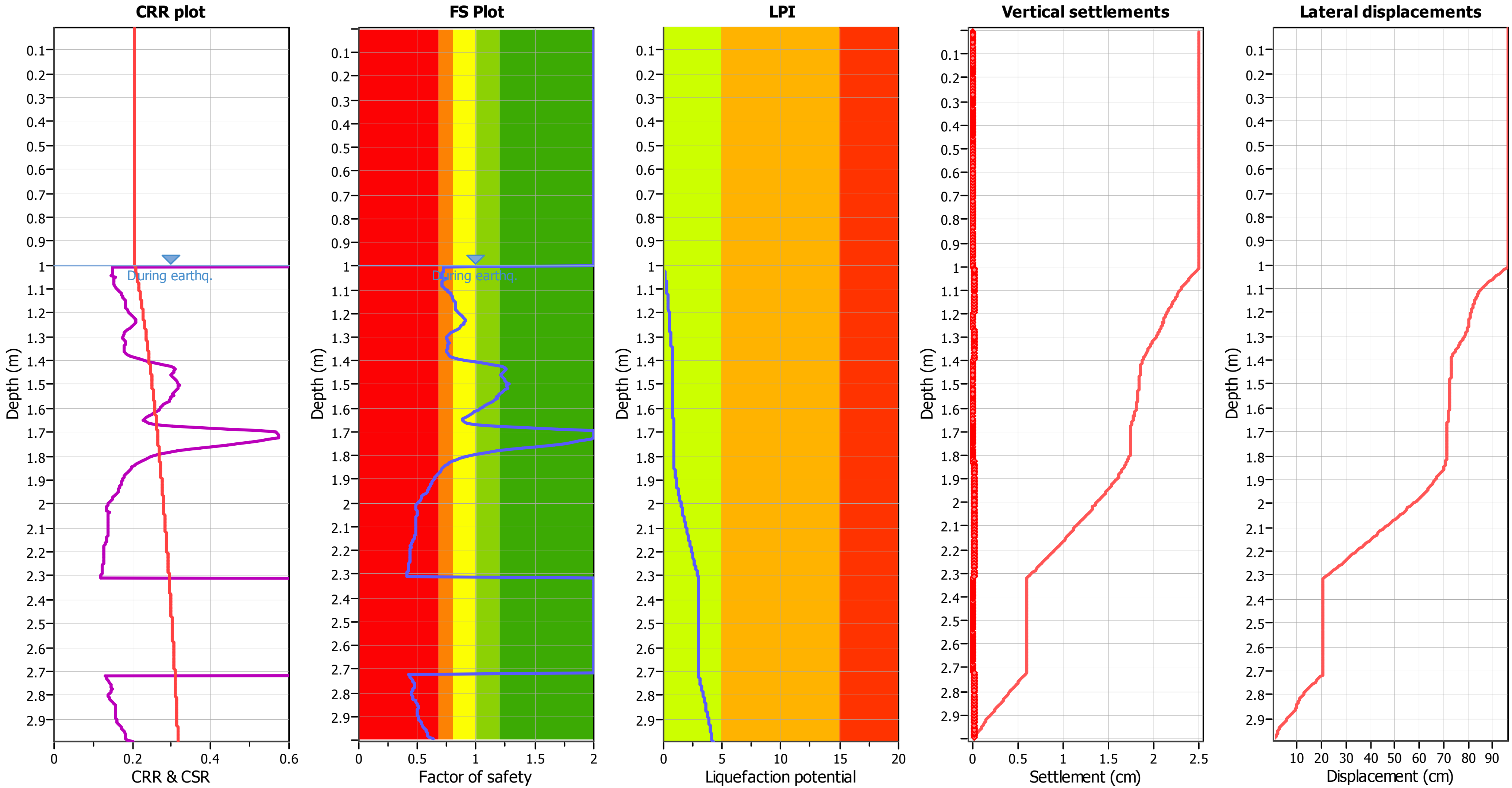






Zone A_1: Cyclic liquefaction likely depending on size and duration of cyclic loading
Zone A_2: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
Zone C: Cyclic liquefaction and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

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	B&I (2014)	Depth to GWT (erthq.):	1.00 m	Fill weight:	N/A
Fines correction method:	B&I (2014)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.50	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sand & Clay
Peak ground acceleration:	0.35	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.00 m	Fill height:	N/A	Limit depth:	N/A

F.S. color scheme

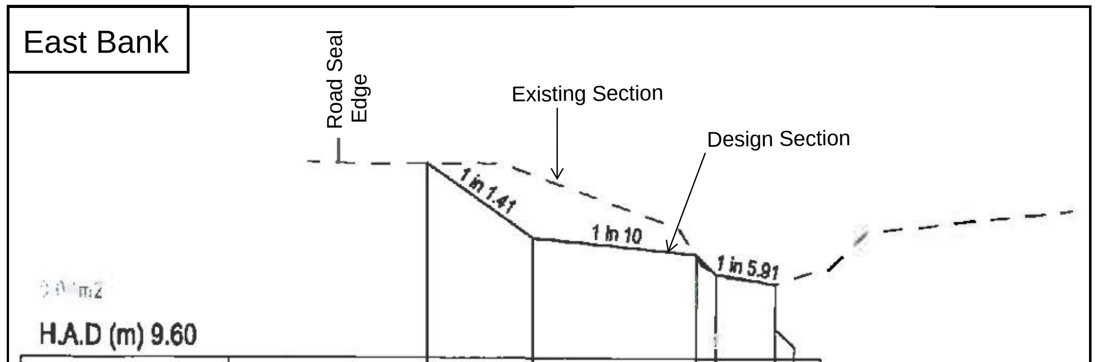
- Almost certain it will liquefy
- Very likely to liquefy
- Liquefaction and no liq. are equally likely
- Unlike to liquefy
- Almost certain it will not liquefy

LPI color scheme

- Very high risk
- High risk
- Low risk

Appendix D

Slope Stability Modelling



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EXISTING LEVELS	12.90	12.69	11.30	11.02	10.85	10.85
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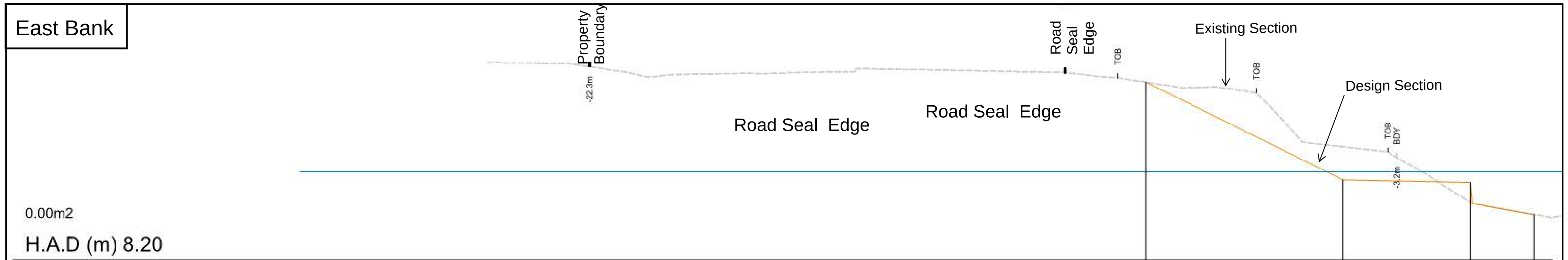
Approximate Project Chainage 2900.00 - Stapletons Road



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EXISTING LEVEL	12.43	10.90	9.58	9.29
OFFSET (m)	-9.16	-4.51	-1.51	0.00

Approximate Project Chainage 4300.00 - Banks Avenue

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PDF ONLY
NO DWG FILE

No.	Revision	By	Chk	Appd	Date
A	ISSUED FOR INFORMATION	BE	MG	MG	29/05/15

Drawing Originator: Beca

Not to Scale

Design	BE	29/05/15	Approved For Construction*
Drawn	BE	29/05/15	
Dsg Verifier	MG	29/05/15	
Dwg Check	MG	29/05/15	Date

* Refer to Revision 1 for Original Signature

Client: Christchurch City Council

Project: Dudley Creek Flood Remediation

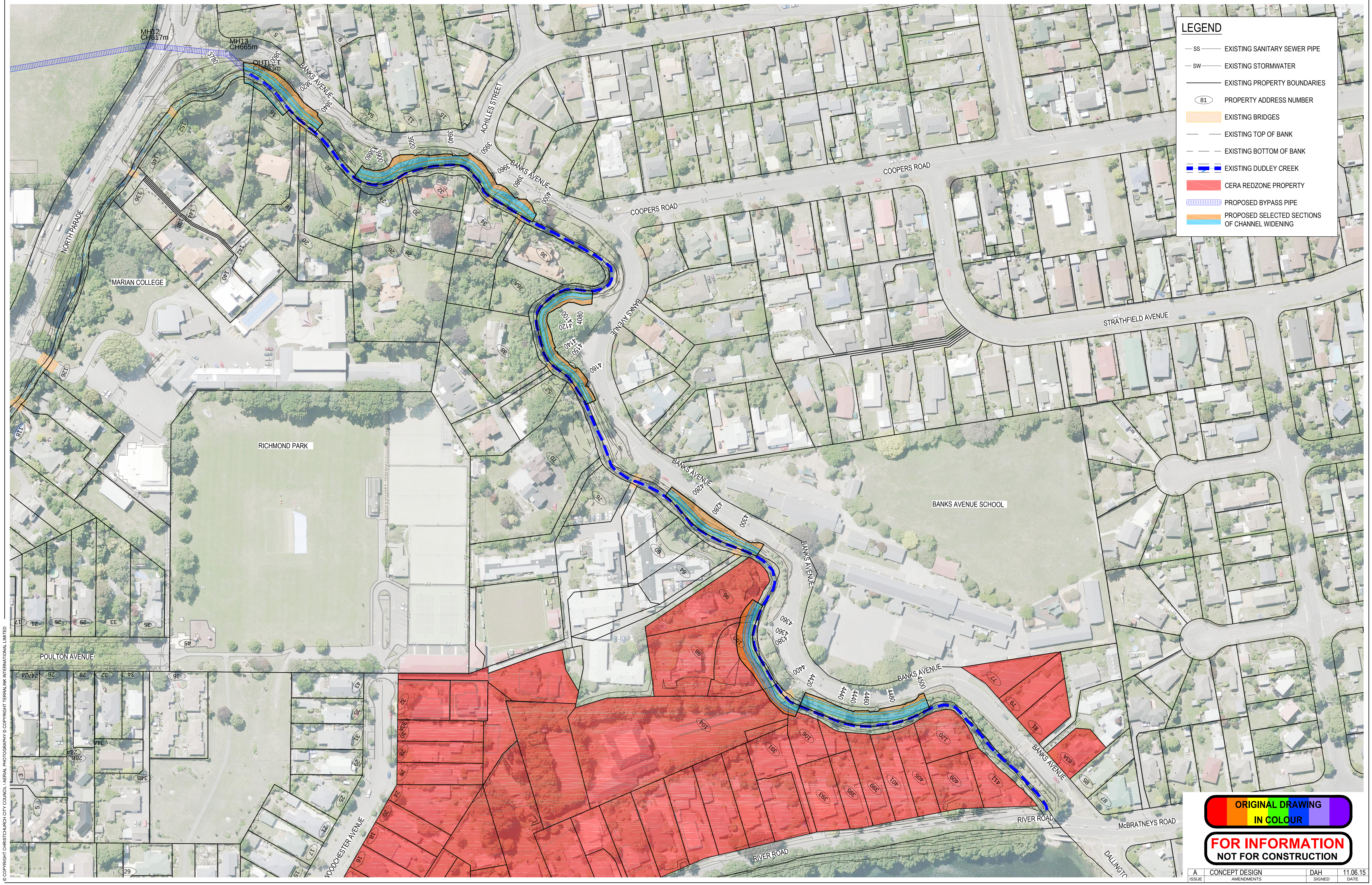
Title: Geotechnical Assessment Cross Sections

Discipline: GEOTECHNICAL

Drawing No. 3384543-G001

Rev. A

BLUEBEAM



ISSUE	AMENDMENTS	SIGNED	DATE
A	CONCEPT DESIGN	DAH	11.06.15

Christchurch City Council
CAPITAL PROGRAMME GROUP

			NAME	SIGNED	DATE
DATUM					
BENCH MK.		DESIGNED	DJG	DJG	06.2015
RL		DES. REVIEW	DAH	DAH	06.2015
SURVEY		DRAWN	DLM	DLM	06.2015
SURVEY LB		DRW. CHECK	DJG	DJG	06.2015
		FILE LOCATION	S:\300 Drawings\CAD\		
DRAIN. REF.		3384543-CE-010.dwg			
SAP WBS		PRINTED ON 11-Jun-15 BY DLM1			

