Sensitivity: General

Te Tapuae/Southern Corridor

Liquefaction Hazard Assessment

Prepared for Queenstown Lakes District Council
Prepared by Beca Limited

9 September 2025

Contents

Appendices

Revision History

Revision N°	Description	Date
1	Draft for client comment	25/07/2025
2	Final	09/09/2025

Executive Summary

Beca Ltd (Beca) has been engaged by the Queenstown Lakes District Council (QLDC) to undertake a liquefaction hazard assessment for an area within the area known as the Te Tapuae/Southern Corridor (referred to herein as the Southern Corridor). The assessment is to be completed in accordance with a 'Level B' calibrated desktop assessment / 'Level C' detailed area-wide assessment as per the MBIE (2017) '*Planning and engineering guidance for potentially liquefaction-prone land' guidance'.* Results of the assessments will inform a subsequent qualitative risk analysis to be completed by Beca in accordance with the methodology outlined in the Hazards and Risks chapter and Appendix 6 of the proposed Otago Regional Policy Statement 2022 (ORC, 2022).

The Southern Corridor is located in a relatively low-lying area bounded by The Remarkables range to the east, Peninsula Hill to the west, and Lake Wakatipu to the south. Much of the low-lying area is underlain by Holocene-aged lake deposits which are locally overlain by lake beach deposits that reflect lowering of lake levels. Alluvial fans are present at the base of The Remarkables and Peninsula Hill and extend onto the lake and lake beach deposits. Pockets of Pleistocene-aged glacial till are preserved on the flanks of The Remarkables and within raised mounds within Hanleys Farm and Jacks Point.

MBIE (2017) presents four levels of assessment detail ranging from a 'Level A' basic qualitative desktop study to a 'Level D' site-specific quantitative liquefaction assessment. Level B and C assessments consider geologic, geomorphic, and ground investigation data supplemented with quantitative liquefaction assessments to estimate the degree of liquefaction-induced ground damage for selected earthquake scenarios. The assessment aims to identify areas of consistent ground performance which are classified according to the land damage criteria outlined in Figure 0-1. Liquefaction vulnerabilities (i.e. *'Very Low', 'Low', 'Medium' or 'High'*) may be assigned where there is sufficient information on the predicted land damage.

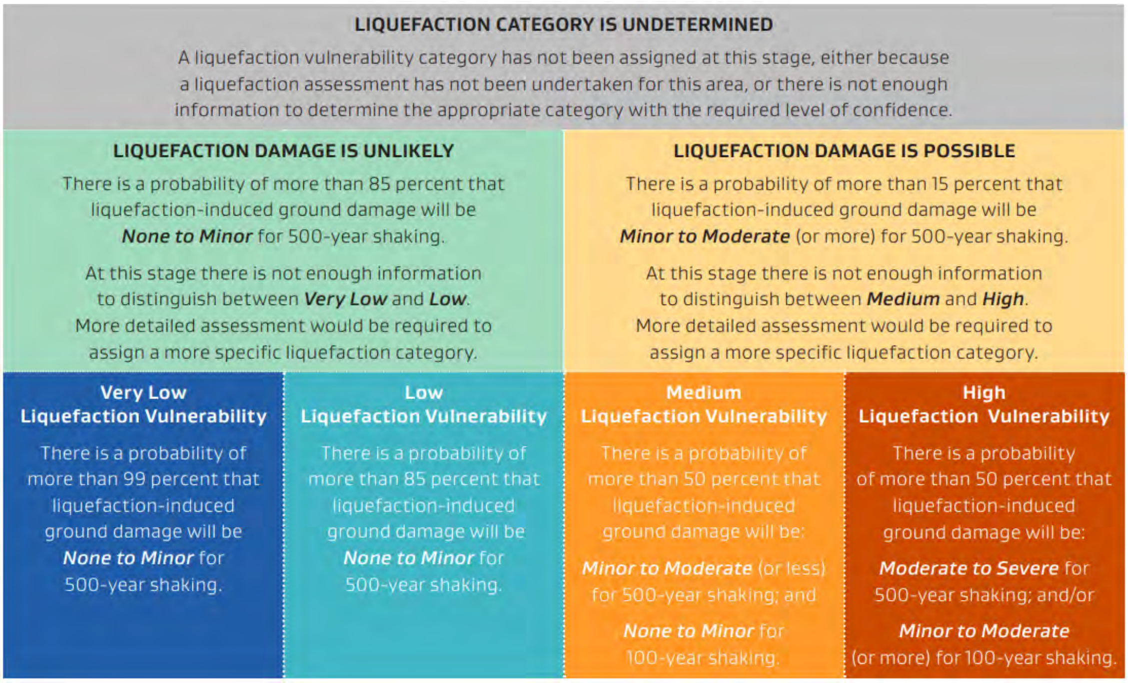

Figure 0-1: Performance criteria for determining the liquefaction vulnerability category (MBIE, 2017).

The liquefaction hazard assessment for the Southern Corridor study area was completed as a desktop exercise using ArcGIS Pro at a scale of 1:15,000 and involved the following:

- Qualitative screening of a ground model developed from geologic, geomorphic, and ground investigation data to identify areas where the presence of liquefiable deposits could be discounted (i.e. '*Liquefaction Damage is Unlikely*'). The assessment approximated a Level A assessment as per MBIE (2017) and identified areas that did not warrant further quantitative liquefaction assessments.
- Quantitative liquefaction assessment for areas identified as containing deposits potentially susceptible to liquefaction (i.e. *'liquefaction Damage is Possible'*) from the qualitative assessment and containing sufficient suitable geotechnical investigations for a Level B/C assessment as per MBIE (2017). The degree of liquefaction-induced ground damage (i.e. none to minor, minor to moderate, or moderate to severe) was quantitatively assessed from the collated geotechnical investigations (CPT and Borehole SPT) for 500-year, 100-year, and 25-year probabilistic earthquake return period scenarios using representative groundwater levels. Results of the 500-year and 100-year return period seismic event assessments were used to assign liquefaction vulnerability categories to each geotechnical investigation in accordance with MBIE (2017) and Figure 0-1.

Results of the qualitative and quantitative liquefaction hazard analyses were overlain with a geologic map produced as part of this assessment to assess the liquefaction vulnerability across the study area. The mapped geology and assessed liquefaction vulnerabilities within the study area are shown in Figures A1-1, A1-2, and A2 in Appendix A. Results of the assessment include:

- Recent alluvial deposits immediately adjacent to the Kawarau River are assessed to have a *'High Liquefaction Vulnerability'*. The proximity to the Kawarau River suggests lateral spreading may occur.
- Holocene lake deposits return *'High'* to '*Low Liquefaction Vulnerabilities'*, with *'Low Liquefaction Vulnerability'* reflecting higher silts contents, above the soil behaviour type index (I_c) cut-off for the liquefaction triggering assessment of the cone penetration test (CPT) data. *'Medium'* and *'High Liquefaction Vulnerabilities'* are adopted where there was consistency in the results of the quantitative assessment. Areas returning varied and/or *'Low'* vulnerabilities are assigned as *'Liquefaction Damage is Possible'* as the presence of more sand-dominated layers/ areas cannot be discounted.
- Alluvial fans overly lake deposits to the west of SH6 at the northern extent of the Southern Corridor. These deposits are identified as having *'Low'* to *'High Liquefaction Vulnerabilities'* depending on the silt content of the underlying lake deposits. *'Medium'* and *'High Liquefaction Vulnerabilities'* are adopted where there is consistency in the results. Other areas and areas of similar elevations immediately east of SH6 are assigned *'Liquefaction Damage is Possible'.*
- Holocene lake beach deposits in areas with visible beach ridges orientated parallel to the existing Lake Wakatipu shoreline are relatively thin and underlain by Holocene lake deposits from approximately 3 to 4 m depth. These areas are assessed to have *'Medium Liquefaction Vulnerability'*. The remaining Lake Beach deposits both adjacent to the existing lakeshore and preserved in raised terraces, contain dense gravels which are shown to uniformly have *'Low Liquefaction Vulnerability'.*
- The toe of the alluvial fan that extends into Homestead Bay is shown to have a *'Low Liquefaction Vulnerability'*. This corresponds to the gravel-dominated deposits identified in the boreholes.
- Areas mapped as containing glacial till are not considered susceptible to liquefaction due to the age of the deposits and predominance of gravel and are assigned *'Liquefaction Damage is Unlikely*.' A quantitative liquefaction assessment was not completed for these deposits.
- The remainder of the alluvial fans east of SH6 are assigned *'Liquefaction Damage is Unlikely'*. This reflects the gravel-dominant behaviour of the deposits and depth to groundwater. The presence of localised areas of liquefiable deposits (i.e. adjacent to stream channels) cannot be discounted.

The map output from this assessment is not a replacement for site specific liquefaction assessments and contains residual uncertainties associated with variations in the map scales used in the assessment and limitations in the input datasets. Further geotechnical investigations may be completed to reduce uncertainty in the assessed hazard and/or refine the liquefaction vulnerability category (i.e. *'Liquefaction Damage is Possible*' may be refined to *'Medium'* or *'High Liquefaction Vulnerability'*). The Holocene lake deposits are considered micaceous. The behaviour of these deposits is outside of that used to develop the simplified liquefaction triggering methodologies used in the quantitative analysis. The simplified liquefaction triggering methodologies were applied in accordance with the Module 3 of the Earthquake Geotechnical Engineering Practice Guidance (NZGS/MBIE, 2021b) and MBIE (2017). It is noted that the use of the simplified liquefaction triggering methodologies may result in an over-prediction of the liquefaction hazard for the lake deposits. Further detailed site-specific assessments combined with extensive laboratory testing would be required to refine the susceptibilities of these deposits.

1 Introduction

Beca Limited (Beca) has been engaged by the Queenstown Lakes District Council (QLDC) to undertake a qualitative risk analysis of natural hazards impacting the area known as the Te Tapuae/Southern Corridor (referred to herein as the Southern Corridor). The assessment is to be completed in accordance with the methodology outlined in the Hazards and Risks chapter and Appendix 6 (APP6) of the proposed Otago Regional Policy Statement (the proposed ORPS) 2022 (ORC, 2022).

The Beca gap analysis '*Te Tapuae/Southern Corridor Natural Hazards and Geotechnical Report - Gap Analysis*' (dated 28 May 2024; Beca, 2024a) and initial desktop assessment '*Te Tapuae/Southern Corridor – Desktop Assessment of Liquefaction, Debris Flow, and Rockfall Hazards (dated 13 December 2024; Beca, 2024b)* identified that further work was required to assess the liquefaction, debris flow, and flood hazards before the qualitative risk analysis could be completed. QLDC commissioned Beca to undertake the additional liquefaction, debris flow, and flood hazard assessments required to inform the qualitative risk assessment. This report presents the findings from the liquefaction hazard assessment. The assessment was completed for the study area shown in Figure 1-1 which was defined by QLDC in their email dated January 17, 2025. The additional debris flow and flood hazard assessments are reported separately to QLDC.

The scope of the liquefaction assessment was informed from the recommendations for further work made in the desktop assessment *(Beca, 2024b)*. This includes:

- Completion of a liquefaction hazard assessment in accordance with 'Level B' calibrated desktop assessment/ 'Level C' detailed area-wide assessment as per the MBIE '*Planning and engineering guidance for potentially liquefaction-prone land' (2017) guidance*'.
- Supervision of additional geotechnical investigations to achieve the minimum spatial density recommended to complete the liquefaction hazard assessment. Factual data collected from the additional geotechnical investigations are presented separately in the factual report (Beca, 2025a).

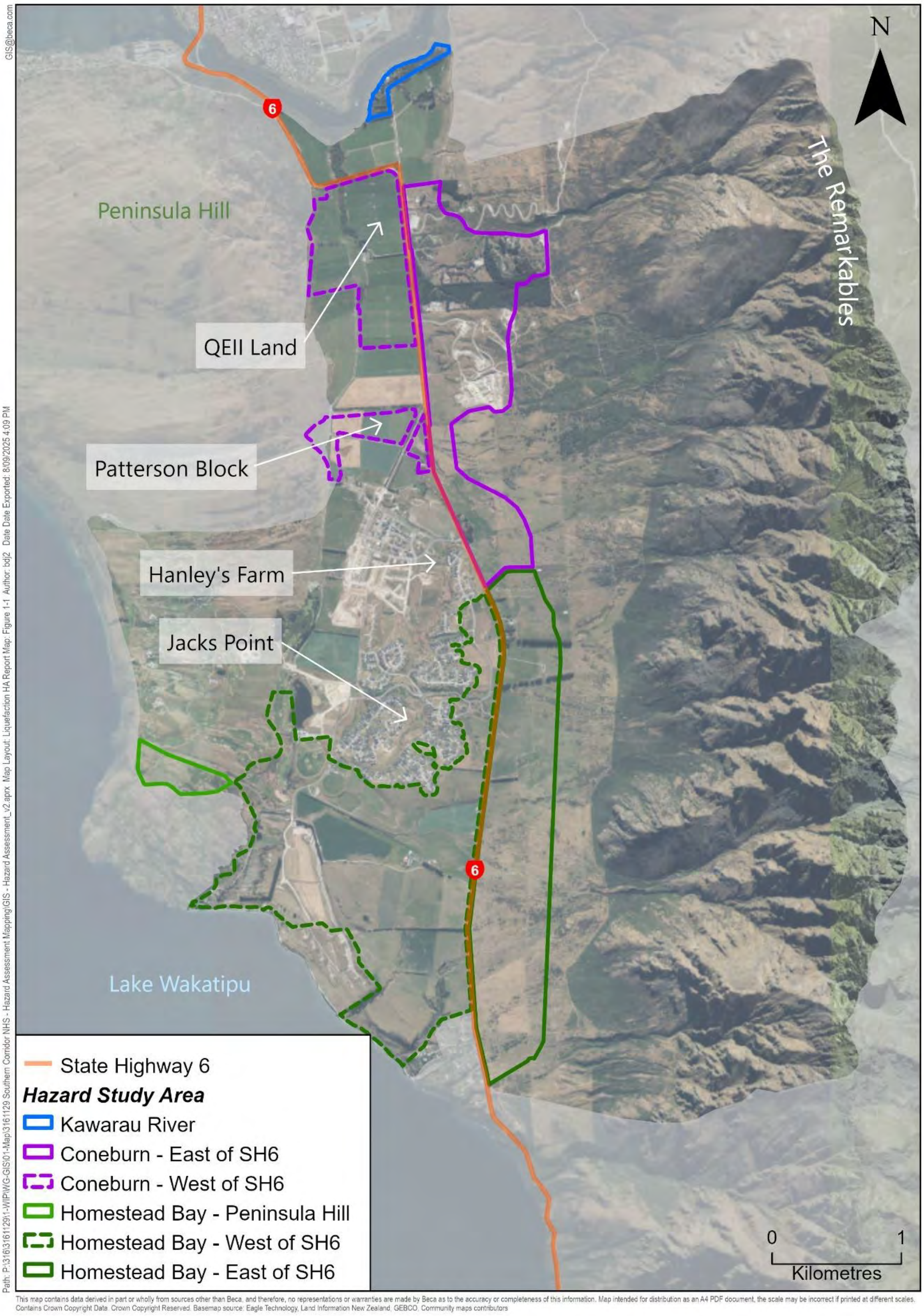

Figure 1-1: Study area considered in the liquefaction hazard assessment.

2 Geologic Setting

The Southern Corridor is located in a relatively low-lying area approximately 8km east of Queenstown, and 2km south of Frankton. The area is bounded by The Remarkables range to the east, Peninsula Hill to the west, and Lake Wakatipu to the south. State Highway 6 runs through the centre of the Southern Corridor (roughly north-south; indicated in Figure 1-1).

The topography of the Southern Corridor area is variable and reflects the geologic history of the area. Pockets of Pleistocene-aged glacial till are preserved on the flanks of The Remarkables and within raised mounds within Hanleys Farm and Jacks Point (see Figure 1-1). Holocene-aged lake deposits underly much of the remaining area. These deposits are less than 12,000 years old and deposited by proto-Lake Wakatipu which occupied much of the area following glacial retreat. The lake discharged into the Mataura River at Kingston with maximum lake levels reaching approximately RL 356m around 7,000 years ago (Thomson, 2013). Localised evidence of lake beach deposits marking maximum lake levels are preserved near the base of The Remarkables. Lake deposits are locally overlain by lake beach deposits towards the southern extent of the Southern Corridor. These deposits reflect retreat of the lake to current levels following formation of Lake Wakatipu.

The Remarkables and Peninsula Hill are shown on the 1:250,000 scale geologic map by Turnbull (2000) as comprising Caples Terrane schist. Alluvial fans are present at the base of The Remarkables and Peninsula Hill. These cone-shaped features form where drainage paths (i.e. streams) exit steep hillslopes as the change in gradient and widening of the flood path causes sediment to be deposited. The alluvial fans beneath The Remarkables extend downslope to at least SH6 and overlie the lake and glacial till deposits. Flood deposits sourced from catchments in The Remarkables locally extend across the low-lying area of the Southern Corridor and overlie the lake and lake beach deposits.

3 Previous Liquefaction Assessments

The liquefaction susceptibility of the deposits within the Southern Corridor has previously been assessed as part of regional assessments by GNS Science (Barrell, 2019) and Tonkin and Taylor (2012). Barrell (2019) identified the central low-lying portion of the Southern Corridor as ‘Domain B’ corresponding with areas where liquefaction damage is considered possible (shown in Figure 3-1a). The surrounding area is assigned ‘Domain A’ reflecting areas where liquefaction damage is considered unlikely (Figure 3-1a). Tonkin + Taylor (2012) additionally identified the central area as having a ‘Possibly Moderate’ susceptibility to liquefaction with an area of ‘Probably Low’ liquefaction susceptibility along the base of The Remarkables (Figure 3-1b). Areas of ‘Nil to Low’ susceptibility are present on Peninsula Hill. Both the assessments were completed at a regional scale and do not consider the likelihood nor consequences of liquefaction, which is required to inform the qualitative risk assessment.

Site specific liquefaction assessments completed for the farmland near Peninsula Hill by Beca (2023a and b) and for Patterson Block by ENGEO (2023) both identified the Holocene lake deposits as being susceptible to liquefaction during a 500-year return period earthquake with a peak ground acceleration (PGA) of 0.4g (Ultimate Limit State (ULS) event). Locations of these sites are indicated in Figure 1-1. Liquefaction was not predicted under a 25-year return period earthquake with a peak ground acceleration of 0.1g (Serviceability Limit State (SLS) event) by either Beca (2023a and b) or ENGEO (2023). The peak ground acceleration required to initiate triggering of liquefaction (i.e. between the SLS and ULS events) was not assessed in either of the previous assessments.

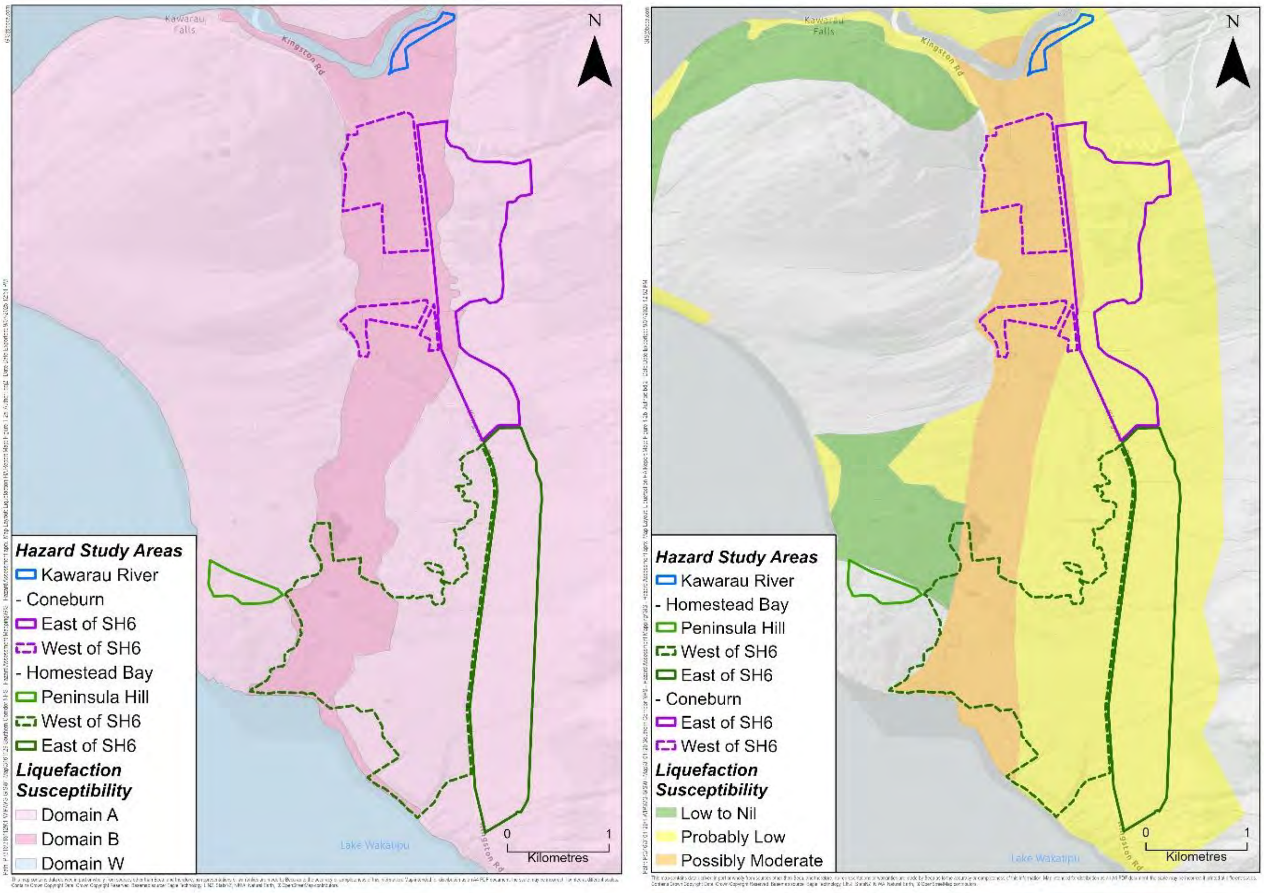

Figure 3-1: a) Barrell (2019) assessed liquefaction susceptibility of Southern Corridor and b) Tonkin + Taylor (2012) assessed liquefaction susceptibility.

4 Liquefaction Hazard

Liquefaction occurs as strong ground shaking during earthquakes causes saturated subsurface soils to lose strength and behave as a fluid. Liquefied deposits may be transported downslope and/or towards a free face, such as a riverbank, which is termed lateral spreading. Soils considered susceptible to liquefaction are young (i.e. <12,000 years), saturated, and non-plastic sands and silts, and in some cases loose gravels. These deposits are typically located in relatively flat areas close to active or abandoned waterways including rivers, lakes, swamps, and/or areas of uncompacted or poorly compacted fill. Geologically older sands and silts, along with dense gravel, and higher plasticity clays generally have low susceptibility to liquefaction. Typical surface effects of liquefaction are shown in Figure 4-1 and include the ejection of liquefied material and groundwater, differential settlement of the ground surface, and cracking of the ground-surface. Structures founded on soils that have liquefied may experience failure of the foundations, differential settlements, and/or large horizontal displacements, while buoyant structures buried in liquefied soils, such as tanks, pipes and manholes, may rise to the surface.

The Ministry of Business, Innovation & Employment (MBIE, 2017) *'Planning and engineering guidance for potentially liquefaction-prone land'* guidance outlines a risk-based approach for managing liquefaction related risk in land use planning and development, and is considered current industry practice for assessing liquefaction hazard and risk. The guidance presents four levels of assessment detail ranging from a 'Level A' basic qualitative desktop study to a 'Level D' site-specific quantitative liquefaction assessment. These assessments are intended to assist regional and territorial/district authorities in managing liquefaction related risk in land use planning and development. The assessments aim to identify the expected range of ground performance according to the matrix shown in Figure 4-2 and which correspond to the liquefaction land damage categories shown in Figure 4-3. The key difference between the levels of assessment (A-D) is the level of detail and the degree of residual uncertainty in the assigned liquefaction category.

All levels of liquefaction assessment detail require a ground model be developed for the assessment area which outlines the anticipated types and extents of subsurface deposits. Liquefaction susceptibility is then inferred from the ground conditions for a 'Level A' assessment, and assessed from ground investigation data for 'Level B' through 'Level D' assessments. The density of geotechnical investigations required for the liquefaction assessment depends on the level of assessment detail (Level B-D).

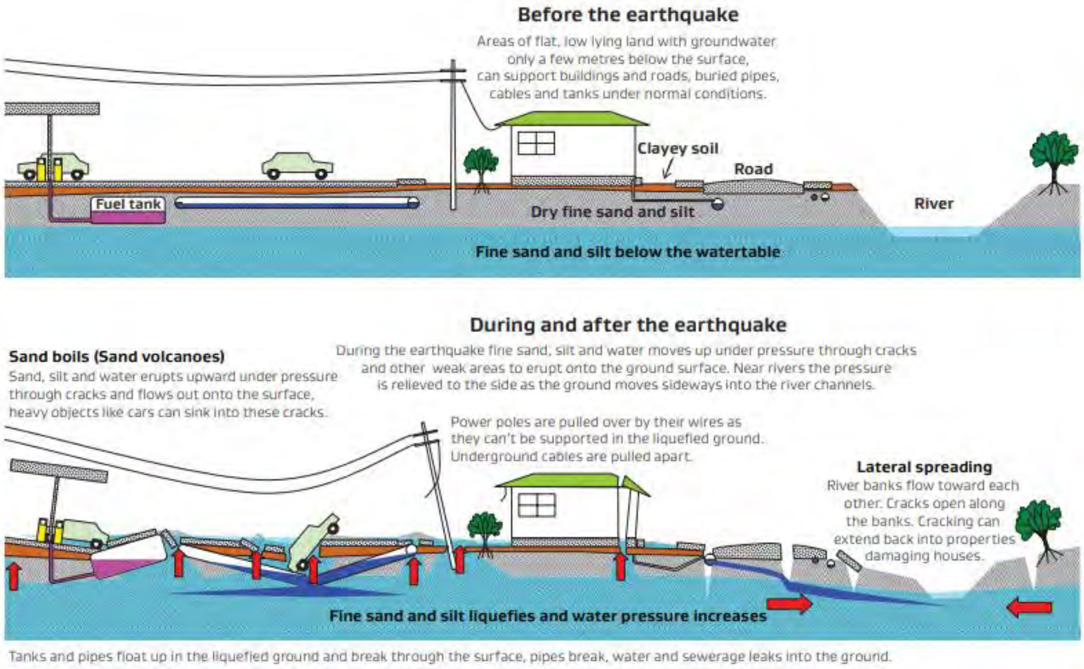

Figure 4-1: Effects of liquefaction from MBIE (2017).

LIQUEFACTION CATEGORY IS UNDETERMINED

A liquefaction vulnerability category has not been assigned at this stage, either because a liquefaction assessment has not been undertaken for this area, or there is not enough information to determine the appropriate category with the required level of confidence.

LIQUEFACTION DAMAGE IS UNLIKELY		LIQUEFACTION DAMAGE IS POSSIBLE	
There is a probability of more than 85 percent that liquefaction-induced ground damage will be ***None to Minor*** for 500-year shaking. At this stage there is not enough information to distinguish between ***Very Low*** and ***Low***. More detailed assessment would be required to assign a more specific liquefaction category.		There is a probability of more than 15 percent that liquefaction-induced ground damage will be ***Minor to Moderate*** (or more) for 500-year shaking. At this stage there is not enough information to distinguish between ***Medium*** and ***High***. More detailed assessment would be required to assign a more specific liquefaction category.	
Very Low Liquefaction Vulnerability	**Low Liquefaction Vulnerability**	**Medium Liquefaction Vulnerability**	**High Liquefaction Vulnerability**
There is a probability of more than 99 percent that liquefaction-induced ground damage will be ***None to Minor*** for 500-year shaking.	There is a probability of more than 85 percent that liquefaction-induced ground damage will be ***None to Minor*** for 500-year shaking.	There is a probability of more than 50 percent that liquefaction-induced ground damage will be: ***Minor to Moderate*** (or less) for 500-year shaking; and ***None to Minor*** for 100-year shaking.	There is a probability of more than 50 percent that liquefaction-induced ground damage will be: ***Moderate to Severe*** for 500-year shaking; and/or ***Minor to Moderate*** (or more) for 100-year shaking.

Figure 4-2: Performance criteria for determining the liquefaction vulnerability category (MBIE, 2017).

DEGREE OF LIQUEFACTION-INDUCED GROUND DAMAGE (example photographs)	TYPICAL CONSEQUENCES AT THE GROUND SURFACE **These are examples of the type of damage that would be expected, they are not intended to be criteria for calculation**
None to Minor 	– ***None to Minor*** no signs of ejected liquefied material at the ground surface[1]. – No more than minor differential settlement of the ground surface (eg undulations less than 25 mm in height). – No apparent lateral spreading ground movement (eg only hairline ground cracks). – Liquefaction causes no or only cosmetic damage to buildings and infrastructure (but damage may still occur due to other earthquake effects).
Minor to Moderate 	– ***Minor to Moderate*** quantities of ejected liquefied material at the ground surface (eg less than 25 percent of a typical residential site covered[2]); and/or – Moderate differential settlement of the ground surface (eg undulations 25–100 mm in height). – No significant lateral spreading ground movement (eg ground cracks less than 50 mm wide may be present, but pattern of cracking suggests the cause is primarily ground oscillation or settlement rather than lateral spreading). – Liquefaction causes moderate but typically repairable damage to buildings and infrastructure. Damage may be substantially less where liquefaction was addressed during design (eg enhanced foundations).
Moderate to Severe 	– Large quantities of ejected liquefied material at the ground surface (eg more than 25 percent of a typical residential site covered[2]); and/or – ***Moderate to Severe*** differential settlement of the ground surface (eg undulations more than 100 mm in height); and/or – Significant lateral spreading ground movement (eg ground cracks greater than 50 mm wide, with pattern of cracking suggesting direction of movement downslope or towards a free-face). – Liquefaction causes substantial damage and disruption to buildings and infrastructure, and repair may be difficult or uneconomic in some cases. Damage may be substantially less, and more likely to be repairable, where liquefaction was addressed during design (eg enhanced foundations and robust infrastructure detailing).

Figure 4-3: Degrees of liquefaction-induced ground damage from MBIE (2017).

4.1 Southern Corridor Ground Model

A desktop geologic map outlining landforms and anticipated ground conditions in the Southern Corridor was developed as part of the initial desktop assessment (Beca, 2024b) and is shown in Figure A1-1 and A1-2 in Appendix A. The map was developed in ArcGIS Pro at a scale of approximately 1:10,000 from a review of the following datasets:

- Regional geological map at 1:250,000 scale (Turnbull, 2000) and local geologic maps (Thomson, 2013).
- Topography visible in the 2021 Otago - Queenstown LiDAR 1m DEM available from LINZ.
- Review of historical aerial imagery flown in 1956, 1959, 1986, and 2001 and available from Retrolens (accessed October 2024), and recent GoogleEarth aerial imagery.
- Subsurface ground conditions as characterised in previous ground investigations and well logs. Locations of the investigations considered in the assessment are shown in Figure A1-1 and A1-2 in Appendix A and referenced in Table A1 in Appendix A.

Geological mapping was supplemented with observations made during a walkover of part of the Southern Corridor by a Beca Senior Engineering Geologist and Engineering Geologist on the 12 November 2024. The methodology, datasets considered in the assessment, and key features used to identify each geologic unit are detailed in Beca (2024b) and are not repeated herein. Mapped deposits are detailed below. The deposits are not considered to be discrete and there are anticipated to be areas where the boundaries between units are interfingered or graded. Holocene deposits are less than 12,000 years old and relate to the period since deglaciation.

- **Holocene river deposits** (recent/active): present in the low-lying area immediately adjacent to the Kawarau River and comprising sand, silt and gravel.
- **Holocene channel deposits** (recent/active): present within stream beds and incised channels and typically comprising gravels to cobbles in incised channels, and sand, silt, and gravel elsewhere.
- **Holocene lake beach deposits**: present adjacent to the shoreline and preserved in the area immediately north as raised ridges parallel to the existing shoreline. The deposits typically comprise gravels.
- **Holocene lake deposits**: Comprising soft laminated silts in low lying areas at the northern extent of the Southern Corridor and along the western margin of Peninsula Hill. Likely underlie the lake beach deposits.
- **Holocene storm beach deposits**: locally preserved at the base of The Remarkables. Typically comprise gravels and reflecting the margin of the elevated lake levels approximately 7,000 years ago.
- **Holocene alluvial fan deposits**: present along the foot of The Remarkables and at the base of Peninsula Hill. Locally extend onto lake deposits and till. Alluvial fans along The Remarkables are further subdivided to the following zones:
  - **Active braided zone** – area at the top of the fan with slopes generally >5° characterised by active and recently active channels on the fan surface. Deposits typically comprise gravels to boulders.
  - **Toe zone** - located at the base of the fan where flood waters spread out and merge with the surrounding flood plain with slopes of generally <5°. Deposits typically comprise, silts, and gravels.
  - **Apron zone** – area between two currently active alluvial fans and containing alluvial fans that have not been recently active. Deposits typically contains gravels to boulders.
  - **Inactive/abandoned fan** – area of braided alluvial fan that is raised above the active fan surface and has not recently been occupied by flood events. Typically contains gravels to boulders.
- **Holocene alluvium**: Present beneath the toe zone and contains flood deposits from the catchments in The Remarkables. Deposits are anticipated to comprise sands, silts, gravels, and cobbles. These deposits locally extend over the lake and till deposits.
- **Late Pleistocene glacial till**: consisting of bouldery gravel, sand, and silt present in pockets on the flanks of The Remarkables and forming the higher elevation areas within the Jacks Point/ Hanley Farm, and Homestead Bay areas.
- **Schist bedrock:** In-situ Caples Terrane schist exposed in The Remarkables and Peninsula Hill.

Specific deposits encountered in the study area along with inferred soil types, and depth to groundwater are outlined in Table 4-2.

4.1.1 Ground Investigation Data

Geotechnical investigations suitable for the liquefaction assessment are defined by MBIE (2017) as machine boreholes with Standard Penetration Testing (SPT) or Cone Penetration Tests (CPT) that characterise the ground to at least 10–15 m depth for residential or light commercial development, or at least 20–25 m depth for heavier structures or critical facilities. The recommended densities of subsurface investigations required for each assessment detailed by MBIE (2017) are outlined in Figure 4-4.

LEVEL OF DETAIL IN THE LIQUEFACTION ASSESSMENT [1,2]	AVERAGE INVESTIGATION DENSITY	AVERAGE SPACING BETWEEN	MINIMUM TOTAL NUMBER OF INVESTIGATIONS
Level A[3] Basic desktop assessment	0.01 to 1 per km^2	1 to 10 km	–
Level B Calibrated desktop assessment	0.5 to 20 per km^2	220 to 1400 m	3 for each geological sub-unit
Level C Detailed area-wide assessment	0.1 to 4 per Ha	50 to 320 m	5 if area > 1 Ha 3 if area 0.25 – 1 Ha 2 if area < 0.25 Ha
Level D[4] Site-specific assessment	2 to 40 per Ha	15 to 70 m	2 within or very close to the building footprint

Figure 4-4: Indicative spatial density of deep ground investigation for adequate ground characterisation for liquefaction assessments to inform planning and consenting processes from MBIE (2017).

Ground investigations suitable for the liquefaction assessment were identified from a review of the New Zealand Geotechnical Database, previous geotechnical reports supplied and/or identified by QLDC, and the internal Beca reports database. The available investigations were overlain with the geologic map to identify whether there was sufficient suitable geotechnical data to meet the requirements set out in Figure 4-4. Additional investigation data that identified the type of subsurface deposits (i.e. well logs) were collated for each study area to help assess the range of ground conditions. Locations of the investigations are shown in Figure A1-1 and A1-2 and referenced in Table A1 in Appendix A.

Additional geotechnical testing was completed for geologic areas identified as having insufficient suitable investigations. The results of the additional investigations were reported to QLDC separately in the geotechnical factual report (Beca, 2025a). Where the cone penetration testing (CPT) was unable to penetrate below 10m depth, the investigation was replaced with a machine borehole with standard penetration testing (SPT) to at least 10m depth. In areas where additional investigations were unable to be completed due to access restrictions, a review of all available geotechnical data (i.e. test pits, water bore logs) was undertaken to identify whether the likelihood of liquefaction could be discounted (i.e. dense gravels) with an appropriate level of confidence. The number of suitable geotechnical investigations available and collated for each study area is outlined in Table 4-2.

4.1.2 Groundwater Scenarios

Liquefaction requires susceptible soils to be saturated and therefore the likelihood of liquefaction is directly impacted by the depth to groundwater. A groundwater model was not available for the Southern Corridor however observations of groundwater levels are available from previous geotechnical investigations.

Recorded groundwater levels from the available geotechnical investigations were overlain with a 1m spatial resolution Digital Elevation Model (DEM) in ArcGIS to identify spatial trends and infer anticipated groundwater depths in each of the geologic units. Ranges in reported depths to groundwater are listed in Table 4-2. Previous investigations by Geosolve (2018) suggest that regional groundwater is >20 m depth within the Southern Corridor. However, groundwater as shallow as 1m below ground level is reported across the study area and interpreted to reflect perched water within the lake deposits. For the purposes of the liquefaction assessment, the shallowest reported depth to groundwater was adopted for the liquefaction assessment as this reflects the depth at which the deposits become saturated. The liquefaction assessment adopted measured depths to groundwater where available, and where measurements aligned with that inferred for the geologic unit. In the absence of measured depths, representative reduced level (RL) depths to groundwater were assigned from a review of proximal data. The review considered the range of reported values to determine a representative value and did not necessarily adopt the shallowest reported depth of perched groundwater. A sensitivity analysis found that raising groundwater levels did not influence the assessed liquefaction vulnerability in areas where representative reduced levels were adopted.

It is noted that the groundwater measurements were generally taken at the completion of testing when groundwater may not have become static. The impact on reported groundwater levels was examined by comparing the range of reported values across different investigation locations within each of the geologic areas. The impact of climate change on groundwater levels in the Southern Corridor was excluded from the scope of the assessment and is not considered further.

4.1.3 Seismic Hazard

The liquefaction hazard assessment needs to consider the probability that liquefaction will occur under given shaking intensities predicted over land use planning horizons. Three earthquake scenarios were considered for the liquefaction assessment to align with the three hazard scenarios that will be required for the qualitative risk analysis. The following scenarios were adopted based on MBIE (2017):

- 500-year return period earthquake scenario which represents an intensity of shaking considered to have a low likelihood of being exceeded within the land use planning horizon. This scenario aligns with the Ultimate Limit State (ULS) design case for most 'normal' buildings as specified in the New Zealand Standard for structural design actions (NZS 1170.0:2002; NZS, 2002). The annual exceedance probability (AEP) for this probabilistic earthquake scenario is 0.2%.
- 100-year return period earthquake scenario which represents an intensity of shaking that is considered to have a high likelihood of occurring within the land use planning horizon. The AEP for this probabilistic earthquake scenario is 1%.
- 25-year return period earthquake scenario which generally aligns with the Serviceability Limit State (SLS) design case specified in the standard for structural design actions (NZS 1170.0:2002; NZS, 2002). The AEP for this probabilistic earthquake scenario is 4%.

Recommended ground motion parameters for these earthquake scenarios are provided in Module 1 of the Earthquake Geotechnical Engineering Practice Guidance (NZGS/MBIE, 2021a) and are listed in Table 4-1. These ground motion parameters are recommended for all site classes and were defined for the Queenstown region using the hazard definition methodology in the NZTA-Bridge Manual (NZTA, 2022).

Table 4-1: Recommended peak ground acceleration and earthquake magnitudes for the Southern Corridor

Earthquake Return Period	Earthquake Magnitude (Mw)	Peak Ground Acceleration (g)
25-year	6.5	0.1
100-year		0.2
500-year		0.41

4.2 Qualitative Liquefaction Assessment

Key relationships between liquefaction susceptibility and the age of sedimentary deposits have been summarised by Youd and Perkins (1978) and are shown in Figure 4-5. MBIE (2017) additionally presents the semi-quantitative screening criteria shown in Figure 4-6 which identifies areas where liquefaction damage is considered unlikely based on soil type, seismic hazard, and depth to groundwater. Both criteria were applied to the deposits encountered within the Southern Corridor study area to identify whether the presence of liquefiable deposits could be discounted (i.e. *'Liquefaction Damage is Unlikely'*). The assessment considered the anticipated range of deposit types and the ground conditions reported in the available geotechnical investigations. Locations of the geotechnical investigations considered in the assessment are shown in Figure A1-1 and A1-2 in Appendix A. The inferred susceptibility of the deposits encountered in the study area is summarised in Table 4-2. The assessment aimed to classify the area into the following liquefaction vulnerability categories from MBIE (2017) and outlined in Figure 4-2:

- *Liquefaction Damage is Unlikely* - geological units considered not susceptible to liquefaction based on their geologic description and/or depositional setting.
    - Refined to *'Very Low Liquefaction Vulnerability* where there is sufficient conclusive geological information that the underlying deposit is not susceptible to liquefaction (i.e. shallow rock).
- *Liquefaction Damage is Possible* – Areas where the geologic setting suggests that the underlying geologic unit may be susceptible to liquefaction.
- *Liquefaction Category is Undetermined* – Areas not considered in the liquefaction assessment or where there is insufficient data to conclusively determine the liquefaction vulnerability of the underlying geologic unit.