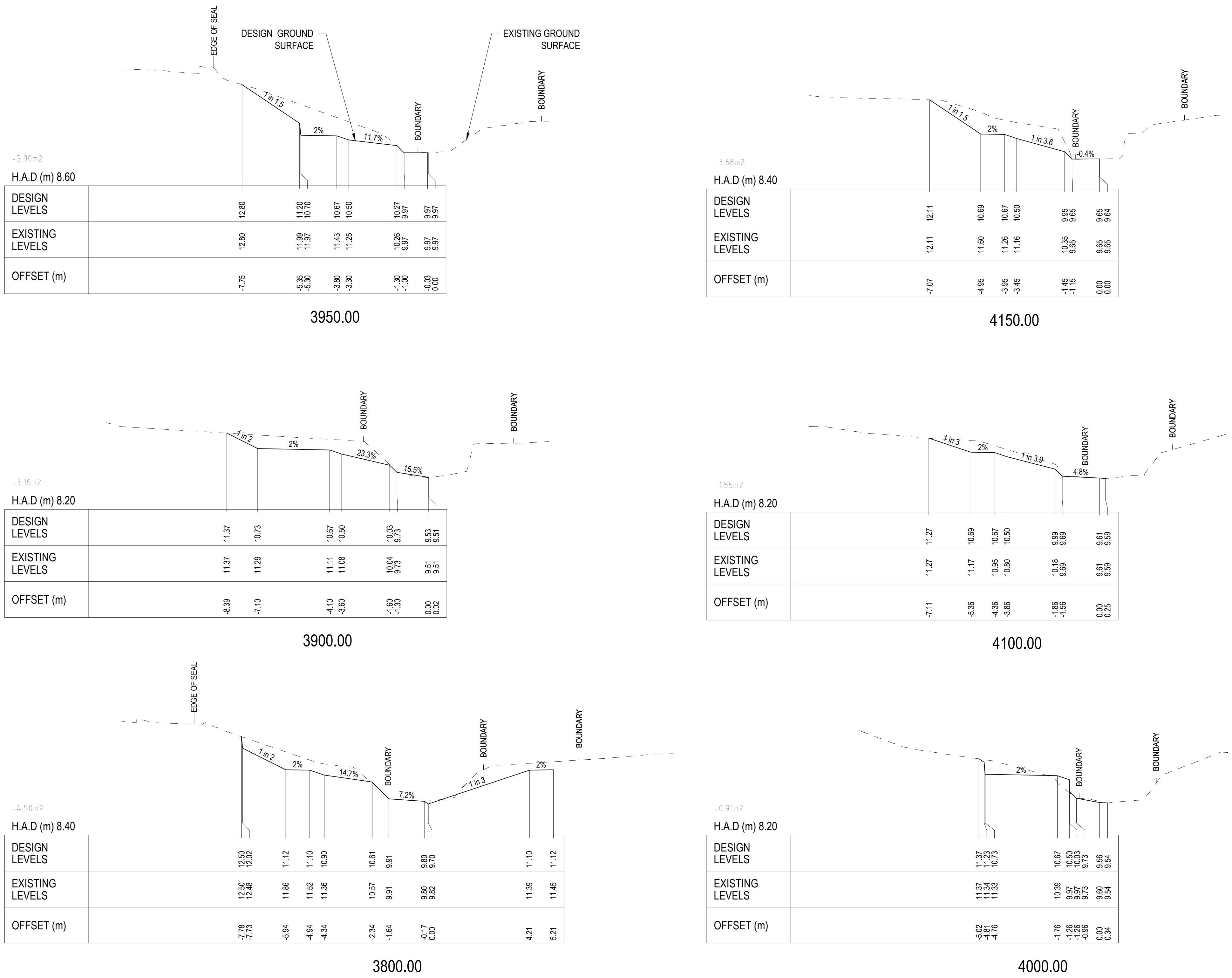
APPROVED
FOR TENDER — DATE / SIGNED
FOR CONSTRUCTION — DATE / SIGNED

CONSULTANT: Beca | OPUS
CONSULTANT PROJECT REF. 3384543 / 3C1262.00
CONSULTANT FILE REF. S:\300 Drawings\CAD

PROJECT TITLE
DUDLEY CREEK FLOOD REMEDIATION

DRAWING TITLE
OPTION A - BANKS AVENUE PLAN

CONTRACT NUMBER 14/15-192
CAD DRAWING FILE REF. 3384543-CE-010
ORIGINAL SHEET SIZE A1
SCALES 1:1000 @ A1
CPG PROJECT FILE NUMBER CP502630
SHEET 1 OF 1



FOR INFORMATION
NOT FOR CONSTRUCTION

ISSUE	AMENDMENTS	SIGNED	DATE
A	CONCEPT DESIGN	DAH	11.06.15

Christchurch City Council
CAPITAL PROGRAMME GROUP

			NAME	SIGNED	DATE
DATUM					
BENCH MK.		DESIGNED	DJG	DJG	06.2015
RL		DES. REVIEW	DAH	DAH	06.2015
SURVEY		DRAWN	DLM	DLM	06.2015
SURVEY LB		DRW. CHECK	DJG	DJG	06.2015
		FILE LOCATION	S:\300 Drawings\CAD\		
DRAIN. REF.			3384543-CE-011.dwg		
SAP WBS		PRINTED ON	11-Jun-15 BY DLM1		

APPROVED
FOR TENDER
DATE SIGNED
FOR CONSTRUCTION
DATE SIGNED

CONSULTANT
Beca OPUS
CONSULTANT PROJECT REF. 3384543 / 3C1262.00
CONSULTANT FILE REF. S:\300 Drawings\CAD

PROJECT TITLE
DUDLEY CREEK FLOOD REMEDIATION

DRAWING TITLE
OPTION A - BANKS AVENUE
CROSS SECTIONS

CONTRACT NUMBER 14/15-192
CAD DRAWING FILE REF. 3384543-CE-011
ORIGINAL SHEET SIZE A1
SCALES 1:100 H @ A1 1:1 V @ A1
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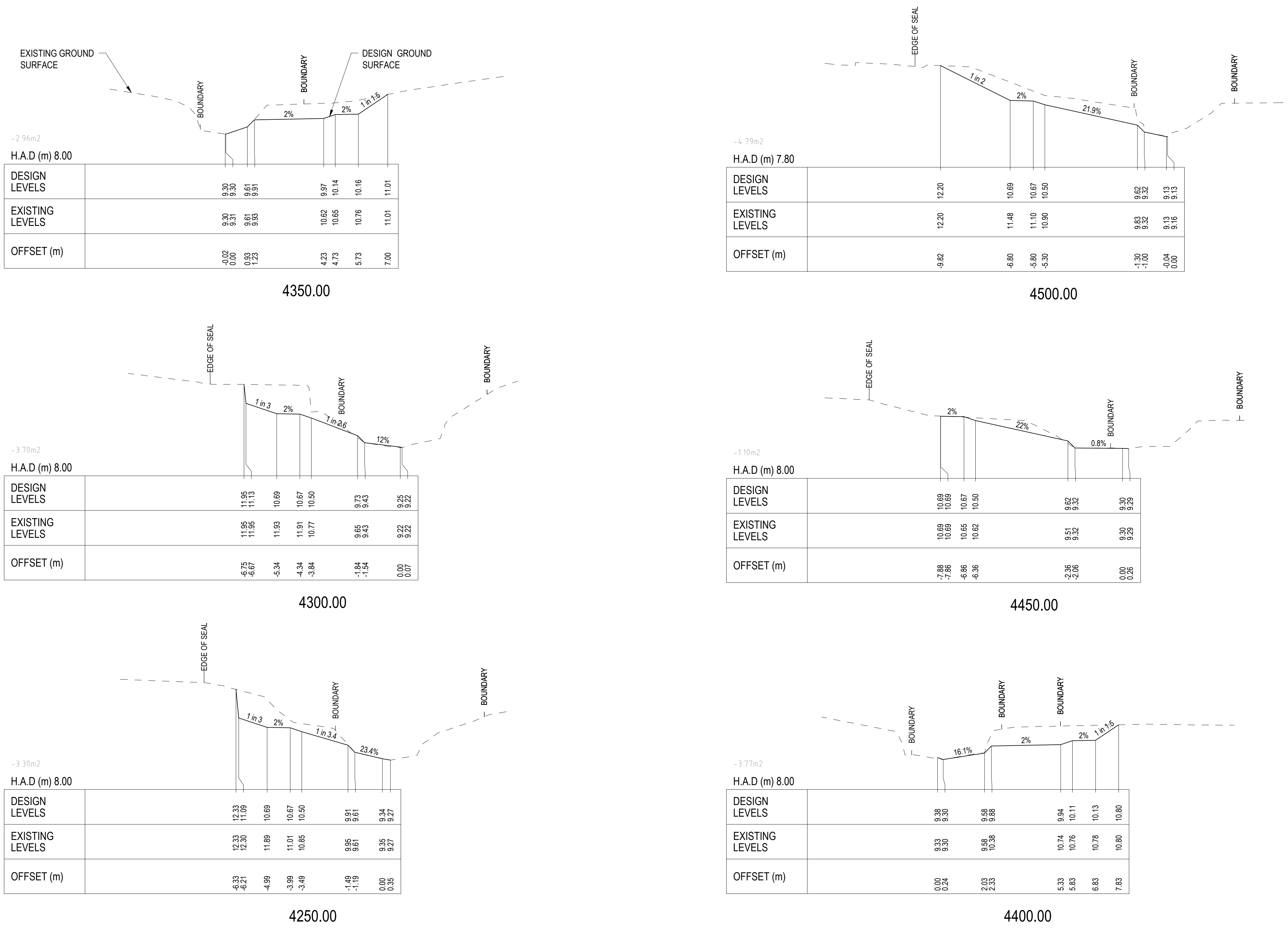
SHEET 1 OF 2



ORIGINAL DRAWING IN COLOUR

FOR INFORMATION
NOT FOR CONSTRUCTION

ISSUE	AMENDMENTS	SIGNED	DATE
A	CONCEPT DESIGN	DAH	11.06.15

Christchurch City Council
CAPITAL PROGRAMME GROUP

			NAME	SIGNED	DATE
DATUM					
BENCH MK.		DESIGNED	DJG	DJG	06.2015
RL		DES. REVIEW	DAH	DAH	06.2015
SURVEY		DRAWN	DLM	DLM	06.2015
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DRAIN. REF.		3384543-CE-012.dwg			
SAP WBS		PRINTED ON 11-Jun-15 BY DLM1			

APPROVED
FOR TENDER — DATE / SIGNED
FOR CONSTRUCTION — DATE / SIGNED

CONSULTANT: Beca OPUS
CONSULTANT PROJECT REF. 3384543 / 3C1262.00
CONSULTANT FILE REF. S:\300 Drawings\CAD

PROJECT TITLE
DUDLEY CREEK FLOOD REMEDIATION

DRAWING TITLE
OPTION A - BANKS AVENUE CROSS SECTIONS

CONTRACT NUMBER 14/15-192
CAD DRAWING FILE REF. 3384543-CE-012
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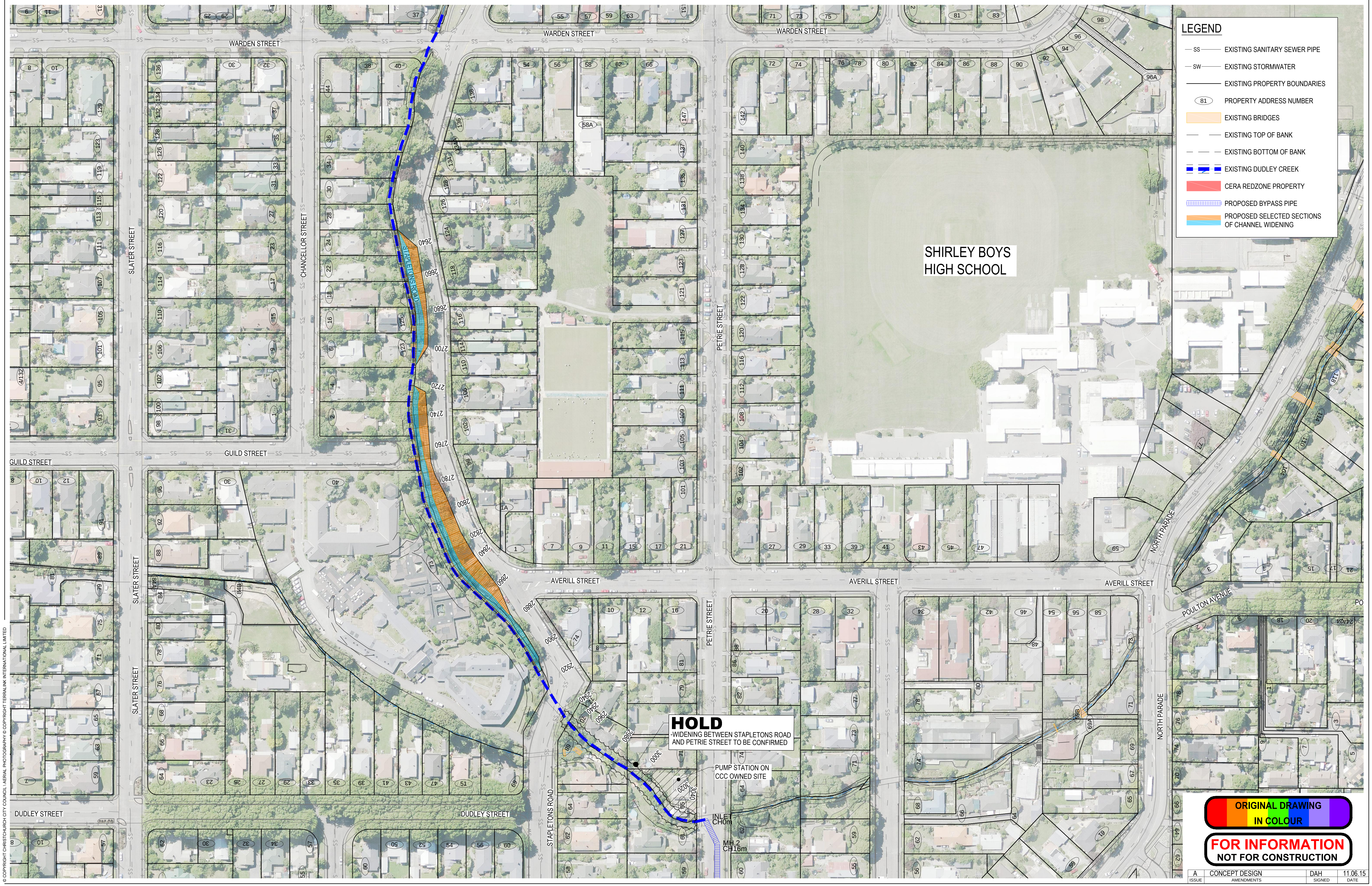
SHEET 2 OF 2