Type of Deposit	General Distribution of Cohesionless Sediments in Deposits	Likelihood that Cohesionless Sediments when Saturated would be Susceptible to Liquefaction (by Age of Deposit)			
		< 500 yr Modern	Holocene < 11 ka	Pleistocene 11 ka - 2Ma	Pre-Pleistocene > 2 Ma
(a) Continental Deposits					
River channel	Locally variable	Very High	High	Low	Very Low
Flood plain	Locally variable	High	Moderate	Low	Very Low
Alluvial fan and plain	Widespread	Moderate	Low	Low	Very Low
Marine terraces and plains	Widespread	---	Low	Very Low	Very Low
Delta and fan-delta	Widespread	High	Moderate	Low	Very Low
Lacustrine and playa	Variable	High	Moderate	Low	Very Low
Colluvium	Variable	High	Moderate	Low	Very Low
Talus	Widespread	Low	Low	Very Low	Very Low
Dunes	Widespread	High	Moderate	Low	Very Low
Loess	Variable	High	High	High	Unknown
Glacial till	Variable	Low	Low	Very Low	Very Low
Tuff	Rare	Low	Low	Very Low	Very Low
Tephra	Widespread	High	High	?	?
Residual soils	Rare	Low	Low	Very Low	Very Low
Sebka	Locally variable	High	Moderate	Low	Very Low
(b) Coastal Zone					
Delta	Widespread	Very High	High	Low	Very Low
Esturine	Locally variable	High	Moderate	Low	Very Low
Beach					
High Wave Energy	Widespread	Moderate	Low	Very Low	Very Low
Low Wave Energy	Widespread	High	Moderate	Low	Very Low
Lagoonal	Locally variable	High	Moderate	Low	Very Low
Fore shore	Locally variable	High	Moderate	Low	Very Low
(c) Artificial					
Uncompacted Fill	Variable	Very High	---	---	---

Figure 4-5: Estimated susceptibility of sedimentary deposits to liquefaction during strong shaking as established by Youd and Perkins (1978).

TYPE OF SOIL DEPOSIT	A LIQUEFACTION VULNERABILITY CATEGORY OF LIQUEFACTION DAMAGE IS UNLIKELY CAN BE ASSIGNED IF EITHER OF THESE CONDITIONS IS MET:	
	DESIGN PEAK GROUND ACCELERATION (PGA) FOR 500-YEAR INTENSITY OF EARTHQUAKE SHAKING[1]	DEPTH TO GROUNDWATER[2]
Late Holocene age Current river channels and their historical floodplains, marshes and estuaries, reclamation fills	Less than 0.1 g[3]	More than 8 m
Holocene age Less than 11,000 years old	Less than 0.2 g	More than 6 m
Latest Pleistocene age Between 11,000 and 15,000 years old	Less than 0.3 g	More than 4 m

Figure 4-6: Semi-quantitative screening criteria from MBIE (2017) for identifying land where liquefaction-induced ground surface damage is unlikely

Table 4-2: Summary of anticipated ground conditions, existing geotechnical investigation data, and inferred liquefaction susceptibility in the Southern Corridor study area

Study Area	Geologic Units	Encountered Soil Types	Measured depth to groundwater		Available Geotechnical Investigations		Qualitative Liquefaction Assessment
			m below ground level (m bgl)	Reduced Level (m RL[1])	Suitable for liquefaction triggering assessment	Not suitable for liquefaction triggering assessment	
Kawarau River	Holocene River Deposits	Silty sand, sandy silt, silt, sandy gravel	-	310	1x CPT	-	*Liquefaction Damage is Possible*
	Holocene Lake Deposits	Soft silt/ sandy silt	14	310	1x CPT 1x Borehole	-	*Liquefaction Damage is Possible*
Coneburn - east of SH6	Late Pleistocene Glacial Till	Sandy gravel, silty gravel, sandy silt, cobbles/boulders	-	-	-	4x Boreholes[2]	*Liquefaction Damage is Unlikely*
	Holocene Alluvial Fan (Inactive/abandoned)	Silty sandy gravel, sandy gravel/ cobbles/ boulders	2 – 23	397 – 420	-	4x Boreholes	*Liquefaction Damage is Unlikely*
	Holocene Alluvial Fan (toe zone)	Silty sandy gravel, sandy gravel, sand, silt	7 – 8	314 – 326	-	4x Water Bore logs	*Liquefaction Category is Undetermined*
	Holocene Storm Beach Deposits	Sandy gravel, gravel, sand	-	-	-	-	*Liquefaction Damage is Unlikely*
Coneburn - west of SH6	Holocene Lake Deposits	Soft silt/ sandy silt	0.5 – 2m	325 – 335	12x CPT 2x Boreholes	-	*Liquefaction Damage is Possible*
	Holocene Alluvial Fan (toe zone)	Silty sandy gravel, sandy gravel, sand, silt	1.5 – 8	330 – 336	9x CPT	1x Borehole	*Liquefaction Damage is Possible*
Homestead Bay – East of SH6	Holocene Alluvial Fan (braided and apron zones)	Sandy gravel, sandy gravel/ cobbles/ boulders	2 – 23	397– 420	-	6x Boreholes 1x Water Bore	*Liquefaction Category is Undetermined*
	Holocene Alluvial Fan (toe)	Silty sandy gravel, sandy gravel, sand, silt; overlies till	1.5 – 8.0	413	-	4x Borehole[3]	*Liquefaction Category is Undetermined*
	Late Pleistocene Till	Sandy gravel, silty gravel, sandy silt, cobbles/boulders	-	-	-	4x Boreholes[2]	*Liquefaction Damage is Unlikely*
Homestead Bay – West of SH6	Holocene Lake Beach Deposits (recent)	Loose gravel, sand, sandy gravel, silt	0.0 – 2.0	310 – 319	1x Borehole	6x Water Bores	*Liquefaction Damage is Possible*
	Holocene Lake Beach	Sandy gravel, gravel, sand, overlies lake deposits	1 – 8	317 – 339	1x CPT 4x Boreholes	2x Water Bores	*Liquefaction Damage is Possible*
	Holocene Lake Deposits	Soft silt/sandy silt	3 – 6	324	15x CPT		*Liquefaction Damage is Possible*
	Holocene Alluvial Fan (toe zone)	Silty sandy gravel, sandy gravel, sand, silt	2 – 15+[4]	387 – 413+	4x Borehole	N/A	*Liquefaction Category is Undetermined*
	Late Pleistocene Till	Sandy gravel, silty gravel, sandy silt, cobbles/boulder	-	-	-	4x Boreholes[2]	*Liquefaction Damage is Unlikely*
Homestead Bay - Peninsula Hill	Late Pleistocene Till	Sandy gravel, silty gravel, sandy silt, cobbles/boulder	-	-	-	4x Boreholes[2]	*Liquefaction Damage is Unlikely*

[1] Elevation referenced to NZVD2016

[2]Ground profile inferred from boreholes completed in till in the wider Southern Corridor area

[3]Inferred from waterbores completed in Coneburn area east of SH6

[4]Groundwater not encountered, inferred to be below base of investigation

N/A – data not available / identified in our review of publicly available information.

4.3 Quantitative Liquefaction Assessment

Quantitative liquefaction assessments identify the range of liquefaction-induced ground damage predicted for selected earthquake scenario(s) from analysis of geotechnical investigation data. The results may be extrapolated across similar geologic and/or geomorphic settings.

A quantitative liquefaction assessment was completed for the areas identified as containing deposits potentially susceptible to liquefaction under the qualitative assessment and containing sufficient geotechnical investigation data in accordance with Figure 4-4. The assessment was completed in accordance with Module 3 of the Earthquake Geotechnical Engineering Practice Guidance (NZGS/MBIE, 2021b) using the collated CPT and borehole SPT data. The assessment aimed to identify the range of liquefaction-induced damage predicted for the 25, 100, and 500- year return period seismic events and provide sufficient information to inform the qualitative risk analysis. Results of the assessment are presented in Appendix B.

- The likelihood of liquefaction was assessed using the Boulanger and Idriss (2014) simplified liquefaction triggering methodology. A probability of liquefaction (PL) of 15% and behaviour type index (I_c) cut off of 2.6 were adopted for the assessment.
- Reported depths to groundwater were adopted for the assessment. Where measured levels were not associated with the investigation data, a representative reduced level (RL) groundwater was assigned from a review of surrounding investigation data.
- Liquefaction-induced ground surface settlements were predicted from the results of the triggering assessment using Zhang et al. (2002).
    - For borehole investigations where the soil is shown to be predominantly gravel dominated, the predicted ground surface settlements in these deposits was reduced by a factor of one-third. This adjustment assumes a 25% gravel content in the soil matrix and reflects the observed post-liquefaction behaviour of gravelly soils (Pokhrel, 2023).
- Surface effects of the predicted liquefaction were assessed through the Liquefaction Potential Index (LPI; Iwasaki et al., 1978) and Liquefaction Severity Number (LSN; van Ballegooy et al., 2014).

Soil parameters assigned to the units encountered in the machine boreholes are listed in Table 4-3. These parameters were adopted for the liquefaction assessment using the SPT results and were assigned based on a review of the ground conditions and values adopted for similar assessments within the Southern Corridor.

Table 4-3: Soil parameters adopted for the liquefaction assessment using SPT data

Material Description	Unit Weight (kN/m^3)	Effective Angle of Friction (degree)	Apparent Cohesion, c' (kPa)	Young's Modulus, Es (MPa)
Alluvial Fan Deposits	18	30	0	10
Glacial Outwash	19	36	0	20
Glacial Till	18	36	0	20
Lake Beach Deposits	18	33	0	10
Lake Deposits	17	28	0	5
Caples Terrane Schist	19	32	10	20

4.4 Estimated degree of liquefaction-induced ground damage

MBIE (2017) describes three degrees of liquefaction-induced ground damage which generally correspond to the calculated ranges of predicted ground surface settlements, LPI, and LSN outlined in Table 4-1Table 4-4. The ranges of ground surface settlements, LPI, and LSN were identified from a review of relevant literature (i.e. MBIE, 2017; van Ballegooy et al., 2014). Categories are coloured to match that used for the liquefaction damage categories shown in Figure 4-3. MBIE (2017) includes a flow chart (Figure 4-7) and conceptual ground damage curves (Figure 4-8) which correlate the predicted liquefaction-induced damage to the liquefaction vulnerability categories. Specific assessment of ground deformation due to lateral spreading has not been included within this regional assessment. It is possible that land damage could be elevated in areas adjacent to free faces such as waterways due to lateral spreading. This is considered applicable to existing and any new/ modification of waterways proposed within the Southern Corridor.

Table 4-4: Land Damage Categories and corresponding indices

Degree of liquefaction-induced ground damage	Description	Corresponding Values
None to Minor	No observed liquefaction-related land damage through to minor observed ground cracking but with no observed ejected liquefied material at the ground surface	Settlement = <25mm LSN = <10 LPI =<5
Minor to Moderate	Observed ground surface undulation and minor-to-moderate quantities of observed ejected liquefied material at the ground surface but with no observed lateral spreading	Settlement = 25 - 100mm LSN = 10-25 LPI = 5-15
Moderate to severe	Large quantities of observed ejected liquefied material at the ground surface and severe ground surface undulation and/or moderate to severe lateral spreading	Settlement = >100mm LSN = >25 LPI = >15

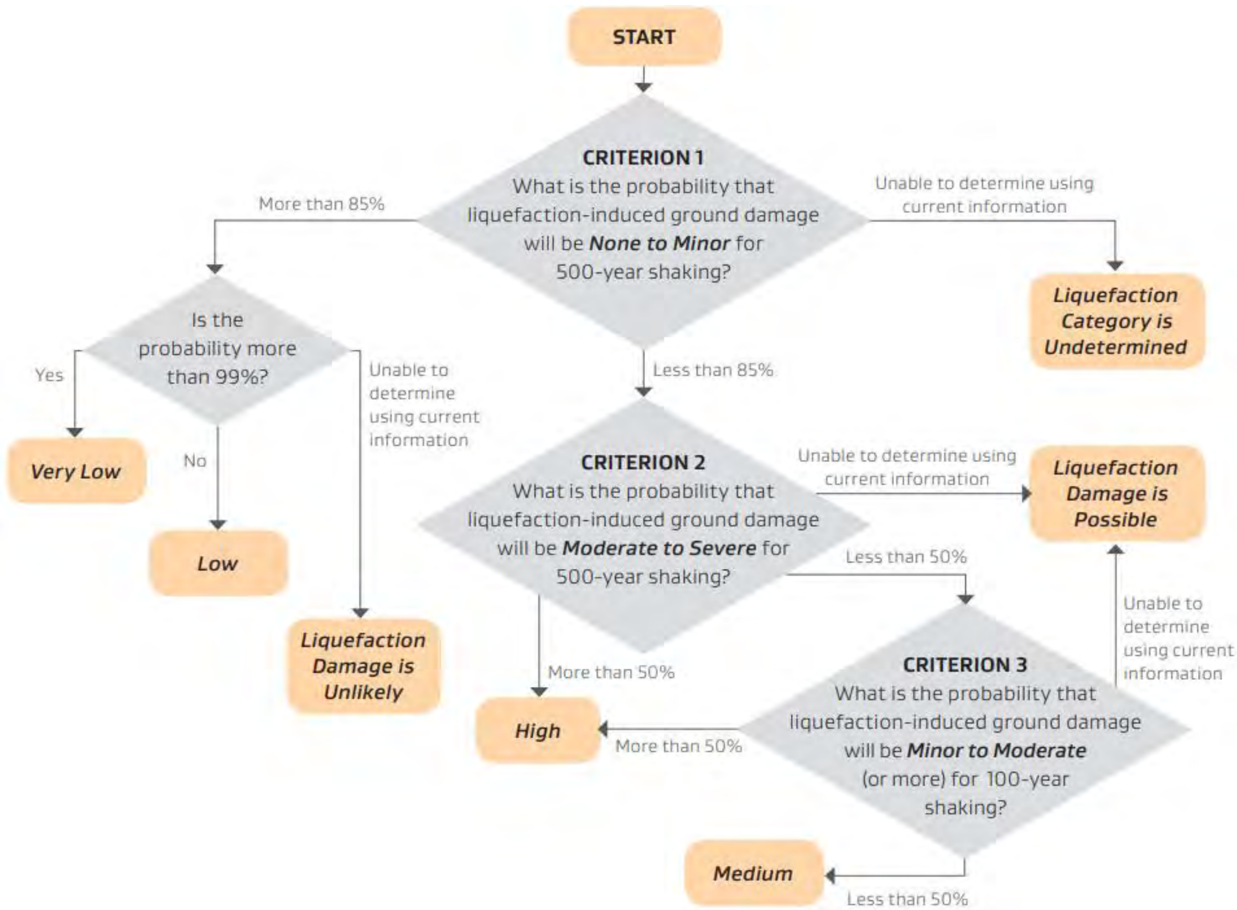

Figure 4-7: Flow chart from MBIE (2017) for determining liquefaction vulnerability categories

Figure 4-8: Ground damage response curves for '*low', 'medium' and 'high liquefaction vulnerability'* categories used for liquefaction categorisation from MBIE (2017).

Representative liquefaction vulnerability categories were assigned to each geotechnical investigation using the predicted liquefaction-induced ground damage for the 500-year and 100-year earthquake return period assessments and performance criteria outlined in Table 4-4, Figure 4-7, and Figure 4-8. The adopted liquefaction vulnerability category assigned to each geotechnical investigation is listed in Table 4-5 along with the corresponding predicted land damage. The predicted liquefaction-induced ground damage is coloured according to the criteria set out in Table 4-4, and the assigned liquefaction vulnerability is coloured in accordance with Figure 4-2. Engineering judgement was applied where only part of the criteria set out in Table 4-4 was met. Emphasis was placed on the predicted ground surface settlements followed by LSN. Less emphasis was placed on LPI as these values were found to misalign with observed liquefaction following the Canterbury earthquakes. The assessed range of liquefaction vulnerabilities was used to inform the assessment of the Southern Corridor study area which is outlined in Section 5.

Table 4-5: Calculated liquefaction damage parameters for each assessed geotechnical investigation and corresponding liquefaction vulnerability category

Study Area	Deposit Type	Investigation ID	25-Year Earthquake Return Period			100-Year Earthquake Return Period			500-Year Earthquake Return Period			Assessed Liquefaction Vulnerability
			Settlement (mm)	LPI	LSN	Settlement (mm)	LPI	LSN	Settlement (mm)	LPI	LSN	
Kawarau River	Holocene River Deposits	CPT-02	32	0	3	303	15	30	337	33	31	*High Liquefaction Vulnerability*
	Holocene Lake Deposits	22BH01 [2]	1	0	0	285	0	9	285	3	42	*High Liquefaction Vulnerability*
		sCPT-01	0	0	0	0	0	0	1	0	0	*Low Liquefaction Vulnerability*
Coneburn – West of SH6	Holocene Lake Deposits	Beca_CPT01	6	0	1	15	2	2	15	3	3	*Low Liquefaction Vulnerability*
		Beca_CPT02	2	0	1	16	1	14	25	5	24	*Medium Liquefaction Vulnerability*
		CPT05	0	0	0	0	0	0	0	0	0	*Low Liquefaction Vulnerability*
		WR-ENG21-CPT01	0	0	0	6	0	3	15	3	8	*Low Liquefaction Vulnerability*
		WR-ENG21-CPT02	4	0	1	40	3	11	60	11	18	*High Liquefaction Vulnerability*
		WR-ENG21-CPT03	5	0	1	56	4	15	72	13	23	*High Liquefaction Vulnerability*
		EIC_ENG22-CPT-01	7	0	2	57	5	20	62	13	24	*High Liquefaction Vulnerability*
		EIC_ENG22-CPT-03	1	0	0	18	1	9	25	5	13	*Medium Liquefaction Vulnerability*
		RDA_CPT09	1	0	0	7	0	1	10	1	3	*Low Liquefaction Vulnerability*
		RDA_CPT10	1	0	0	21	1	6	29	5	9	*Medium Liquefaction Vulnerability*
	Holocene Alluvial Fan (toe)	WR-ENG21-CPT04	9	0	2	75	6	13	87	15	17	*High Liquefaction Vulnerability*
		WR-ENG21-CPT05	2	0	1	23	1	6	33	6	8	*Medium Liquefaction Vulnerability*
		CPT03	0	0	0	11	0	1	94	3	6	*Medium Liquefaction Vulnerability*
Homestead Bay – West of SH6	Holocene Lake Deposits	RDA_CPT46	1	0	0	8	0	0	27	1	2	*Medium Liquefaction Vulnerability*
		RDA_CPT49	1	0	0	37	1	4	75	5	7	*High Liquefaction Vulnerability*
		RDA_CPT50	0	0	0	26	0	2	66	4	5	*High Liquefaction Vulnerability*
		RDA_CPT51	5	0	1	50	2	7	75	8	12	*High Liquefaction Vulnerability*
		RDA_CPT52	5	0	0	35	1	3	40	3	3	*High Liquefaction Vulnerability*
		RDA_CPT59	4	0	0	34	1	5	53	7	10	*High Liquefaction Vulnerability*
		RDA_CPT60	6	0	1	92	3	10	149	14	16	*High Liquefaction Vulnerability*
		RDA_CPT61	2	0	0	16	1	1	18	2	2	*Low Liquefaction Vulnerability*
		CPT06B	0	0	0	10	0	1	59	5	9	*Medium Liquefaction Vulnerability*
		CPT07	2	0	0	72	2	8	153	19	22	*High Liquefaction Vulnerability*
	Holocene Lake Beach Deposits	CPT13	1	0	0	8	0	2	21	3	10	*Low Liquefaction Vulnerability*
		BHLQ_04 [1]	0	0	0	0	0	0	9	3	9	*Low Liquefaction Vulnerability*
		BHLQ_09	0	0	0	0	0	0	0	0	0	*Low Liquefaction Vulnerability*
		BH LQ_11	0	0	0	2	0	0	34	1	3	*Medium Liquefaction Vulnerability*
		BHLQ_16	0	0	0	0	0	0	0	0	0	*Low Liquefaction Vulnerability*
		BH01 Geosolve 2022 [2,3]	0	0	0	1	0	2	21	4	5	*Low Liquefaction Vulnerability*
	Holocene Alluvial Fan (toe)	BH02 Geosolve 2022	0	0	0	0	0	0	2	1	5	*Low Liquefaction Vulnerability*
		BH03 Geosolve 2024	0	0	0	0	0	0	0	0	0	*Low Liquefaction Vulnerability*
		BH01 Geosolve 2024 [1,2]	0	0	0	5	1	4	31	16	12	*Medium Liquefaction Vulnerability*

Notes:

1. Estimated settlements have been reduced to one-third of the originally predicted values, accounting for the effect of gravel within the liquefaction-susceptible soil layers based on Pokhrel (2023).
2. LSN reduced to account for effect of gravel based on Pokhrel (2023).
3. Liquefiable soils below 20m have been excluded for this assessment as land damage at the surface is anticipated to be minor due to thickness of overlying non liquefiable soils.

5 Assessed Liquefaction Vulnerability

The liquefaction vulnerability of the study area in the Southern Corridor was assessed from a review of the following:

- Ground model of anticipated ground conditions as developed from consideration of geologic, geomorphic, and ground investigation data,
- Types of sub-surface deposits identified in available ground investigation data,
- Recorded and anticipated depths to groundwater,
- Qualitatively assessed liquefaction susceptibility
- Estimated degree of liquefaction-induced ground damage for the selected earthquake scenarios based on representative groundwater levels; and
- Spatial distribution of assigned liquefaction vulnerabilities from the geotechnical investigations.

The liquefaction vulnerability assigned to each geotechnical investigation from the quantitative analysis was overlain with the geologic map to identify spatial trends and variations across the study area. Revised liquefaction categories were then assigned based on a review of the range of assessed vulnerabilities and mapped geology. Observations that formed the basis for the assigned liquefaction vulnerability categories are outlined below. Areas correspond to those named in Figure 1-1.

The assessed liquefaction categories assigned to the Southern Corridor study area are shown in Figure A2 in Appendix A. The level of liquefaction assessment detail (i.e. Level A-D) achieved in the study area is shown in Figure A3 in Appendix A.

5.1.1 Kawarau River

- Recent alluvial deposits in the low-lying area immediately adjacent to the Kawarau River are assessed to have a *'High Liquefaction Vulnerability'*. The vulnerability reflects the loosely consolidated silt, sand, and gravel in this area. The proximity of the site to the Kawarau River suggests lateral spreading may occur when liquefaction is triggered.
- The Holocene lake deposits on the terrace raised above the river are assessed to have either *'Low'* or *'High Liquefaction Vulnerability'* depending on the depth to groundwater. The range in predicted damage suggests that these deposits are susceptible to liquefaction however there is insufficient information to refine the liquefaction vulnerability of these deposits. Further investigations including assessment of the groundwater table would be required to refine the vulnerability.

5.1.2 Coneburn west of SH6

5.1.2.1 QEII land

- The CPT adjacent to the stream channel return a *'Moderate'* to *'Low Liquefaction Vulnerability'.* The variability reflects differences in the silt content, with the *Low Liquefaction Vulnerability'* deposits having an I_c above the 2.6 cut-off adopted for the assessment. The presence of more sand-dominated deposits/ layers in this area cannot be discounted, therefore the area is assigned as *'Liquefaction Damage is Possible'*. There is insufficient information to support refinement of the liquefaction vulnerability due to the inconsistency in predicted damage and limited investigation data. Lateral spreading may also occur adjacent to the stream channel which would increase surface effects of liquefaction.
- The alluvial fan toe zone (CPT5) returns a *'Low Liquefaction Vulnerability'* which reflects the silt content of the lake deposits underlying the alluvial deposits. The presence of relatively low-density soft silts and moderate groundwater depths (~6m) means liquefaction damage cannot be discounted for this area. The area is therefore assigned *'Liquefaction Damage is Possible'*.

- Further investigations would be required to refine the liquefaction hazard for this area and may be completed as part of a site-specific assessment. This may be supplemented with a more in-depth assessment of the behaviour of the lake silts (see Section 5.2).

5.1.2.2 Patterson Block

- The lake deposits and alluvial fan toe zone in the central portion of the site is assessed to have a *'High Liquefaction Vulnerability'*. *'Moderate Liquefaction Vulnerability'* is assessed for the margins of the site and adjacent alluvial fan toe.
- Investigations along the western margin of the site return *'Low Liquefaction Vulnerability'* which reflects a higher silt content of the deposits which are above the I_c 2.6 cut-off. The presence of localised sandier lenses within these deposits cannot be discounted, therefore the area is assigned as *'Liquefaction Damage is Possible'*. Further investigations would be required to refine the liquefaction vulnerability in this area.
- The western margin of the site contains alluvium/ alluvial fan deposits derived from Peninsula Hill and is raised above the low-lying lake deposits. This area is considered unlikely to be susceptible to liquefaction due to the inferred deeper depth to groundwater and nature of the deposits overlying the lake deposits and is assigned *'Liquefaction Damage is Unlikely'*.

5.1.3 Homestead Bay west of SH6

- Areas mapped as containing glacial till are not considered susceptible to liquefaction due to the age of the deposits and predominance of gravel. These areas are assigned *'Liquefaction Damage is Unlikely'*. A quantitative liquefaction assessment was not completed for these deposits as they were not considered susceptible under the qualitative assessment and suitable geotechnical investigations were not available. This includes the area on Peninsula Hill.
- The areas mapped as containing lake beach deposits with visible beach ridges orientated parallel to the existing Lake Wakatipu shoreline are assessed to have *'Medium Liquefaction Vulnerability'*. This reflects the relatively shallow depth to the underlying lake deposits (3-4 m below ground level) encountered in BHLQ_11 and adjacent ORC water bores. The surrounding areas are assigned as *'Low Liquefaction Vulnerability'*. The machine boreholes indicate these deposits comprise dense gravels which are shown in the quantitative liquefaction assessment to uniformly have *'Low Liquefaction Vulnerability'*. Liquefaction damage is therefore not predicted in these areas under the assessed seismic events.
- The lake deposits adjacent to the golf course are shown to have an overall *'High Liquefaction Vulnerability'*. The assessed susceptibly reflects the soft sandy silt deposits and relatively shallow depths to groundwater. This is consistent with the lake deposits identified within Patterson Block. Lateral spreading may additionally occur along the lake edge when liquefaction is triggered.
- The lower portion of the alluvial fan/ area of Holocene alluvium near the eastern extent of the QLDC sports field is shown to have a *'Moderate Liquefaction Vulnerability'*. Only one investigation is available for this area and no additional investigations were able to be undertaken due to land access restrictions. As such, there is insufficient information to constrain where, or if the liquefaction vulnerability uniformly decreases from *'High'* to *'Medium'* from the adjacent lake deposits. The area is therefore assigned as *'Liquefaction Damage is Possible'*. The transition from the lake deposits to the alluvial fan/ Holocene alluvium deposits has additionally been inferred from topography. Further geotechnical investigations would be required to refine the position of this transition, and additional investigations would be required to assign *'Medium'* or *'High Liquefaction Vulnerability'* to this area.
- The upper portion of the toe zone of the alluvial fan that extends across SH6, from The Remarkables, is shown to have a *'Low Liquefaction Vulnerability'*. This corresponds to the gravel-dominated deposits identified in the boreholes completed within this area. Previous reports (Geosolve, 2023) suggests that shallow groundwater seepage (i.e. <3m depth) was encountered in test pit investigations in the eastern area of the site. The presence of localised liquefaction as a result of perched groundwater in

localised sandier-deposits cannot be discounted and further investigations would be required to reassess the liquefaction hazard in these areas and confirm the low vulnerability.

5.1.4 Coneburn and Homestead Bay areas east of SH6

- The alluvial fan deposits overlie lake deposits immediately east of the QEII and Patterson block sites. Well bores indicate that these areas locally contain approximately 6m of alluvium comprising sandy gravel underlain by 20m of lake deposits. Low-lying areas with elevations similar to that west of SH6 were assigned as *'Liquefaction Damage is Possible'* to reflect the likelihood that the liquefiable deposits extend beneath the highway. Further geotechnical investigations would be required to refine the liquefaction hazard in these areas.
- The remainder of the alluvial fan and glacial till deposits to the east of SH6 were assigned *'Liquefaction Damage is Unlikely'*. This reflects the gravel-dominant behaviour of the deposits and depth to groundwater, as assessed at a regional scale. The presence of localised areas of liquefiable deposits (i.e. adjacent to stream channels) cannot be discounted. The liquefaction category cannot be refined further (i.e. *'Low' Liquefaction Vulnerability'*) as the area has not been quantitatively assessed due to a lack of suitable geotechnical investigations.

5.2 Impact of Micaceous Soils

The soft lake silts encountered in the Southern Corridor and also present in the wider Lake Wakatipu area are considered micaceous. Mica is a silicate sheet mineral characterised by its ability to split into elastic plates/sheets. In the Southern Corridor, mica is derived from the basement Caples Terrane schist. The behaviour of the micaceous silts is different to that of the typical clean quartz-dominated sand which the conventional simplified liquefaction triggering analysis methods are based (i.e. Boulanger and Idriss, 2014). The use of the simplified triggering approaches may therefore inaccurately account for the behaviour of these deposits and may not reflect actual susceptibility.

The liquefaction susceptibility of the Lake Wakatipu micaceous silts has previously been evaluated by Giannakogiorgos et al., (2017). The study found no clear relationship between the behaviour of micaceous silts on the outcome of the conventional empirical liquefaction analyses. A site-specific study by Bowen et al. (2015) utilising advanced laboratory testing concluded that 'classical liquefaction' behaviour was not observed in any of the tests and that 'cyclic mobility' was more likely. This work confirms that the micaceous silts do not behave the same as the clean sands that the simplified liquefaction triggering methodologies are based on. However, cyclic mobility may still result in large surface deformations and therefore warrants further assessment. A site-specific assessment by Beca (2023a) adopted an I_c cut-off of 2.8 for the micaceous soils based on site-specific laboratory testing however there is no evidence to support adopting this value at a regional scale.

The previous studies do not provide recommendations for alternative methodologies for assessing the liquefaction susceptibility and no other studies outlining the impact of these soils on liquefaction triggering, nor alternative assessment methodologies were identified in our literature review. Therefore, in absence of studies in support of alternative assessment methodologies, the conventional assessment methodologies were applied. Results of Bowen et al. (2015) suggests the conventional methodologies may be conservative, particularly at the lower annual exceedance probability (AEP) events (25-year and 100-year return period events) where shaking intensities are lower. As no to minor liquefaction is primarily predicted for the low AEP events, the impact of micaceous soils on the output is considered to be negligible. Further site-specific assessments could be considered to refine the liquefaction hazard assessment in areas containing Holocene lake deposits including consideration of adopting the higher I_c cut-off value.

6 Assumptions and Limitations

Specific assumptions and limitations of this liquefaction hazard assessment are outlined below.

- The ground model which underpins the liquefaction assessment was completed at a scale of 1:15,000 which is in general accordance with MBIE (2017). The output is not considered a replacement for site-specific liquefaction assessments and it is intended to be used at a consistent or greater scale.
- The assessment assumed that the mapped geology shown in the ground model is representative of the underlying deposits where geotechnical investigation data is not available.
- The output of this assessment reflects the regionally assessed liquefaction vulnerability within the study area based on mapped geology and qualitative and quantitative liquefaction assessments. The results are not considered a replacement for site-specific investigations and no inferences can be made on the hazard outside of the study area boundaries.
- The assessment considers the likelihood of liquefaction based on the available investigation data. Ground conditions between each of the investigation points have been inferred from topography. It is possible that there is variability in the deposits between the investigation points that is not captured due to the spacing of the investigations. The hazard may be refined through additional testing as part of site-specific investigations. The spacing of investigations used in this assessment is considered suitable for the level of assessment detail.
- A Soil Behaviour Type (I_c) cut-off value of 2.6 was adopted for the liquefaction assessment. Site specific assessments may support adopting a higher cut-off value for certain soils such as the micaceous silts. This may result in a higher liquefaction vulnerability being predicted for some areas.
- The assessment considers the typical range of deposit types across the mapped geologic units, as inferred from site-specific information. It does not consider site-specific development nor modifications to the landscape such as ground improvement under development and/or modification to waterways.
- The scale of mapping and density of investigations means that localised areas of susceptible soils, such as abandoned channels, are not identified within larger geological units. There is potential for localised areas of liquefaction-induced damage in areas identified as *'Liquefaction Damage is Unlikely'* or *'Low Liquefaction Vulnerability'*.
- The datasets considered in our assessment contain residual uncertainties and accuracy limitations which are not explicitly stated in the data sources. These limitations may result in boundaries that do not precisely align with geologic features and/ or variations in the subsurface deposit types.
- The assessment does not assess nor quantify lateral spread ground deformation. Liquefaction-induced lateral spreading could result in increased ground damage which would locally increase the liquefaction vulnerability from that reported (i.e. *'Medium' to 'High' Liquefaction Vulnerability'*).
- The assessment assumed that the measured depth to groundwater is representative of existing groundwater levels. Seasonal fluctuations, perched water tables (where not specifically evident within investigations), anthropogenic modifications, and the impact of climate change on future ground water levels were not considered as part of this assessment.
- Perched water levels were assessed where possible based on available investigation data. It is acknowledged that perched water levels may vary over short distances and the identification of such levels is difficult with limited investigation data.

7 Applicability Statement

This report has been prepared by Beca Limited (Beca) on the specific instructions of Queenstown Lakes District Council (Client). It is solely for our Client's use for the purpose for which it is intended in accordance with the agreed scope of work. Any use or reliance by any person contrary to the above, to which Beca has not given its prior written consent, is at that person's own risk. Should you be in any doubt as to the applicability of this report and/or its recommendations for the proposed development as described herein, and/or encounter materials on site that differ from those described herein, it is essential that you discuss these issues with the authors before proceeding with any work based on this document. In preparing this report Beca has relied on key information listed in the reference list attached and in Table A1. Unless specifically stated otherwise in this report, Beca has relied on the accuracy, completeness, currency and sufficiency of all information provided to it by, or on behalf of, the Client, including the information listed above, and has not sought independently to verify the information provided. This report should be read in full, having regard to all stated assumptions, limitations and disclaimers. No part of this report shall be taken out of context and, to the maximum extent permitted by law, no responsibility is accepted by Beca for the use of any part of this report in any context, or for any purpose, other than that stated herein.

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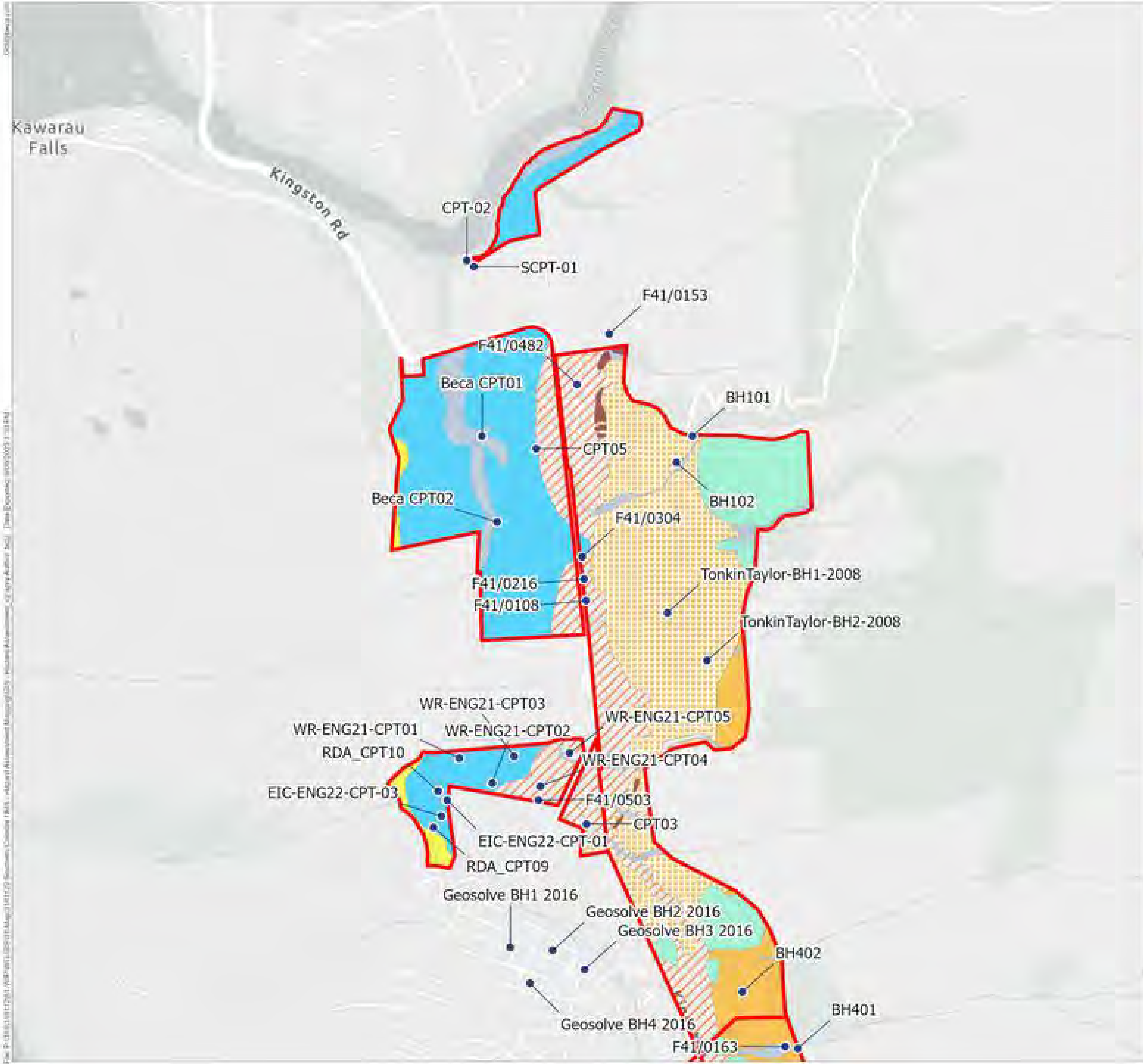
A

Appendix A – Southern Corridor Maps and Investigation Locations

Geology and Investigations Considered in Assessment

Figure A1-1



- Geotechnical Investigations
- Hazard Study Area

Mapped Geology

- Modified Land
- Holocene Alluvial Fan (Active Braided Zone)
- Holocene Alluvial Fan (Apron Zone)
- Holocene Alluvial Fan (Inactive/Abandoned)
- Holocene Alluvial Fan (Toe Zone)
- Holocene Alluvium
- Holocene Lake Beach Deposits
- Holocene Lake Beach Deposits (Recent)
- Holocene Lake Deposits
- Holocene Storm Beach Deposits
- Holocene Channel Deposits
- Late Pleistocene Glacial Till
- Schist (Bedrock)

For full unit definitions please refer to Beca report "Te Tapuae/Southern Corridor Liquefaction Hazard Assessment" 3161129-1286181819-904

This map should be read in conjunction with the Beca report Te Tapuae/Southern Corridor Liquefaction Hazard Assessment" 3161129-1286181819-904

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Map Scale @ A4: 1:25,000

0 0.25 0.5 Kilometres

N

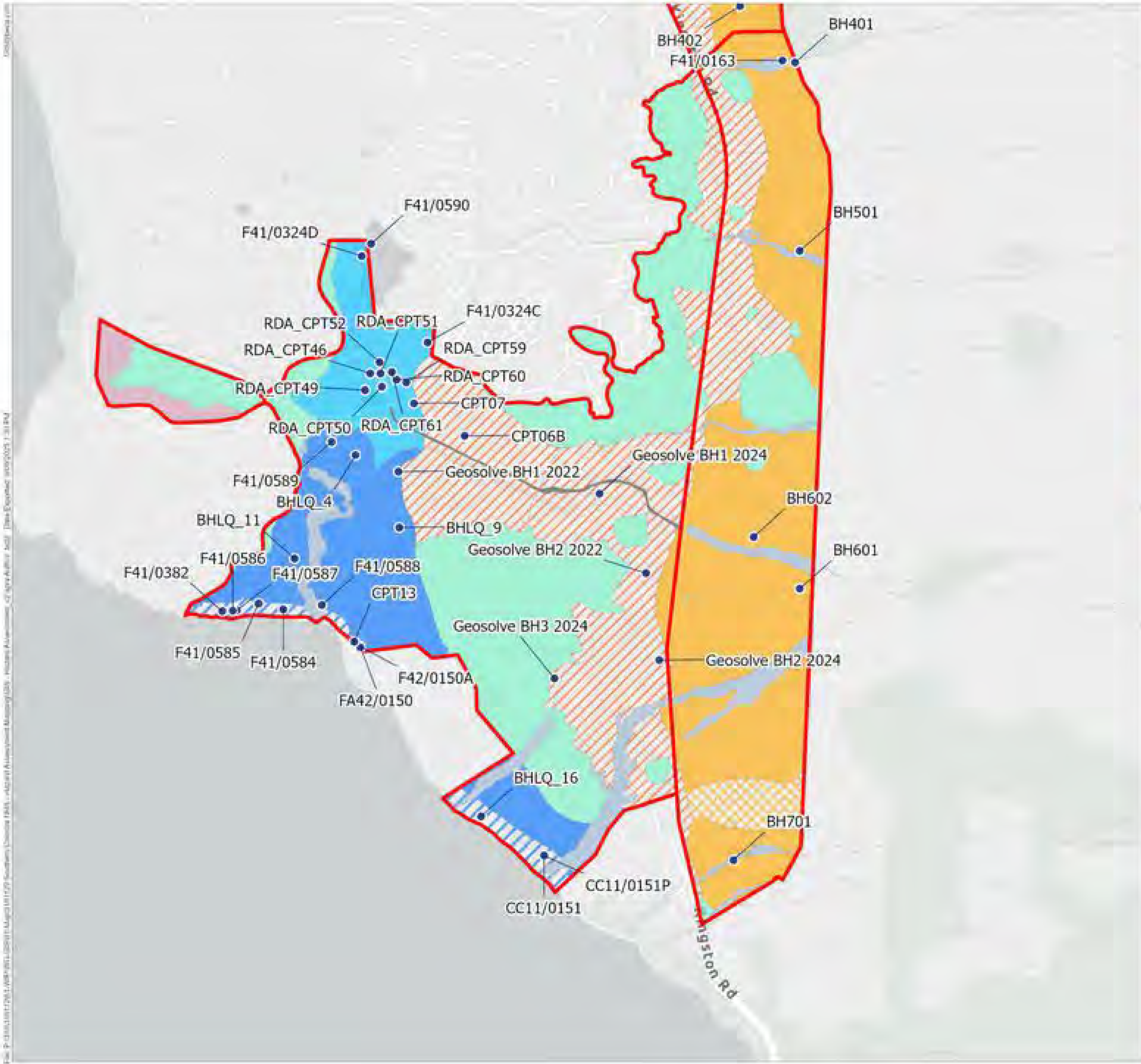
Queenstown Lakes District Council | GIS

Te Tapuae / Southern Corridor Natural Hazards Study | GIS-3161129-02-01-01

Beca

Geology and Investigations Considered in Assessment

Figure A1-2



- Geotechnical Investigations
- Hazard Study Area

Mapped Geology

- Modified Land
- Holocene Alluvial Fan (Active Braided Zone)
- Holocene Alluvial Fan (Apron Zone)
- Holocene Alluvial Fan (Inactive/Abandoned)
- Holocene Alluvial Fan (Toe Zone)
- Holocene Alluvium
- Holocene Lake Beach Deposits
- Holocene Lake Beach Deposits (Recent)
- Holocene Lake Deposits
- Holocene Storm Beach Deposits
- Holocene Channel Deposits
- Late Pleistocene Glacial Till
- Schist (Bedrock)