ISSUE	AMENDMENTS	SIGNED	DATE
A	CONCEPT DESIGN	DAH	11.06.15

Christchurch City Council

CAPITAL PROGRAMME GROUP

			NAME	SIGNED	DATE
DATUM					
BENCH MK.		DESIGNED	DJG	DJG	06.2015
RL		DES. REVIEW	DAH	DAH	06.2015
SURVEY		DRAWN	DLM	DLM	06.2015
SURVEY LB		DRW. CHECK	DJG	DJG	06.2015
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DRAIN. REF.		3384543-CE-050.dwg			
SAP WBS		PRINTED ON 11-Jun-15 BY DLM1			

APPROVED	
FOR TENDER	
DATE	SIGNED
FOR CONSTRUCTION	
DATE	SIGNED

CONSULTANT: Beca, OPUS

CONSULTANT PROJECT REF.: 3384543 / 3C1262.00

CONSULTANT FILE REF.: S:\300 Drawings\CAD

PROJECT TITLE

DUDLEY CREEK FLOOD REMEDIATION

DRAWING TITLE

OPTION C - STAPLETONS ROAD

CONTRACT NUMBER	ORIGINAL SHEET SIZE	SCALES
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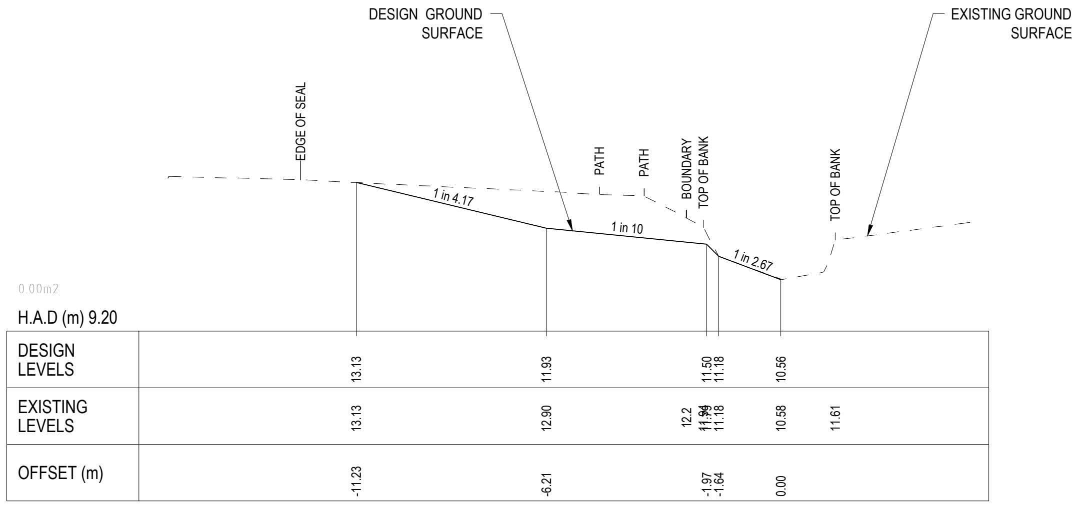

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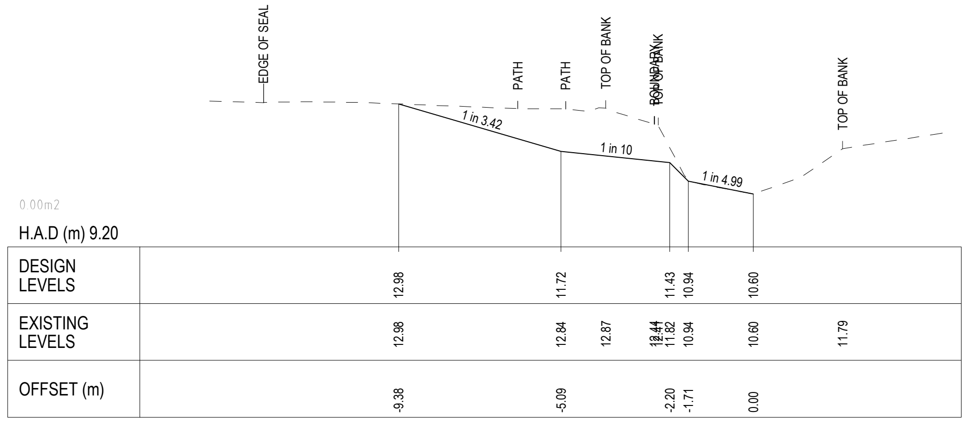

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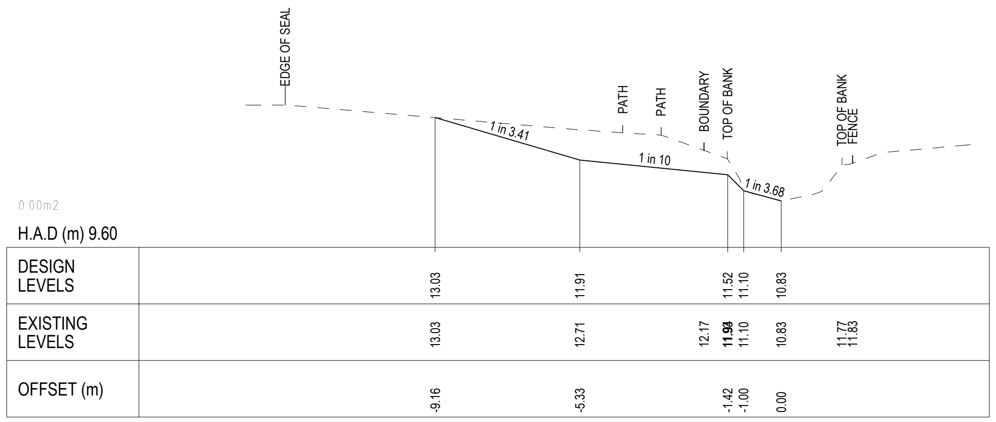

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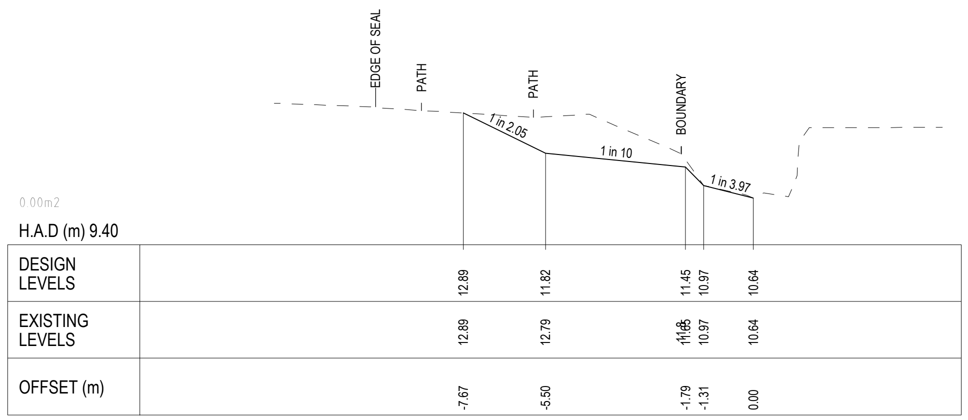

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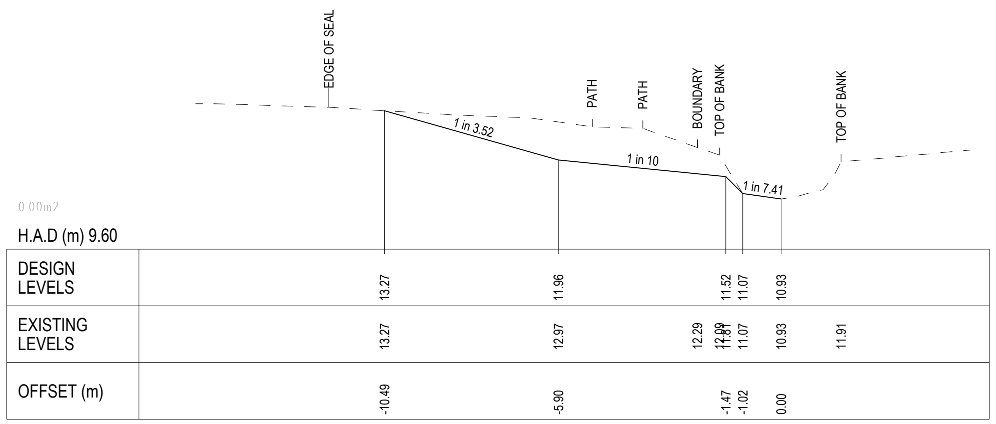

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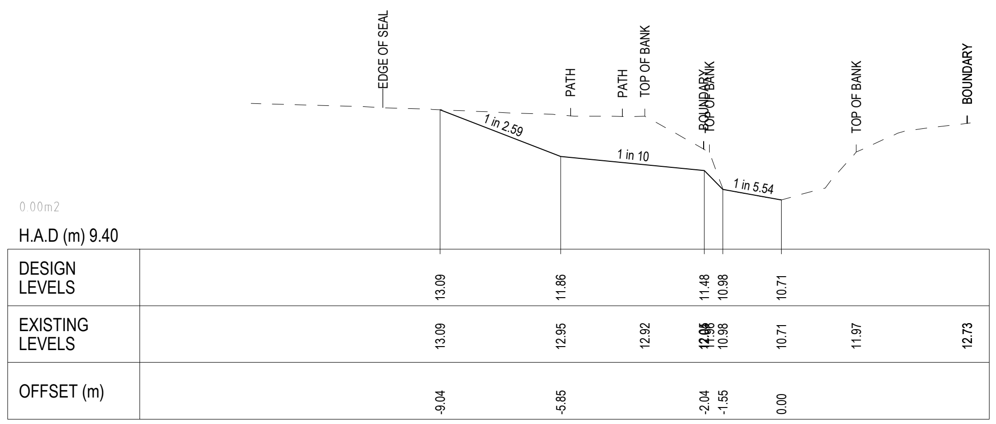

2675.00

ORIGINAL DRAWING IN COLOUR

FOR INFORMATION
NOT FOR CONSTRUCTION

ISSUE	AMENDMENTS	SIGNED	DATE
A	CONCEPT DESIGN	DAH	11.06.15

Christchurch City Council
CAPITAL PROGRAMME GROUP

	NAME	SIGNED	DATE
DESIGNED	DJG	DJG	06.2015
DES. REVIEW	DAH	DAH	06.2015
DRAWN	DLM	DLM	06.2015
DRW. CHECK	DJG	DJG	06.2015

DATUM / BENCH MK. / RL / SURVEY / SURVEY LB / DRAIN. REF. / SAP WBS

FILE LOCATION S:\300 Drawings\CAD\
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APPROVED
FOR TENDER — DATE / SIGNED
FOR CONSTRUCTION — DATE / SIGNED