For full unit definitions please refer to Beca report "Te Tapuae/Southern Corridor Liquefaction Hazard Assessment" 3161129-1286181819-904

This map should be read in conjunction with the Beca report Te Tapuae/Southern Corridor Liquefaction Hazard Assessment" 3161129-1286181819-904

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0 0.25 0.5 Kilometres

N

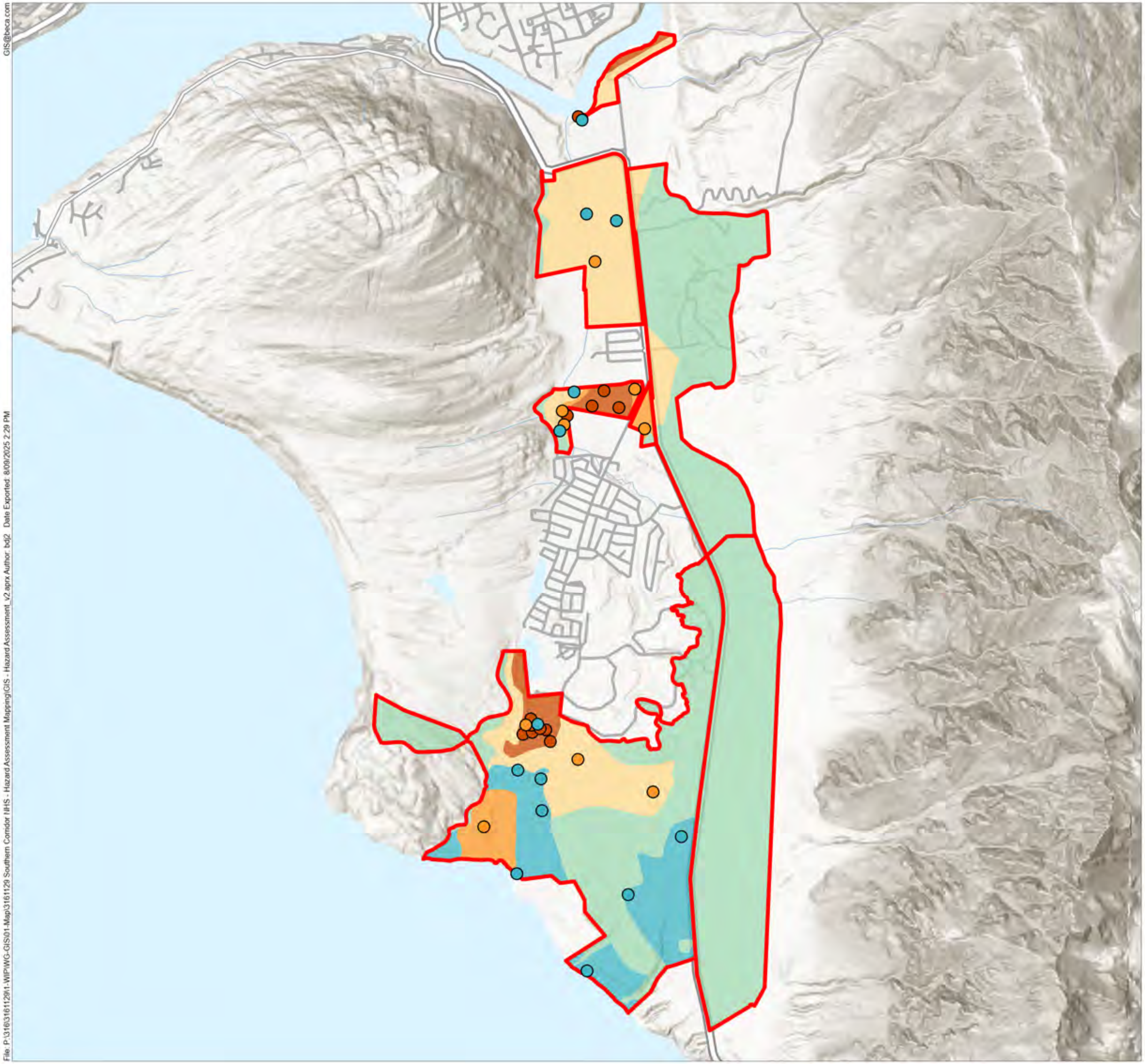
Client: Queenstown Lakes District Council

Discipline: GIS

Project: Te Tapuae / Southern Corridor Natural Hazards Study

Drawing No: GIS-3161129-02-01-02

Beca



Assigned Liquefaction Susceptibility of Te Tapuae / Southern Corridor

Figure A2

Legend

Hazard Study Area

Liquefaction Vulnerability Category

LIQUEFACTION CATEGORY IS UNDETERMINED			
LIQUEFACTION DAMAGE IS UNLIKELY		LIQUEFACTION DAMAGE IS POSSIBLE	
VERY LOW LIQUEFACTION VULNERABILITY	LOW LIQUEFACTION VULNERABILITY	MEDIUM LIQUEFACTION VULNERABILITY	HIGH LIQUEFACTION VULNERABILITY

Assessed Liquefaction Vulnerability

- High
- Medium
- Low

For full unit definitions please refer to Beca report "Te Tapuae/Southern Corridor Liquefaction Hazard Assessment" 3161129-1286181819-904

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Basemap source: Esri, NASA, NGA, USGS, LINZ, Stats NZ, Esri, TomTom, Garmin, METI/ NASA, USGS

Revision	Author	Verified	Approved	Date
2	BDJ2	LLB	MG	08/09/2025
1	BDJ2	DRAFT	DRAFT	23/07/2025

Map Scale @ A4: 1:45,000

0 0.5 1 Kilometres

N

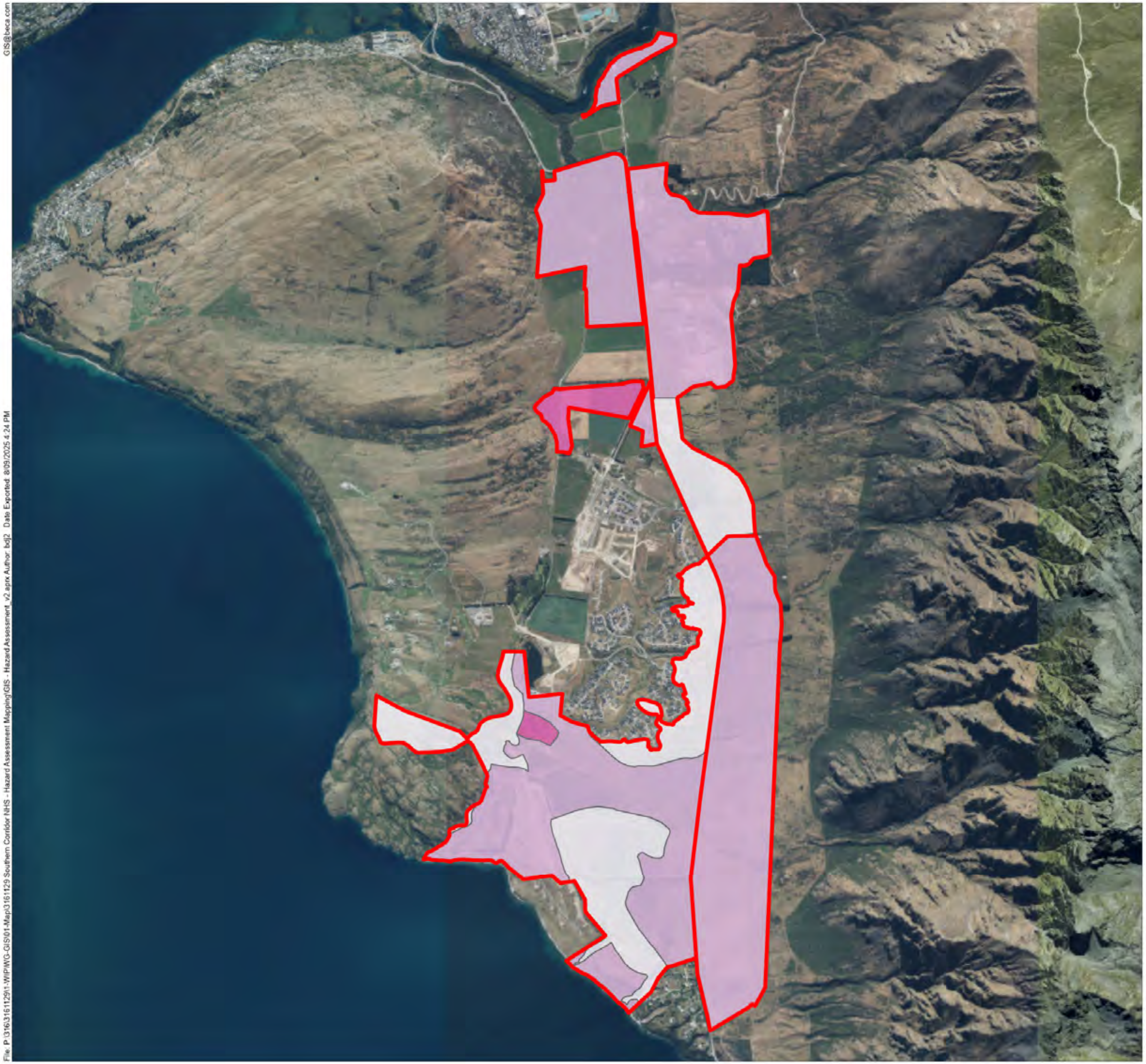
Client: Queenstown Lakes District Council

Discipline: GIS

Project: Te Tapuae / Southern Corridor Natural Hazards Study

Drawing No: GIS-3161129-02-02

Beca



Liquefaction Level of Detail
Te Tapuae / Southern Corridor
Figure A3

Legend

Hazard Study Area

Assessment Level of Detail

Level

A - Basic Desktop Assessment

B - Calibrated Desktop Assessment

C - Detailed Area-wide Assessment

As defined by MBIE Planning and engineering guidance for potentially liquefaction-prone land, 2017.

For full unit definitions please refer to Beca report "Te Tapuae/Southern Corridor Liquefaction Hazard Assessment" 3161129-1286181819-904

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Revision	Author	Verified	Approved	Date
2	BDJ2	LLB	MG	08/09/2025
1	BDJ2	DRAFT	DRAFT	14/08/2025

Map Scale @ A4: 1:45,000

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Kilometres

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Client: Queenstown Lakes District Council

Discipline: GIS

Project: Te Tapuae / Southern Corridor Natural Hazards Study

Drawing No: GIS-3161129-02-02

Beca

Table A1: Summary of geotechnical investigations utilised in the liquefaction assessment.

Investigation ID	Source
CPT-02	Beca (2023a)
22BH01	
sCPT-01	
Beca_CPT01	Beca (2023b)
Beca_CPT02	
CPT03	Beca (2025a)
CPT05	
CPT06B	
CPT07	
CPT04	
CPT13	
BHLQ_4	
BHLQ_9	
BHLQ_11	
BHLQ_16	
BH101	Beca (2025b)
BH102	
BH401	
BH402	
BH501	
VH601	
BH602	
BH701	
WR-ENG21-CPT01	ENGEO (2023)
WR-ENG21-CPT02	
WR-ENG21-CPT03	
EIC_ENG22-CPT-01	
EIC_ENG22-CPT-03	
WR-ENG21-CPT04	
WR-ENG21-CPT05	
RDA_CPT09	RDA Consulting (2016)
RDA_CPT10	
RDA_CPT46	
RDA_CPT49	
RDA_CPT50	
RDA_CPT51	
RDA_CPT52	
RDA_CPT59	
RDA_CPT60	

RDA_CPT61	
TonkinTaylor - BH1 - 2008	Tonkin & Taylor Ltd (2008)
TonkinTaylor - BH2 - 2008	
Geosolve BH1 2016	GeoSolve Limited (2018)
Geosolve BH2 2016	
Geosolve BH3 2016	
Geosolve BH4 2016	
BH01 Geosolve 2022	GeoSolve Limited (2025)
BH02 Geosolve 2022	
BH01 Geosolve 2024	
BH02 Geosolve 2024	
BH03 Geosolve 2024	
F41/0153	Otago Regional Council Wells Database (drilled 1995)
F41/0163	Otago Regional Council Wells Database (drilled 1995)
F41/0108	Otago Regional Council Wells Database (drilled 1998)
F41/0216	
F41/0590	Otago Regional Council Wells Database (drilled 2002)
F41/0588	
F41/0584	
F41/0585	
F41/0587	
F41/0586	
F41/0589	
F41/0304	Otago Regional Council Wells Database (drilled 2003)
F41/0324C	Otago Regional Council Wells Database (drilled 2005)
F41/0324D	
F41/0382	Otago Regional Council Wells Database (drilled 2006)
F41/0482	Otago Regional Council Wells Database (drilled 2016)
F41/0503	Otago Regional Council Wells Database (drilled 2017)
F42/0150A	
FA42/0150	
CC11/0151P	Otago Regional Council Wells Database (drilled 2024)
CC11/0151	

B

Appendix B – Liquefaction Assessment Results

Liquefaction Assessment Result

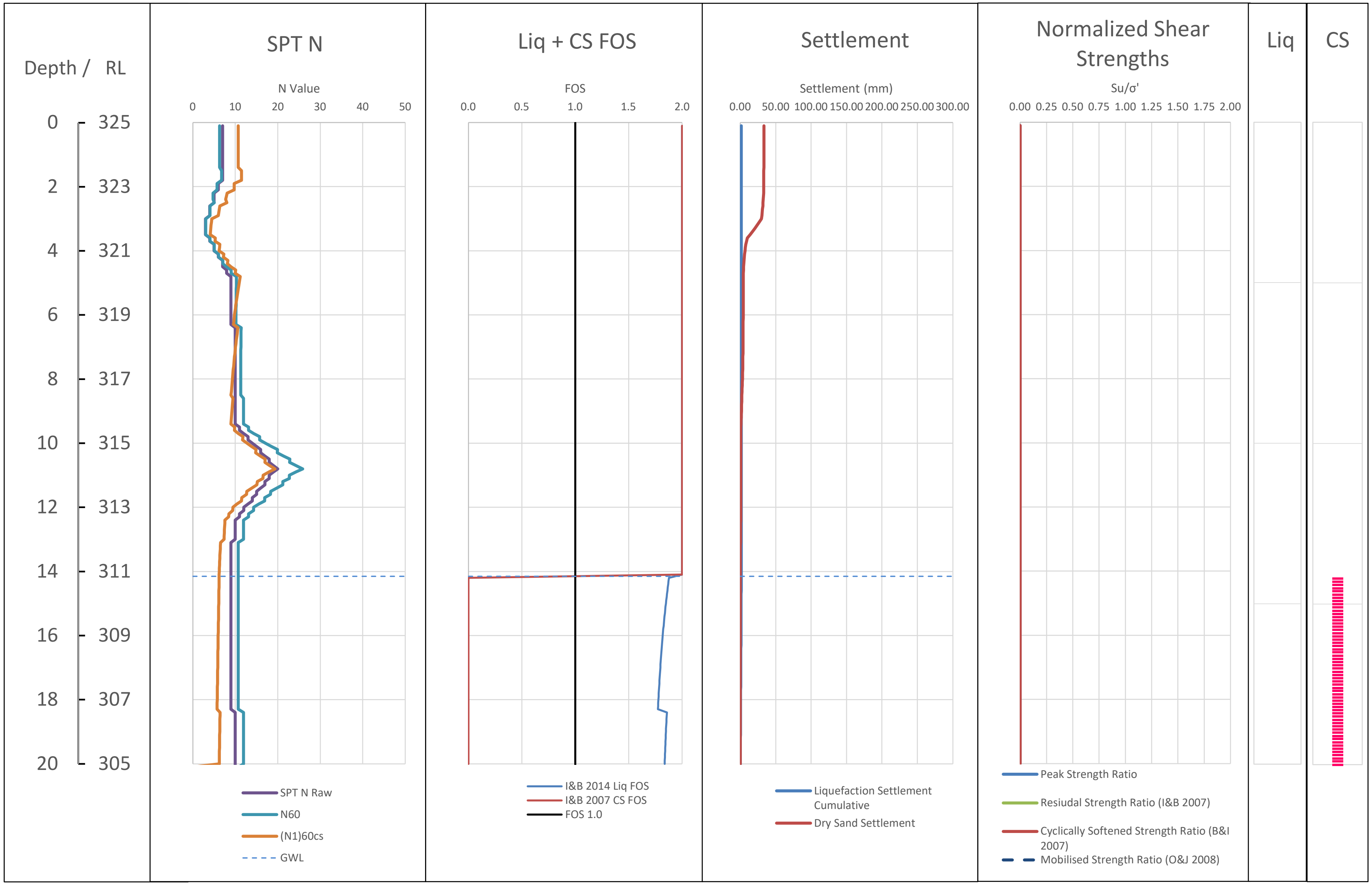
Earthquake Return Period = 25-year
Earthquake Magnitude (Mw) = 6.5
Peak Ground Acceleration (g) = 0.10

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
22BH01	User Input	48.75	14.15	0.1	6.5	1	33	34	0	0	0	0.0

Made using data from 22BH01.ags

Project Summary	
Project Name	Tapuae/Southern Cor
Project Number	3161129
Unscaled PGA (g)	0.1
Magnitude	6.5
Liquefaction Settlement (mm)	1

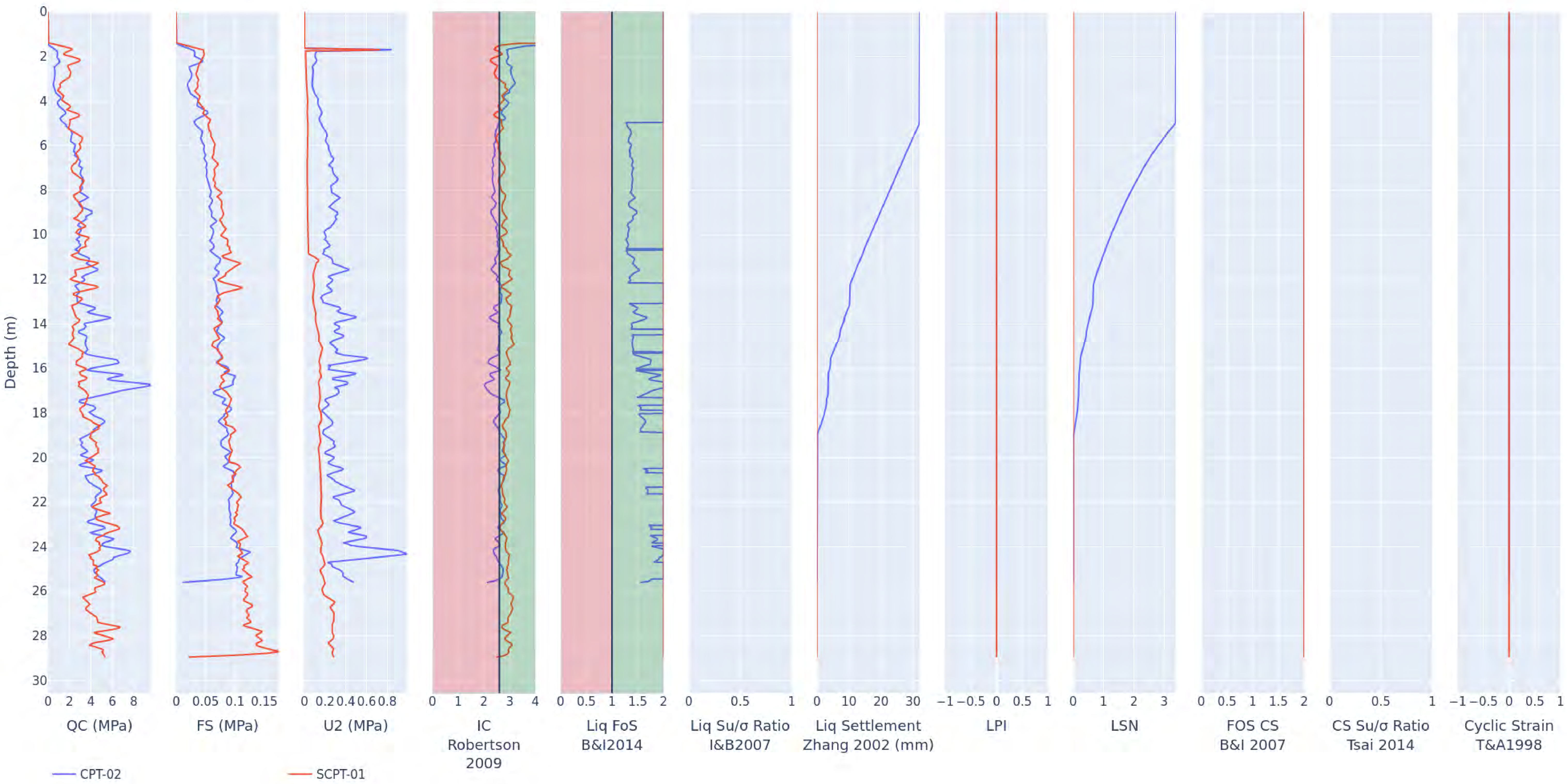
Borehole Information	
BH ID:	22BH01
BH Depth (m):	20.0
Ground Level:	325
Water Level:	14.15
Fill:	0



ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
CPT-02	25.59	1.6	0.1	6.5	32	0	0	3
SCPT-01	28.95	13.0	0.1	6.5	0	0	0	0

Made using data from CPTs.ags

Liquefaction Standard Output

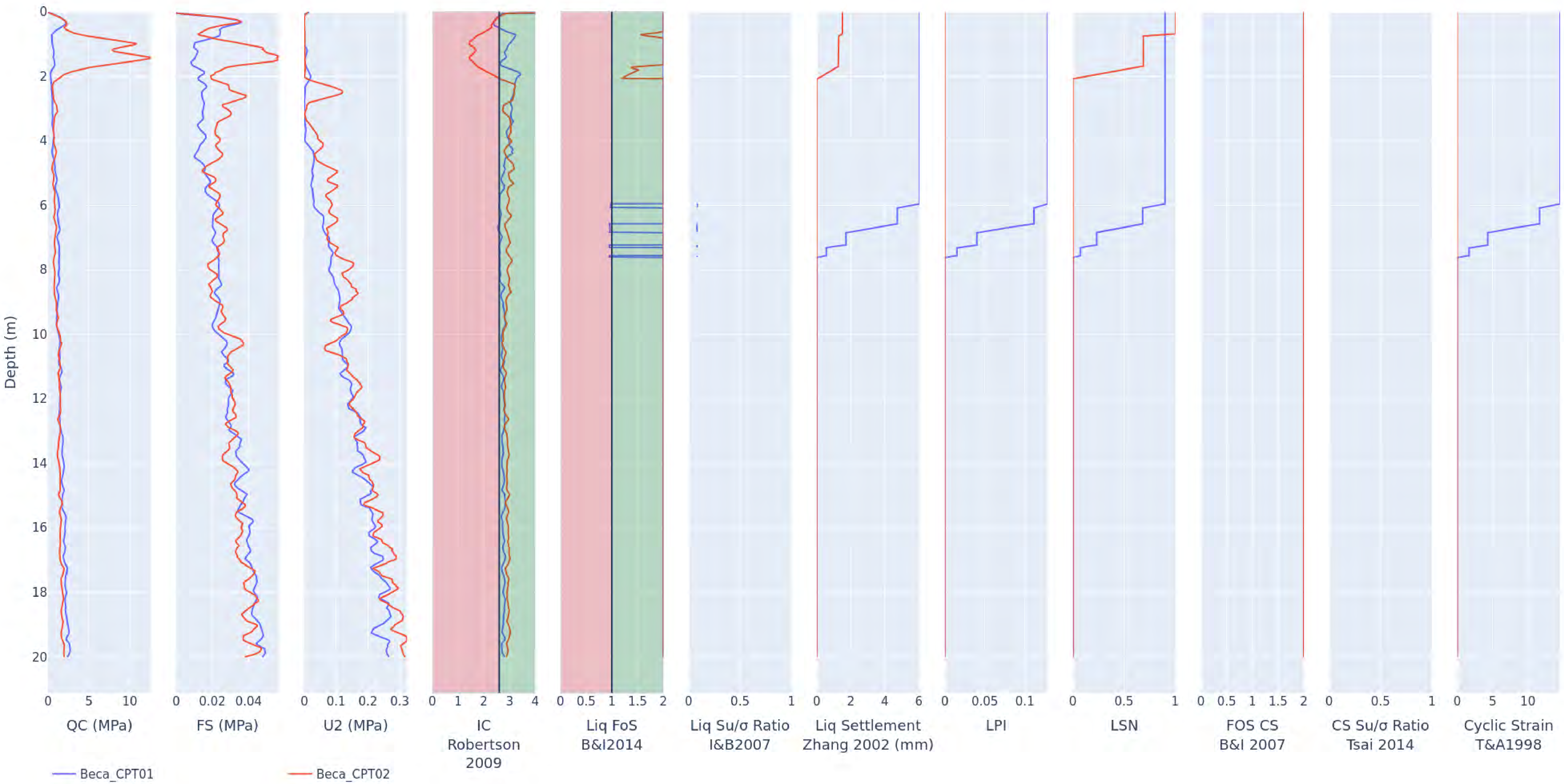


Made using data from CPTs.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
Beca_CPT01	20.0	0.5	0.1	6.5	6	15	0	1
Beca_CPT02	20.0	0.5	0.1	6.5	2	0	0	1

Made using data from Beca CPT - 2023.ags

Liquefaction Standard Output

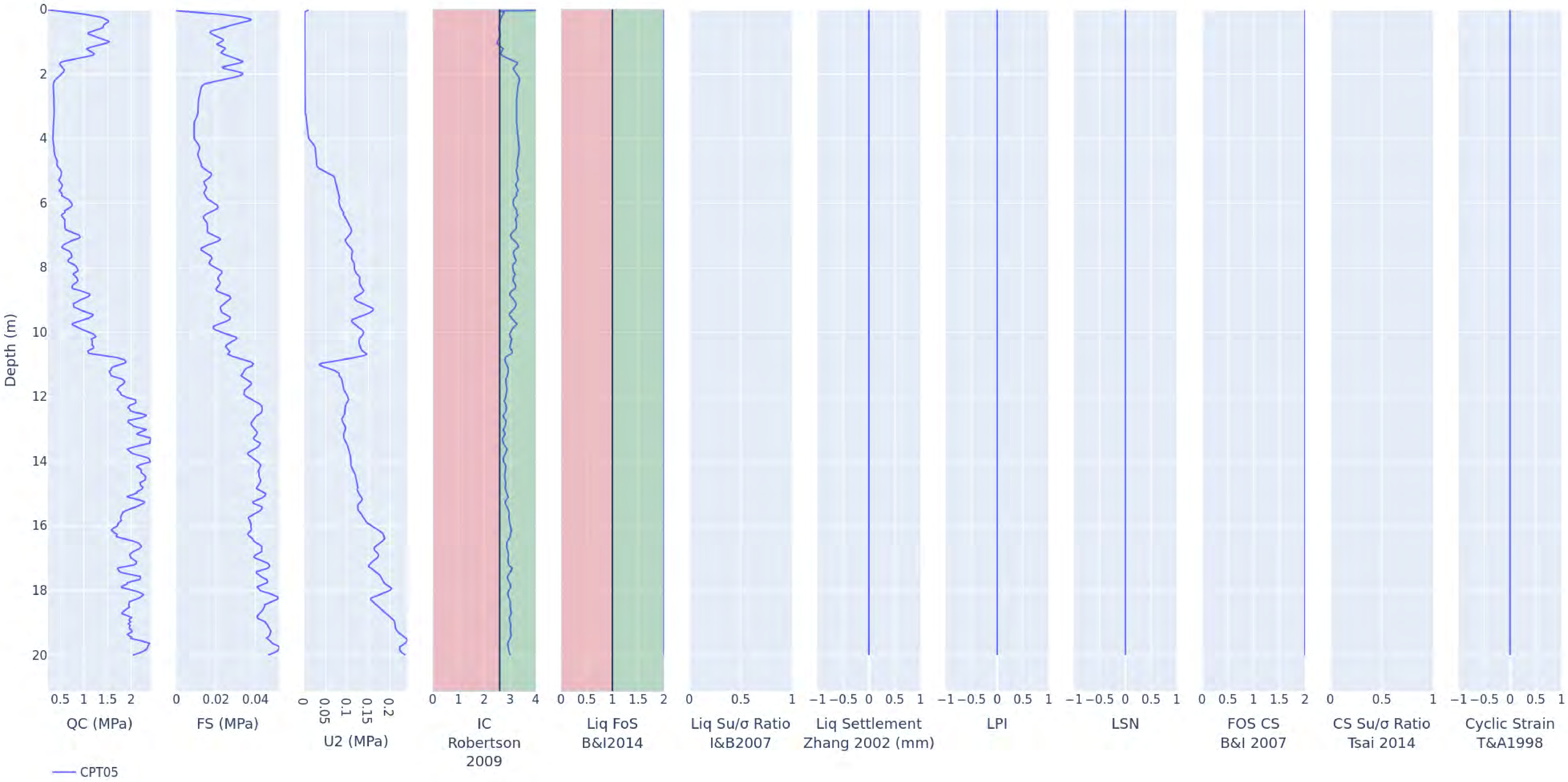


Made using data from Beca CPT - 2023.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
CPT05	20.0	6.0	0.1	6.5	0	0	0	0

Made using data from CPT05.ags

Liquefaction Standard Output

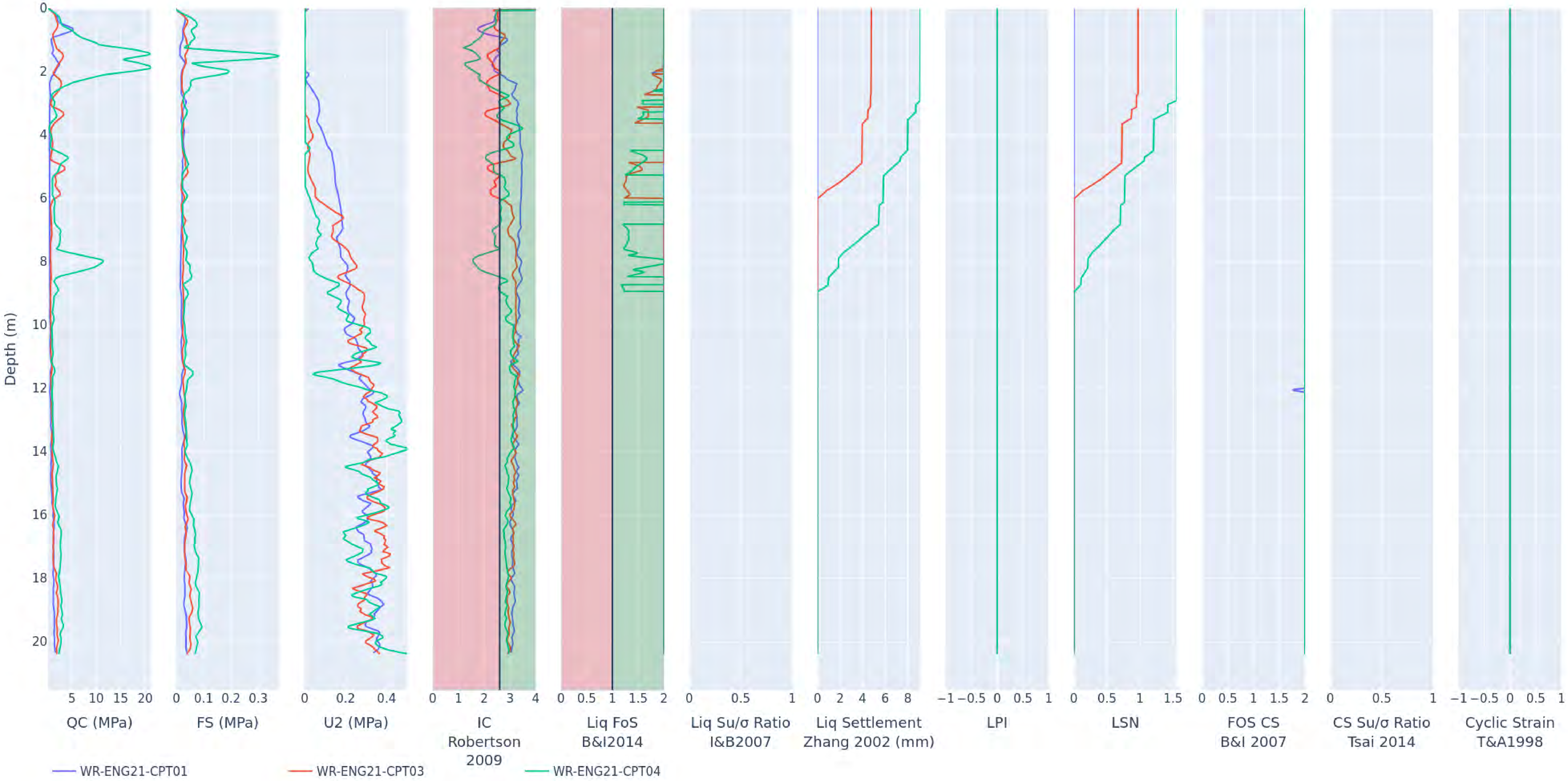


Made using data from CPT05.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
WR-ENG21-CPT01	20.35	1.5	0.1	6.5	0	0	0	0
WR-ENG21-CPT03	20.39	1.5	0.1	6.5	5	0	0	1
WR-ENG21-CPT04	20.38	1.5	0.1	6.5	9	0	0	2

Made using data from WR-ENG21-CPT01-03-04.ags

Liquefaction Standard Output

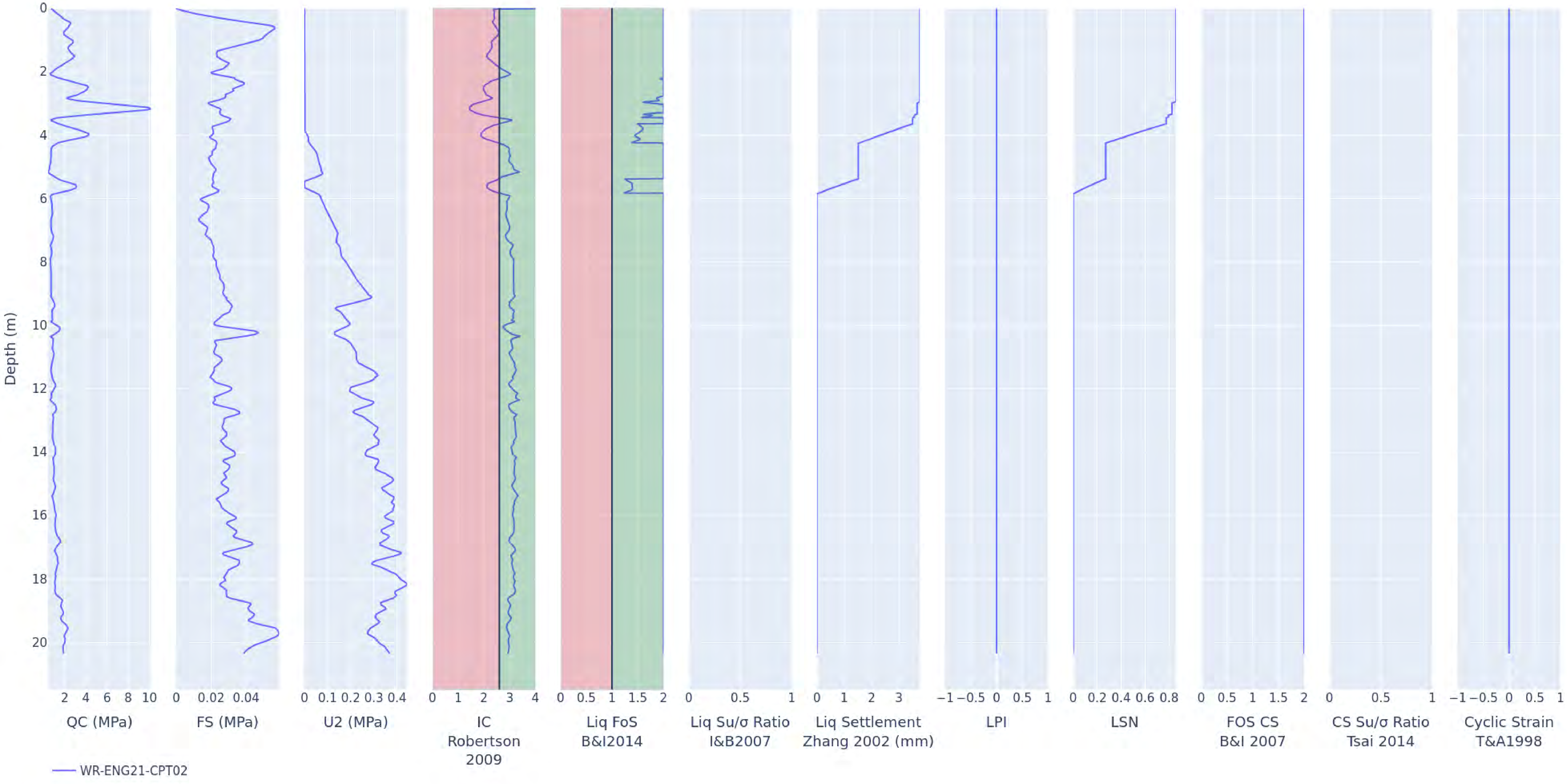


Made using data from WR-ENG21-CPT01-03-04.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
WR-ENG21-CPT02	20.35	1.7	0.1	6.5	4	0	0	1

Made using data from WR-ENG21-CPT02.ags

Liquefaction Standard Output

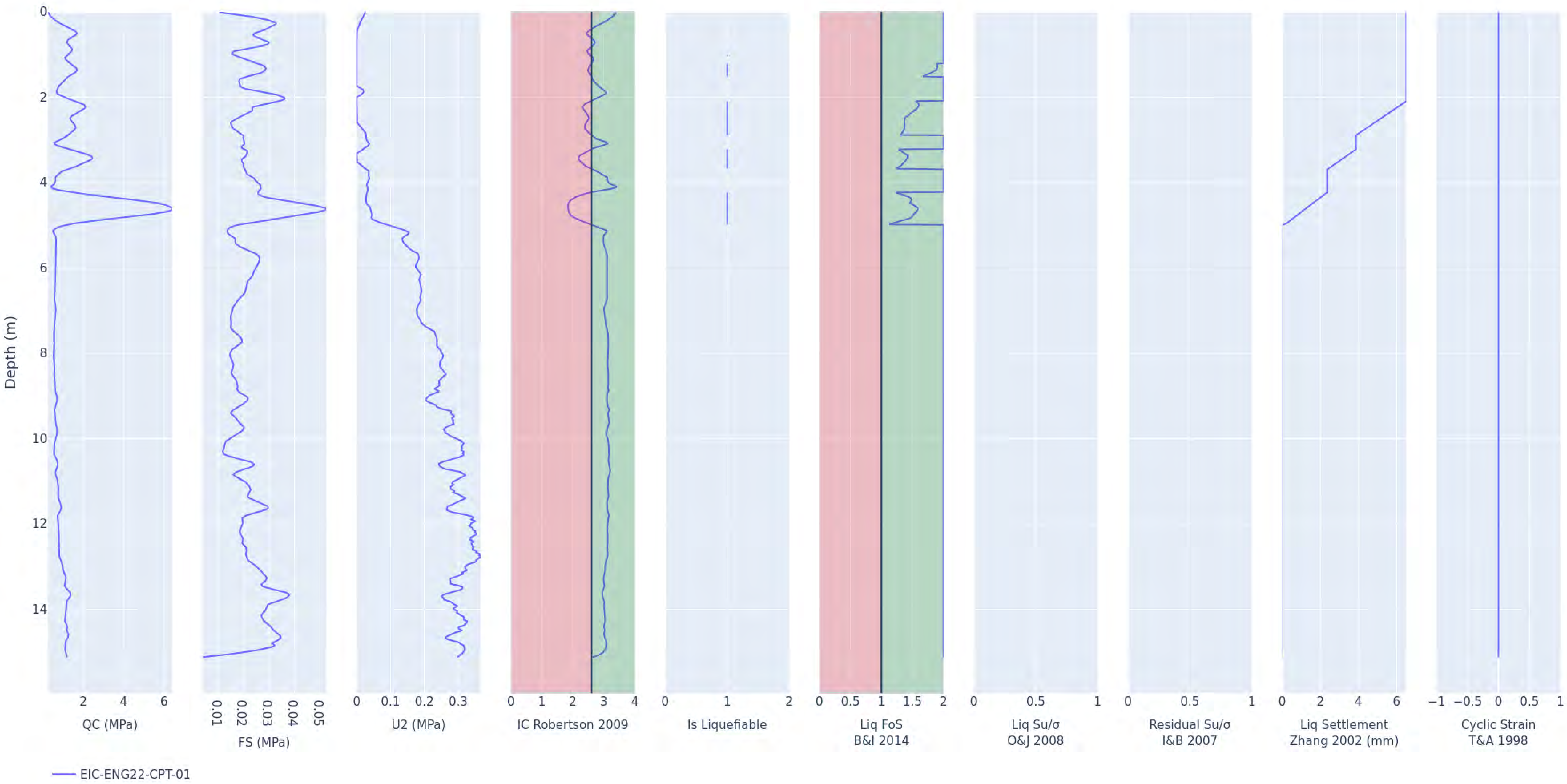


Made using data from WR-ENG21-CPT02.ags

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
EIC-ENG22-CPT-01	User Input	15.12	1.0	0.1	6.5	7	0	7	0	0	2	0.0

Made using data from 10 EIC-ENG22-CPT-01.ags

Liquefaction Analysis

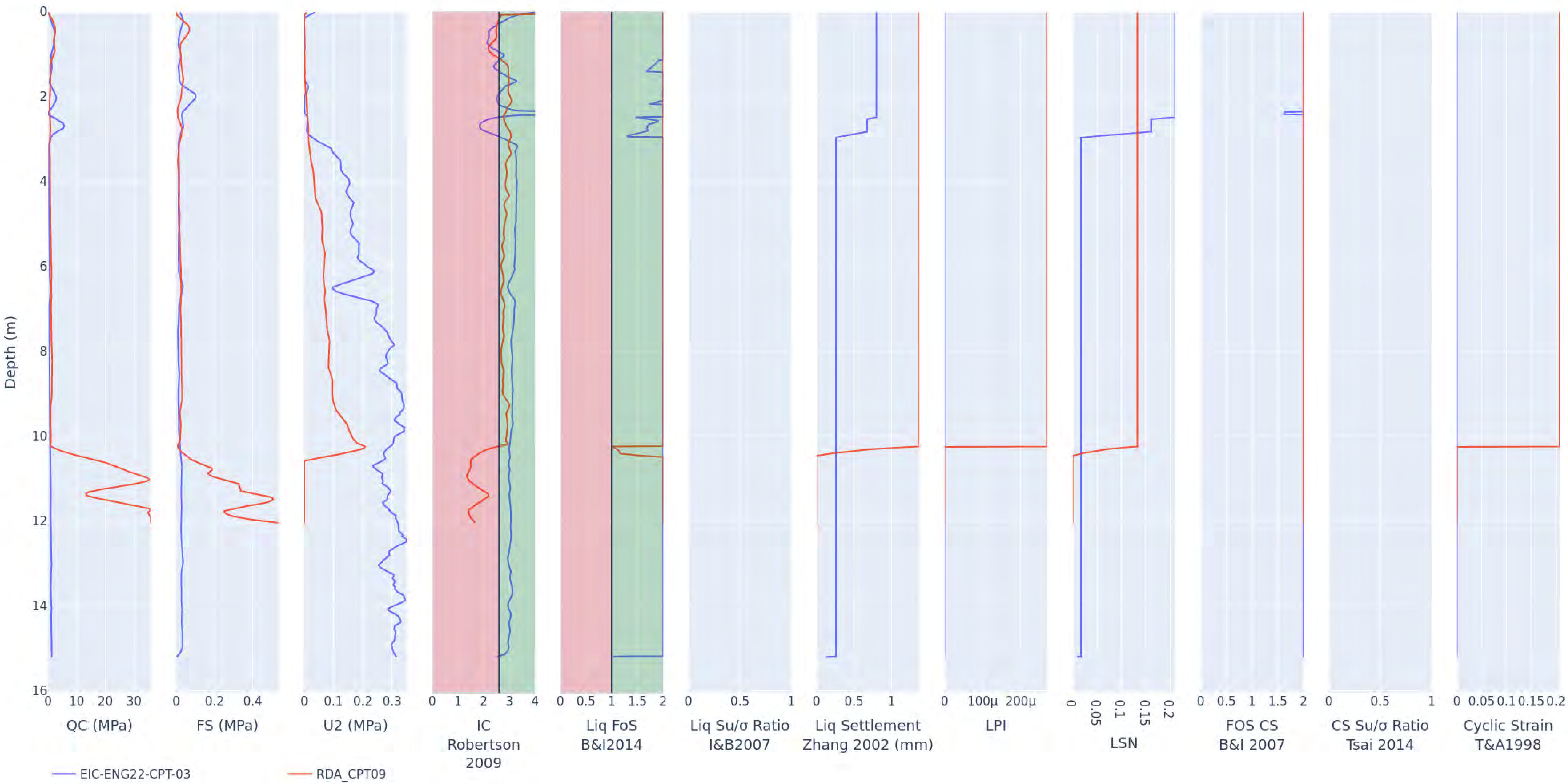


Made using data from 10 EIC-ENG22-CPT-01.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
EIC-ENG22-CPT-03	15.2	1.0	0.1	6.5	1	0	0	0
RDA_CPT09	12.04	1.0	0.1	6.5	1	0	0	0

Made using data from RDA CPT - 09 - EIC-ENG22-CPT-03.ags

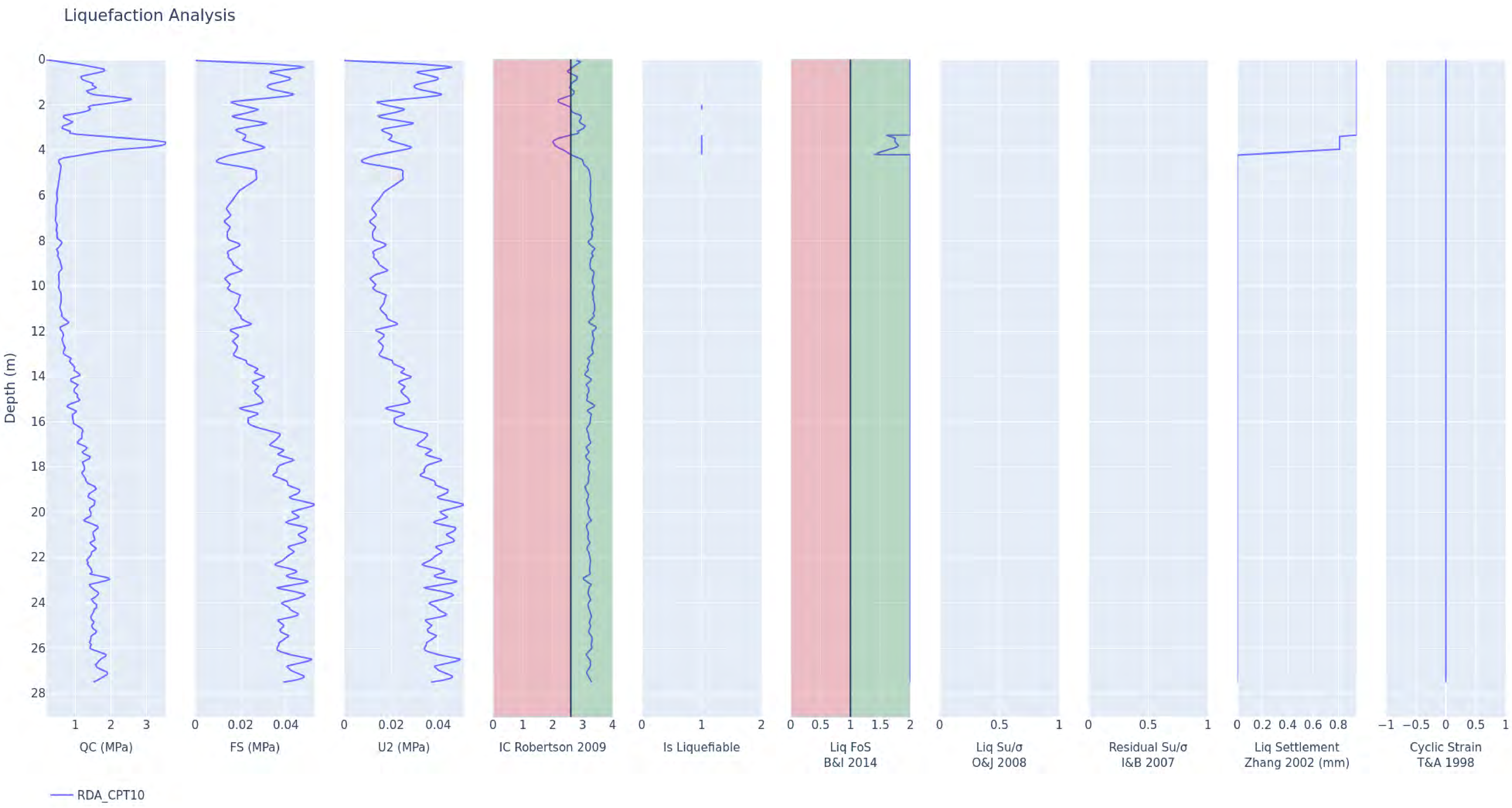
Liquefaction Standard Output



Made using data from RDA CPT - 09 - EIC-ENG22-CPT-03.ags

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
RDA_CPT10	User Input	27.5	2.0	0.1	6.5	1	0	1	0	0	0	0.0

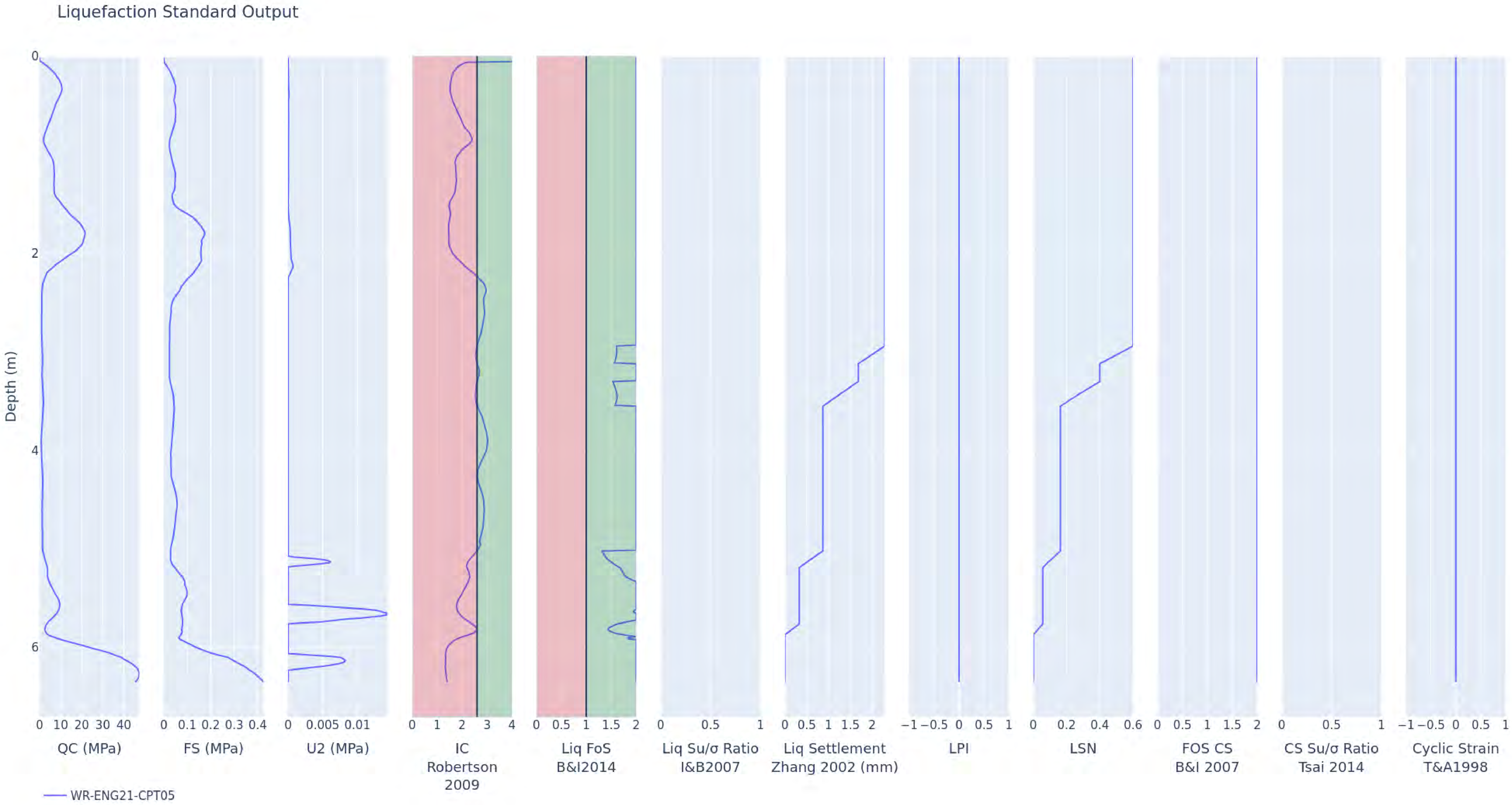
Made using data from 13 RDA - CPT10.ags



Made using data from 13 RDA - CPT10.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
WR-ENG21-CPT05	6.35	1.6	0.1	6.5	2	0	0	1

Made using data from WR-ENG21-CPT05.ags

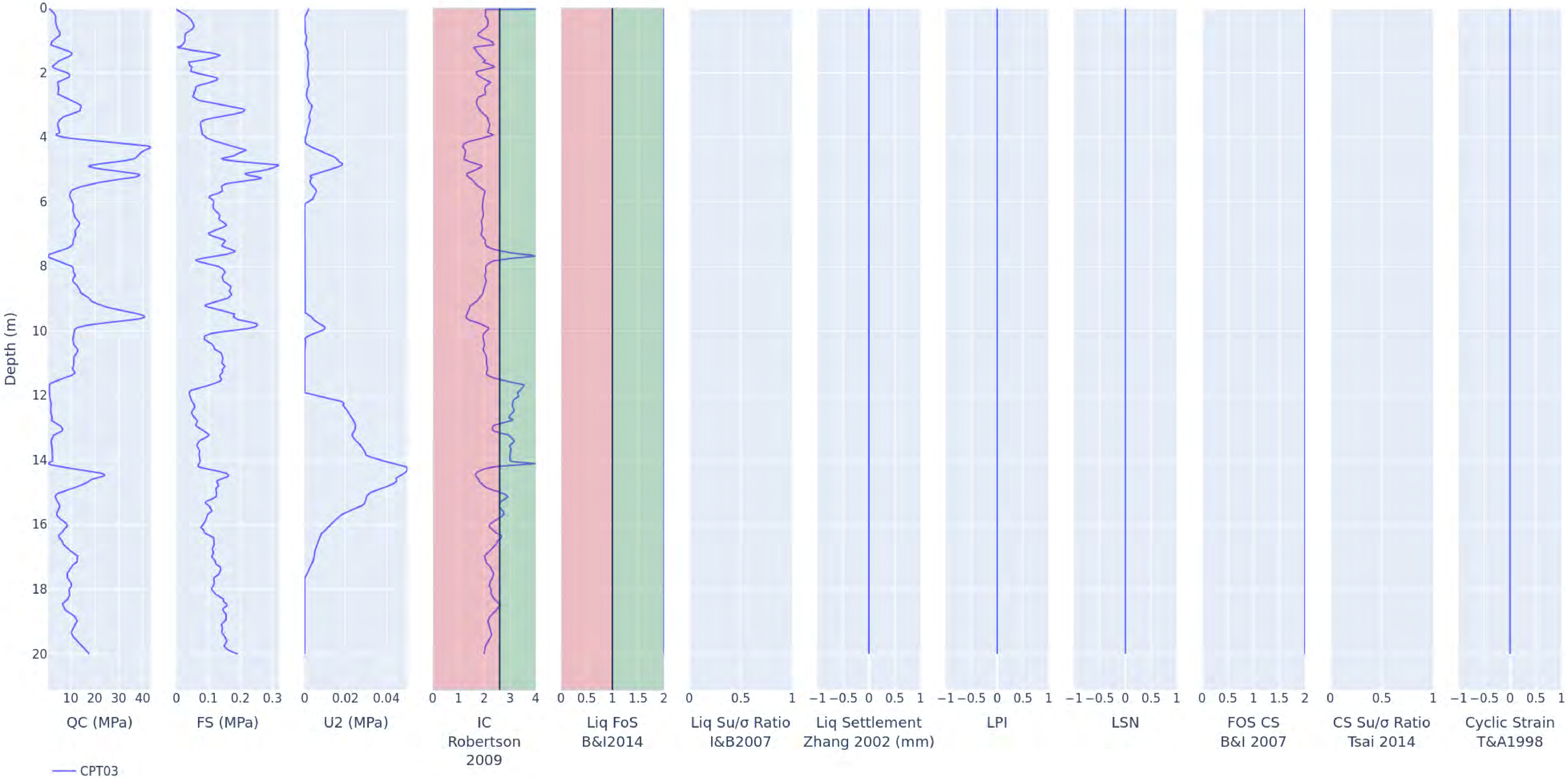


Made using data from WR-ENG21-CPT05.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
CPT03	20.0	8.0	0.1	6.5	0	0	0	0

Made using data from CPT03.ags

Liquefaction Standard Output

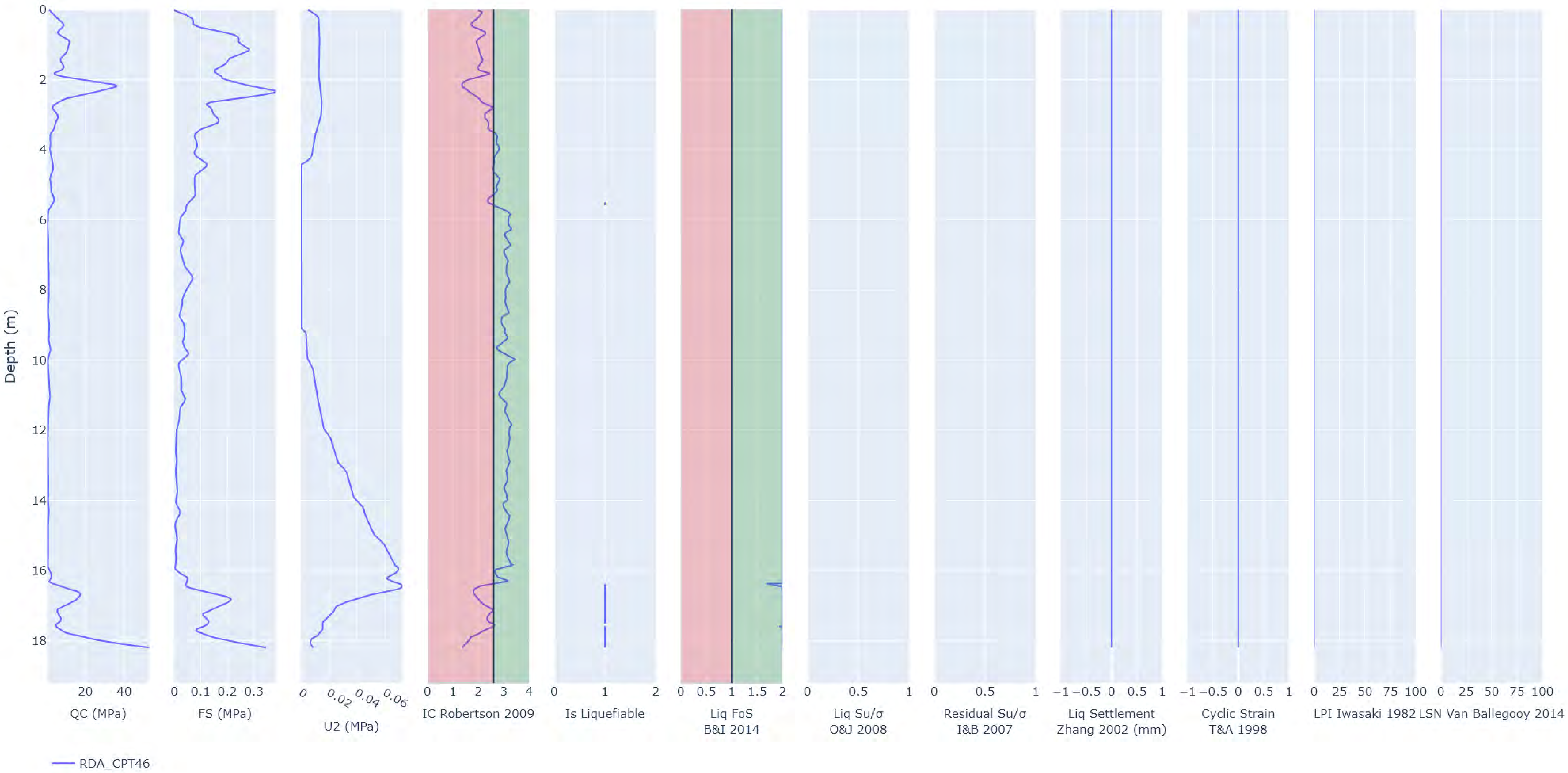


Made using data from CPT03.ags

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
RDA_CPT46	User Input	18.2	5.5	0.1	6.5	1	1	1	0	0	0	0.0
RDA_CPT51	User Input	17.8	2.2	0.1	6.5	5	0	5	0	0	1	0.0
RDA_CPT52	User Input	14.02	4.0	0.1	6.5	5	1	5	0	0	0	0.0
RDA_CPT61	User Input	11.02	4.0	0.1	6.5	2	1	2	0	0	0	0.0

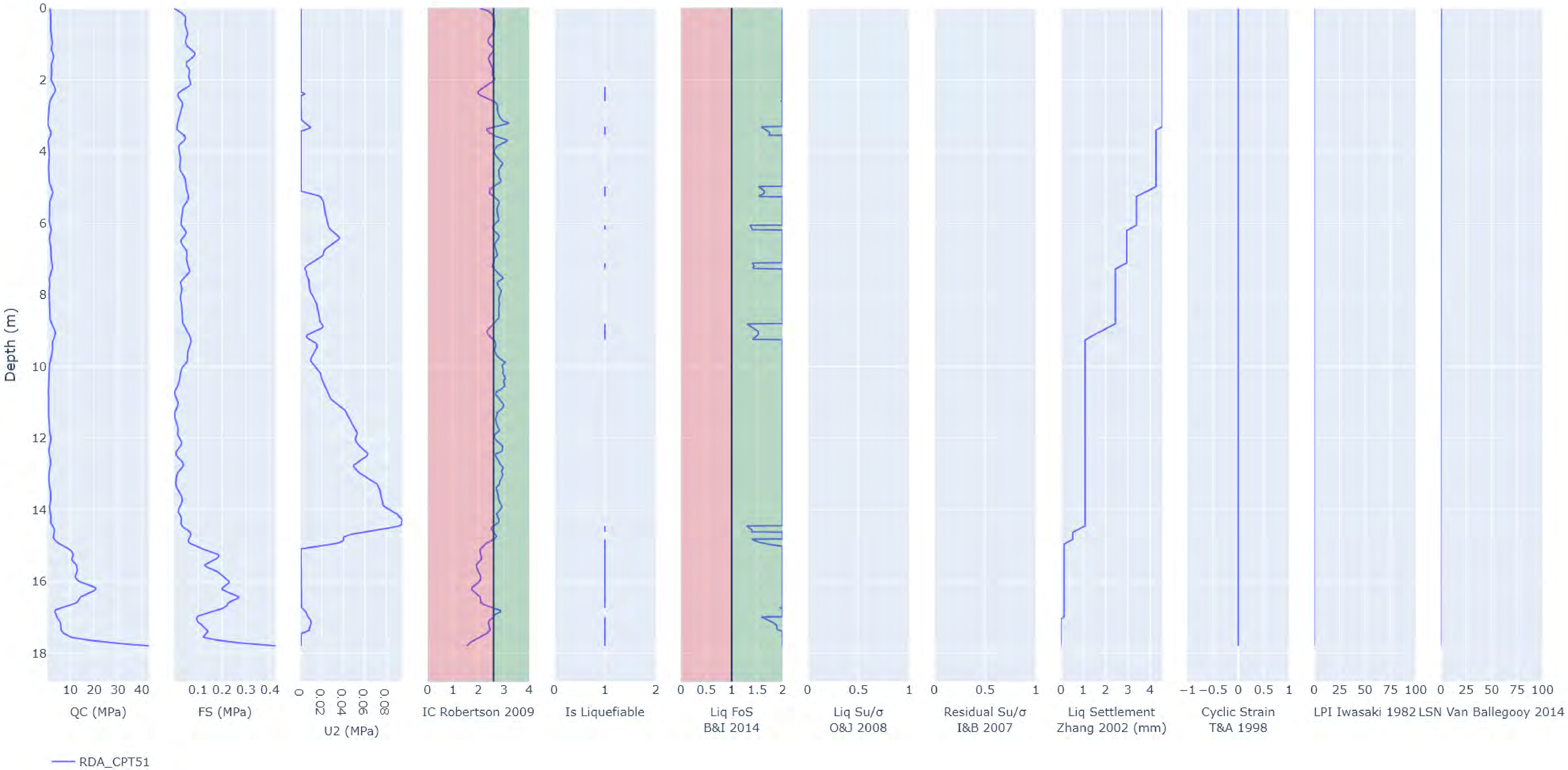
Made using data from RDA CPT-43-51-52-61.ags

Liquefaction Output for RDA_CPT46



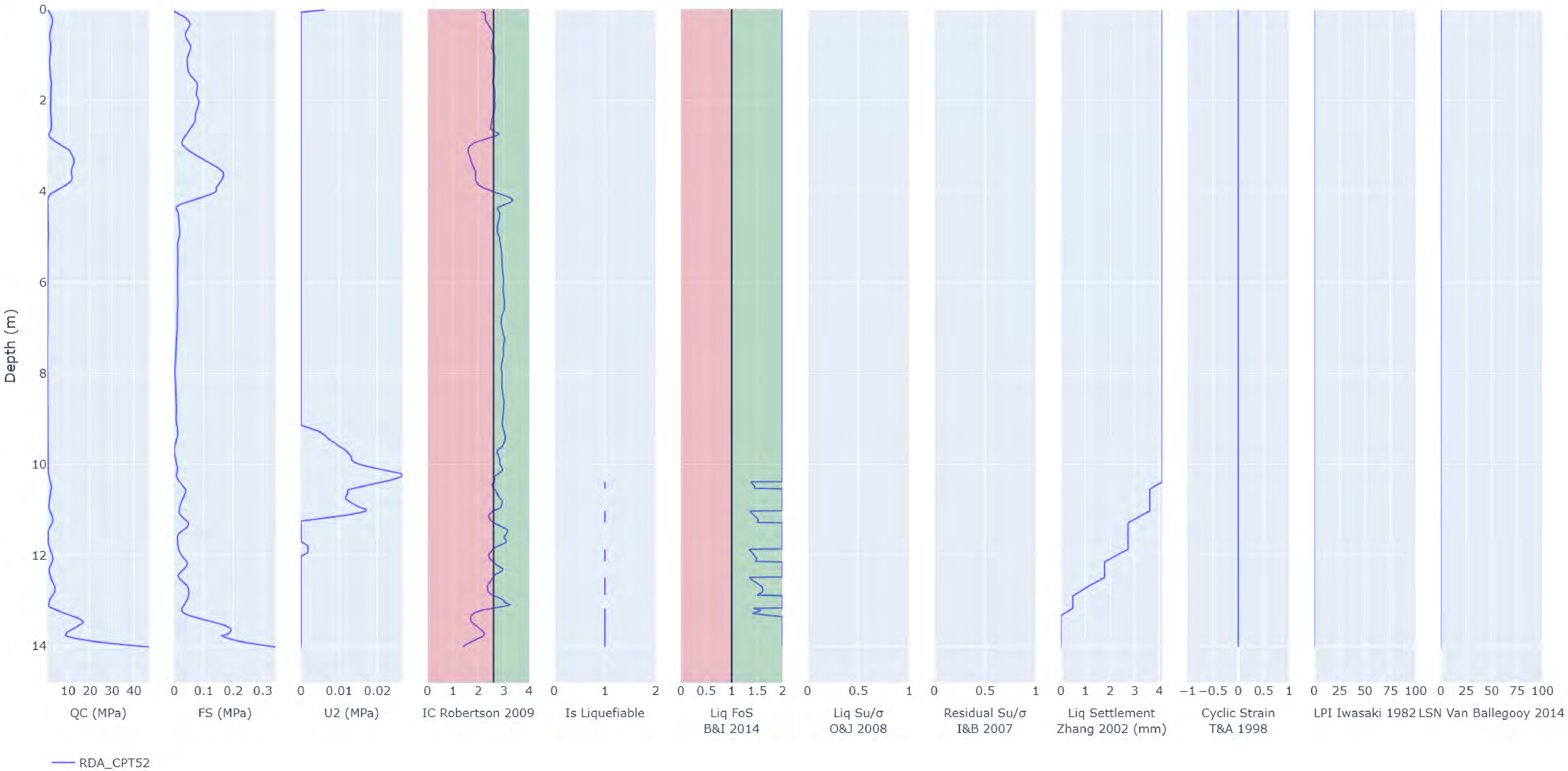
Made using data from RDA CPT-43-51-52-61.ags

Liquefaction Output for RDA_CPT51



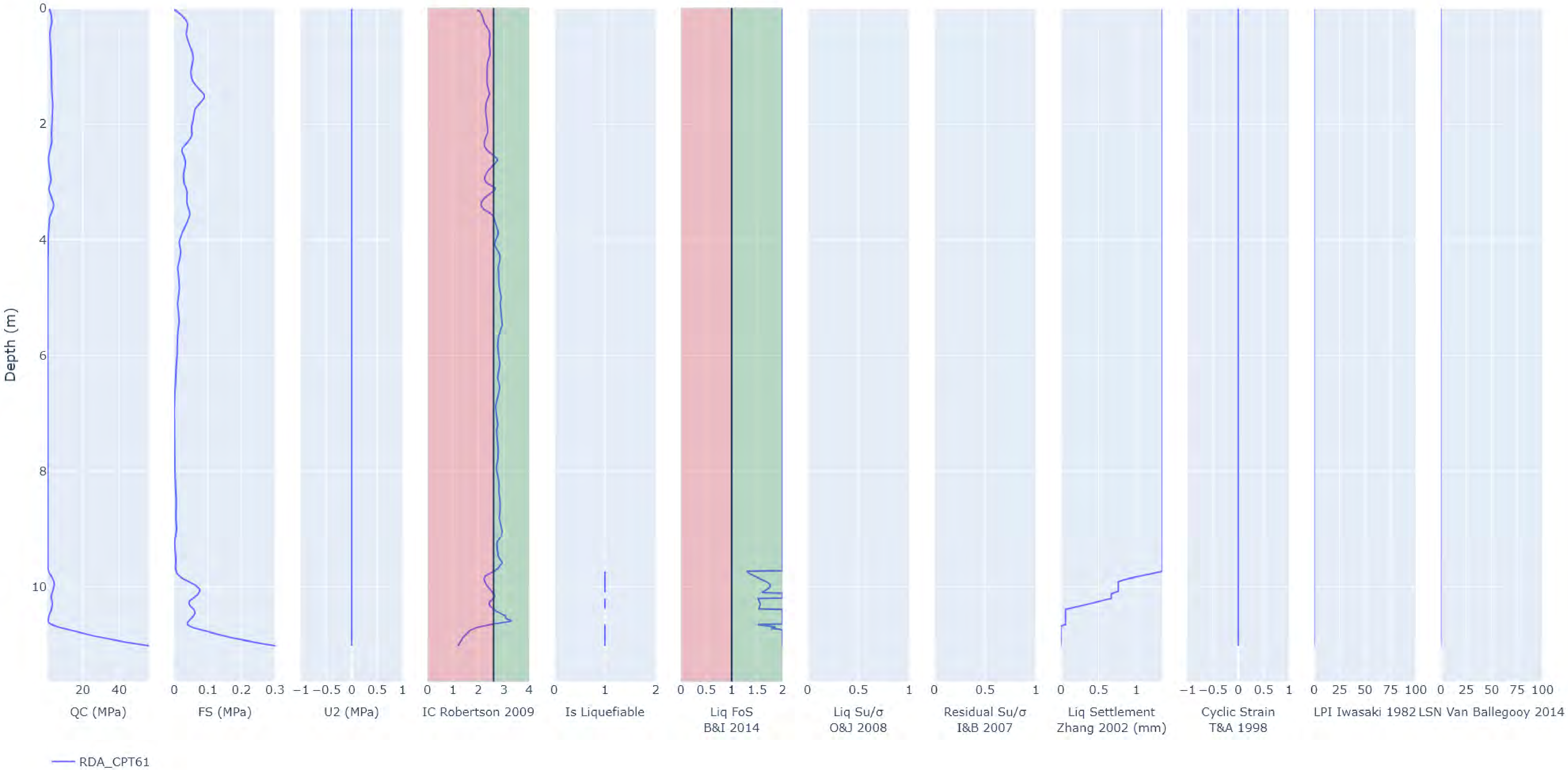
Made using data from RDA CPT-43-51-52-61.ags

Liquefaction Output for RDA_CPT52



Made using data from RDA CPT-43-51-52-61.ags

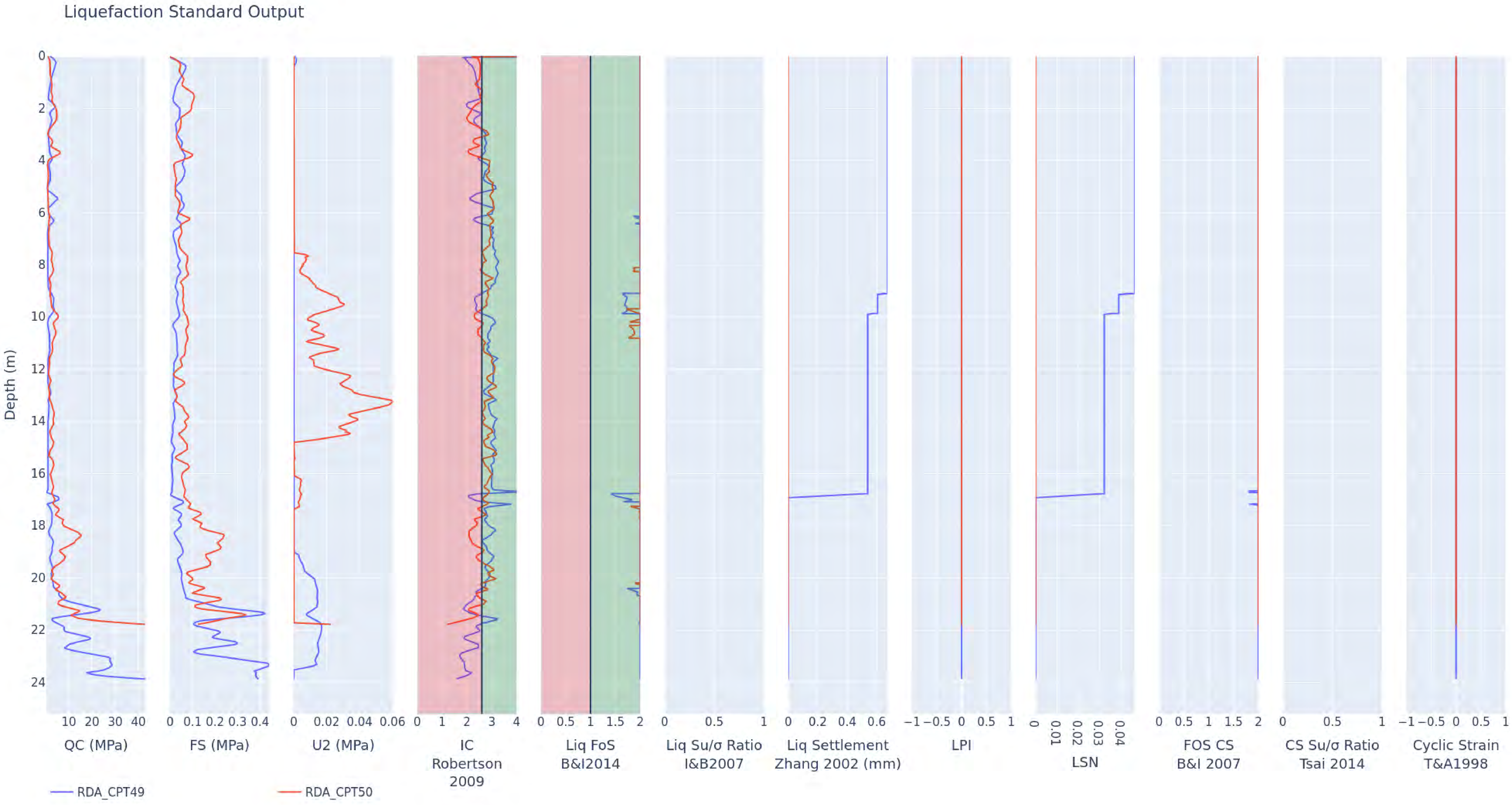
Liquefaction Output for RDA_CPT61



Made using data from RDA CPT-43-51-52-61.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
RDA_CPT49	23.88	5.0	0.1	6.5	1	0	0	0
RDA_CPT50	21.78	5.0	0.1	6.5	0	0	0	0

Made using data from RDA - CPT49-50.ags

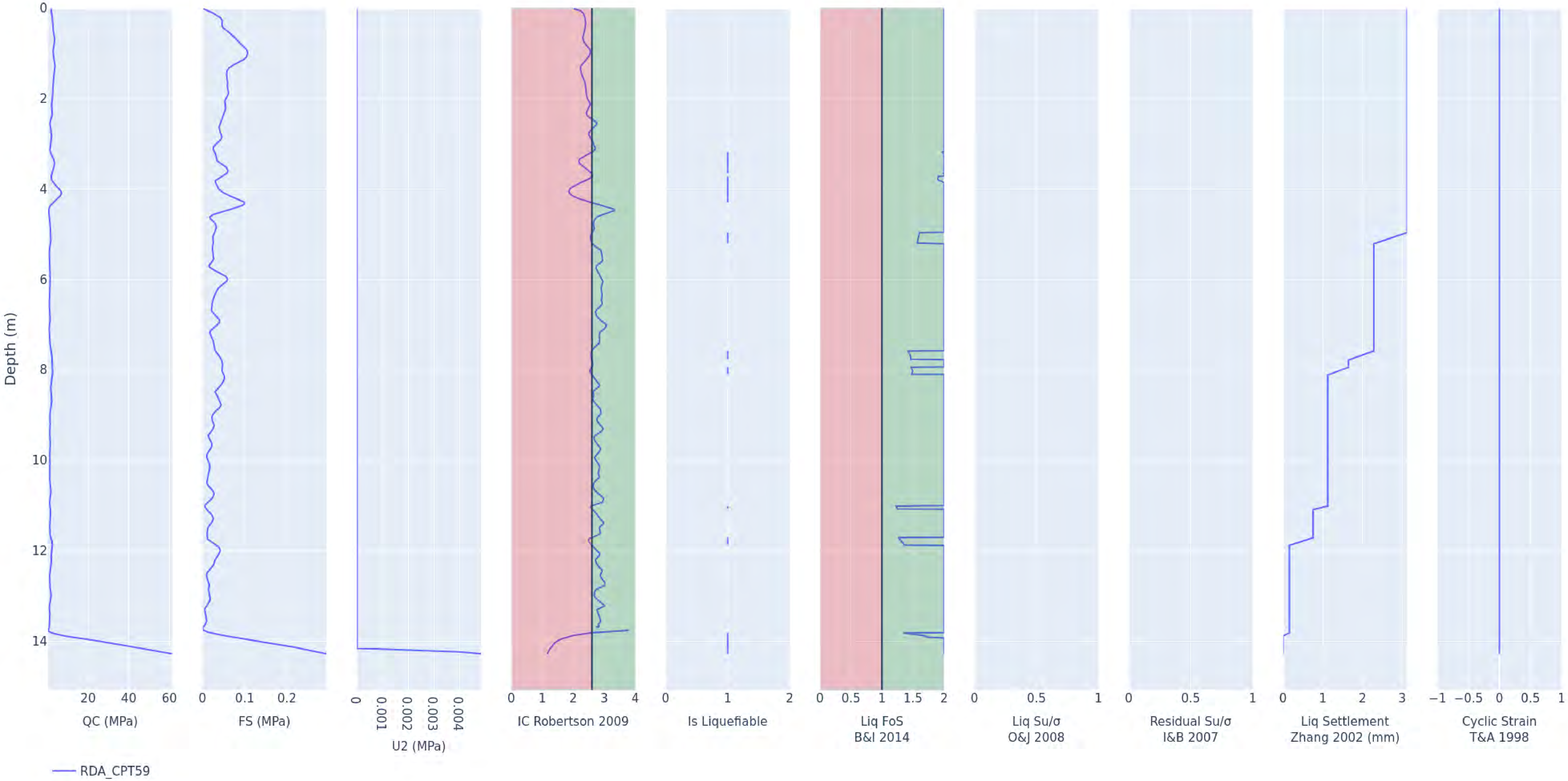


Made using data from RDA - CPT49-50.ags

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
RDA_CPT59	User Input	14.28	3.0	0.1	6.5	4	0	4	0	0	0	0.0
RDA_CPT60	User Input	23.74	3.0	0.1	6.5	6	0	6	0	0	1	0.0