CONSULTANT: Beca / OPUS
CONSULTANT PROJECT REF. 3384543 / 3C1262.00
CONSULTANT FILE REF. S:\300 Drawings\CAD

PROJECT TITLE
DUDLEY CREEK FLOOD REMEDIATION

DRAWING TITLE
OPTION C - STAPLETONS ROAD CROSS SECTIONS

CONTRACT NUMBER 14/15-192
CAD DRAWING FILE REF. 3384543-CE-051
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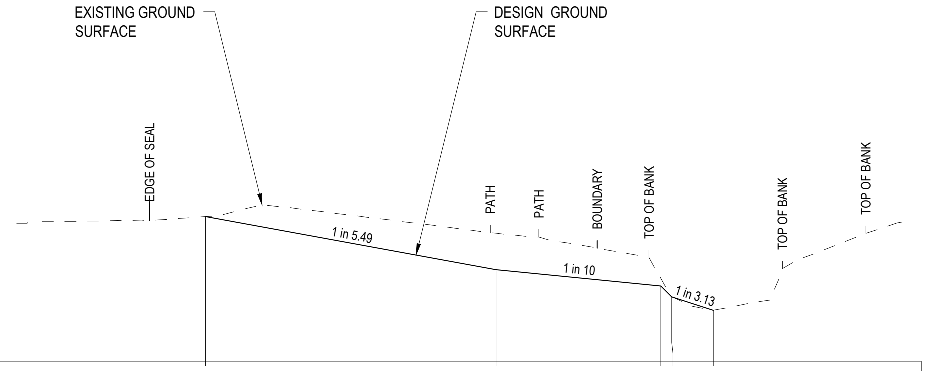
SHEET 1 OF 3



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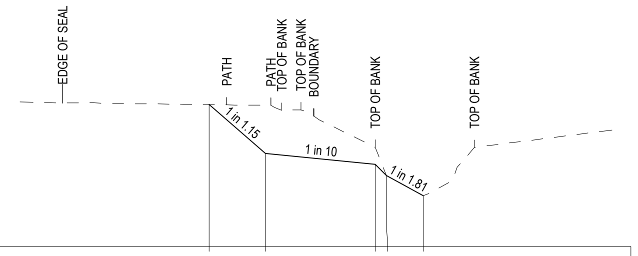
H.A.D (m) 9.40

DESIGN LEVELS	13.22	11.82		11.39 11.10	10.75		
EXISTING LEVELS	13.22	12.78	12.39	12.14 11.59 11.10	10.75	11.84	12.78
OFFSET (m)	-13.44	-5.75		-1.39 -1.10	0.00		

2800.00

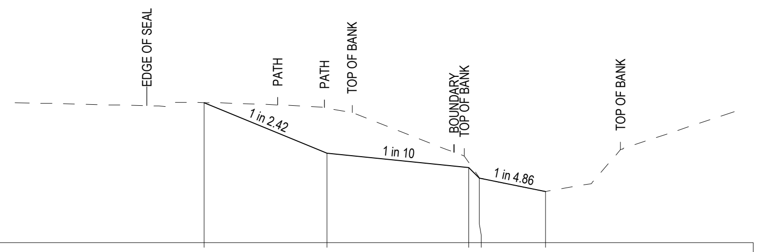


0.00m2

H.A.D (m) 9.20

DESIGN LEVELS	12.95	11.67			11.38 11.08	10.54	
EXISTING LEVELS	12.95	12.94	12.8	12.82 12.65	11.83 11.08	10.54	11.82
OFFSET (m)	-5.66	-4.17			-1.27 -0.97	0.00	

2875.00

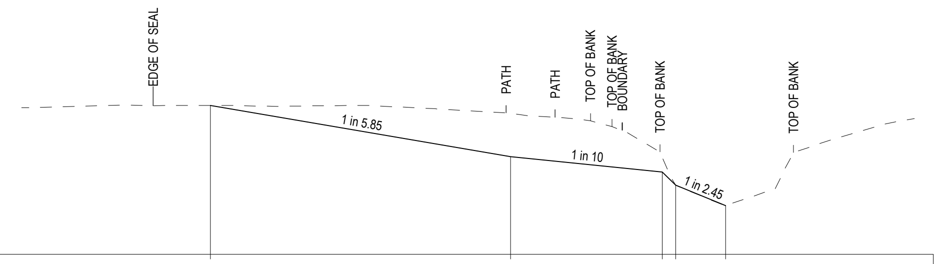


0.00m2

H.A.D (m) 9.40

DESIGN LEVELS	13.11	11.77		11.39 11.11	10.75	
EXISTING LEVELS	13.11	12.97	12.84	11.8 11.7 11.52 11.11	10.75	11.87
OFFSET (m)	-9.03	-5.78		-2.03 -1.75	0.00	

2775.00

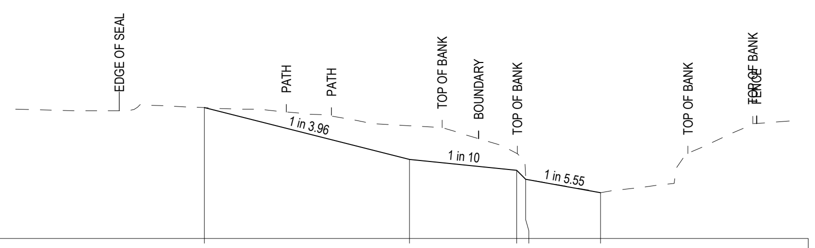


0.00m2

H.A.D (m) 9.20

DESIGN LEVELS	13.14	11.78			11.38 11.03	10.49	
EXISTING LEVELS	13.14	12.92	12.73	12.57 12.48	11.91 11.77 11.03	10.49	11.89
OFFSET (m)	-13.62	-5.68			-1.67 -1.32	0.00	

2850.00

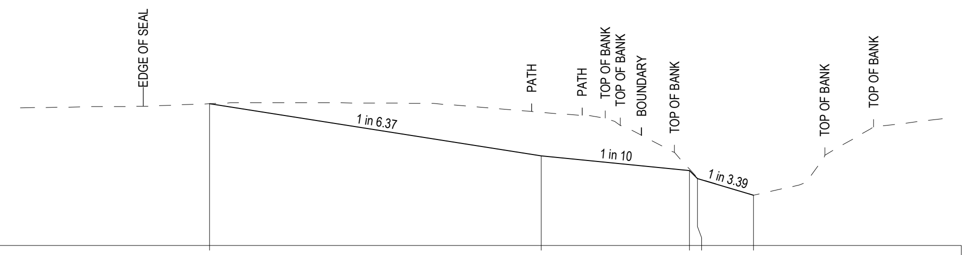


0.00m2

H.A.D (m) 9.60

DESIGN LEVELS	13.06	11.69			11.41 11.16	10.81		
EXISTING LEVELS	13.06	12.58	12.53	12.24	11.86 11.85 11.16	10.81	11.85	12.64
OFFSET (m)	-10.47	-5.05			-2.22 -1.97	0.00		

2750.00



0.00m2

H.A.D (m) 9.40

DESIGN LEVELS	13.15	11.77			11.38 11.17	10.73		
EXISTING LEVELS	13.15	12.92	12.77 12.58	12.32	11.86 11.42 11.17	10.73	11.79	12.54
OFFSET (m)	-14.38	-5.61			-1.69 -1.48	0.00		

2825.00

ORIGINAL DRAWING IN COLOUR

FOR INFORMATION
NOT FOR CONSTRUCTION

ISSUE	AMENDMENTS	SIGNED	DATE
A	CONCEPT DESIGN	DAH	11.06.15

Christchurch City Council

CAPITAL PROGRAMME GROUP

			NAME	SIGNED	DATE
DATUM					
BENCH MK.		DESIGNED	DJG	DJG	06.2015
RL		DES. REVIEW	DAH	DAH	06.2015
SURVEY		DRAWN	DLM	DLM	06.2015
SURVEY LB		DRW. CHECK	DJG	DJG	06.2015
		FILE LOCATION	S:\300 Drawings\CAD\		
DRAIN. REF.		3384543-CE-052.dwg			
SAP WBS		PRINTED ON 11-Jun-15 BY DLM1			

APPROVED

FOR TENDER

DATE	SIGNED

FOR CONSTRUCTION

DATE	SIGNED

CONSULTANT

Beca OPUS

CONSULTANT PROJECT REF. 3384543 / 3C1262.00

CONSULTANT FILE REF. S:\300 Drawings\CAD

PROJECT TITLE

DUDLEY CREEK FLOOD REMEDIATION

DRAWING TITLE

OPTION C - STAPLETONS ROAD CROSS SECTIONS

CONTRACT NUMBER 14/15-192

CAD DRAWING FILE REF. 3384543-CE-052

ORIGINAL SHEET SIZE A1

SCALES 1:100 H @ A1 1:1 V @ A1

CPG PROJECT FILE NUMBER CP502630

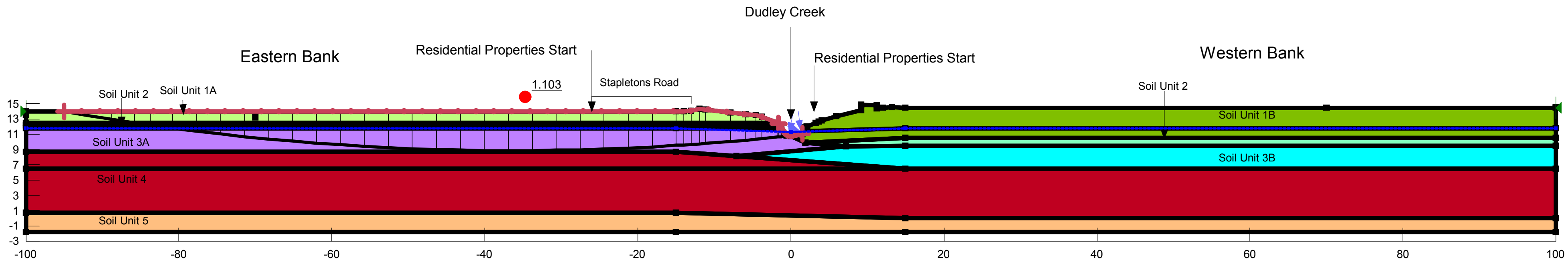
SHEET 2 OF 3

Method: Morgenstern-Price

Horz Seismic Coef.: 0.4

F of S: 1.103

Name: #1Ab Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 30 kPa Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #2b Firm SILT. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 50 kPa Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Ab Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 30 kPa Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #4 Medium dense to very dense sandy fine to coarse GRAVEL Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 ° Constant Unit Wt. Above Water Table: 20 kN/m³
Name: #5a Dense to very dense fine to medium SAND, minor silt, trace organics. Model: Mohr-Coulomb Unit Weight: 21 kN/m³ Cohesion': 0 kPa Phi': 32 ° Constant Unit Wt. Above Water Table: 19 kN/m³
Name: #1Ba Medium Dense to dense SAND, some silt. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 1 kPa Phi': 30 ° Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Ba Medium Dense to dense SAND, some silt. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 0 kPa Phi': 30 ° Constant Unit Wt. Above Water Table: 17 kN/m³



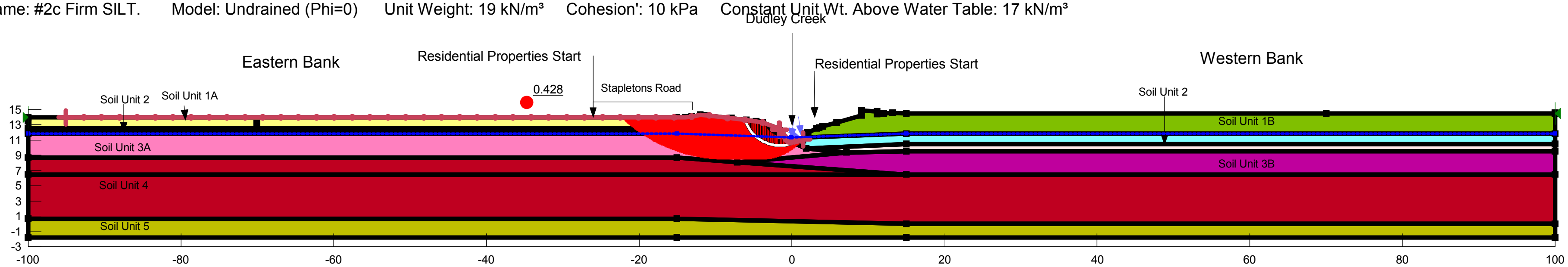
Beca	Title: Dudley Creek Flooding	Created by: Ben Ellis
	Name: Bi) CH2800 Exisiting-EQ no liq L2R - depth limited	Date: 1/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.:

F of S: 0.428

Name: #1Aa Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 3 kPa Phi': 28 ° Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #1Ac Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.08 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Ac Soft to firm sandy SILT & SILT. Lens of fine SAND Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.1 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #4 Medium dense to very dense sandy fine to coarse GRAVEL Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 ° Constant Unit Wt. Above Water Table: 20 kN/m³
Name: #5b Dense to very dense fine to medium SAND, minor silt, trace organics. Model: S=f(overburden) Unit Weight: 21 kN/m³ Tau/Sigma Ratio: 0.25 Constant Unit Wt. Above Water Table: 19 kN/m³
Name: #1Ba Medium Dense to dense SAND, some silt. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 1 kPa Phi': 30 ° Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #1Bc Medium Dense to dense SAND, some silt. Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.45 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Bc Medium Dense to dense SAND, some silt. Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.1 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #2c Firm SILT. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 10 kPa Constant Unit Wt. Above Water Table: 17 kN/m³



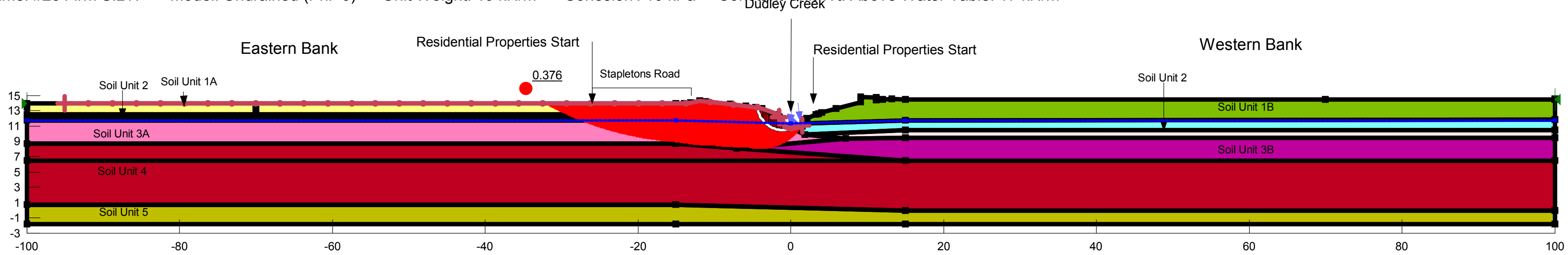
Beca	Title: Dudley Creek Flooding	Created by: Ben Ellis
	Name: Ci) CH2800 Exisiting - Static liq L2R - depth limited	Date: 1/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.: 0.05

F of S: 0.376

Name: #1Aa Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 3 kPa Phi': 28 ° Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #1Ac Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.08 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Ac Soft to firm sandy SILT & SILT. Lens of fine SAND Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.1 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #4 Medium dense to very dense sandy fine to coarse GRAVEL Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 ° Constant Unit Wt. Above Water Table: 20 kN/m³
Name: #5b Dense to very dense fine to medium SAND, minor silt, trace organics. Model: S=f(overburden) Unit Weight: 21 kN/m³ Tau/Sigma Ratio: 0.25 Constant Unit Wt. Above Water Table: 19 kN/m³
Name: #1Ba Medium Dense to dense SAND, some silt. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 1 kPa Phi': 30 ° Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #1Bc Medium Dense to dense SAND, some silt. Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.45 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Bc Medium Dense to dense SAND, some silt. Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.1 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #2c Firm SILT. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 10 kPa Constant Unit Wt. Above Water Table: 17 kN/m³



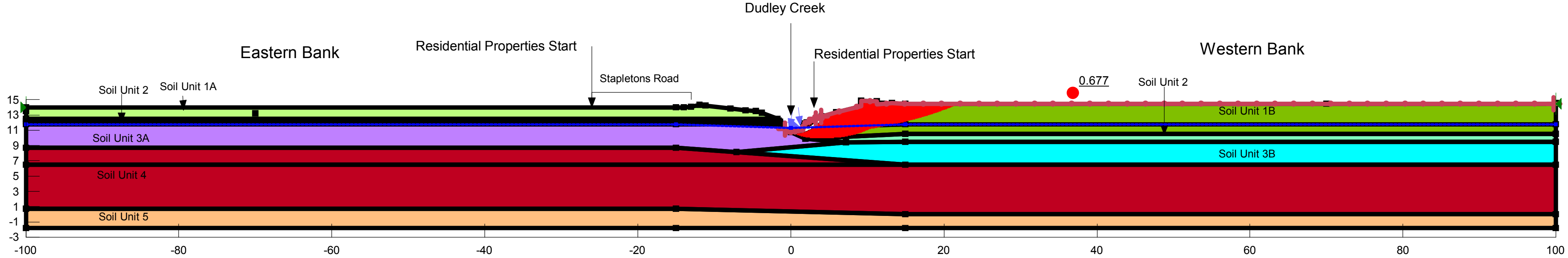
	Title: Dudley Creek Flooding	Created by: Ben Ellis
	Name: Ciii)CH2800 Exisiting -liq+0.05g L2R	Date: 1/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.: 0.4

F of S: 0.677

Name: #1Ab Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 30 kPa Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #2b Firm SILT. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 50 kPa Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Ab Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 30 kPa Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #4 Medium dense to very dense sandy fine to coarse GRAVEL Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 ° Constant Unit Wt. Above Water Table: 20 kN/m³
Name: #5a Dense to very dense fine to medium SAND, minor silt, trace organics. Model: Mohr-Coulomb Unit Weight: 21 kN/m³ Cohesion': 0 kPa Phi': 32 ° Constant Unit Wt. Above Water Table: 19 kN/m³
Name: #1Ba Medium Dense to dense SAND, some silt. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 1 kPa Phi': 30 ° Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Ba Medium Dense to dense SAND, some silt. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 0 kPa Phi': 30 ° Constant Unit Wt. Above Water Table: 17 kN/m³



Title: Dudley Creek Flooding

Created by: Ben Ellis

Name: Bii) CH2800 Exisiting-EQ no liq R2L

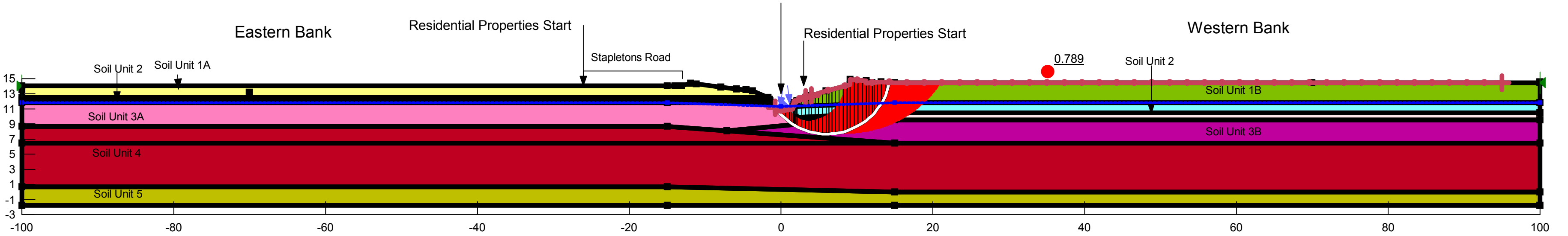
Date: 1/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.:

F of S: 0.789

Name: #1Aa Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 3 kPa Phi': 28 ° Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #1Ac Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.08 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Ac Soft to firm sandy SILT & SILT. Lens of fine SAND Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.1 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #4 Medium dense to very dense sandy fine to coarse GRAVEL Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 ° Constant Unit Wt. Above Water Table: 20 kN/m³
Name: #5b Dense to very dense fine to medium SAND, minor silt, trace organics. Model: S=f(overburden) Unit Weight: 21 kN/m³ Tau/Sigma Ratio: 0.25 Constant Unit Wt. Above Water Table: 19 kN/m³
Name: #1Ba Medium Dense to dense SAND, some silt. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 1 kPa Phi': 30 ° Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #1Bc Medium Dense to dense SAND, some silt. Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.45 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Bc Medium Dense to dense SAND, some silt. Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.1 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #2c Firm SILT. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 10 kPa Constant Unit Wt. Above Water Table: 17 kN/m³



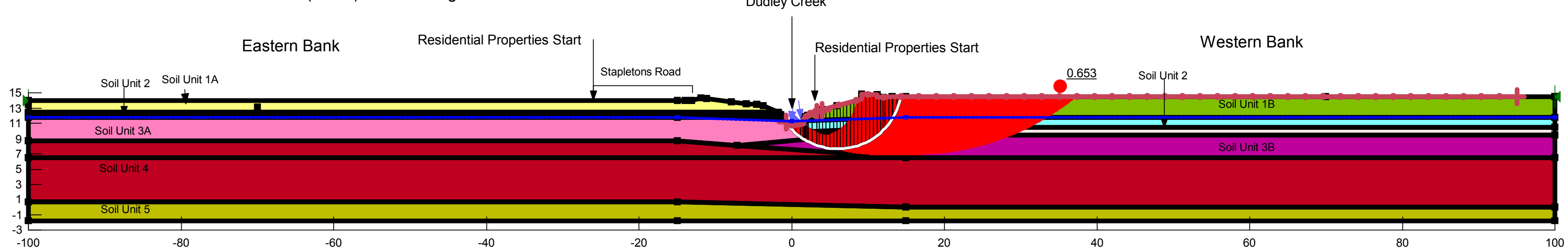
Beca	Title: Dudley Creek Flooding	Created by: Ben Ellis
	Name: Cii) CH2800 Exisiting - Static liq R2L	Date: 1/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.: 0.05

F of S: 0.653

Name: #1Aa Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 3 kPa Phi': 28 ° Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #1Ac Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.08 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Ac Soft to firm sandy SILT & SILT. Lens of fine SAND Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.1 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #4 Medium dense to very dense sandy fine to coarse GRAVEL Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 ° Constant Unit Wt. Above Water Table: 20 kN/m³
Name: #5b Dense to very dense fine to medium SAND, minor silt, trace organics. Model: S=f(overburden) Unit Weight: 21 kN/m³ Tau/Sigma Ratio: 0.25 Constant Unit Wt. Above Water Table: 19 kN/m³
Name: #1Ba Medium Dense to dense SAND, some silt. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 1 kPa Phi': 30 ° Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #1Bc Medium Dense to dense SAND, some silt. Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.45 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Bc Medium Dense to dense SAND, some silt. Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.1 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #2c Firm SILT. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 10 kPa Constant Unit Wt. Above Water Table: 17 kN/m³



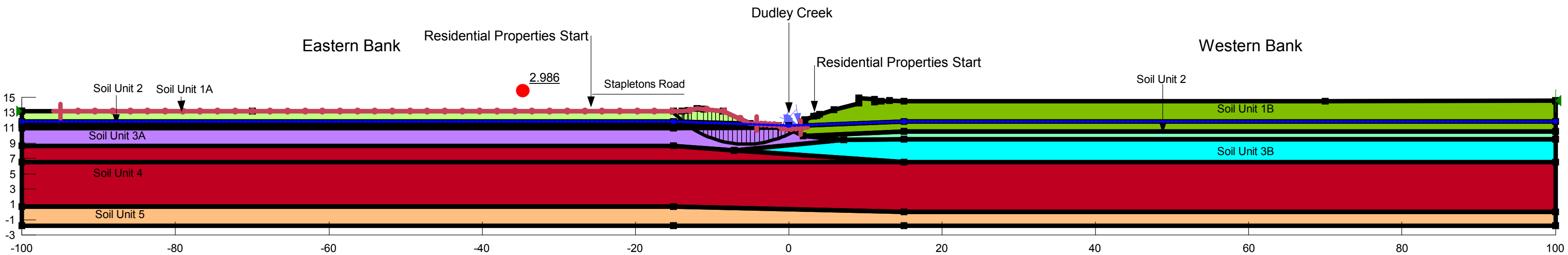
Beca	Title: Dudley Creek Flooding	Created by: Ben Ellis
	Name: Civ)CH2800 Exisiting-liq+0.05g R2L	Date: 1/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.: 0.13

F of S: 2.986

Name: #1Ab Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 30 kPa Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #2b Firm SILT. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 50 kPa Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Ab Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 30 kPa Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #4 Medium dense to very dense sandy fine to coarse GRAVEL Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 ° Constant Unit Wt. Above Water Table: 20 kN/m³
Name: #5a Dense to very dense fine to medium SAND, minor silt, trace organics. Model: Mohr-Coulomb Unit Weight: 21 kN/m³ Cohesion': 0 kPa Phi': 32 ° Constant Unit Wt. Above Water Table: 19 kN/m³
Name: #1Ba Medium Dense to dense SAND, some silt. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 1 kPa Phi': 30 ° Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Ba Medium Dense to dense SAND, some silt. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 0 kPa Phi': 30 ° Constant Unit Wt. Above Water Table: 17 kN/m³



Beca

Title: Dudley Creek Flooding

Name: Bi) CH2800 Design -EQ SLS no liq L2R

Created by: Ben Ellis

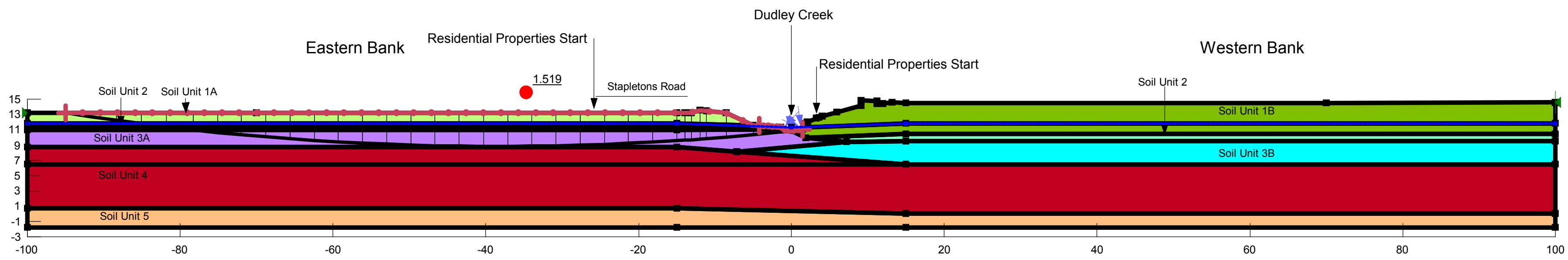
Date: 3/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.: 0.35