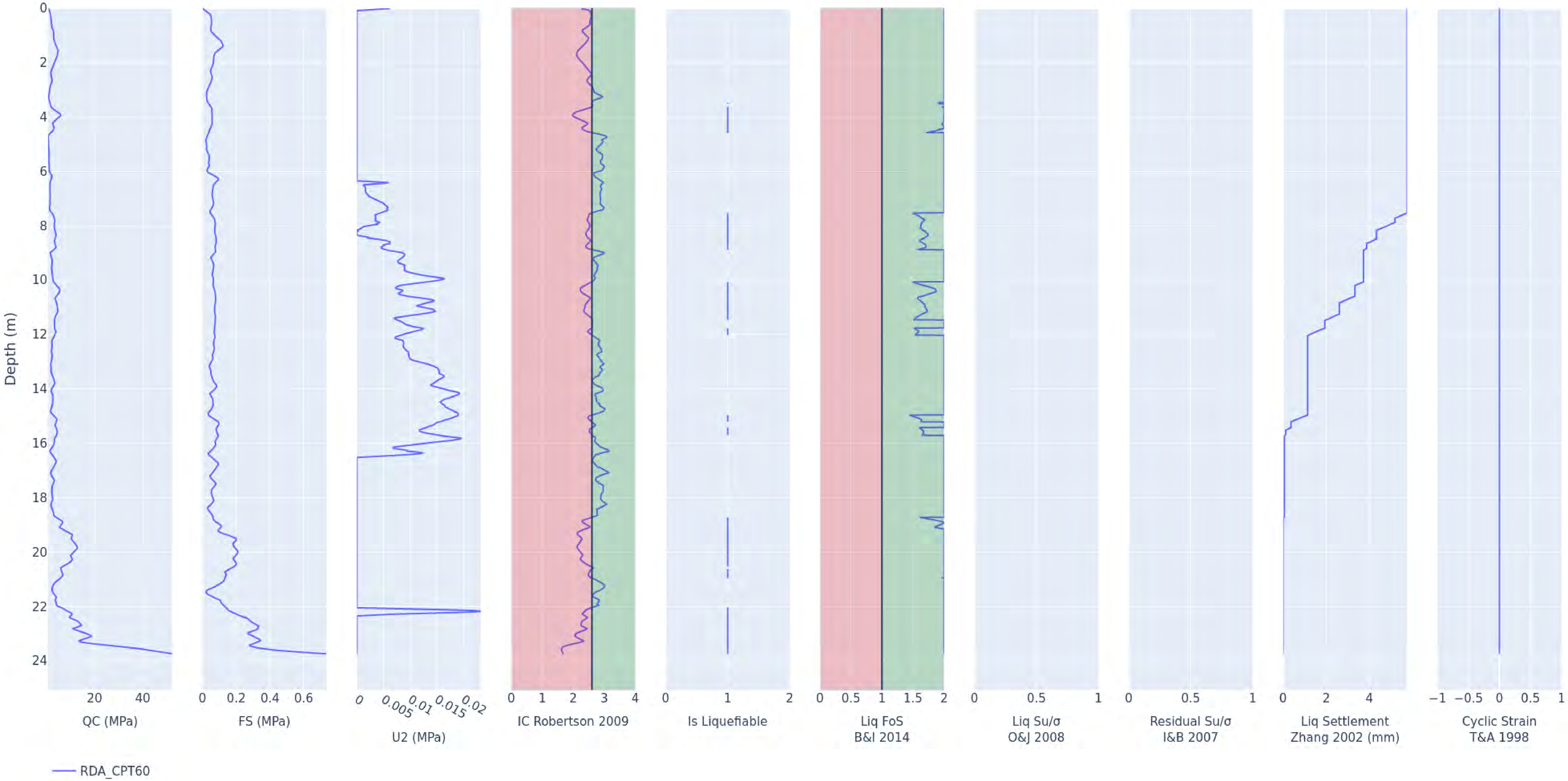
Made using data from 22-23 RDA-CPT 59-60.ags

Liquefaction Output for RDA_CPT59



Made using data from 22-23 RDA-CPT 59-60.ags

Liquefaction Output for RDA_CPT60

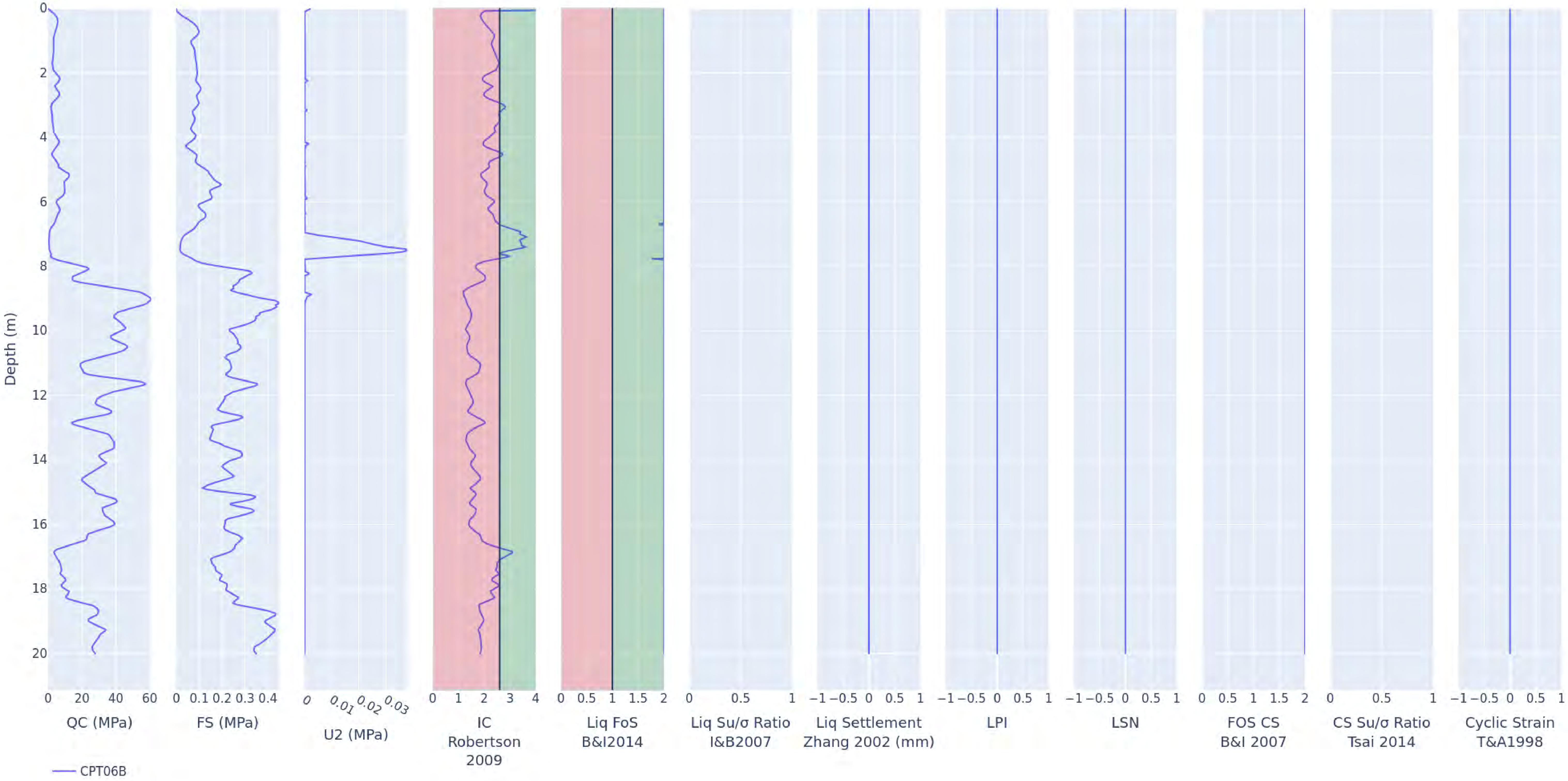


Made using data from 22-23 RDA-CPT 59-60.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
CPT06B	20.02	4.0	0.1	6.5	0	0	0	0

Made using data from CPT6.ags

Liquefaction Standard Output

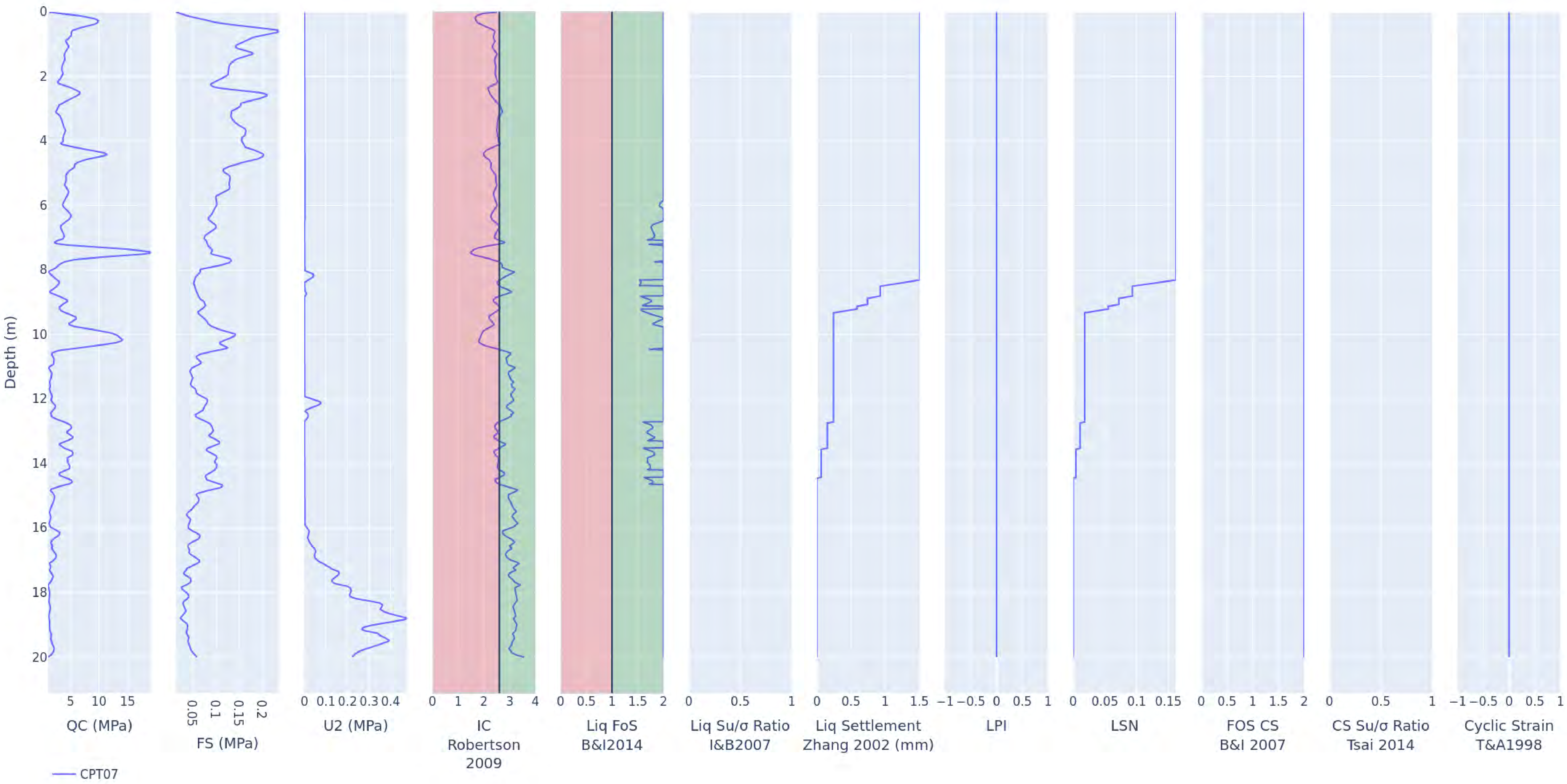


Made using data from CPT6.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
CPT07	20.0	3.0	0.1	6.5	2	0	0	0

Made using data from CPT07.ags

Liquefaction Standard Output

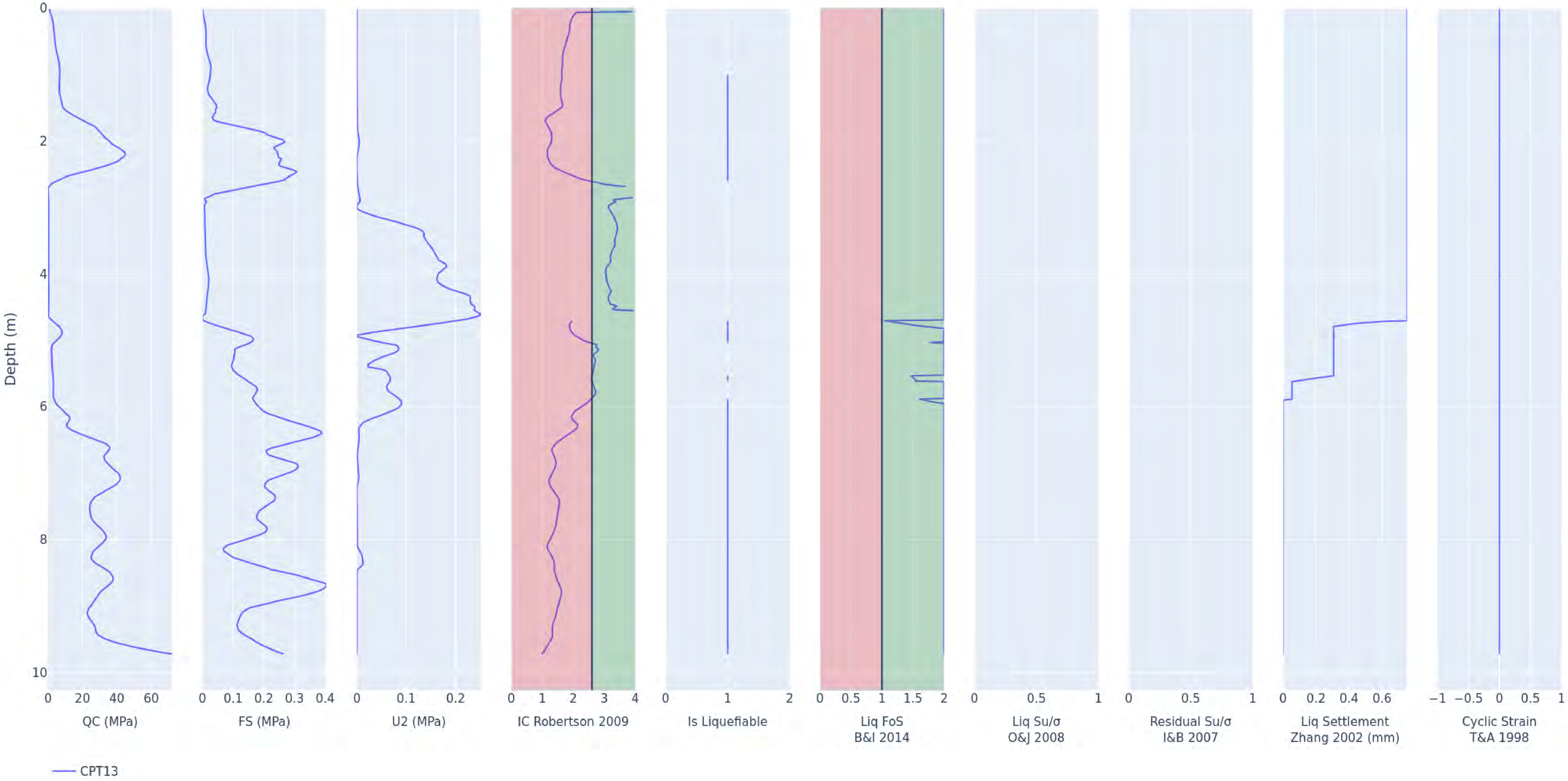


Made using data from CPT07.ags

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
CPT13	User Input	9.72	1.0	0.1	6.5	1	0	1	0	0	0	0.0

Made using data from CPT13.ags

Liquefaction Analysis



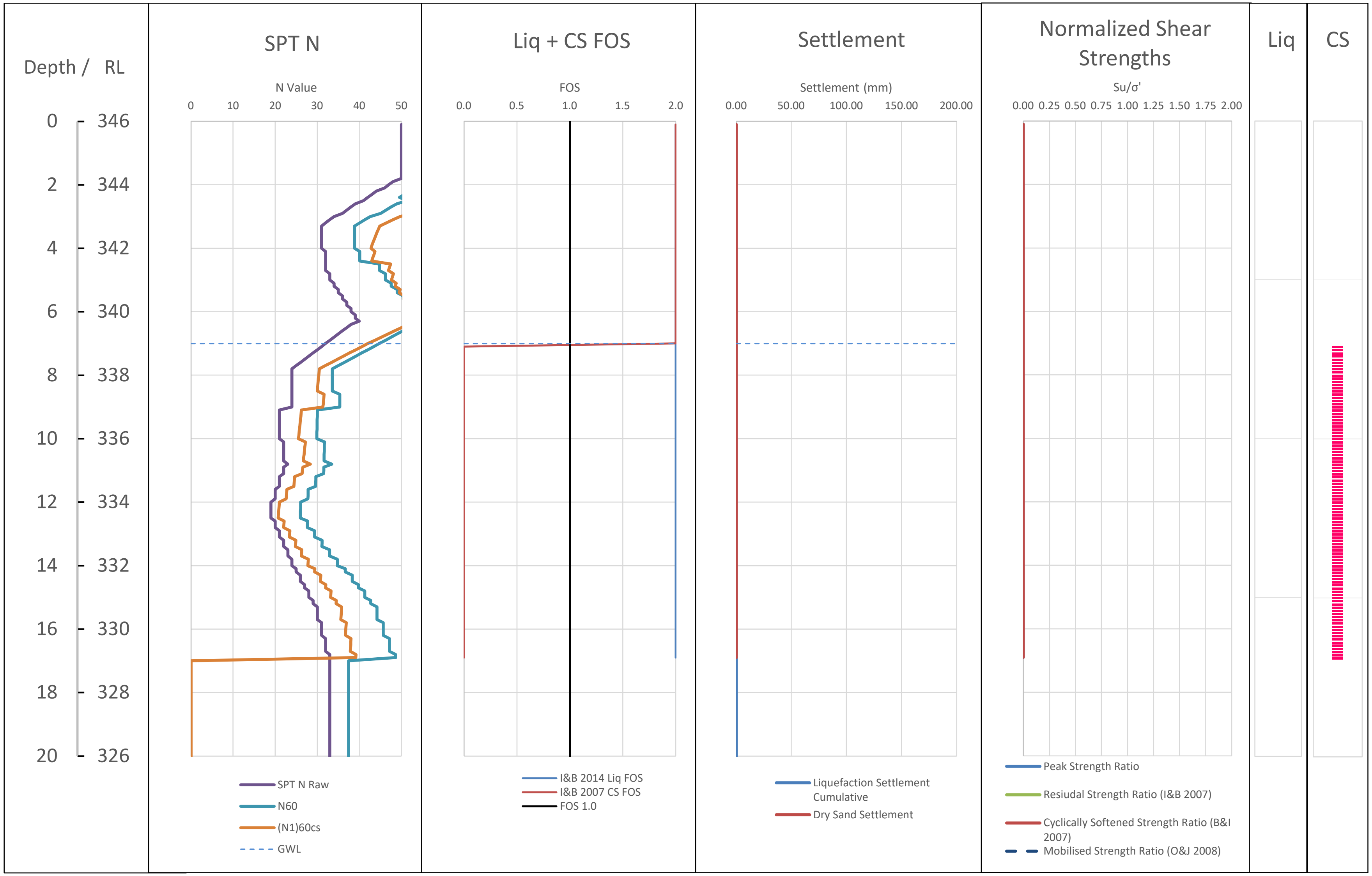
Made using data from CPT13.ags

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
BHLQ_04	User Input	17.25	7.0	0.1	6.5	0	0	0	0	0	0	0.0
BHLQ_09	User Input	12.5	7.0	0.1	6.5	0	0	0	0	0	0	0.0

Made using data from BHLQ_4-9.ags

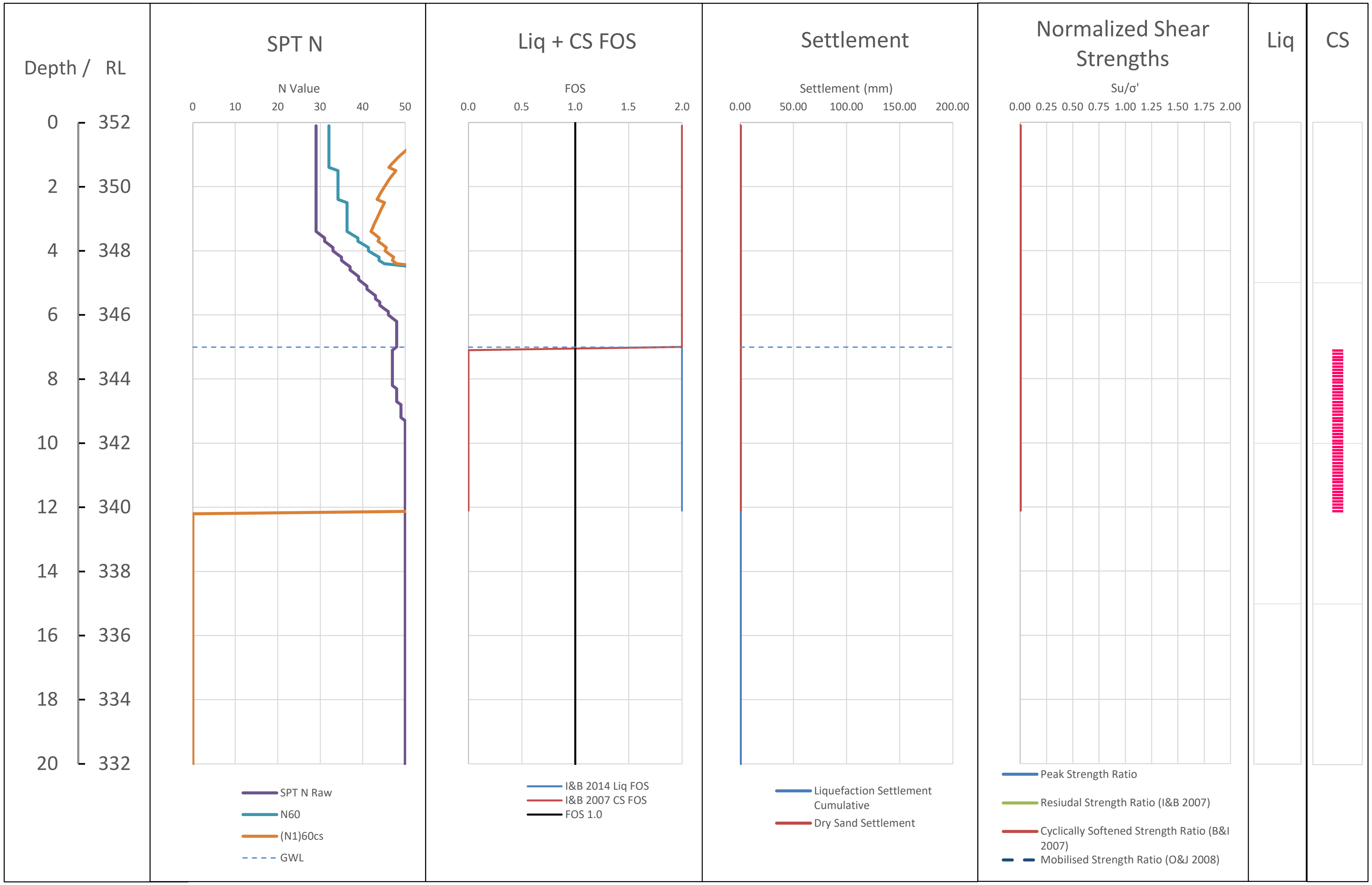
Project Summary	
Project Name	Tapuae/Southern Corri
Project Number	3161129
Unscaled PGA (g)	0.1
Magnitude	6.5
Total Settlement (mm)	0

Borehole Information	
BH ID:	BHLQ_04
BH Depth (m):	17.0
Ground Level:	346
Water Level:	7
Fill:	0



Project Summary	
Project Name	Tapuae/Southern Corr
Project Number	3161129.0
Unscaled PGA (g)	0.1
Magnitude	6.5
Total Settlement (mm)	0.00

Borehole Information	
BH ID:	BHLQ_09
BH Depth (m):	12.2
Ground Level:	352
Water Level:	7
Fill:	0

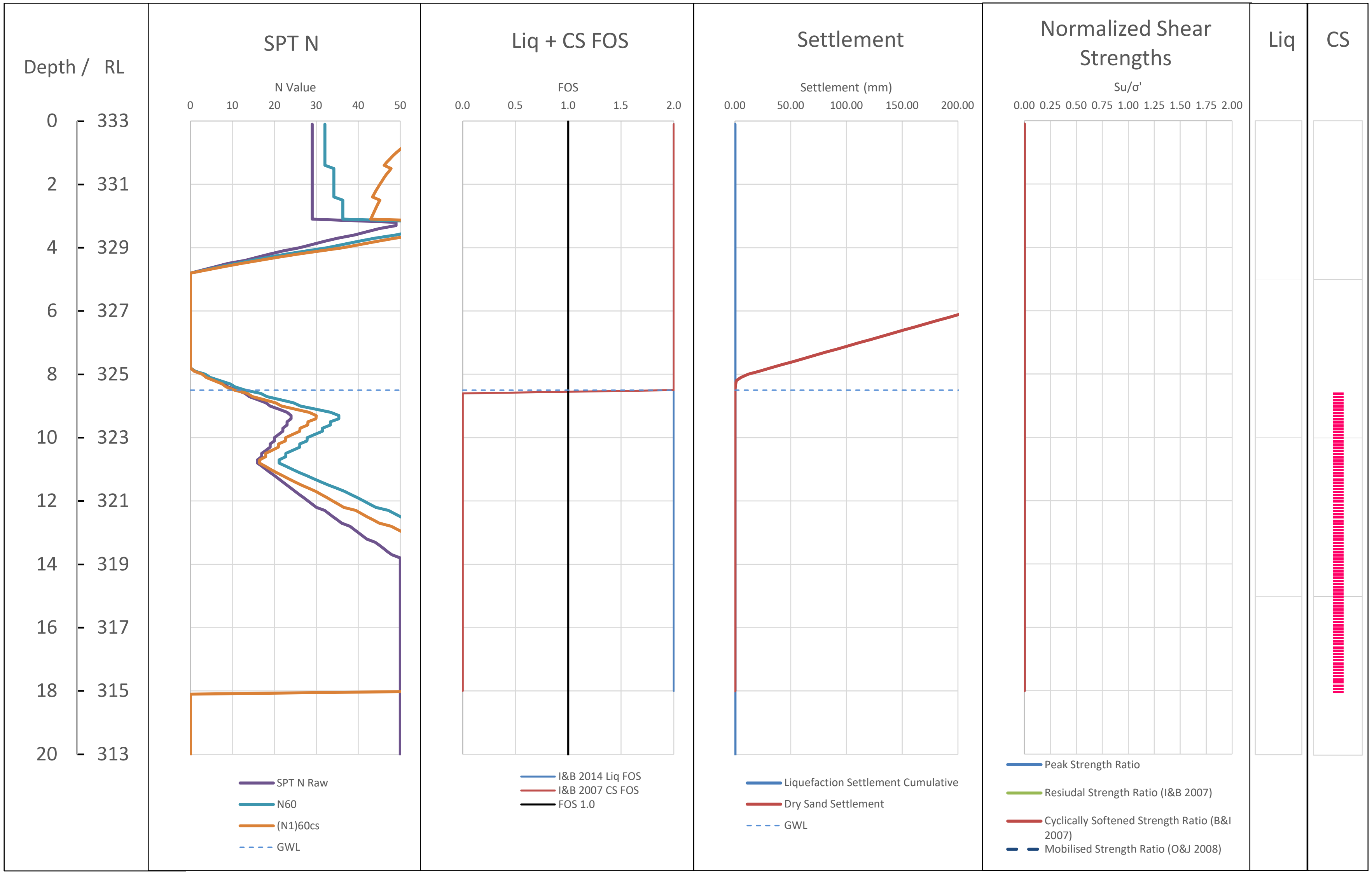


ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
BHLQ_11	User Input	18.3	8.5	0.1	6.5	0	336	336	0	0	0	0.0

Made using data from BHLQ_11.ags

Project Summary	
Project Name	Tapuae/Southern Cor
Project Number	3161129
Unscaled PGA (g)	0.1
Magnitude	6.5
Liquefaction Settlement (mm)	0

Borehole Information	
BH ID:	BHLQ_11
BH Depth (m):	18.0
Ground Level:	333
Water Level:	8.5
Fill:	0



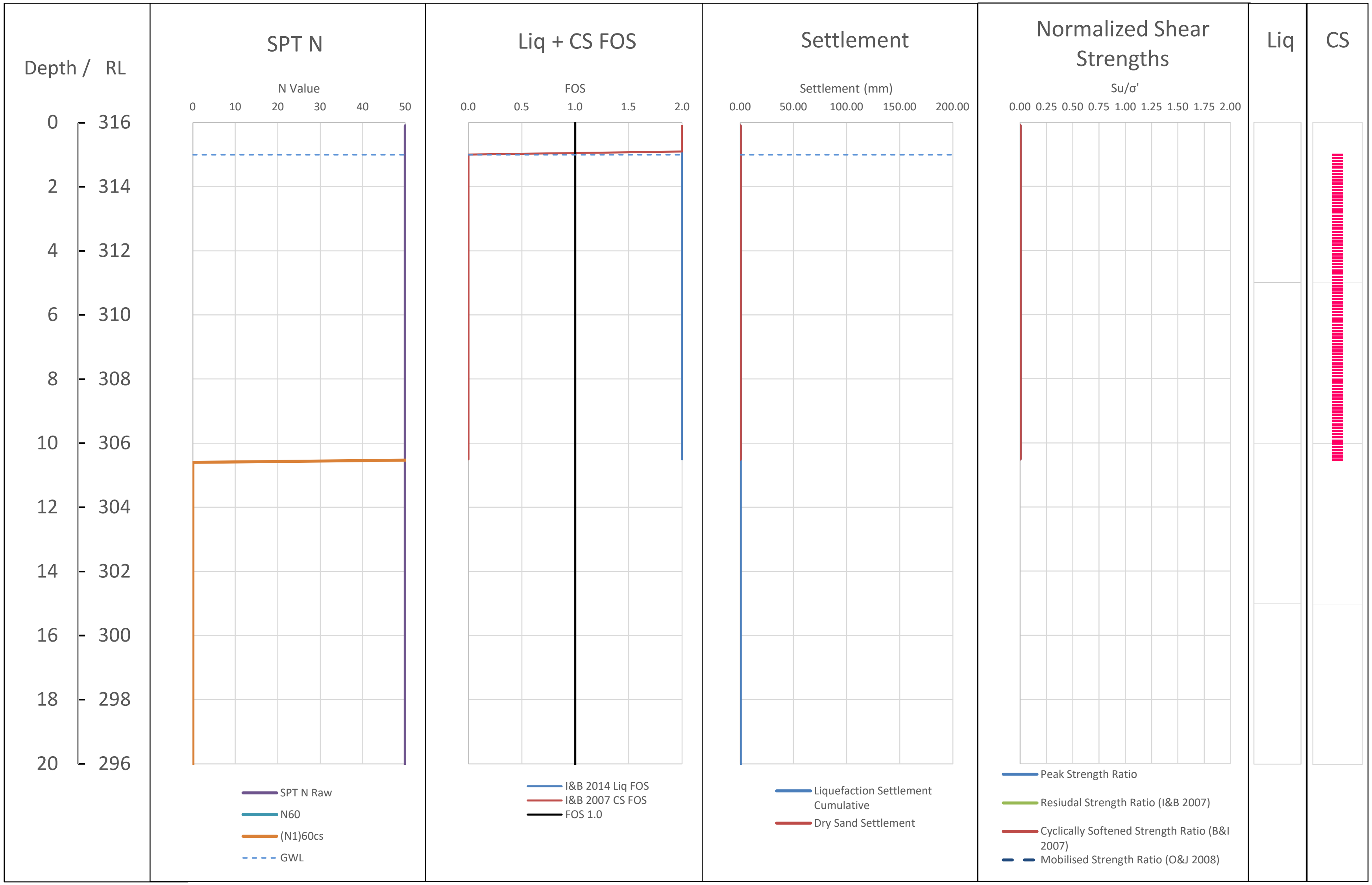
Beca SPT Seismic Analysis Spreadsheet v53

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
BHLQ_16	User Input	10.81	1.0	0.1	6.5	0	0	0	0	0	0	0.0

Made using data from BHLQ_16.ags

Project Summary	
Project Name	Tapuae/Southern Cori
Project Number	3161129
Unscaled PGA (g)	0.1
Magnitude	6.5
Liquefaction Settlement (mm)	0.00

Borehole Information	
BH ID:	BHLQ_16
BH Depth (m):	10.5
Ground Level:	316
Water Level:	1
Fill:	0



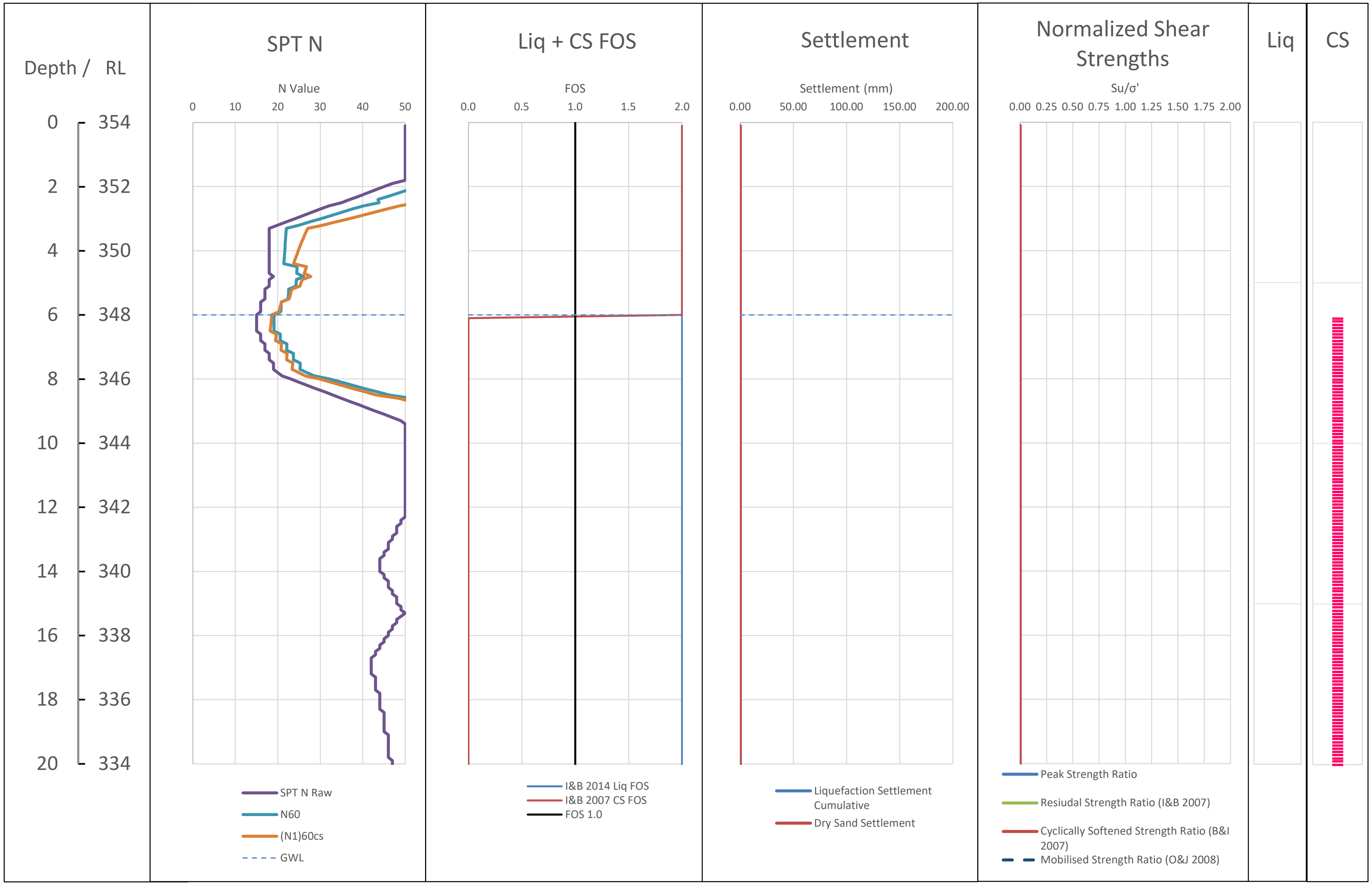
Beca SPT Seismic Analysis Spreadsheet v53

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
BH01 Geosolve 2022	User Input	30.43	6.0	0.1	6.5	0	0	0	0	0	0	0.0

Made using data from BH01 Geosolve 2022.ags

Project Summary	
Project Name	Tapuae/Southern Cor
Project Number	3161129.0
Unscaled PGA (g)	0.1
Magnitude	6.5
Liquefaction Settlement (mm)	0

Borehole Information	
BH ID:	solve 2022
BH Depth (m):	30.1
Ground Level:	354
Water Level:	6
Fill:	0

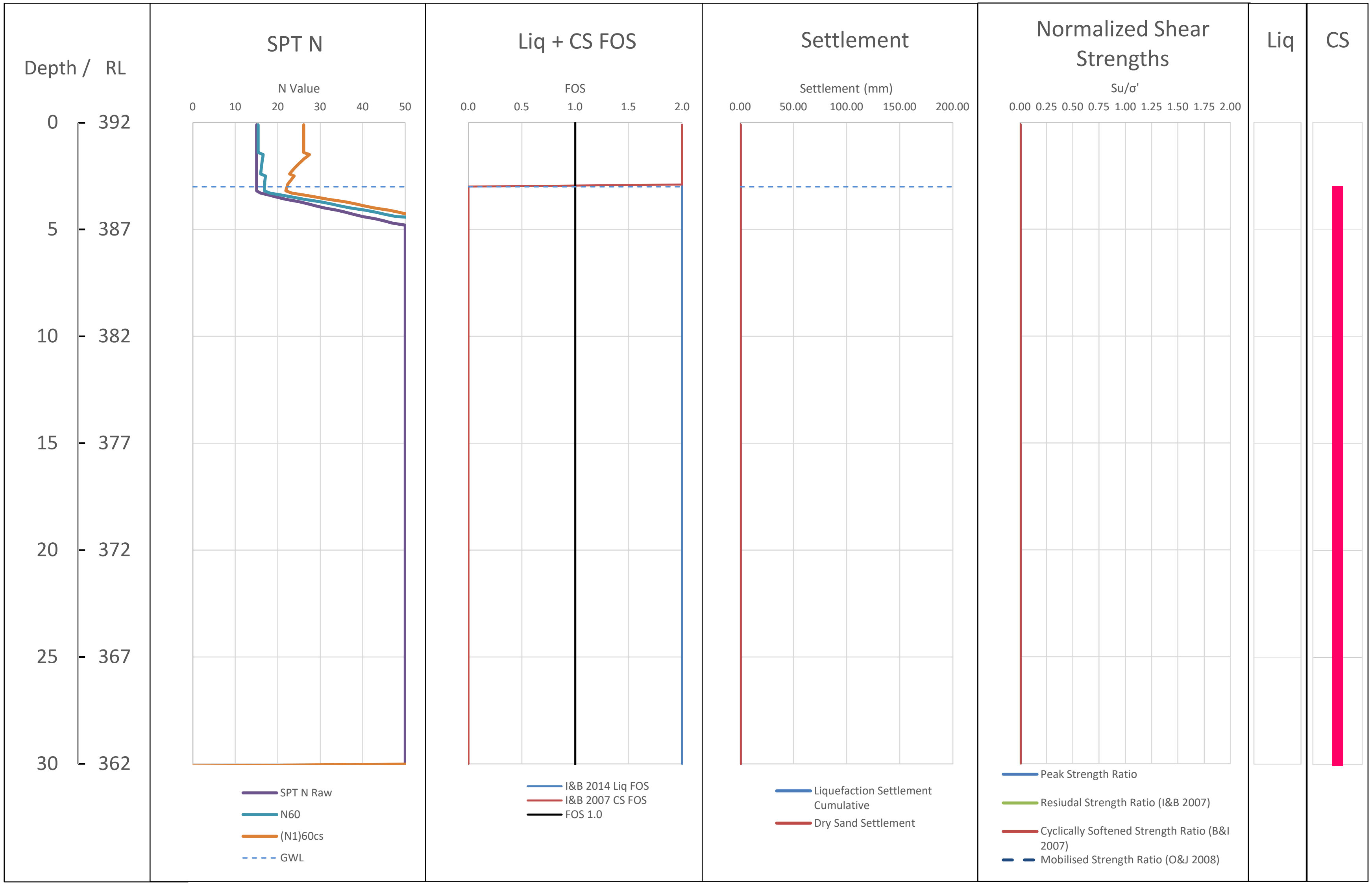


ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
BH02 Geosolve 2022	User Input	30.3	3.0	0.1	6.5	0	0	0	0	0	0	0.0

Made using data from BH02 Geosolve 2022.ags

Project Summary	
Project Name	Tapuae/Southern Corr
Project Number	3161129
Unscaled PGA (g)	0.1
Magnitude	6.5
Liquefaction Settlement (mm)	0

Borehole Information	
BH ID:	solve 2022
BH Depth (m):	30.0
Ground Level:	392
Water Level:	3
Fill:	0



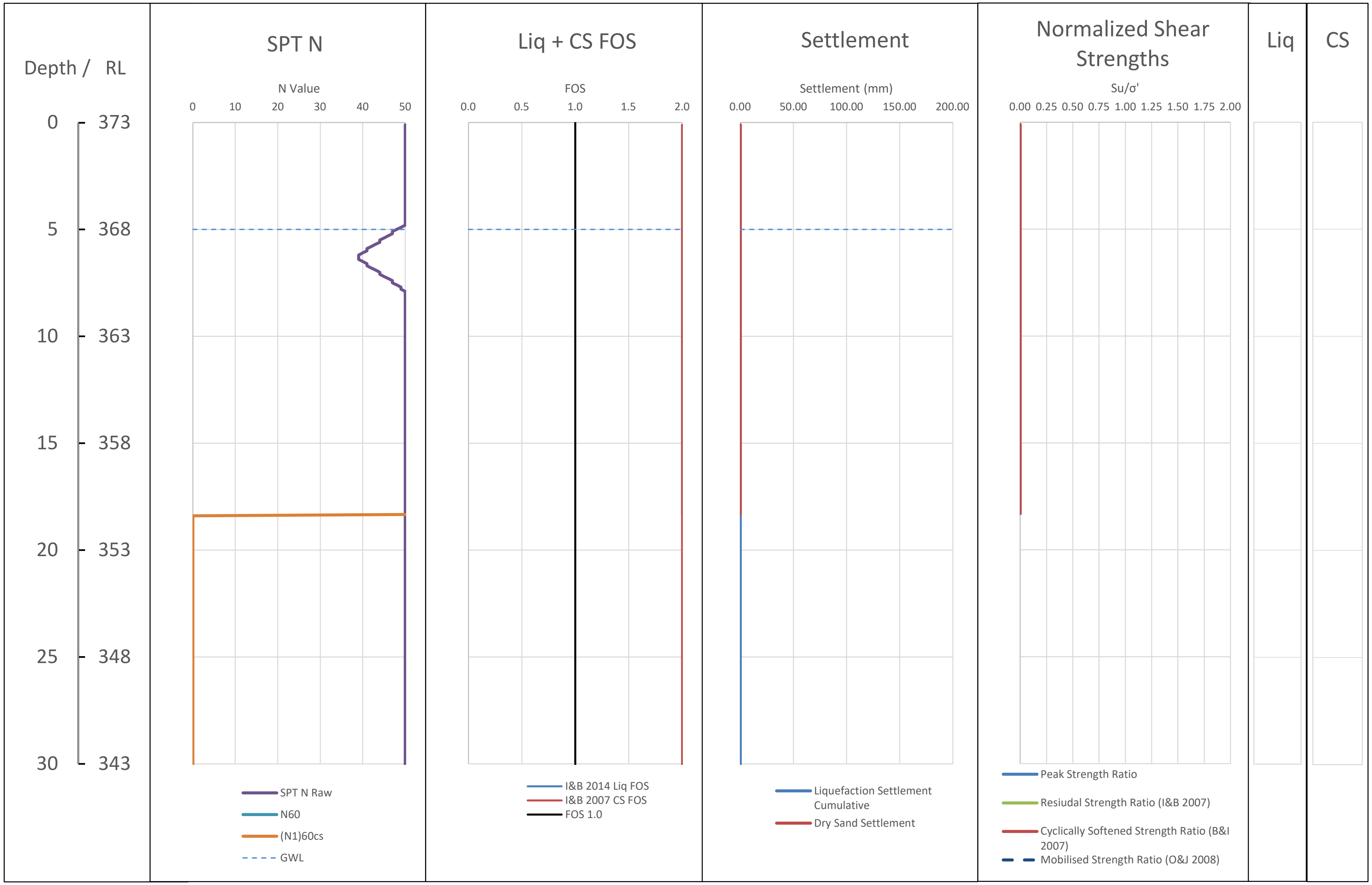
Beca SPT Seismic Analysis Spreadsheet v53

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
BH03 Geosolve 2024	User Input	20.11	5.0	0.1	6.5	0	0	0	0	0	0	0.0

Made using data from BH03 Geosolve 2024-1.ags

Project Summary	
Project Name	Tapuae/Southern Cori
Project Number	3161129.0
Unscaled PGA (g)	0.1
Magnitude	6.5
Liquefaction Settlement (mm)	0.00

Borehole Information	
BH ID:	solve 2024
BH Depth (m):	18.3
Ground Level:	373
Water Level:	5
Fill:	0

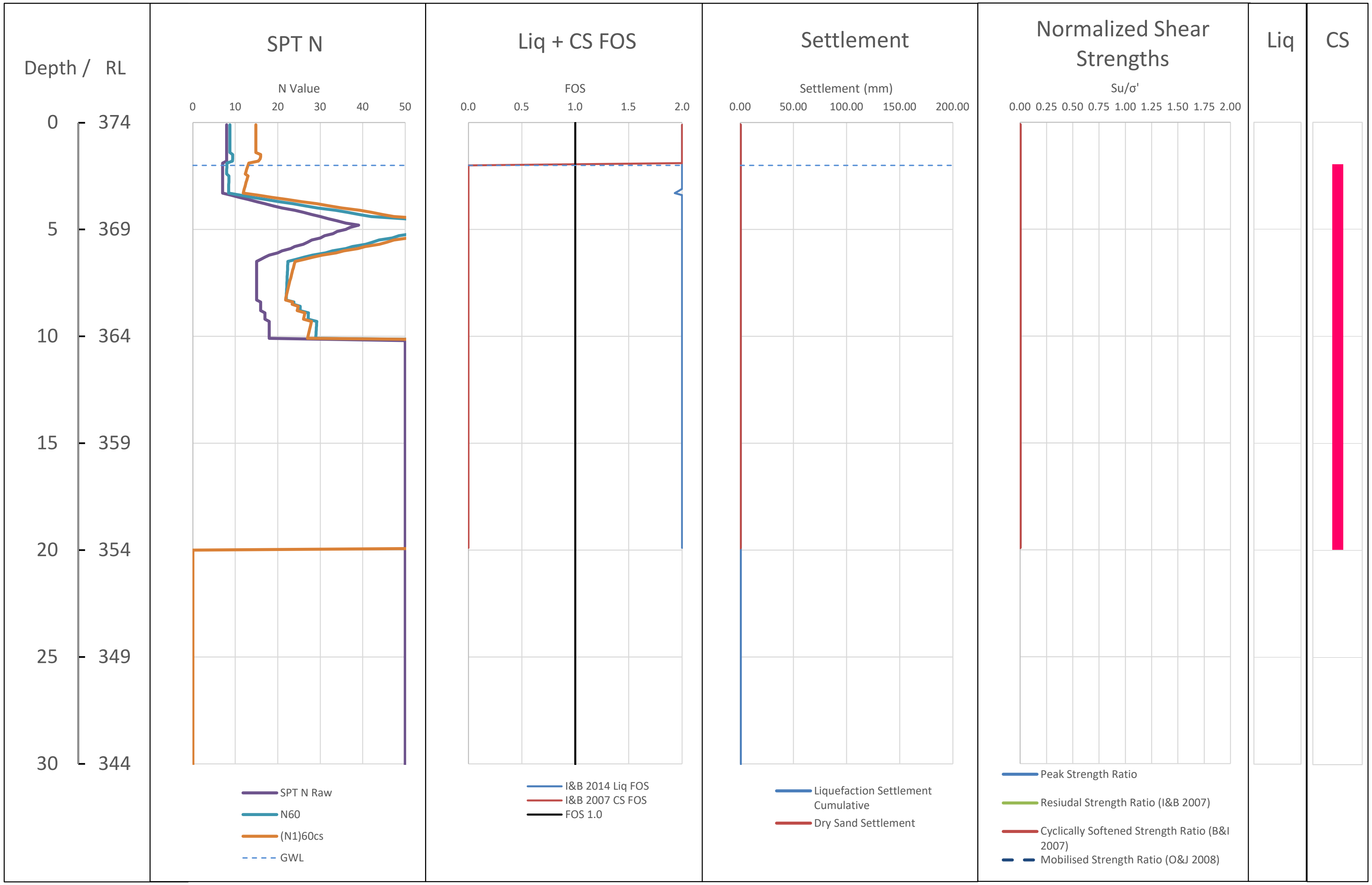


ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
BH01 Geosolve 2024	User Input	20.25	2.0	0.1	6.5	0	0	0	0	0	0	0.0

Made using data from BH01 Geosolve 2024 -1.ags

Project Summary	
Project Name	Tapuae/Southern Cori
Project Number	3161129
Unscaled PGA (g)	0.1
Magnitude	6.5
Liquefaction Settlement (mm)	0

Borehole Information	
BH ID:	solve 2024
BH Depth (m):	20.0
Ground Level:	374
Water Level:	2
Fill:	0



Liquefaction Assessment Result

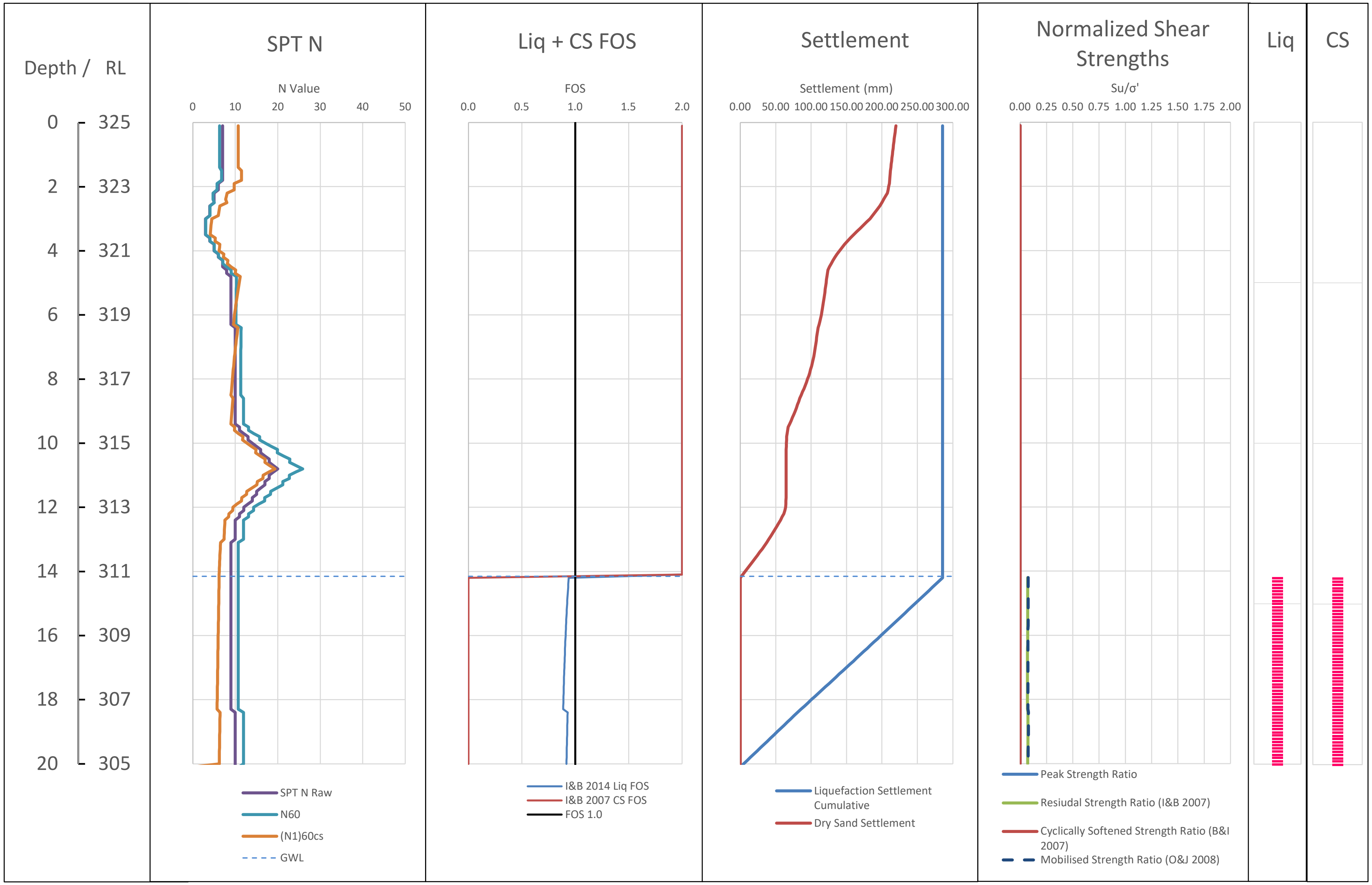
Earthquake Return Period = 100-year
Earthquake Magnitude (Mw) = 6.5
Peak Ground Acceleration (g) = 0.20

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
22BH01	User Input	48.75	14.15	0.2	6.5	285	220	505	236	0	9	70.0

Made using data from 22BH01.ags

Project Summary	
Project Name	Tapuae/Southern Corr
Project Number	3161129
Unscaled PGA (g)	0.2
Magnitude	6.5
Liquefaction Settlement (mm)	285

Borehole Information	
BH ID:	22BH01
BH Depth (m):	20.0
Ground Level:	325
Water Level:	14.15
Fill:	0

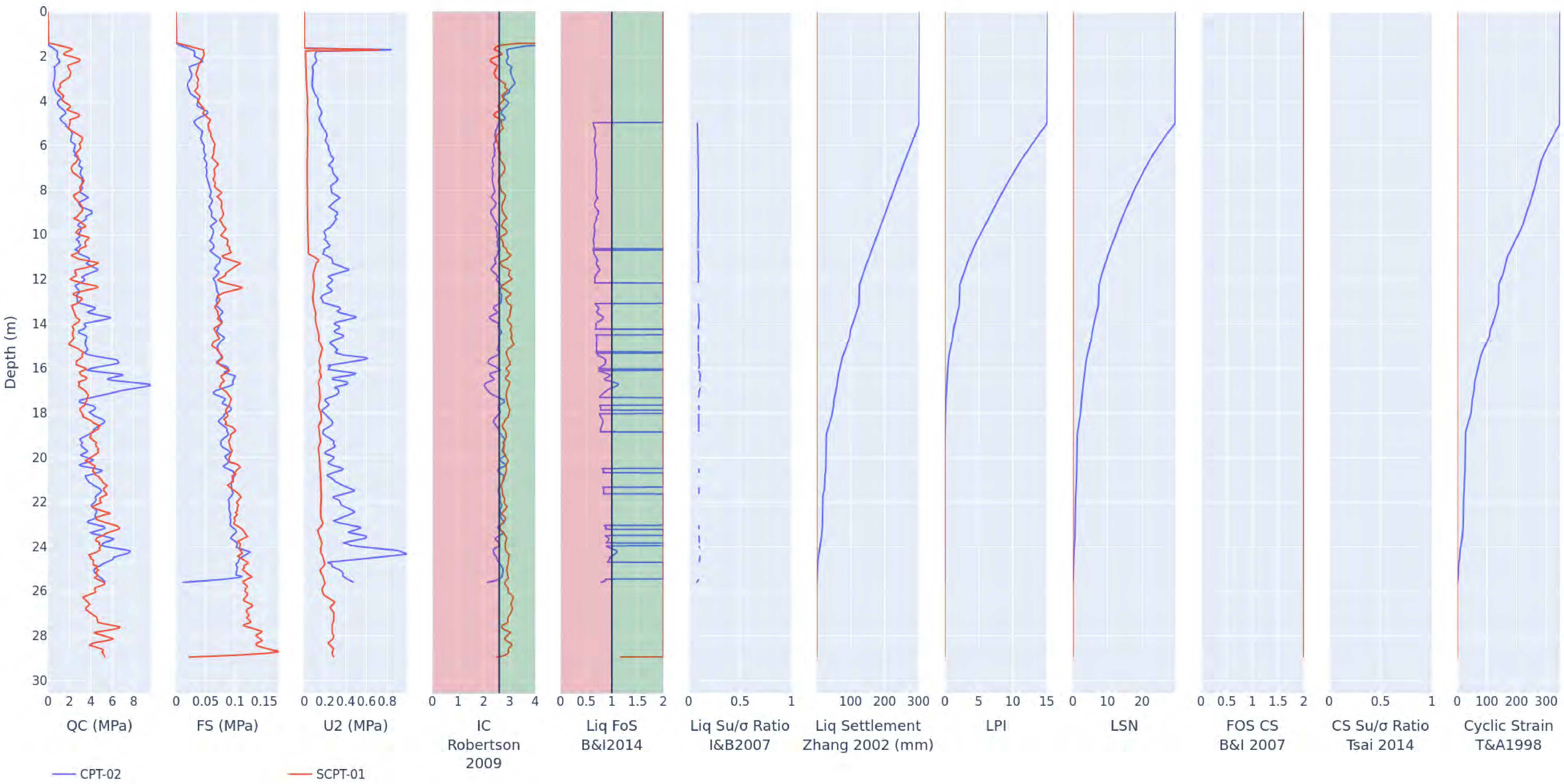


Beca SPT Seismic Analysis Spreadsheet v53

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
CPT-02	25.59	1.6	0.2	6.5	303	347	15	30
SCPT-01	28.95	13.0	0.2	6.5	0	0	0	0

Made using data from CPTs.ags

Liquefaction Standard Output

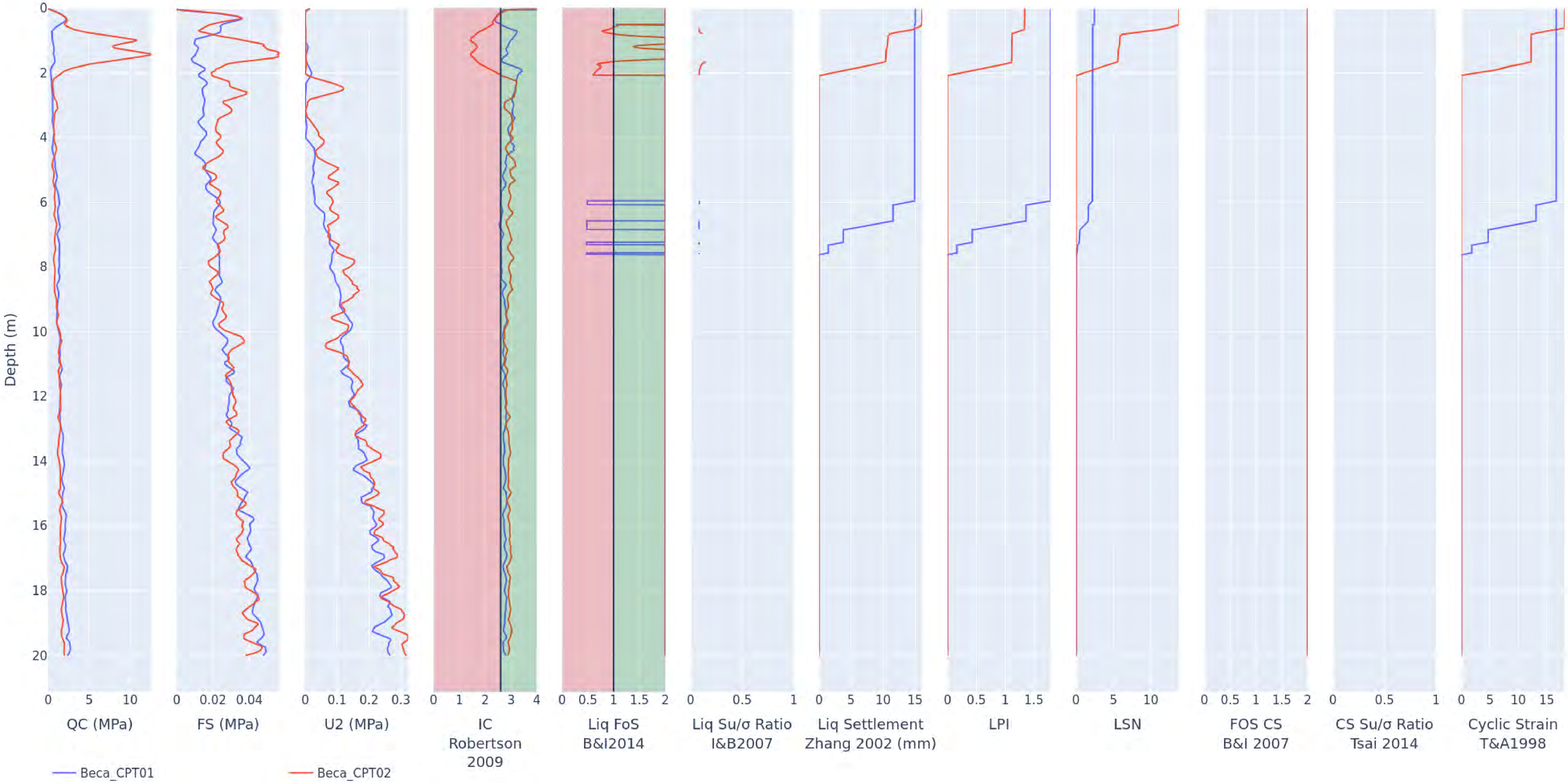


Made using data from CPTs.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
Beca_CPT01	20.0	0.5	0.2	6.5	15	17	2	2
Beca_CPT02	20.0	0.5	0.2	6.5	16	18	1	14

Made using data from Beca CPT - 2023.ags

Liquefaction Standard Output

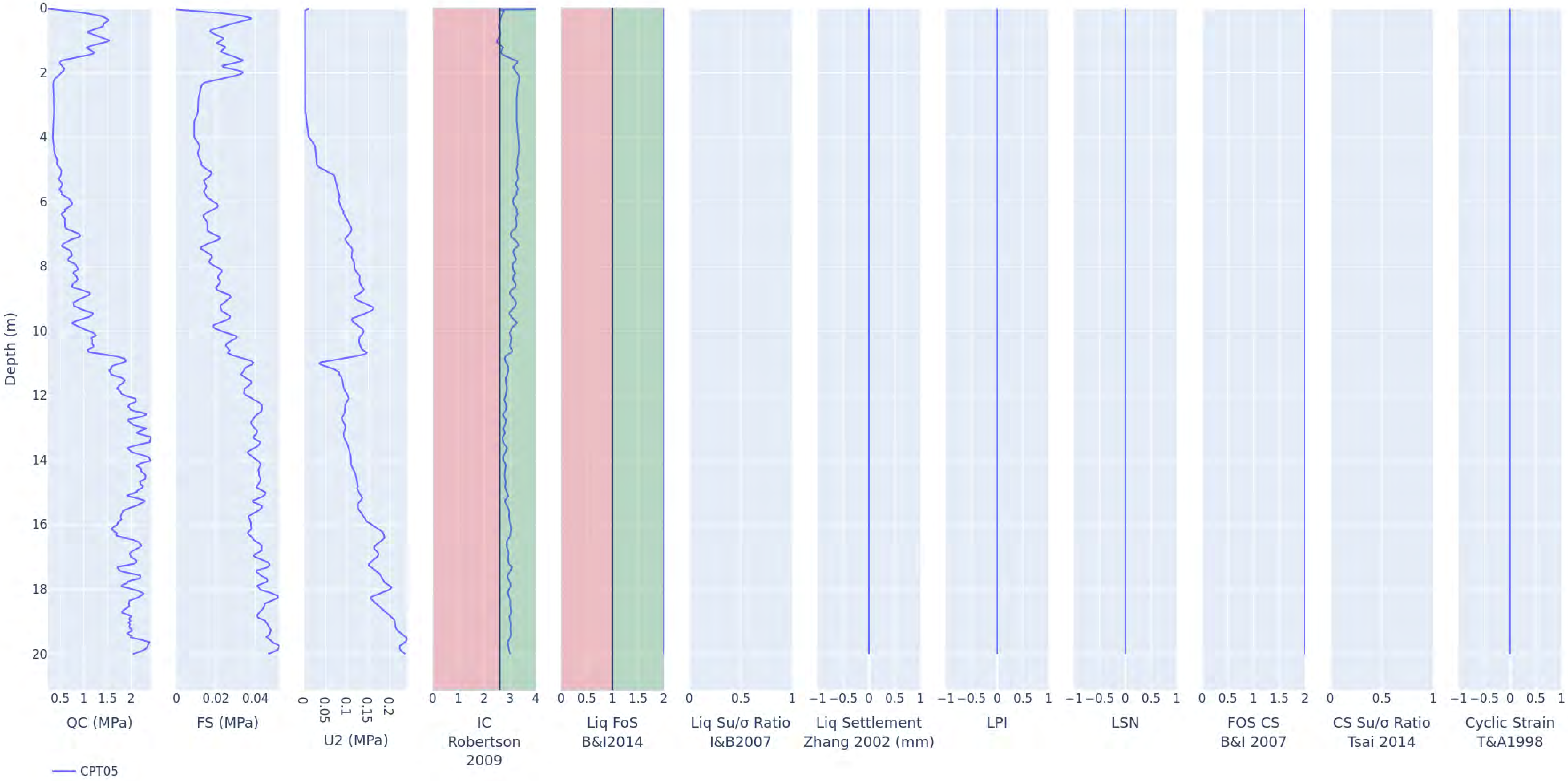


Made using data from Beca CPT - 2023.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
CPT05	20.0	6.0	0.2	6.5	0	0	0	0

Made using data from CPT05.ags

Liquefaction Standard Output

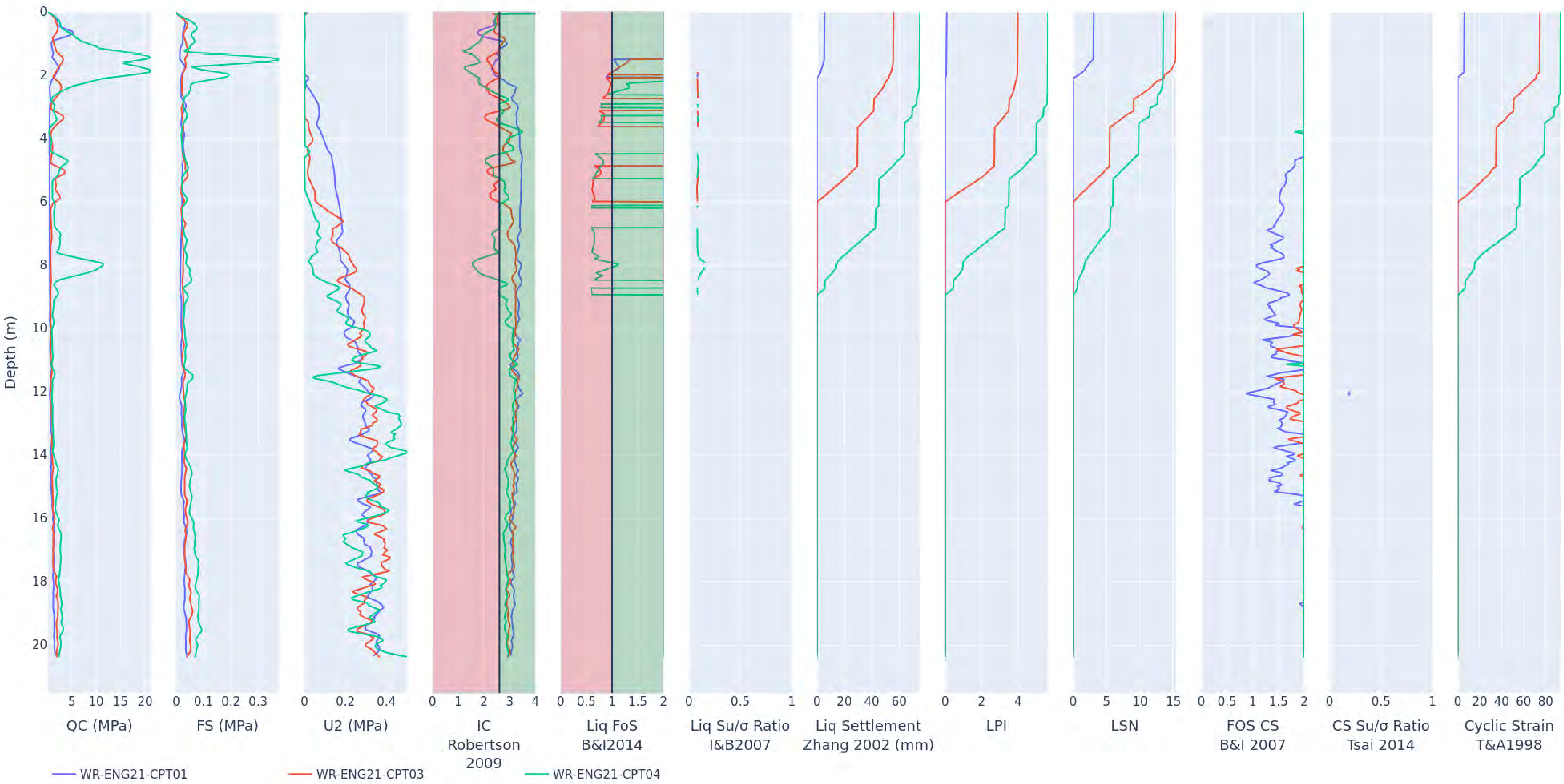


Made using data from CPT05.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
WR-ENG21-CPT01	20.35	1.5	0.2	6.5	6	6	0	3
WR-ENG21-CPT03	20.39	1.5	0.2	6.5	56	75	4	15
WR-ENG21-CPT04	20.38	1.5	0.2	6.5	75	94	6	13

Made using data from WR-ENG21-CPT01-03-04.ags

Liquefaction Standard Output

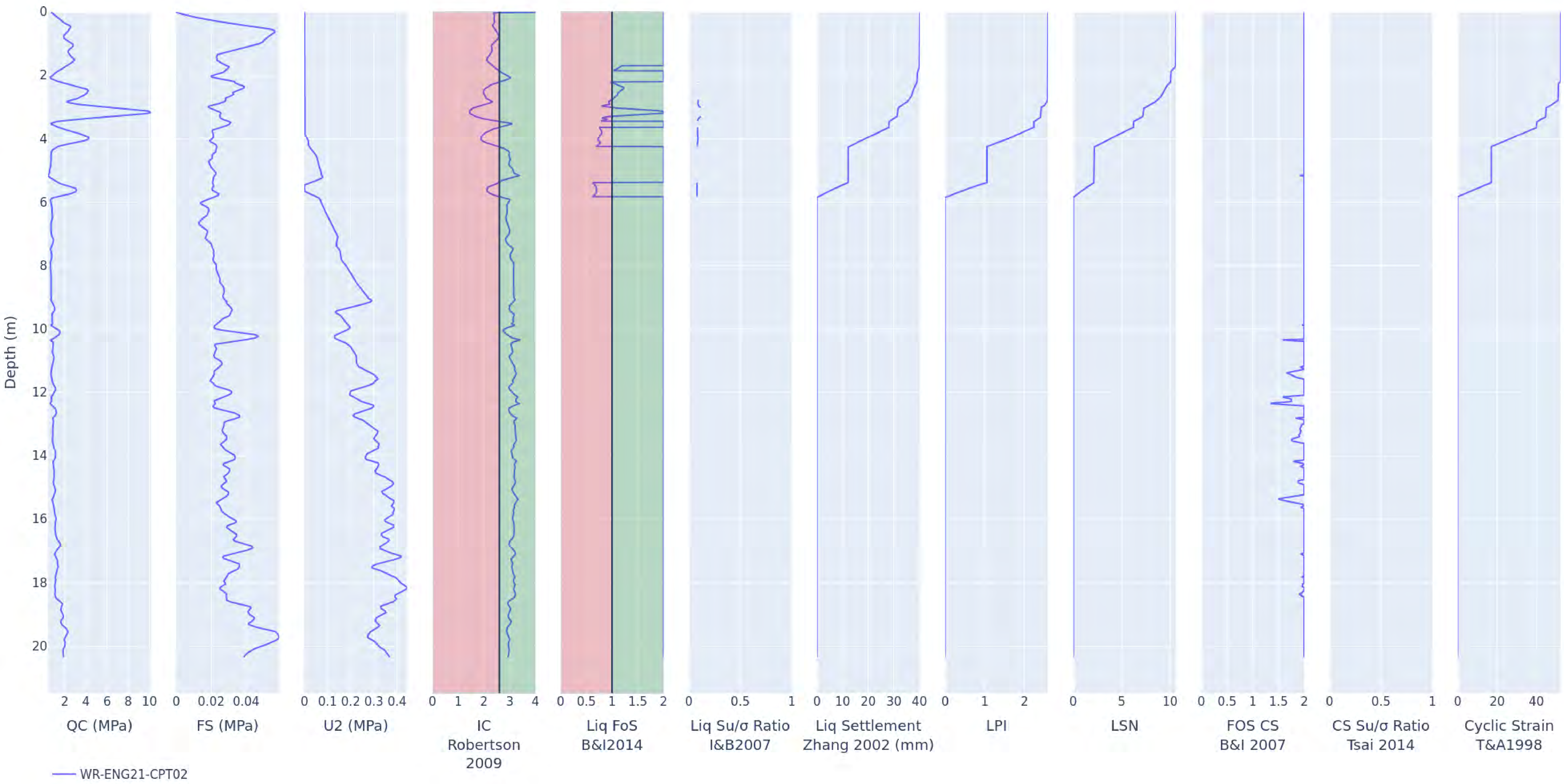


Made using data from WR-ENG21-CPT01-03-04.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
WR-ENG21-CPT02	20.35	1.7	0.2	6.5	40	52	3	11

Made using data from WR-ENG21-CPT02.ags

Liquefaction Standard Output

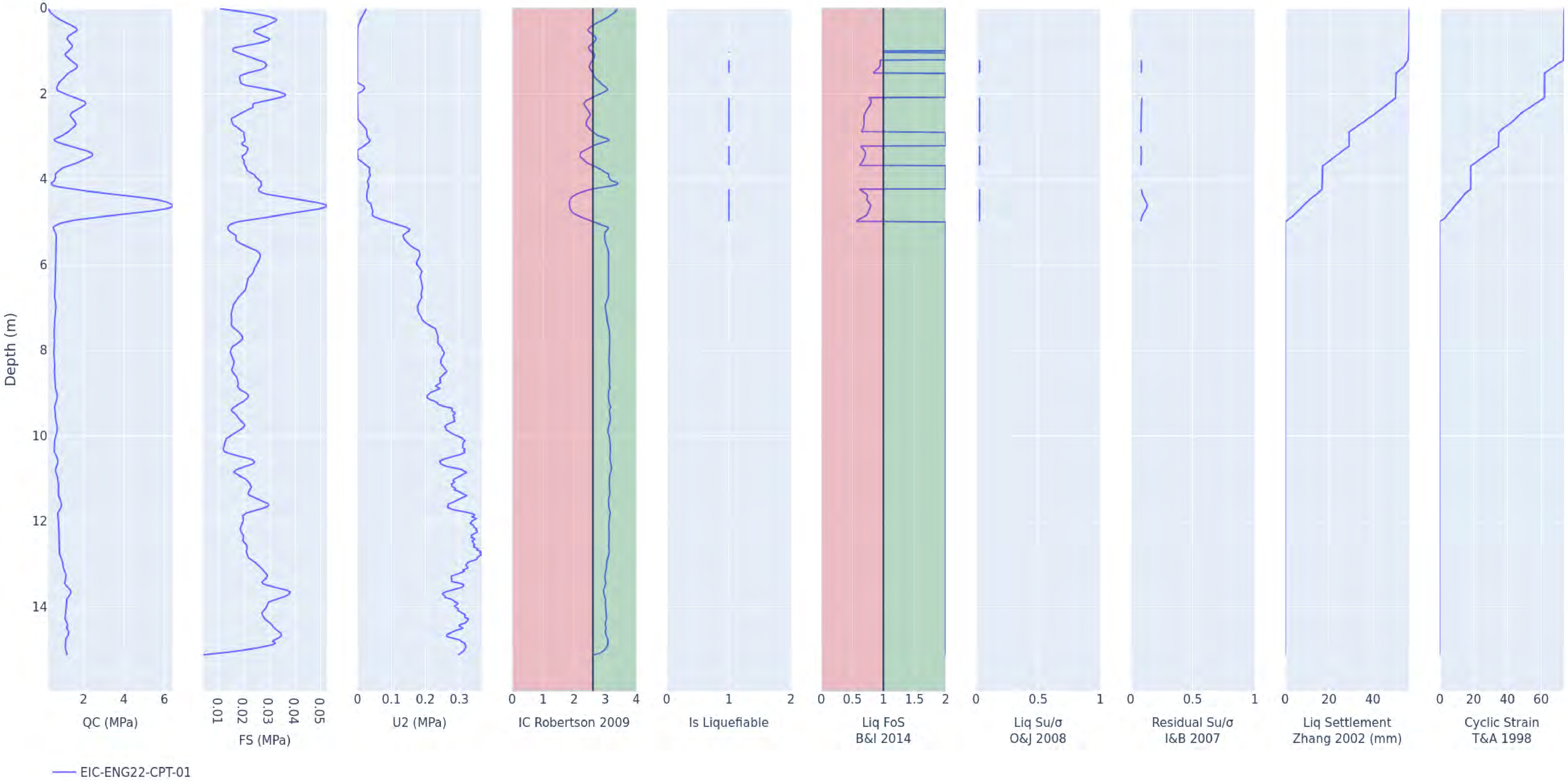


Made using data from WR-ENG21-CPT02.ags

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
EIC-ENG22-CPT-01	User Input	15.12	1.0	0.2	6.5	57	0	57	74	5	20	25.0

Made using data from 10 EIC-ENG22-CPT-01.ags

Liquefaction Analysis

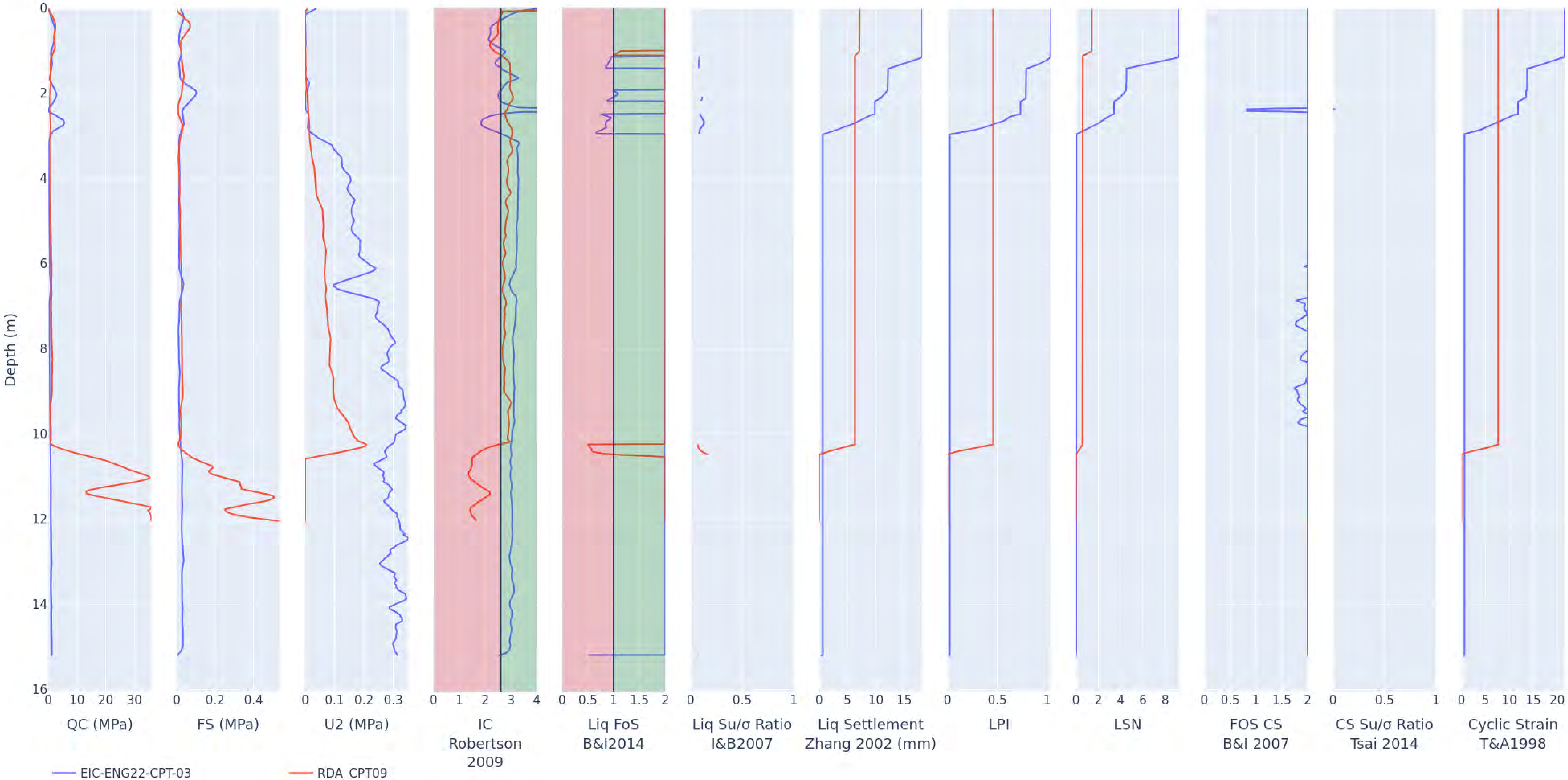


Made using data from 10 EIC-ENG22-CPT-01.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
EIC-ENG22-CPT-03	15.2	1.0	0.2	6.5	18	22	1	9
RDA_CPT09	12.04	1.0	0.2	6.5	7	8	0	1

Made using data from RDA CPT - 09 - EIC-ENG22-CPT-03.ags

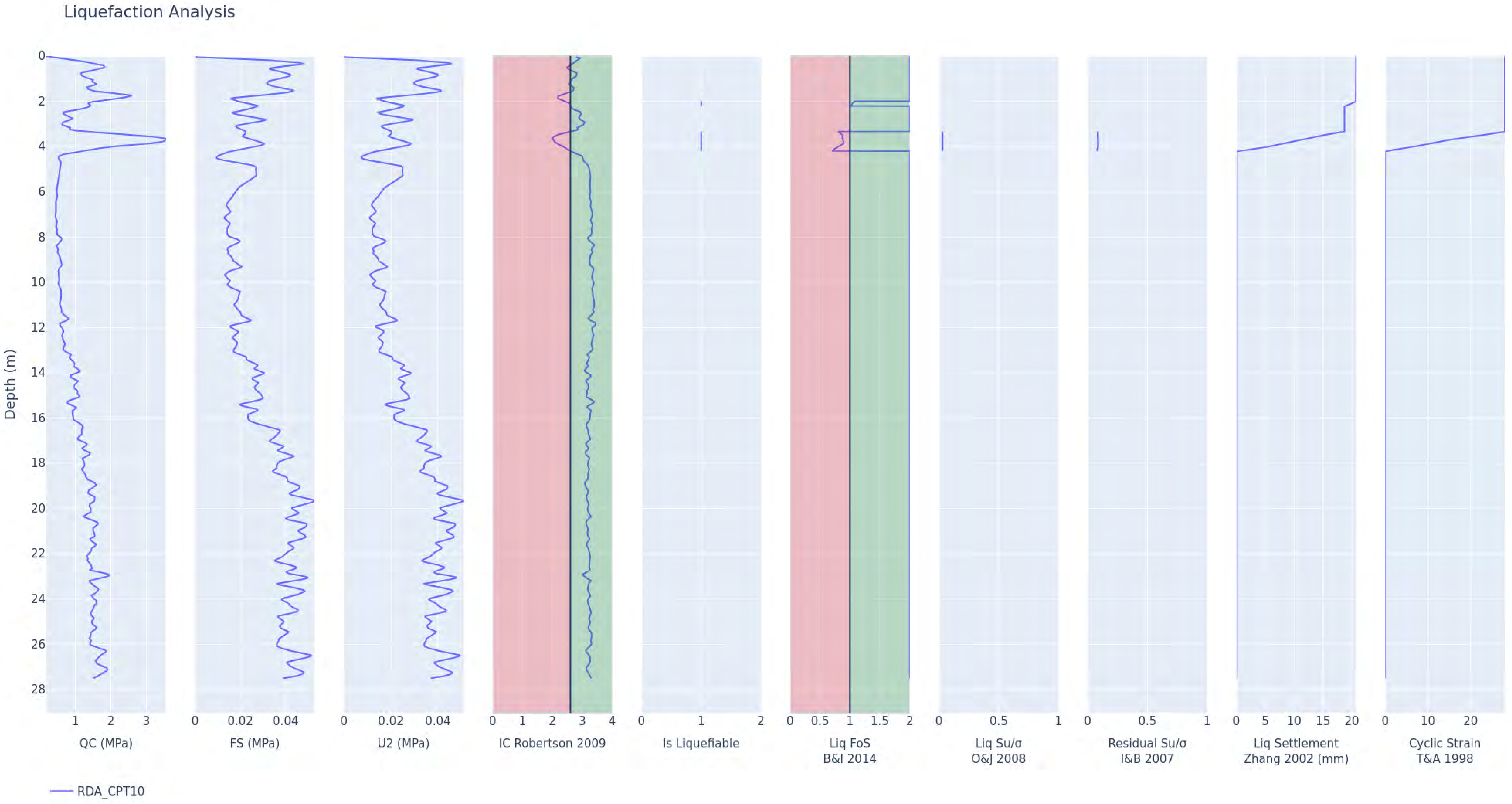
Liquefaction Standard Output



Made using data from RDA CPT - 09 - EIC-ENG22-CPT-03.ags

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
RDA_CPT10	User Input	27.5	2.0	0.2	6.5	21	0	21	28	1	6	9.0