F of S: 1.519

Name: #1Ab Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 30 kPa Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #2b Firm SILT. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 50 kPa Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Ab Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 30 kPa Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #4 Medium dense to very dense sandy fine to coarse GRAVEL Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 ° Constant Unit Wt. Above Water Table: 20 kN/m³
Name: #5a Dense to very dense fine to medium SAND, minor silt, trace organics. Model: Mohr-Coulomb Unit Weight: 21 kN/m³ Cohesion': 0 kPa Phi': 32 ° Constant Unit Wt. Above Water Table: 19 kN/m³
Name: #1Ba Medium Dense to dense SAND, some silt. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 1 kPa Phi': 30 ° Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Ba Medium Dense to dense SAND, some silt. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 0 kPa Phi': 30 ° Constant Unit Wt. Above Water Table: 17 kN/m³



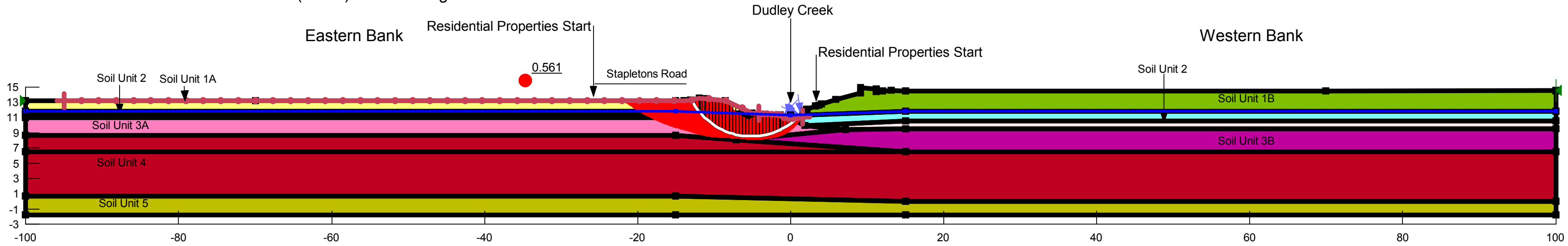
Beca	Title: Dudley Creek Flooding	Created by: Ben Ellis
	Name: Biii) CH2800 Design -EQ ULS no liq L2R	Date: 3/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.:

F of S: 0.561

Name: #1Aa Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 3 kPa Phi': 28 ° Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #1Ac Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.08 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Ac Soft to firm sandy SILT & SILT. Lens of fine SAND Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.1 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #4 Medium dense to very dense sandy fine to coarse GRAVEL Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 ° Constant Unit Wt. Above Water Table: 20 kN/m³
Name: #5b Dense to very dense fine to medium SAND, minor silt, trace organics. Model: S=f(overburden) Unit Weight: 21 kN/m³ Tau/Sigma Ratio: 0.25 Constant Unit Wt. Above Water Table: 19 kN/m³
Name: #1Ba Medium Dense to dense SAND, some silt. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 1 kPa Phi': 30 ° Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #1Bc Medium Dense to dense SAND, some silt. Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.45 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Bc Medium Dense to dense SAND, some silt. Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.1 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #2c Firm SILT. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 10 kPa Constant Unit Wt. Above Water Table: 17 kN/m³



Title: Dudley Creek Flooding

Created by: Ben Ellis

Name: Ci) CH2800 Design - Static + liq L2R

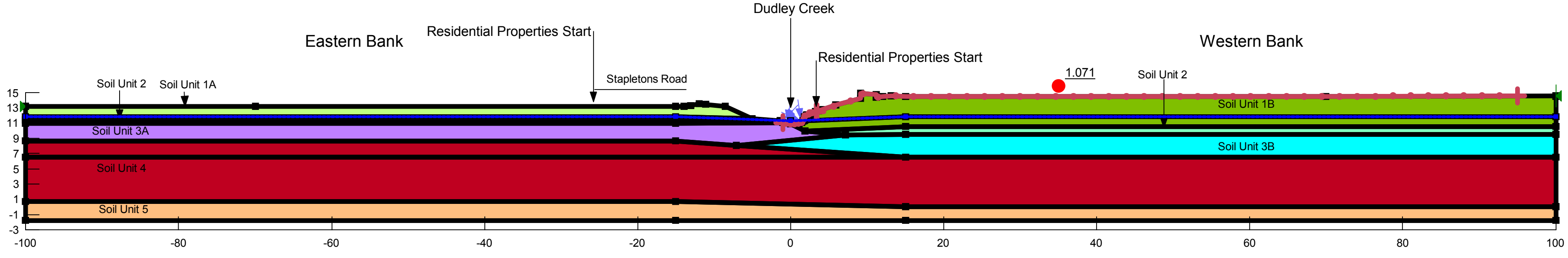
Date: 3/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.: 0.13

F of S: 1.071

Name: #1Ab Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 30 kPa Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #2b Firm SILT. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 50 kPa Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Ab Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 30 kPa Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #4 Medium dense to very dense sandy fine to coarse GRAVEL Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 ° Constant Unit Wt. Above Water Table: 20 kN/m³
Name: #5a Dense to very dense fine to medium SAND, minor silt, trace organics. Model: Mohr-Coulomb Unit Weight: 21 kN/m³ Cohesion': 0 kPa Phi': 32 ° Constant Unit Wt. Above Water Table: 19 kN/m³
Name: #1Ba Medium Dense to dense SAND, some silt. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 1 kPa Phi': 30 ° Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Ba Medium Dense to dense SAND, some silt. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 0 kPa Phi': 30 ° Constant Unit Wt. Above Water Table: 17 kN/m³



Title: Dudley Creek Flooding

Created by: Ben Ellis

Name: Bii) CH2800 Design -EQ SLS no liq R2L

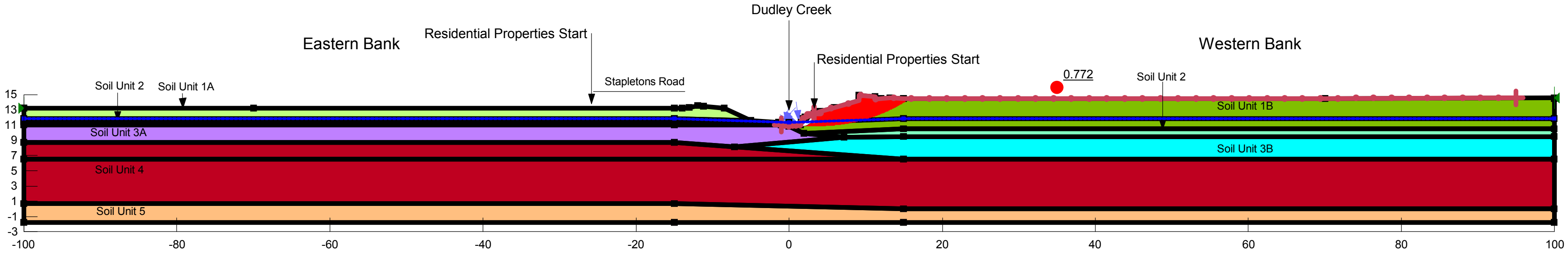
Date: 3/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.: 0.35

F of S: 0.772

Name: #1Ab Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 30 kPa Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #2b Firm SILT. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 50 kPa Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Ab Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 30 kPa Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #4 Medium dense to very dense sandy fine to coarse GRAVEL Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 ° Constant Unit Wt. Above Water Table: 20 kN/m³
Name: #5a Dense to very dense fine to medium SAND, minor silt, trace organics. Model: Mohr-Coulomb Unit Weight: 21 kN/m³ Cohesion': 0 kPa Phi': 32 ° Constant Unit Wt. Above Water Table: 19 kN/m³
Name: #1Ba Medium Dense to dense SAND, some silt. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 1 kPa Phi': 30 ° Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Ba Medium Dense to dense SAND, some silt. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 0 kPa Phi': 30 ° Constant Unit Wt. Above Water Table: 17 kN/m³



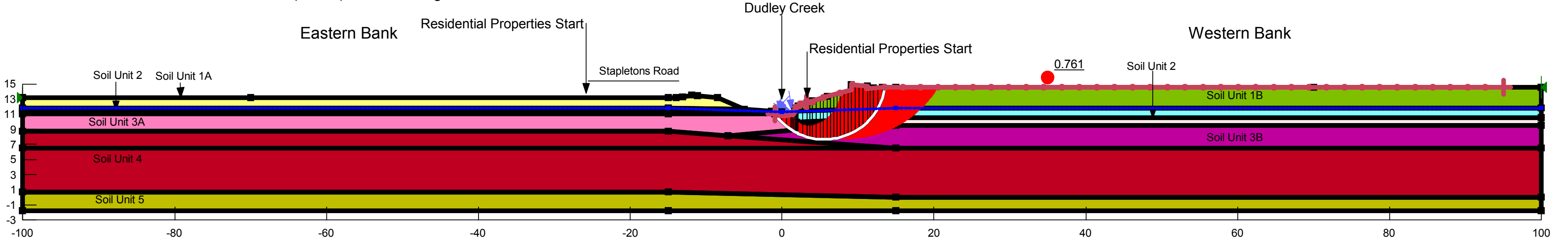
Beca	Title: Dudley Creek Flooding	Created by: Ben Ellis
	Name: Biv) CH2800 Design -EQ ULS no liq R2L	Date: 3/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.:

F of S: 0.761

Name: #1Aa Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 3 kPa Phi': 28 ° Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #1Ac Soft to firm sandy SILT & SILT. Lens of fine SAND. Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.08 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Ac Soft to firm sandy SILT & SILT. Lens of fine SAND Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.1 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #4 Medium dense to very dense sandy fine to coarse GRAVEL Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 ° Constant Unit Wt. Above Water Table: 20 kN/m³
Name: #5b Dense to very dense fine to medium SAND, minor silt, trace organics. Model: S=f(overburden) Unit Weight: 21 kN/m³ Tau/Sigma Ratio: 0.25 Constant Unit Wt. Above Water Table: 19 kN/m³
Name: #1Ba Medium Dense to dense SAND, some silt. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 1 kPa Phi': 30 ° Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #1Bc Medium Dense to dense SAND, some silt. Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.45 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #3Bc Medium Dense to dense SAND, some silt. Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.1 Constant Unit Wt. Above Water Table: 17 kN/m³
Name: #2c Firm SILT. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 10 kPa Constant Unit Wt. Above Water Table: 17 kN/m³



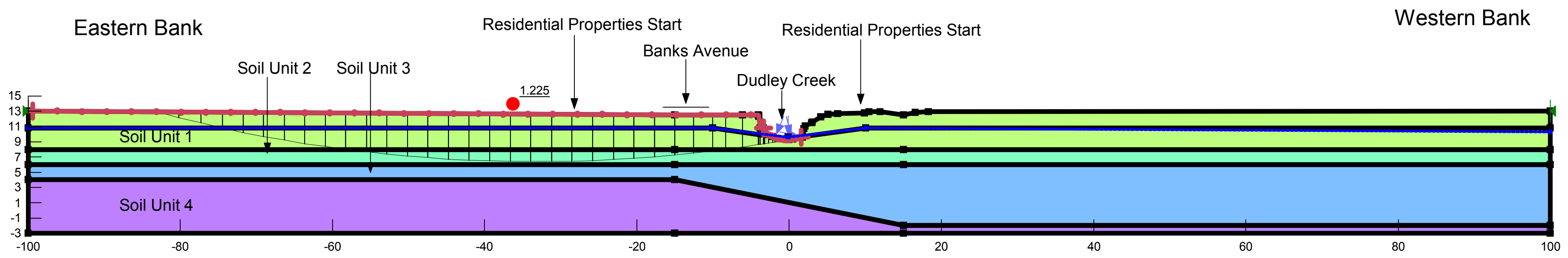
Beca	Title: Dudley Creek Flooding	Created by: Ben Ellis
	Name: Cii) CH2800 Design- Static + liq R2L	Date: 3/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.: 0.4

F of S: 1.225

Name: #1b Stiff to very stiff SILT, some sand. Undrained. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 50 kPa
Name: #2a Loose to medium dense fine to coarse SAND Model: Mohr-Coulomb Unit Weight: 20 kN/m³ Cohesion': 1 kPa Phi': 30 °
Name: #3a Medium dense sandy fine to coarse GRAVEL. Drained. Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 °
Name: #4a Medium dense to fine to coarse SAND Model: Mohr-Coulomb Unit Weight: 21 kN/m³ Cohesion': 0 kPa Phi': 32 °