Made using data from 13 RDA - CPT10.ags

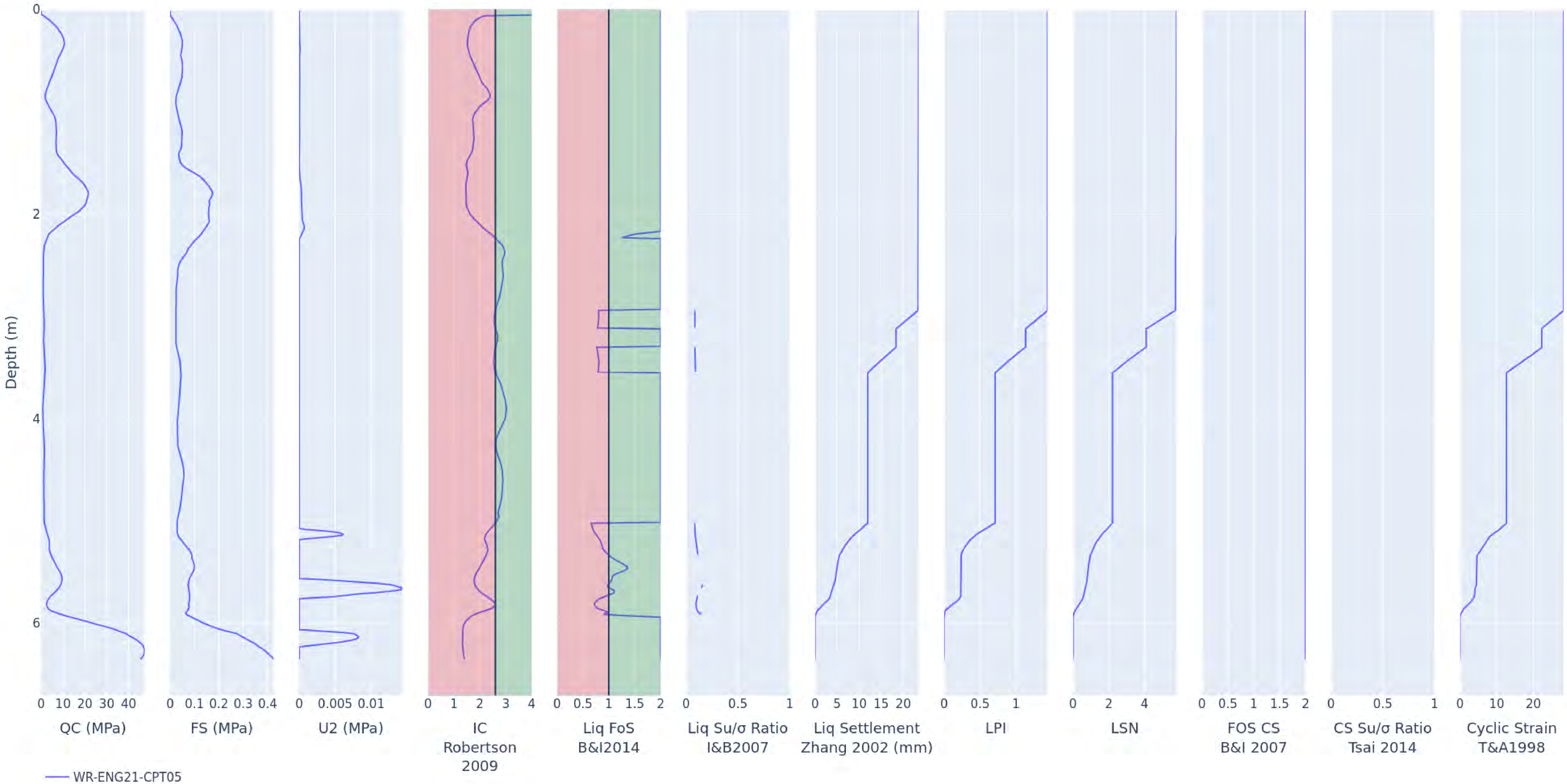


Made using data from 13 RDA - CPT10.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
WR-ENG21-CPT05	6.35	1.6	0.2	6.5	23	28	1	6

Made using data from WR-ENG21-CPT05.ags

Liquefaction Standard Output

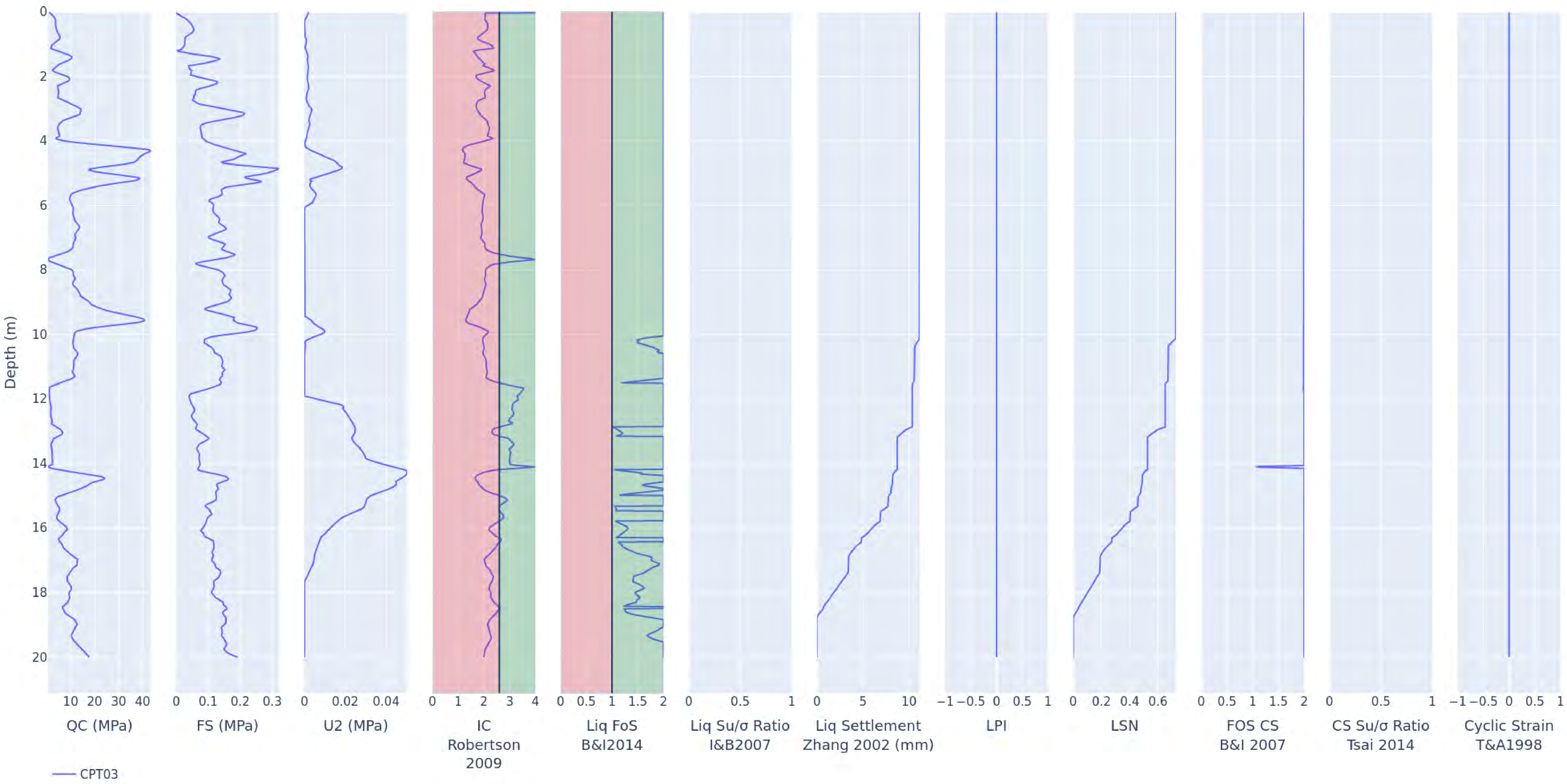


Made using data from WR-ENG21-CPT05.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
CPT03	20.0	8.0	0.2	6.5	11	0	0	1

Made using data from CPT03.ags

Liquefaction Standard Output

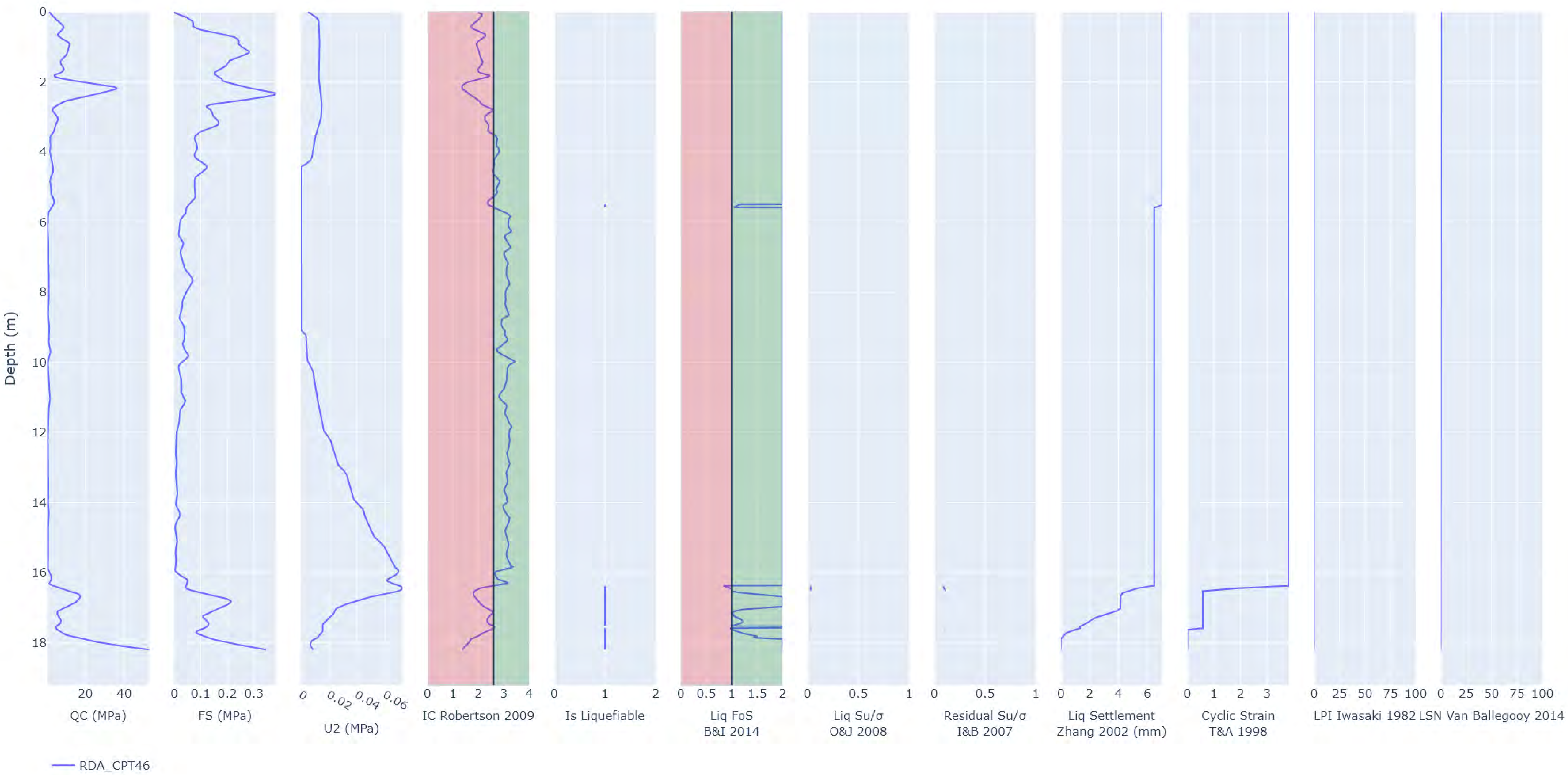


Made using data from CPT03.ags

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
RDA_CPT46	User Input	18.2	5.5	0.2	6.5	8	1	8	4	0	0	0.0
RDA_CPT51	User Input	17.8	2.2	0.2	6.5	50	0	50	60	2	7	12.0
RDA_CPT52	User Input	14.02	4.0	0.2	6.5	35	0	35	42	1	3	5.0
RDA_CPT61	User Input	11.02	4.0	0.2	6.5	16	1	16	19	1	1	3.0

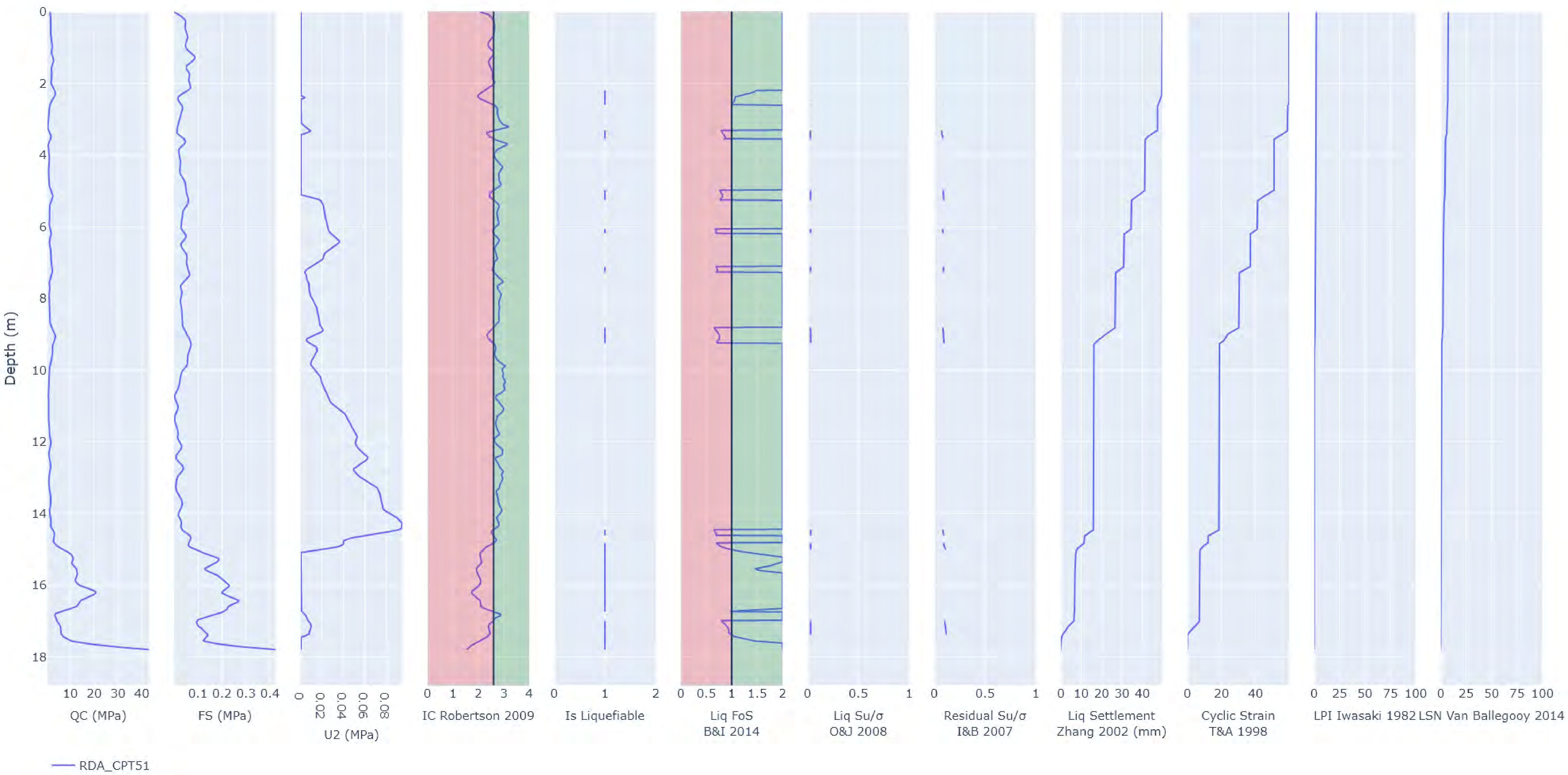
Made using data from RDA CPT-43-51-52-61.ags

Liquefaction Output for RDA_CPT46



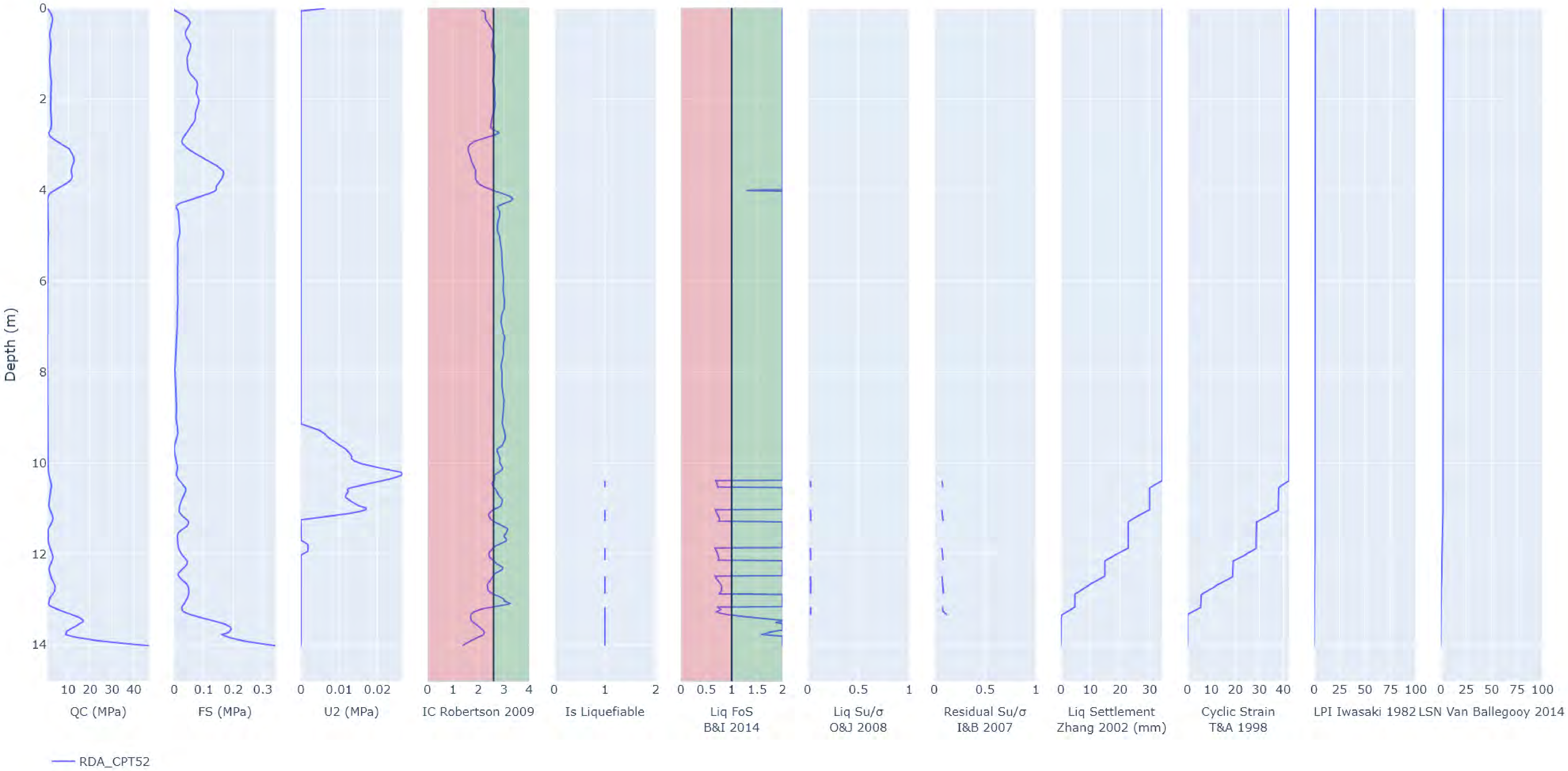
Made using data from RDA CPT-43-51-52-61.ags

Liquefaction Output for RDA_CPT51



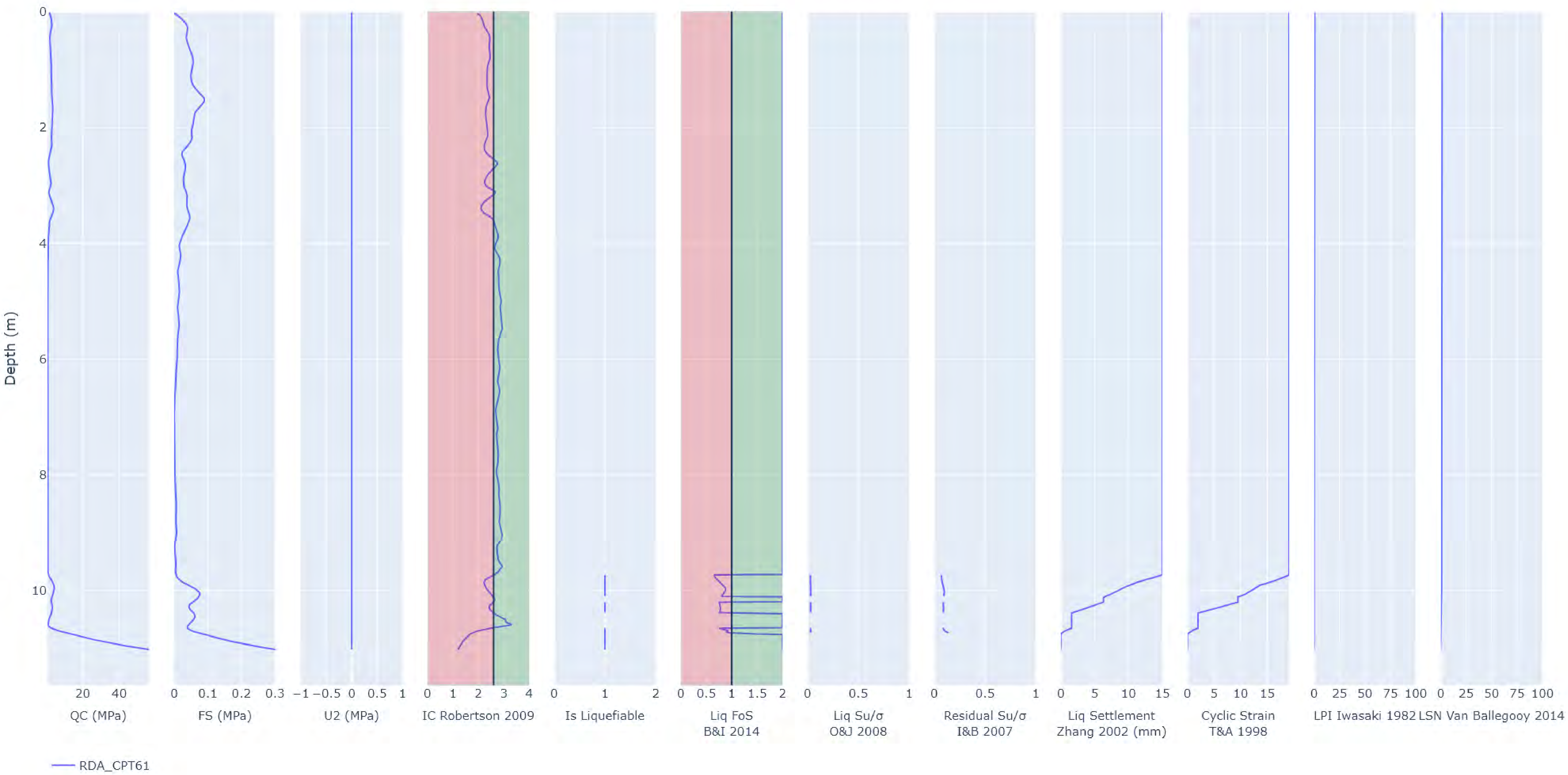
Made using data from RDA CPT-43-51-52-61.ags

Liquefaction Output for RDA_CPT52



Made using data from RDA CPT-43-51-52-61.ags

Liquefaction Output for RDA_CPT61

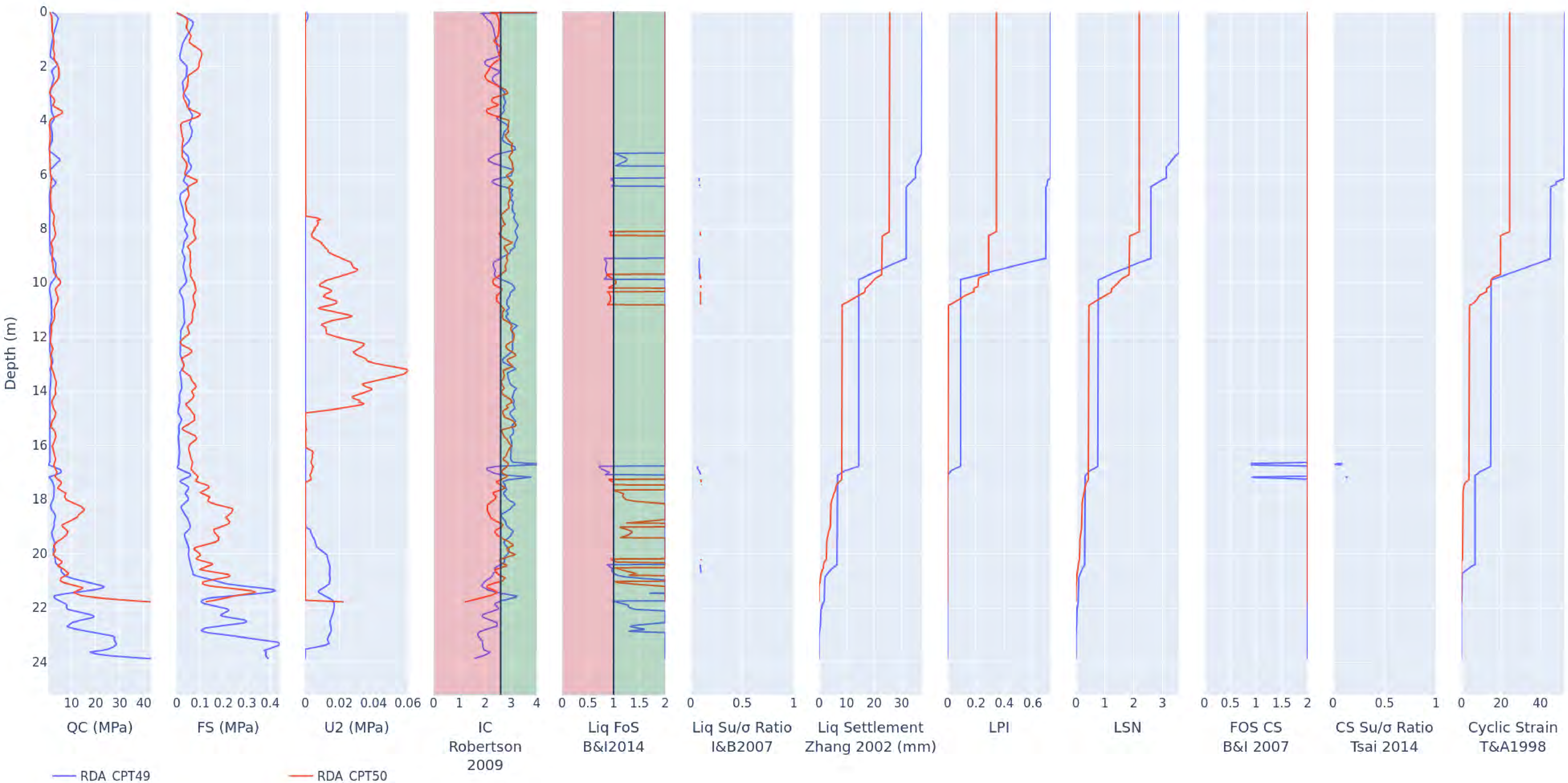


Made using data from RDA CPT-43-51-52-61.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
RDA_CPT49	23.88	5.0	0.2	6.5	37	52	1	4
RDA_CPT50	21.78	5.0	0.2	6.5	26	24	0	2

Made using data from RDA - CPT49-50.ags

Liquefaction Standard Output

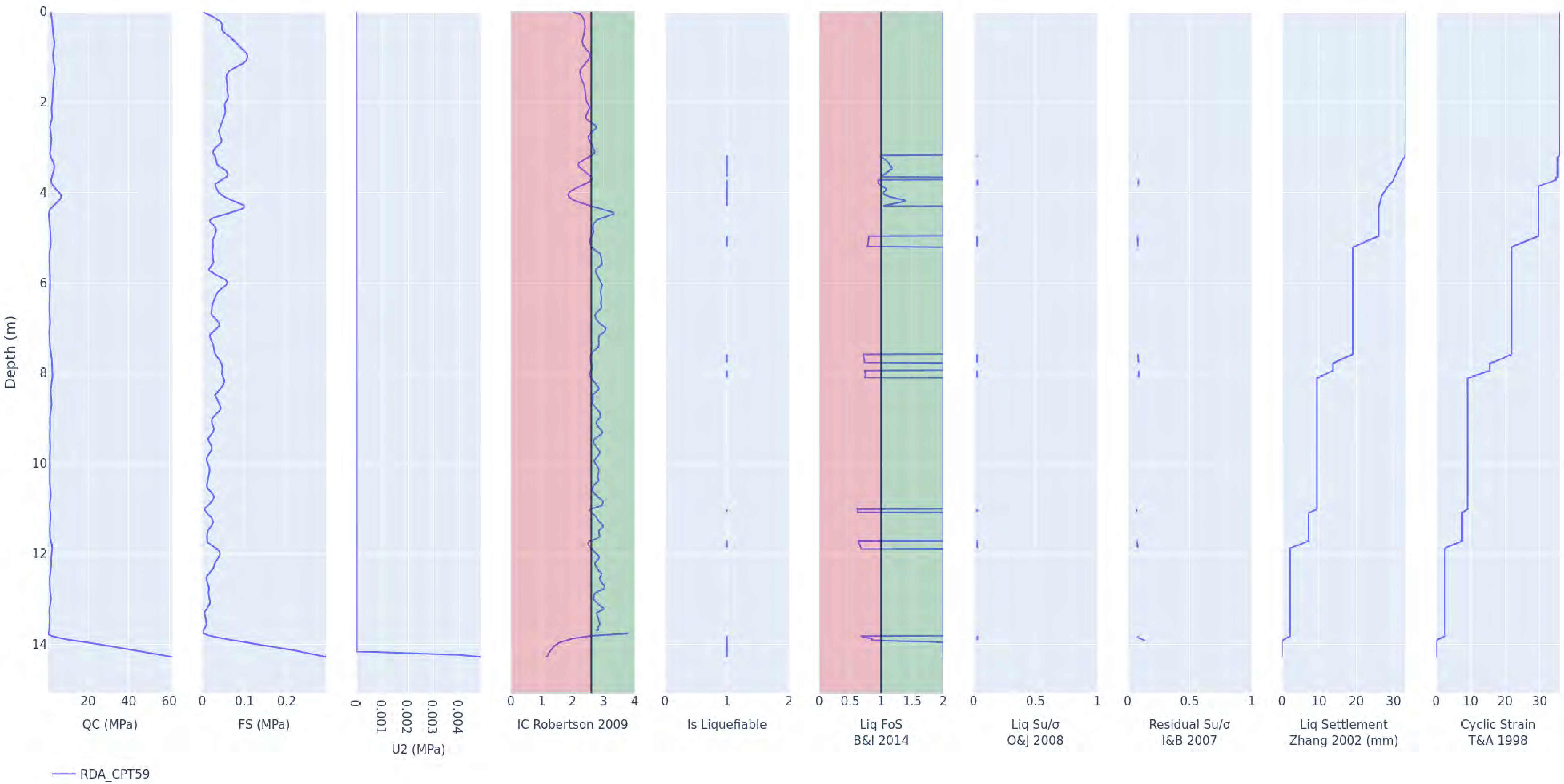


Made using data from RDA - CPT49-50.ags

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
RDA_CPT59	User Input	14.28	3.0	0.2	6.5	34	0	34	36	1	5	15.0
RDA_CPT60	User Input	23.74	3.0	0.2	6.5	92	0	92	104	3	10	6.0

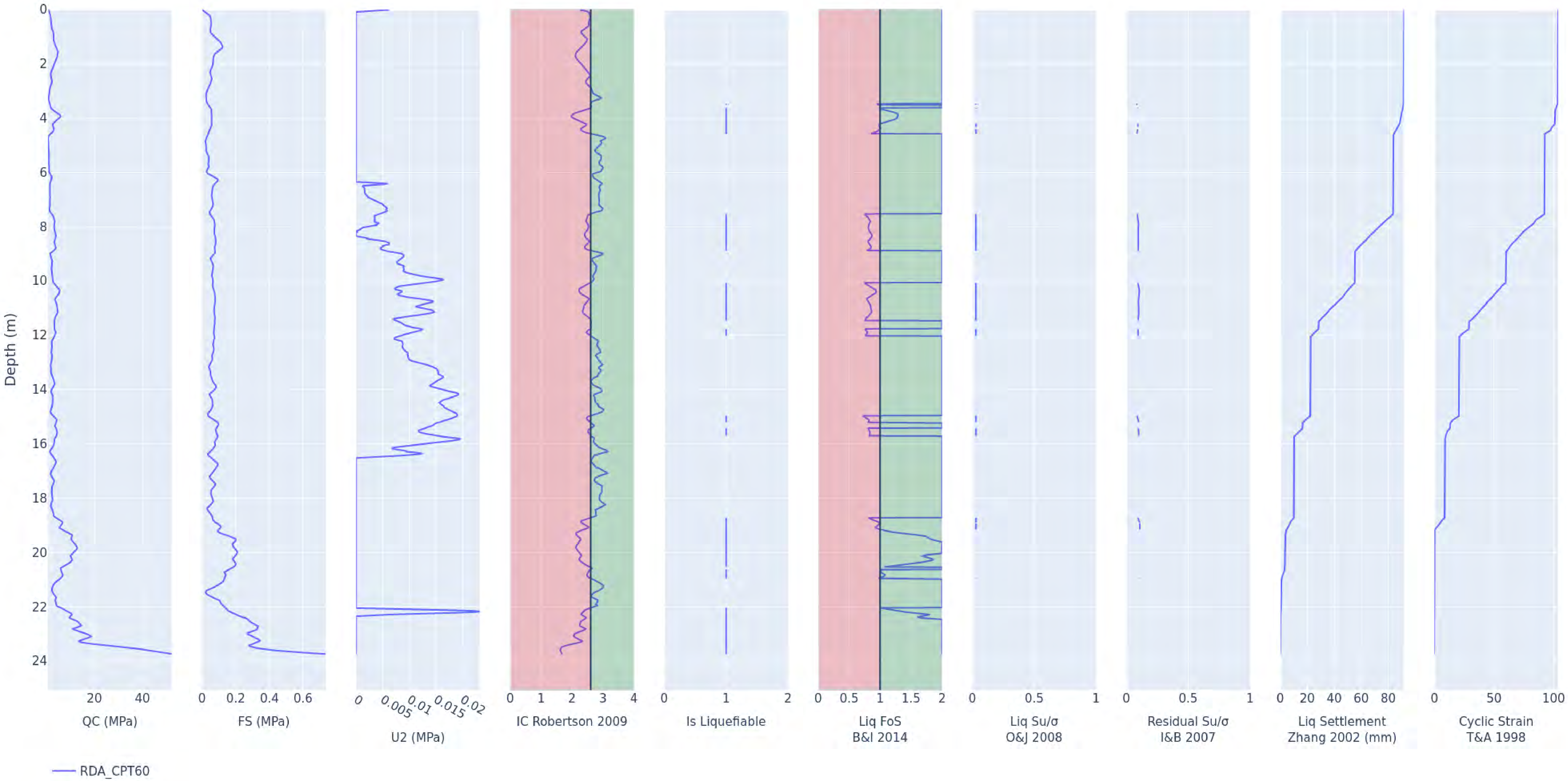
Made using data from 22-23 RDA-CPT 59-60.ags

Liquefaction Output for RDA_CPT59



Made using data from 22-23 RDA-CPT 59-60.ags

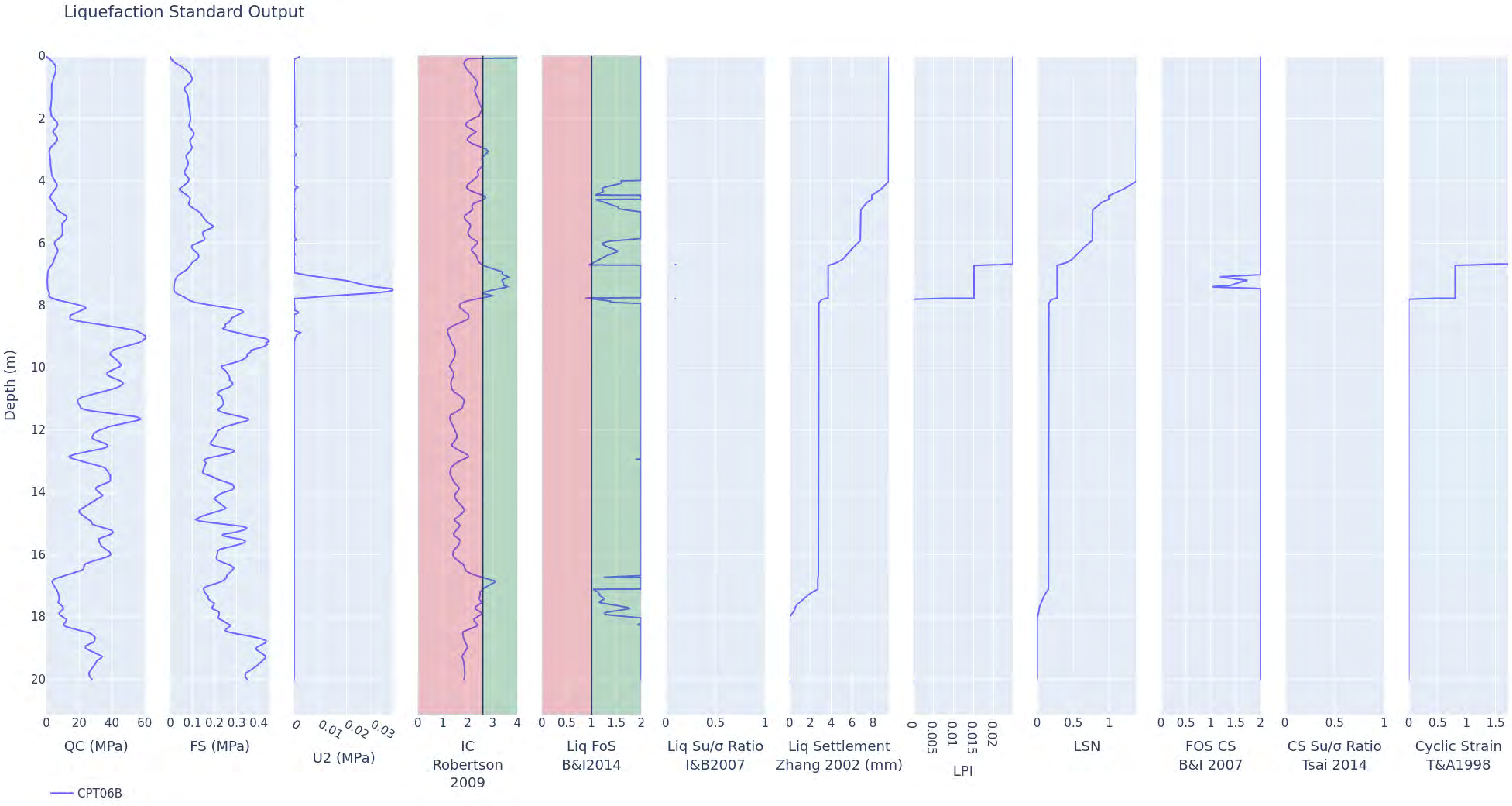
Liquefaction Output for RDA_CPT60



Made using data from 22-23 RDA-CPT 59-60.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
CPT06B	20.02	4.0	0.2	6.5	10	2	0	1