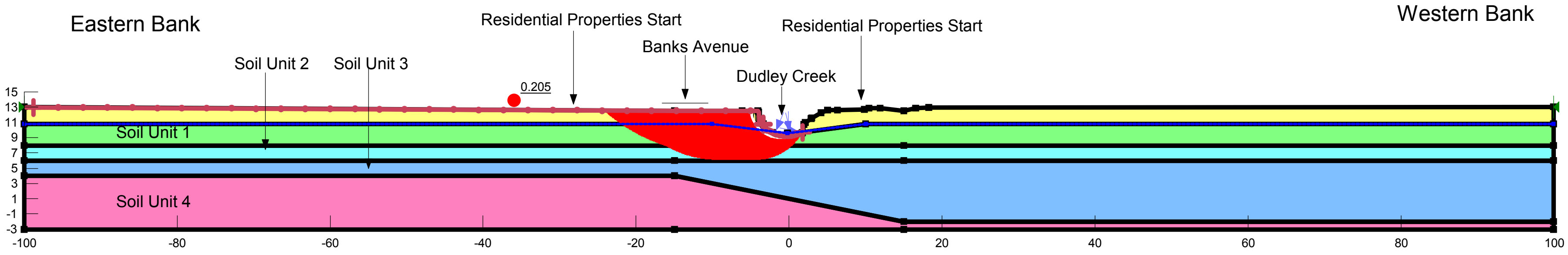
Beca	Title: Dudley Creek Flooding	Created by: Ben Ellis
	Name: Bi) CH4300 Exisiting-EQ no liq L2R	Date: 11/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.:

F of S: 0.205

Name: #1a Stiff to very stiff SILT, some sand. Drained. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 5 kPa Phi': 30 °
Name: #1c Stiff to very stiff SILT, some sand. Liquified Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.1 Minimum Strength: 1 kPa
Name: #2b Loose to medium dense fine to coarse SAND. Liquified Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.12 Minimum Strength: 1 kPa
Name: #3a Medium dense sandy fine to coarse GRAVEL. Drained. Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 °
Name: #4b Medium dense fine to coarse SAND. Liquified Model: S=f(overburden) Unit Weight: 21 kN/m³ Tau/Sigma Ratio: 0.12 Minimum Strength: 1 kPa



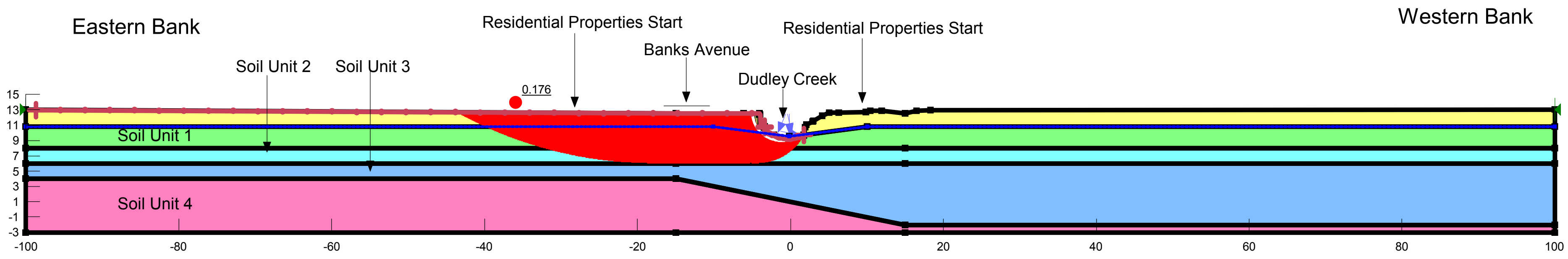
Beca	Title: Dudley Creek Flooding	Created by: Ben Ellis
	Name: Ci) CH4300 Exisiting - static liq L2R	Date: 11/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.: 0.05

F of S: 0.176

Name: #1a Stiff to very stiff SILT, some sand. Drained. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 5 kPa Phi': 30 °
Name: #1c Stiff to very stiff SILT, some sand. Liquified Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.1 Minimum Strength: 1 kPa
Name: #2b Loose to medium dense fine to coarse SAND. Liquified Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.12 Minimum Strength: 1 kPa
Name: #3a Medium dense sandy fine to coarse GRAVEL. Drained. Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 °
Name: #4b Medium dense fine to coarse SAND. Liquified Model: S=f(overburden) Unit Weight: 21 kN/m³ Tau/Sigma Ratio: 0.12 Minimum Strength: 1 kPa



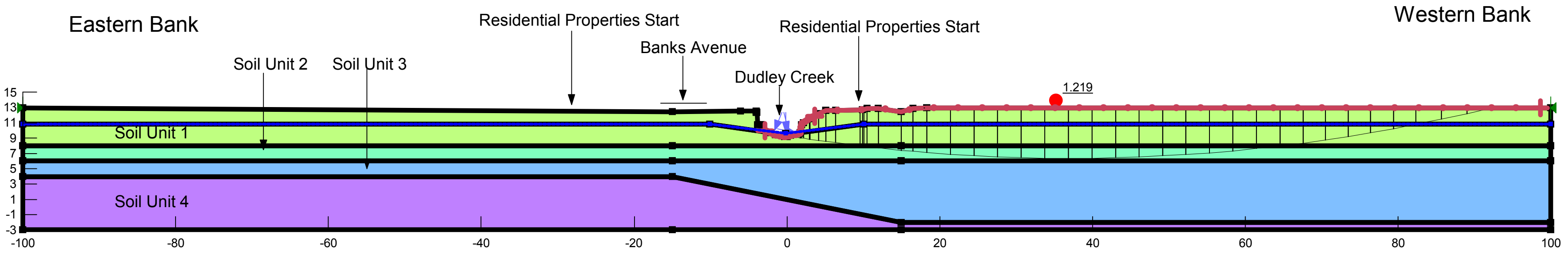
Beca	Title: Dudley Creek Flooding	Created by: Ben Ellis
	Name: Ciii) CH4300 Exisiting -liq+0.05g L2R	Date: 27/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.: 0.4

F of S: 1.219

Name: #1b Stiff to very stiff SILT, some sand. Undrained. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 50 kPa
Name: #2a Loose to medium dense fine to coarse SAND Model: Mohr-Coulomb Unit Weight: 20 kN/m³ Cohesion': 1 kPa Phi': 30 °
Name: #3a Medium dense sandy fine to coarse GRAVEL. Drained. Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 °
Name: #4a Medium dense to fine to coarse SAND Model: Mohr-Coulomb Unit Weight: 21 kN/m³ Cohesion': 0 kPa Phi': 32 °



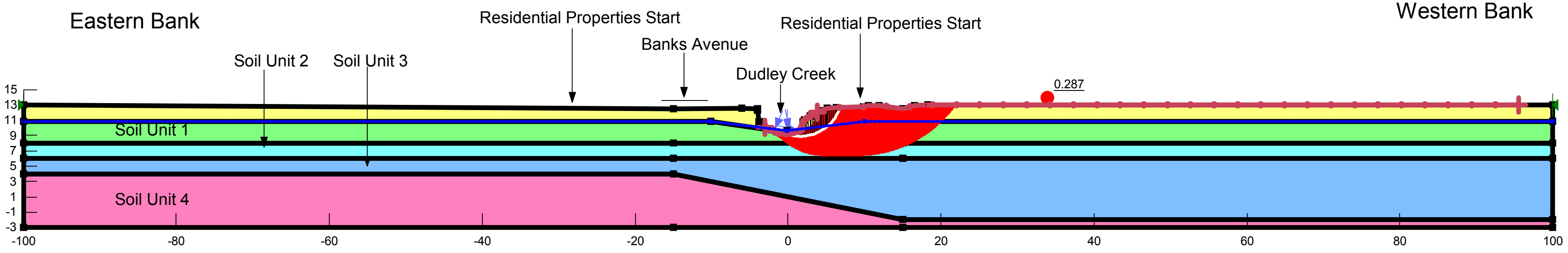
Beca	Title: Dudley Creek Flooding	Created by: Ben Ellis
	Name: Bii) CH4300 Exisiting-EQ no liq R2L	Date: 11/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.:

F of S: 0.287

Name: #1a Stiff to very stiff SILT, some sand. Drained. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 5 kPa Phi': 30 °
Name: #1c Stiff to very stiff SILT, some sand. Liquified Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.1 Minimum Strength: 1 kPa
Name: #2b Loose to medium dense fine to coarse SAND. Liquified Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.12 Minimum Strength: 1 kPa
Name: #3a Medium dense sandy fine to coarse GRAVEL. Drained. Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 °
Name: #4b Medium dense fine to coarse SAND. Liquified Model: S=f(overburden) Unit Weight: 21 kN/m³ Tau/Sigma Ratio: 0.12 Minimum Strength: 1 kPa



Beca	Title: Dudley Creek Flooding	Created by: Ben Ellis
	Name: Cii) CH4300 Exisiting - static liq R2L	Date: 11/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.: 0.05

F of S: 0.252

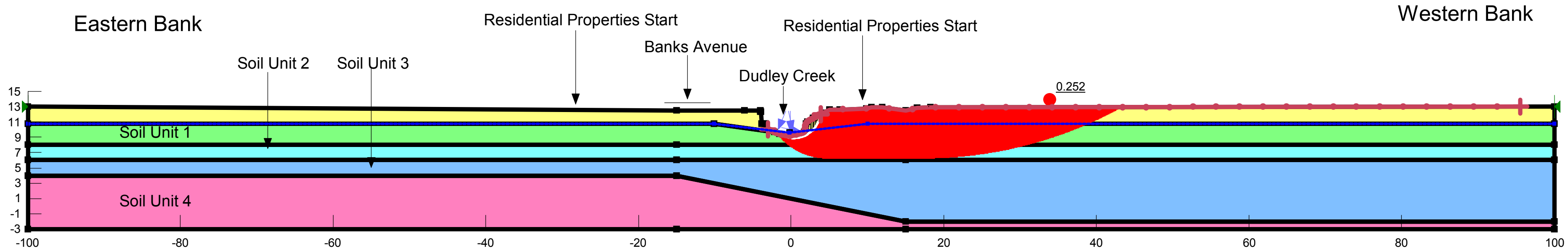
Name: #1a Stiff to very stiff SILT, some sand. Drained. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 5 kPa Phi': 30 °

Name: #1c Stiff to very stiff SILT, some sand. Liquified Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.1 Minimum Strength: 1 kPa

Name: #2b Loose to medium dense fine to coarse SAND. Liquified Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.12 Minimum Strength: 1 kPa

Name: #3a Medium dense sandy fine to coarse GRAVEL. Drained. Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 °

Name: #4b Medium dense fine to coarse SAND. Liquified Model: S=f(overburden) Unit Weight: 21 kN/m³ Tau/Sigma Ratio: 0.12 Minimum Strength: 1 kPa



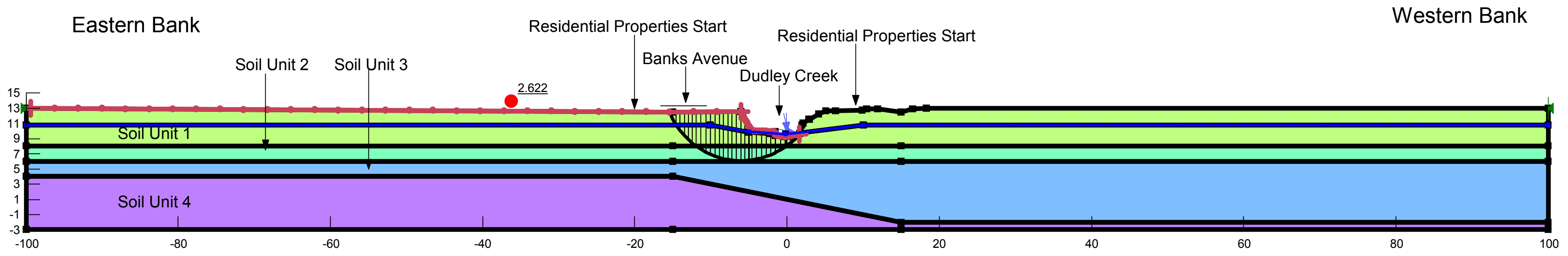
Beca	Title: Dudley Creek Flooding	Created by: Ben Ellis
	Name: Civ) CH4300 Exisiting - liq+0.05g R2L	Date: 27/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.: 0.13

F of S: 2.622

Name: #1b Stiff to very stiff SILT, some sand. Undrained. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 50 kPa
Name: #2a Loose to medium dense fine to coarse SAND Model: Mohr-Coulomb Unit Weight: 20 kN/m³ Cohesion': 1 kPa Phi': 30 °
Name: #3a Medium dense sandy fine to coarse GRAVEL. Drained. Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 °
Name: #4a Medium dense to fine to coarse SAND Model: Mohr-Coulomb Unit Weight: 21 kN/m³ Cohesion': 0 kPa Phi': 32 °



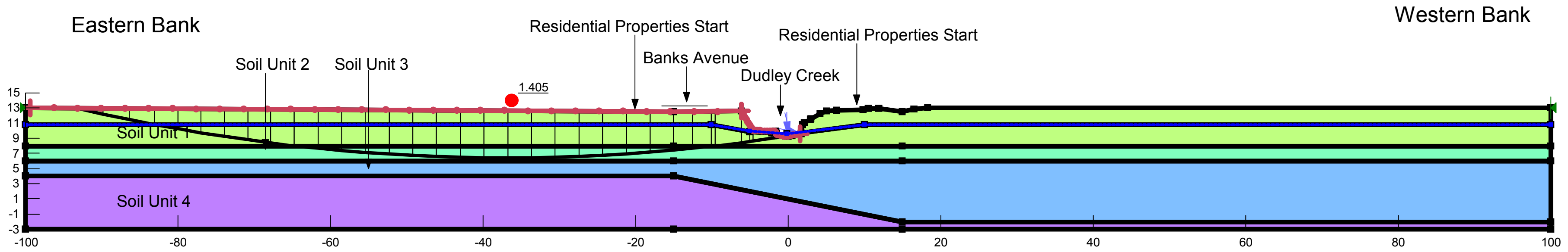
Beca	Title: Dudley Creek Flooding	Created by: Ben Ellis
	Name: Bi) CH4300 Design -EQ SLS no liq L2R	Date: 27/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.: 0.35

F of S: 1.405

Name: #1b Stiff to very stiff SILT, some sand. Undrained. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 50 kPa
Name: #2a Loose to medium dense fine to coarse SAND Model: Mohr-Coulomb Unit Weight: 20 kN/m³ Cohesion': 1 kPa Phi': 30 °
Name: #3a Medium dense sandy fine to coarse GRAVEL. Drained. Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 °
Name: #4a Medium dense to fine to coarse SAND Model: Mohr-Coulomb Unit Weight: 21 kN/m³ Cohesion': 0 kPa Phi': 32 °



Beca	Title: Dudley Creek Flooding	Created by: Ben Ellis
	Name: Biii) CH4300 Design -EQ ULS no liq L2R	Date: 27/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.:

F of S: 0.287

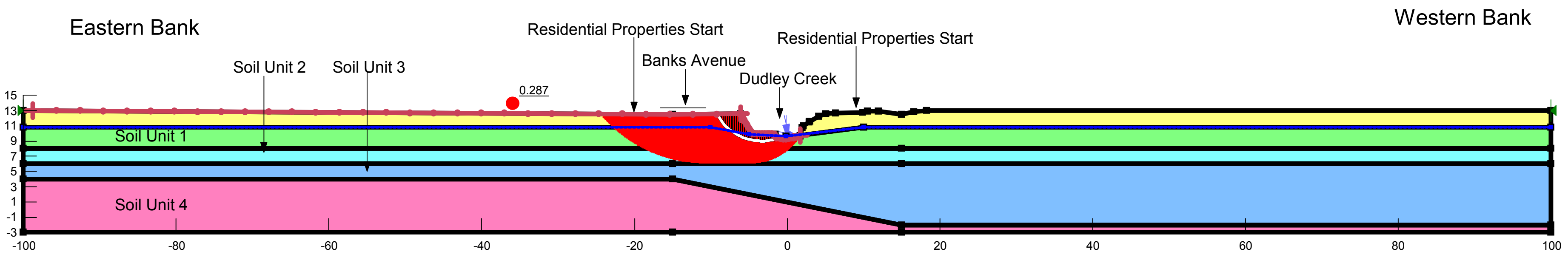
Name: #1a Stiff to very stiff SILT, some sand. Drained. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 5 kPa Phi': 30 °

Name: #1c Stiff to very stiff SILT, some sand. Liquified Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.1 Minimum Strength: 1 kPa

Name: #2b Loose to medium dense fine to coarse SAND. Liquified Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.12 Minimum Strength: 1

Name: #3a Medium dense sandy fine to coarse GRAVEL. Drained. Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 °

Name: #4b Medium dense fine to coarse SAND. Liquified Model: S=f(overburden) Unit Weight: 21 kN/m³ Tau/Sigma Ratio: 0.12 Minimum Strength: 1 kPa



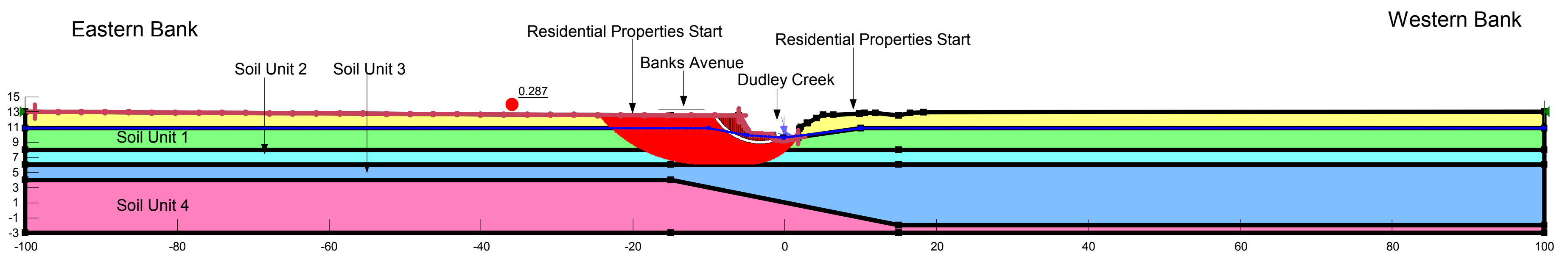
Beca	Title: Dudley Creek Flooding	Created by: Ben Ellis
	Name: Ci) CH4300 Design - static liq L2R	Date: 11/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.:

F of S: 0.287

Name: #1a Stiff to very stiff SILT, some sand. Drained. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 5 kPa Phi': 30 °
Name: #1c Stiff to very stiff SILT, some sand. Liquified Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.1 Minimum Strength: 1 kPa
Name: #2b Loose to medium dense fine to coarse SAND. Liquified Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.12 Minimum Strength: 1 kPa
Name: #3a Medium dense sandy fine to coarse GRAVEL. Drained. Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 °
Name: #4b Medium dense fine to coarse SAND. Liquified Model: S=f(overburden) Unit Weight: 21 kN/m³ Tau/Sigma Ratio: 0.12 Minimum Strength: 1 kPa



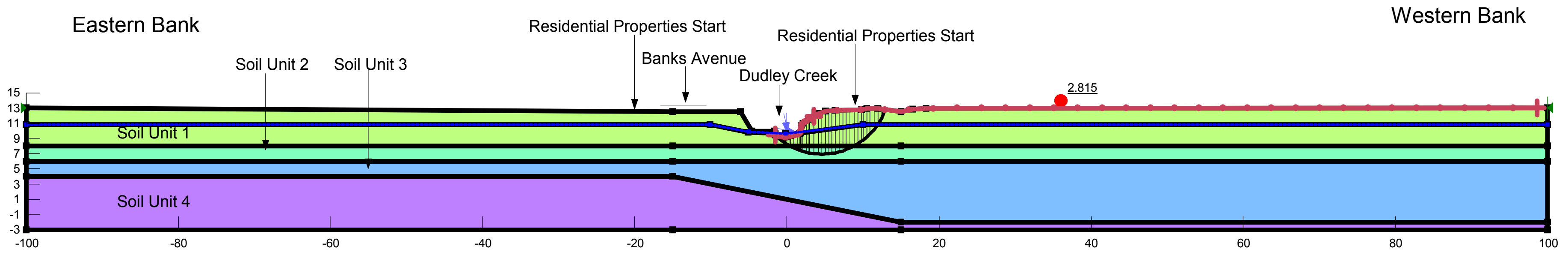
Beca	Title: Dudley Creek Flooding	Created by: Ben Ellis
	Name: Ci) CH4300 Design - static liq L2R	Date: 11/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.: 0.13

F of S: 2.815

Name: #1b Stiff to very stiff SILT, some sand. Undrained. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 50 kPa
Name: #2a Loose to medium dense fine to coarse SAND Model: Mohr-Coulomb Unit Weight: 20 kN/m³ Cohesion': 1 kPa Phi': 30 °
Name: #3a Medium dense sandy fine to coarse GRAVEL. Drained. Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 °
Name: #4a Medium dense to fine to coarse SAND Model: Mohr-Coulomb Unit Weight: 21 kN/m³ Cohesion': 0 kPa Phi': 32 °



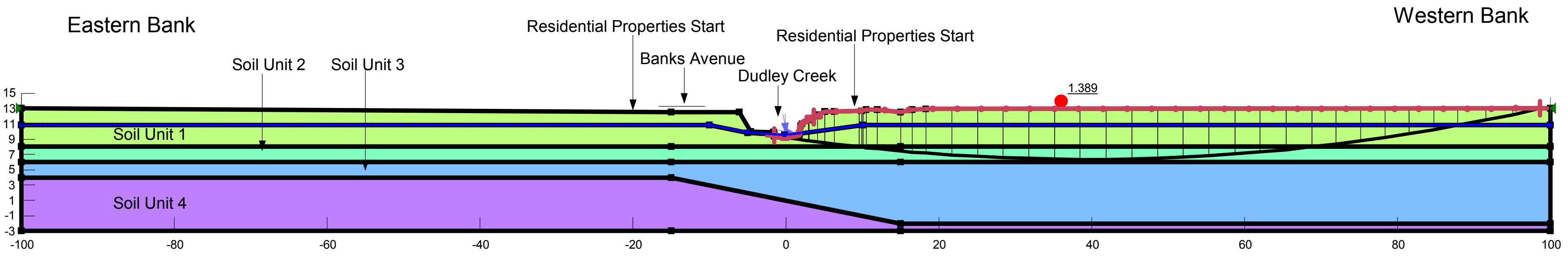
Beca	Title: Dudley Creek Flooding	Created by: Ben Ellis
	Name: Bii) CH4300 Design-EQ SLS no liq R2L	Date: 27/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.: 0.35

F of S: 1.389

Name: #1b Stiff to very stiff SILT, some sand. Undrained. Model: Undrained (Phi=0) Unit Weight: 19 kN/m³ Cohesion': 50 kPa
Name: #2a Loose to medium dense fine to coarse SAND Model: Mohr-Coulomb Unit Weight: 20 kN/m³ Cohesion': 1 kPa Phi': 30 °
Name: #3a Medium dense sandy fine to coarse GRAVEL. Drained. Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 °
Name: #4a Medium dense to fine to coarse SAND Model: Mohr-Coulomb Unit Weight: 21 kN/m³ Cohesion': 0 kPa Phi': 32 °



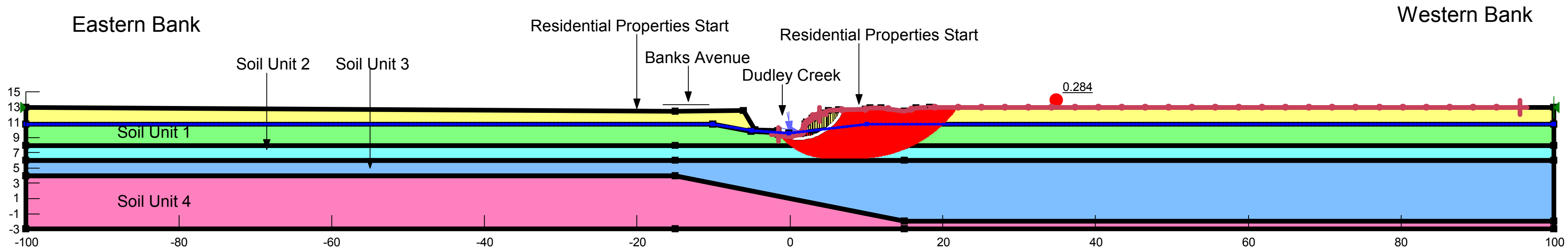
Beca	Title: Dudley Creek Flooding	Created by: Ben Ellis
	Name: Biv) CH4300 Design-EQ ULS no liq R2L	Date: 11/05/2015

Method: Morgenstern-Price

Horz Seismic Coef.:

F of S: 0.284

Name: #1a Stiff to very stiff SILT, some sand. Drained. Model: Mohr-Coulomb Unit Weight: 19 kN/m³ Cohesion': 5 kPa Phi': 30 °
Name: #1c Stiff to very stiff SILT, some sand. Liquified Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.1 Minimum Strength: 1 kPa
Name: #2b Loose to medium dense fine to coarse SAND. Liquified Model: S=f(overburden) Unit Weight: 19 kN/m³ Tau/Sigma Ratio: 0.12 Minimum Strength: 1 kP
Name: #3a Medium dense sandy fine to coarse GRAVEL. Drained. Model: Mohr-Coulomb Unit Weight: 22 kN/m³ Cohesion': 1 kPa Phi': 34 °
Name: #4b Medium dense fine to coarse SAND. Liquified Model: S=f(overburden) Unit Weight: 21 kN/m³ Tau/Sigma Ratio: 0.12 Minimum Strength: 1 kPa



Beca	Title: Dudley Creek Flooding	Created by: Ben Ellis
	Name: Cii) CH4300 Design - stat liq R2L	Date: 11/05/2015