Made using data from CPT6.ags

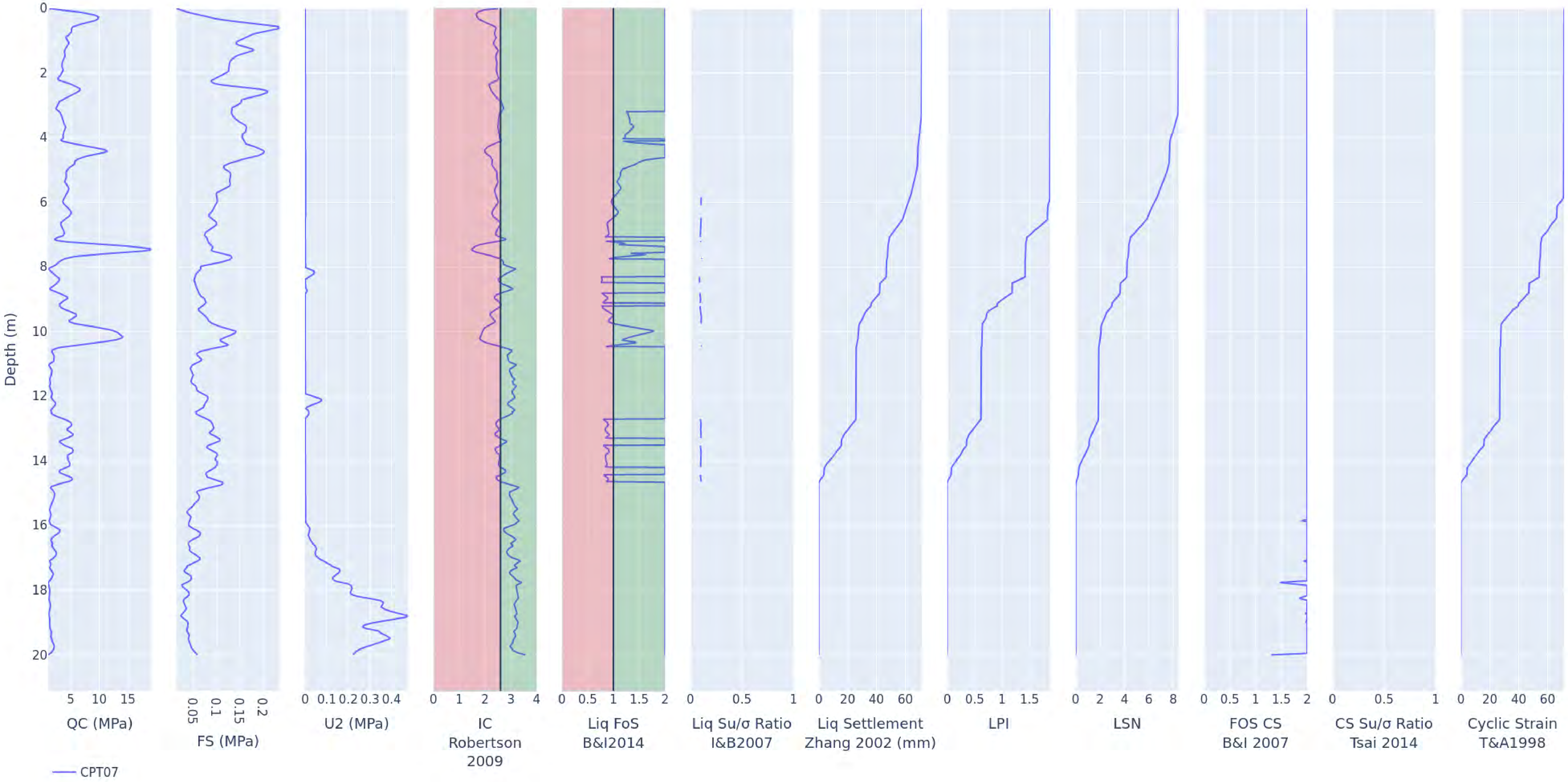


Made using data from CPT6.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
CPT07	20.0	3.0	0.2	6.5	72	71	2	8

Made using data from CPT07.ags

Liquefaction Standard Output

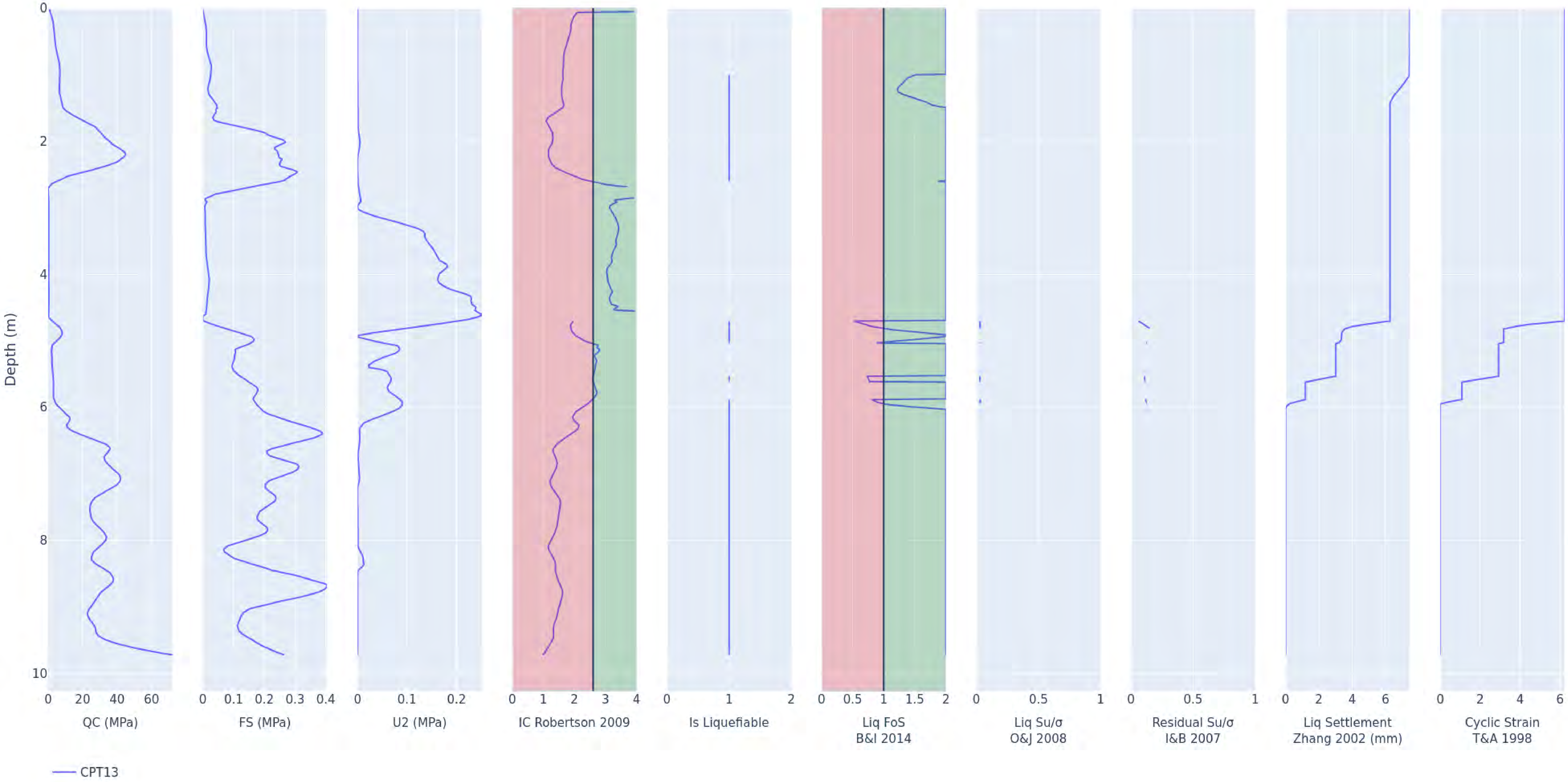


Made using data from CPT07.ags

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
CPT13	User Input	9.72	1.0	0.2	6.5	8	0	8	6	0	2	2.0

Made using data from CPT13.ags

Liquefaction Analysis



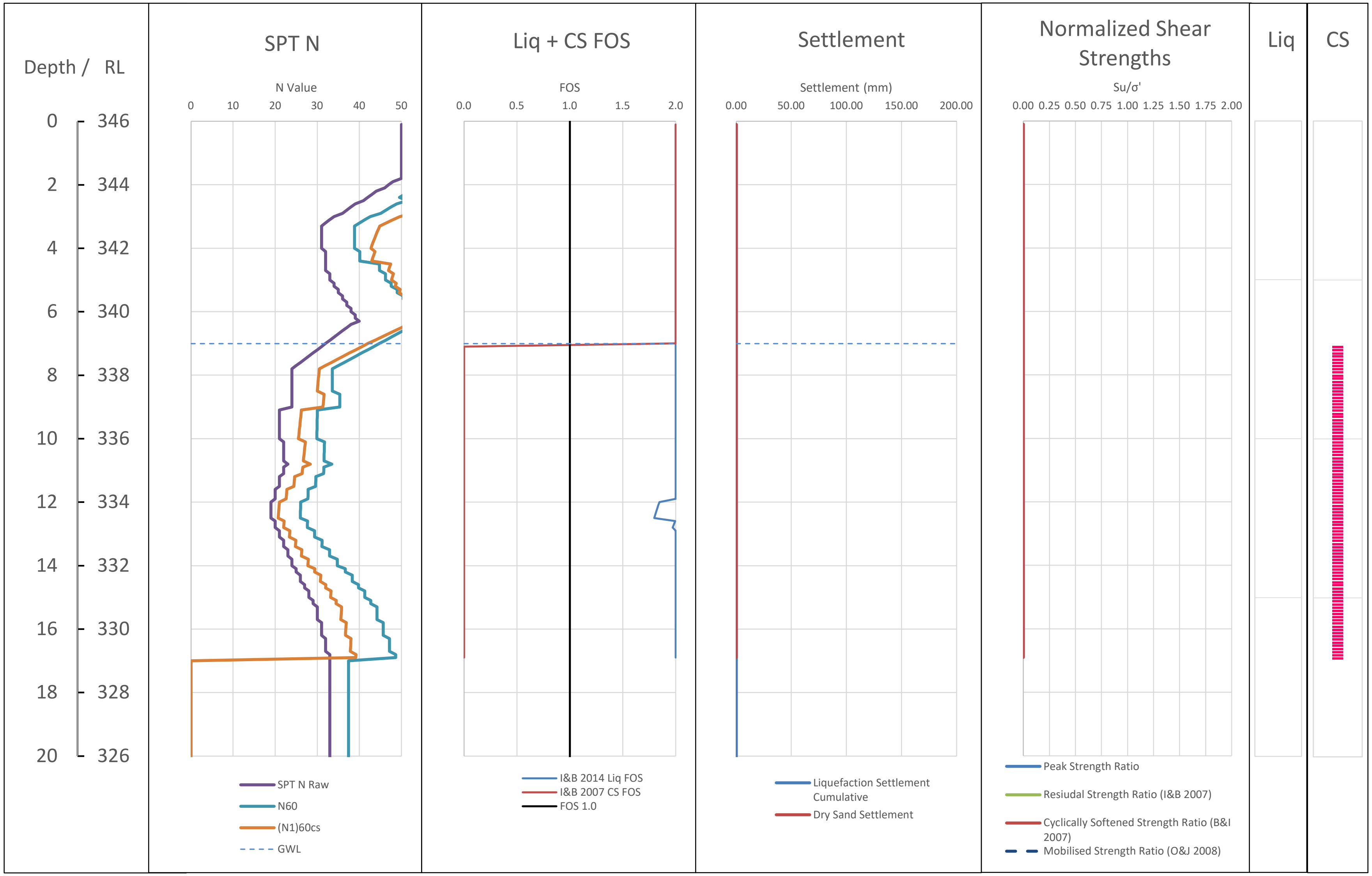
Made using data from CPT13.ags

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
BHLQ_04	User Input	17.25	7.0	0.2	6.5	0	0	0	0	0	0	0.0
BHLQ_09	User Input	12.5	7.0	0.2	6.5	0	0	0	0	0	0	0.0

Made using data from BHLQ_4-9.ags

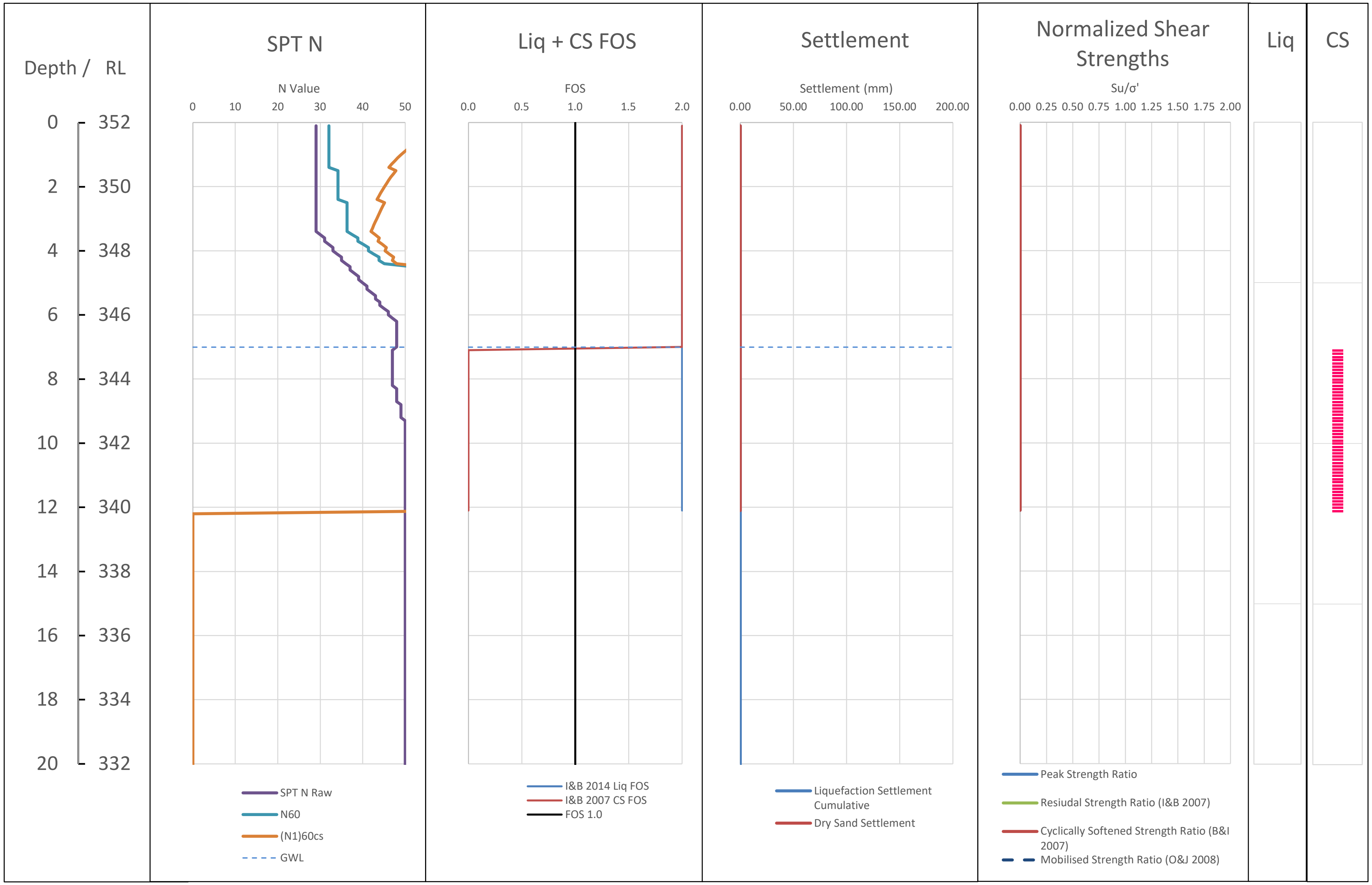
Project Summary	
Project Name	Tapuae/Southern Corri
Project Number	3161129
Unscaled PGA (g)	0.2
Magnitude	6.5
Total Settlement (mm)	0

Borehole Information	
BH ID:	BHLQ_04
BH Depth (m):	17.0
Ground Level:	346
Water Level:	7
Fill:	0



Project Summary	
Project Name	Tapuae/Southern Cor
Project Number	3161129.0
Unscaled PGA (g)	0.2
Magnitude	6.5
Total Settlement (mm)	0.00

Borehole Information	
BH ID:	BHLQ_09
BH Depth (m):	12.2
Ground Level:	352
Water Level:	7
Fill:	0

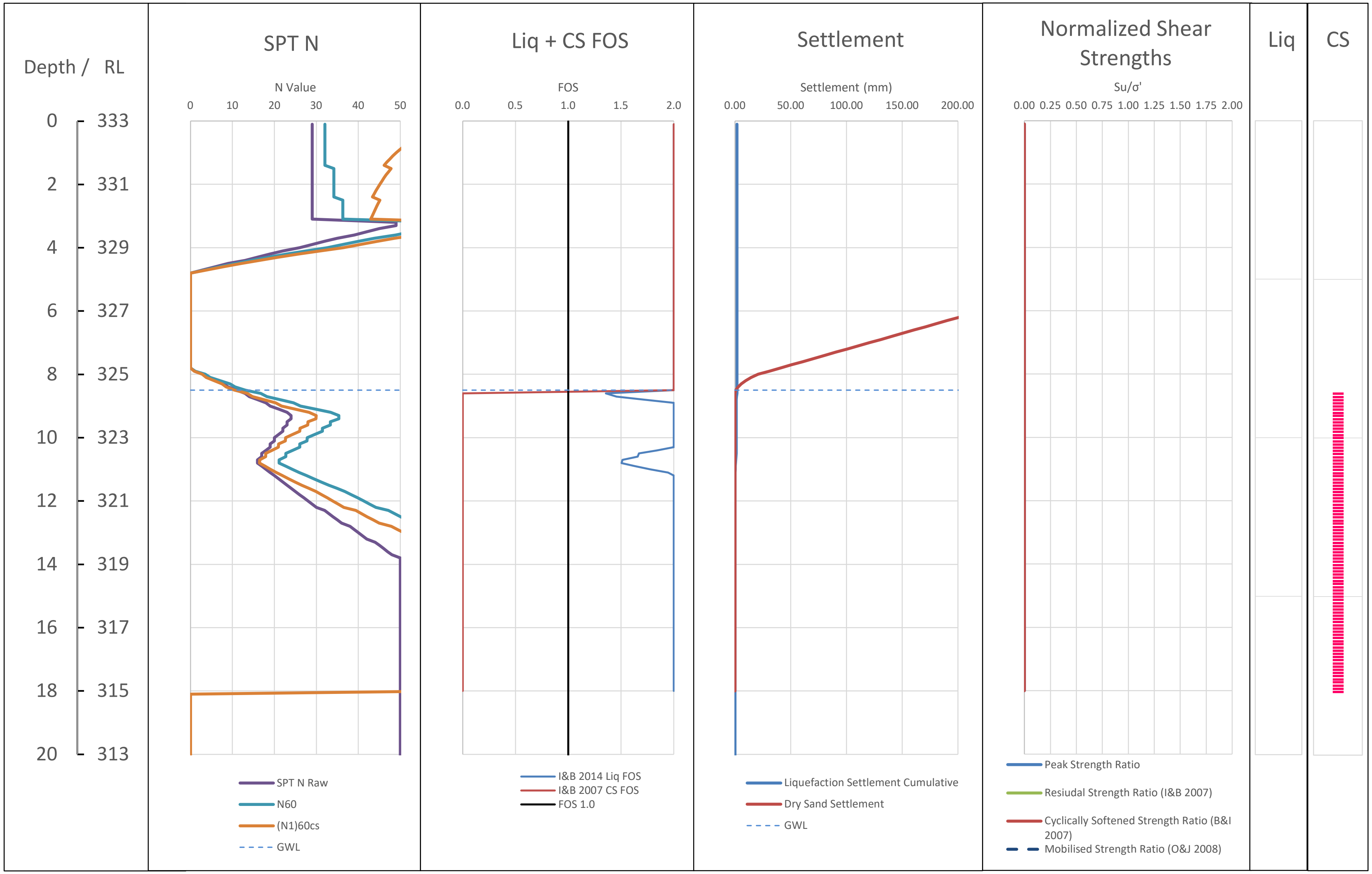


ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
BHLQ_11	User Input	18.3	8.5	0.2	6.5	2	349	351	0	0	0	3.0

Made using data from BHLQ_11.ags

Project Summary	
Project Name	Tapuae/Southern Cori
Project Number	3161129
Unscaled PGA (g)	0.2
Magnitude	6.5
Liquefaction Settlement (mm)	2

Borehole Information	
BH ID:	BHLQ_11
BH Depth (m):	18.0
Ground Level:	333
Water Level:	8.5
Fill:	0

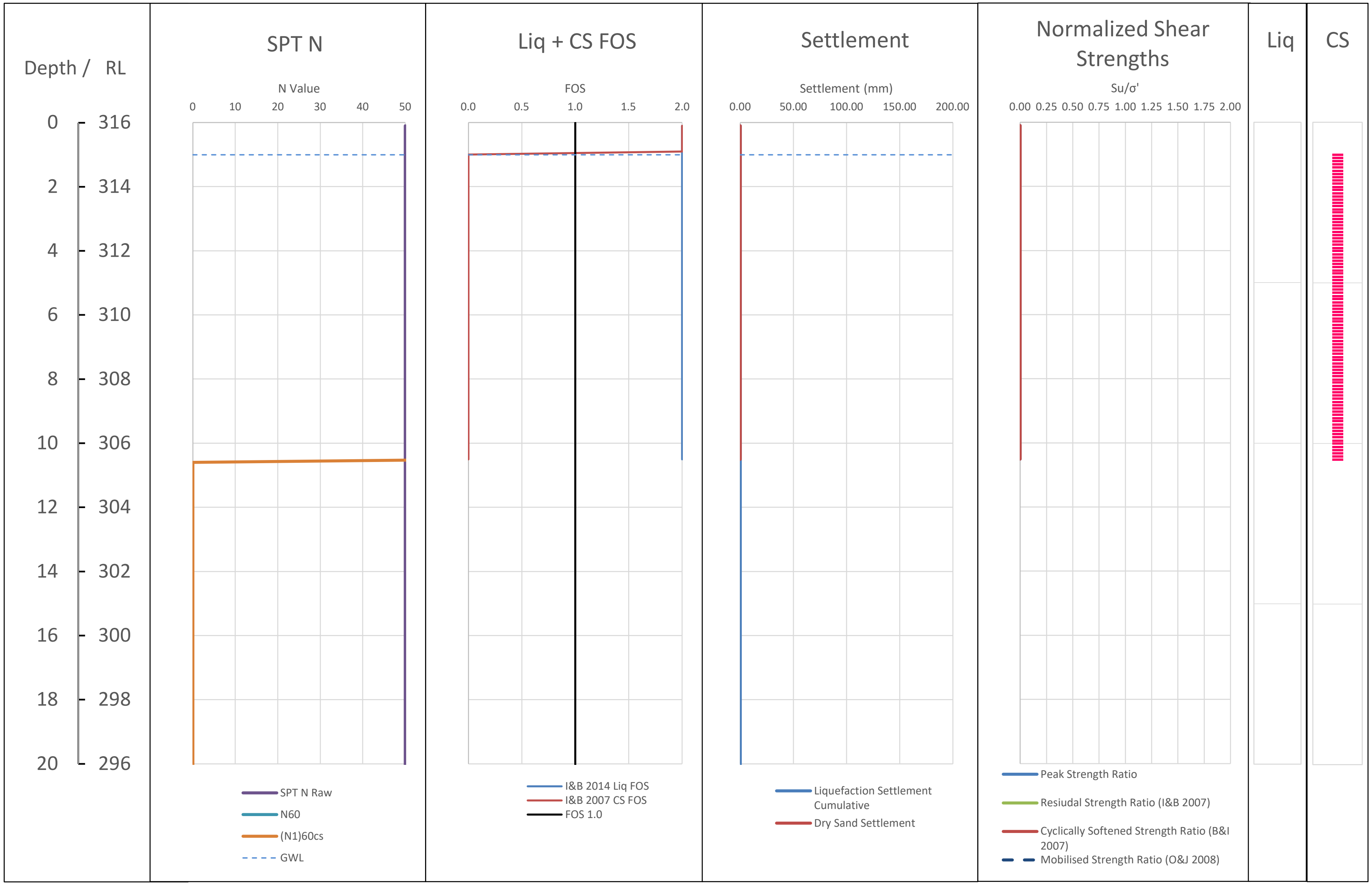


ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
BHLQ_16	User Input	10.81	1.0	0.2	6.5	0	0	0	0	0	0	0.0

Made using data from BHLQ_16.ags

Project Summary	
Project Name	Tapuae/Southern Cor
Project Number	3161129
Unscaled PGA (g)	0.2
Magnitude	6.5
Liquefaction Settlement (mm)	0.00

Borehole Information	
BH ID:	BHLQ_16
BH Depth (m):	10.5
Ground Level:	316
Water Level:	1
Fill:	0

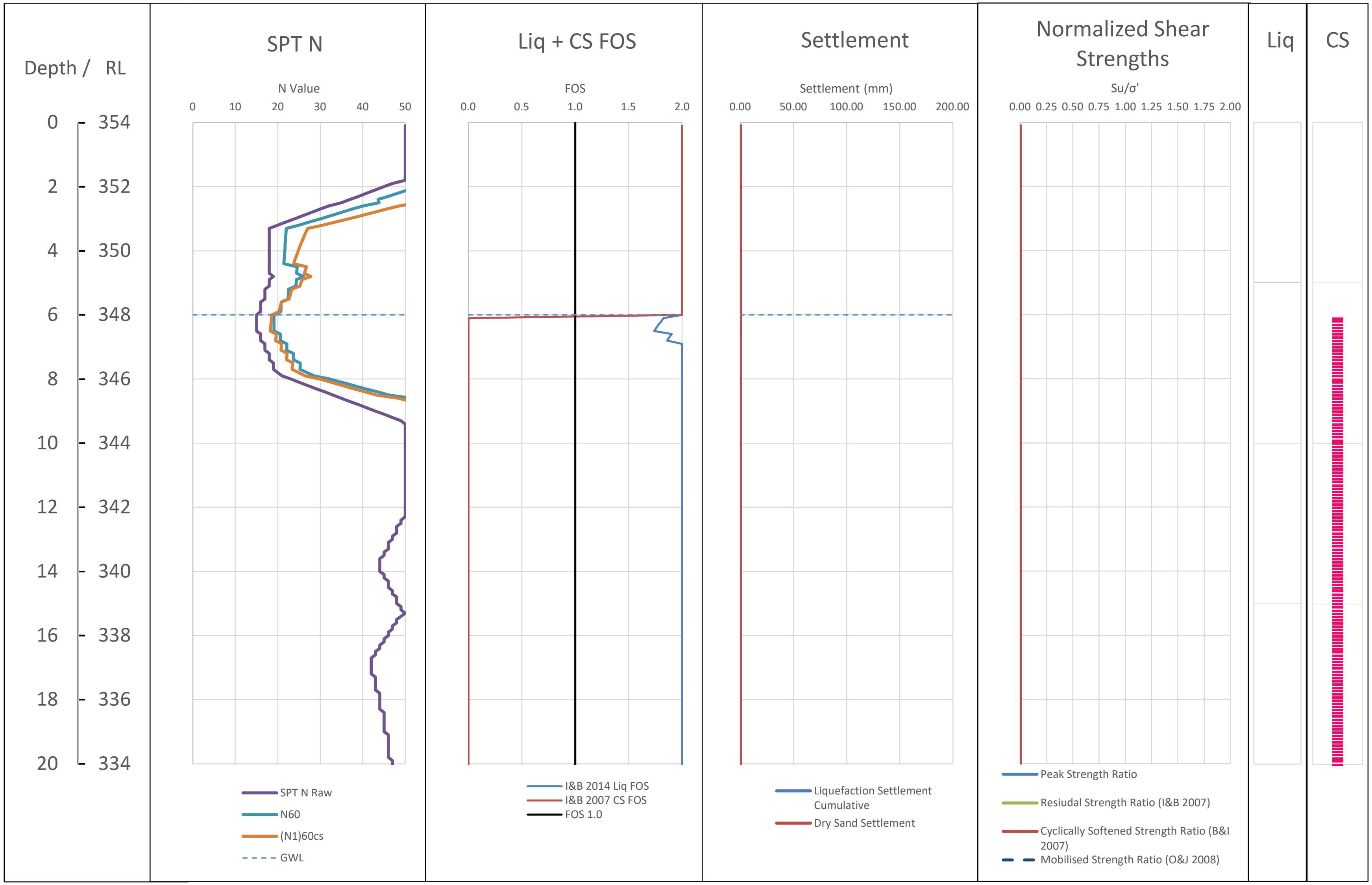


ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
BH01 Geosolve 2022	User Input	30.43	6.0	0.2	6.5	1	0	1	1	0	2	0

Made using data from BH01 Geosolve 2022.ags

Project Summary	
Project Name	Tapuae/Southern Cor
Project Number	3161129
Unscaled PGA (g)	0.2
Magnitude	6.5
Liquefaction Settlement (mm)	1

Borehole Information	
BH ID:	solve 2022
BH Depth (m):	30.1
Ground Level:	354
Water Level:	6
Fill:	0

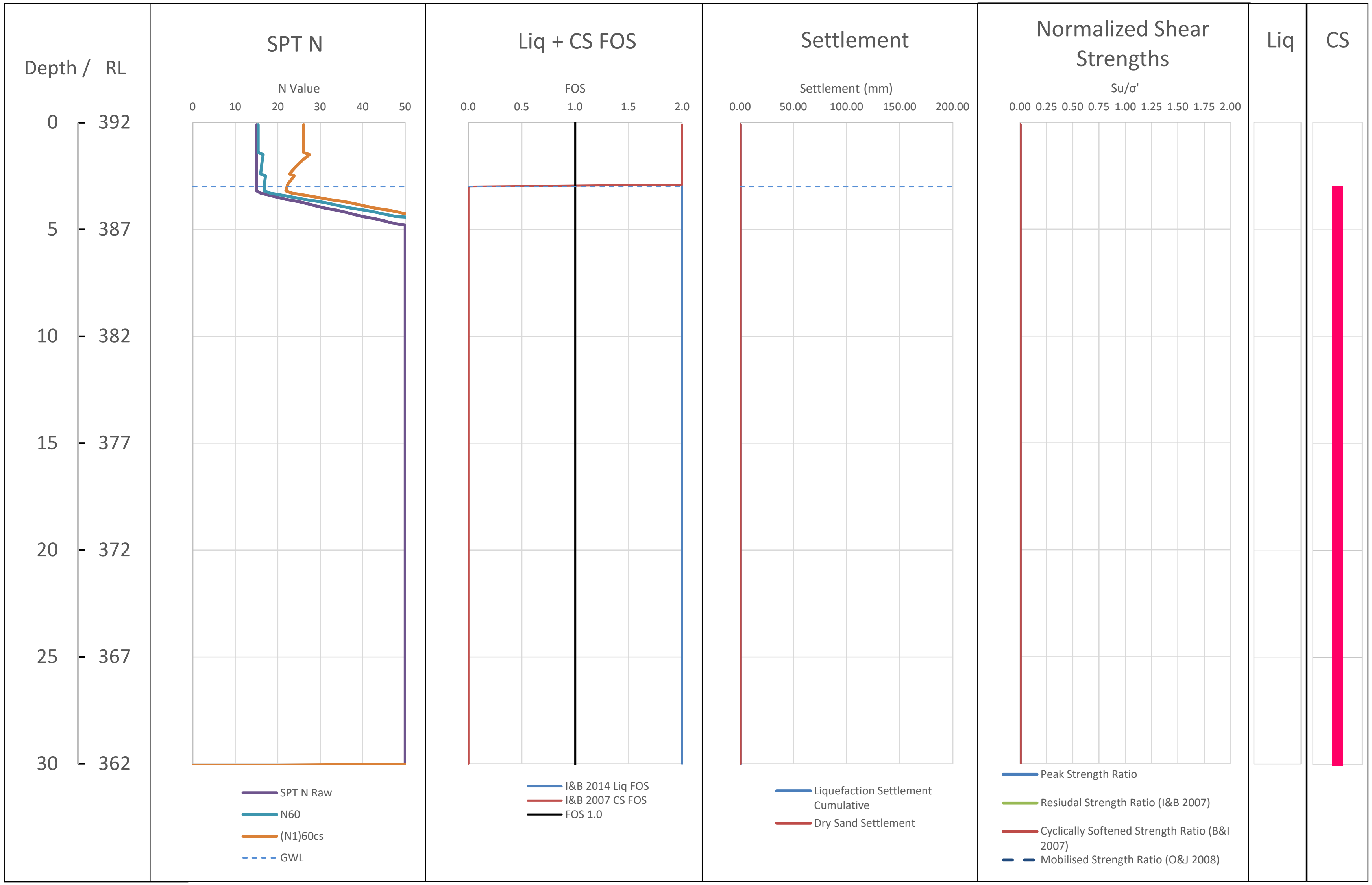


ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
BH02 Geosolve 2022	User Input	30.3	3.0	0.2	6.5	0	0	0	0	0	0	0.0

Made using data from BH02 Geosolve 2022.ags

Project Summary	
Project Name	Tapuae/Southern Cor
Project Number	3161129
Unscaled PGA (g)	0.2
Magnitude	6.5
Liquefaction Settlement (mm)	0

Borehole Information	
BH ID:	solve 2022
BH Depth (m):	30.0
Ground Level:	392
Water Level:	3
Fill:	0

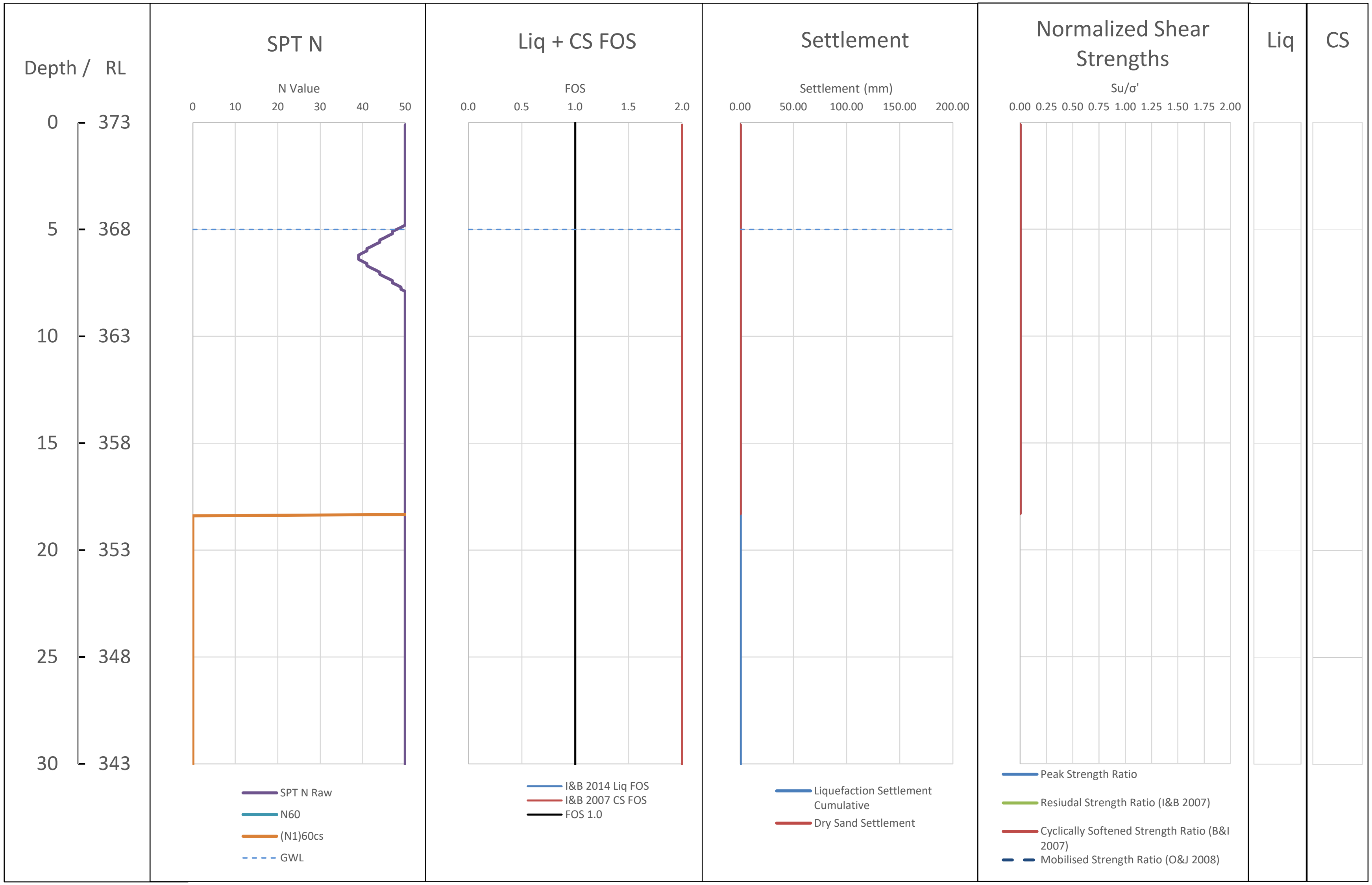


ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
BH03 Geosolve 2024	User Input	20.11	5.0	0.2	6.5	0	0	0	0	0	0	0.0

Made using data from BH03 Geosolve 2024-1.ags

Project Summary	
Project Name	Tapuae/Southern Cori
Project Number	3161129.0
Unscaled PGA (g)	0.2
Magnitude	6.5
Liquefaction Settlement (mm)	0.00

Borehole Information	
BH ID:	solve 2024
BH Depth (m):	18.3
Ground Level:	373
Water Level:	5
Fill:	0

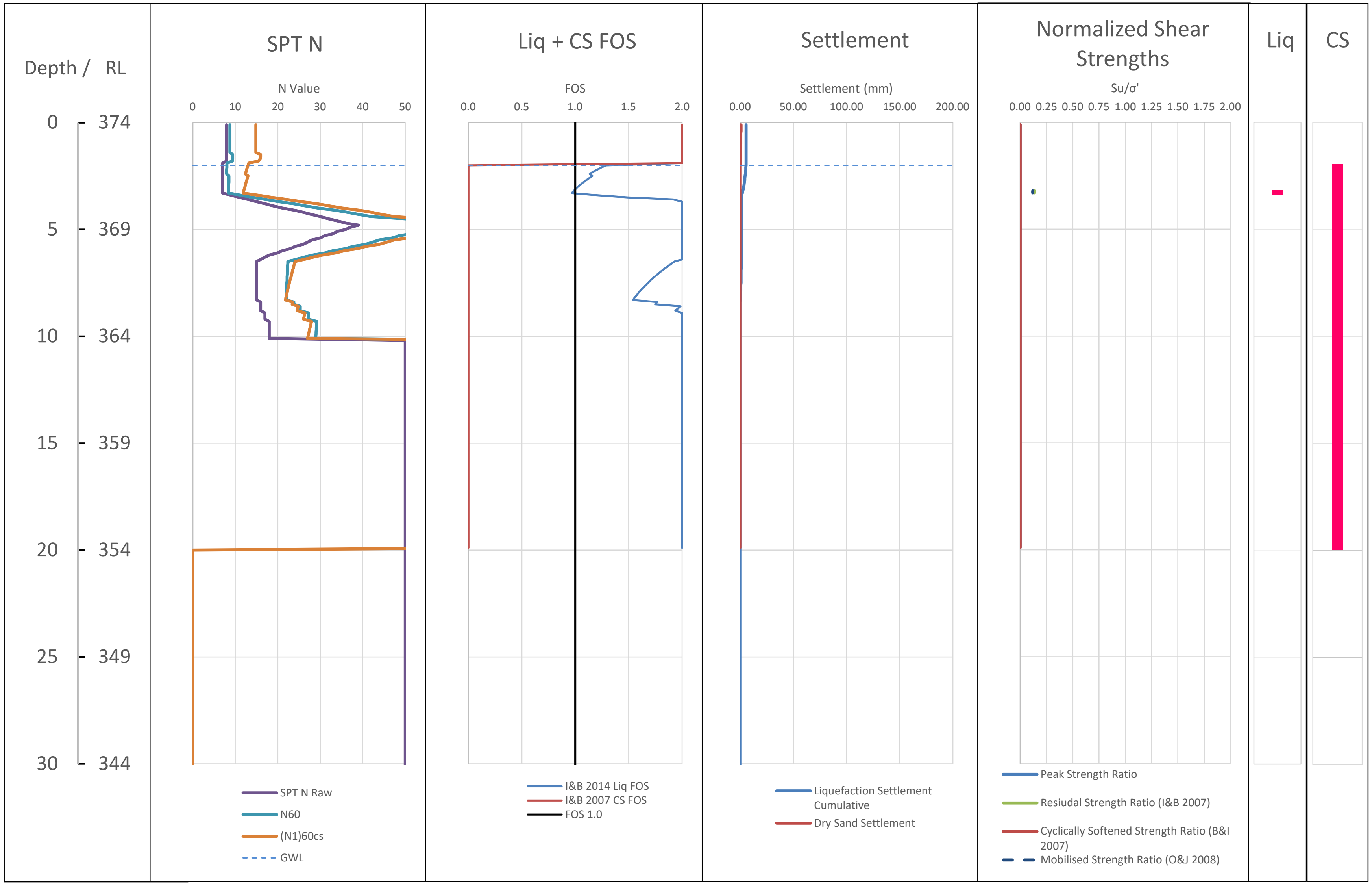


ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
BH01 Geosolve 2024	User Input	20.25	2.0	0.2	6.5	5	0	5	4	1	4	0.0

Made using data from BH01 Geosolve 2024 -1.ags

Project Summary	
Project Name	Tapuae/Southern Cor
Project Number	3161129
Unscaled PGA (g)	0.2
Magnitude	6.5
Liquefaction Settlement (mm)	5

Borehole Information	
BH ID:	solve 2024
BH Depth (m):	20.0
Ground Level:	374
Water Level:	2
Fill:	0



Liquefaction Assessment Result

Earthquake Return Period = 500-year

Earthquake Magnitude (Mw) = 6.5

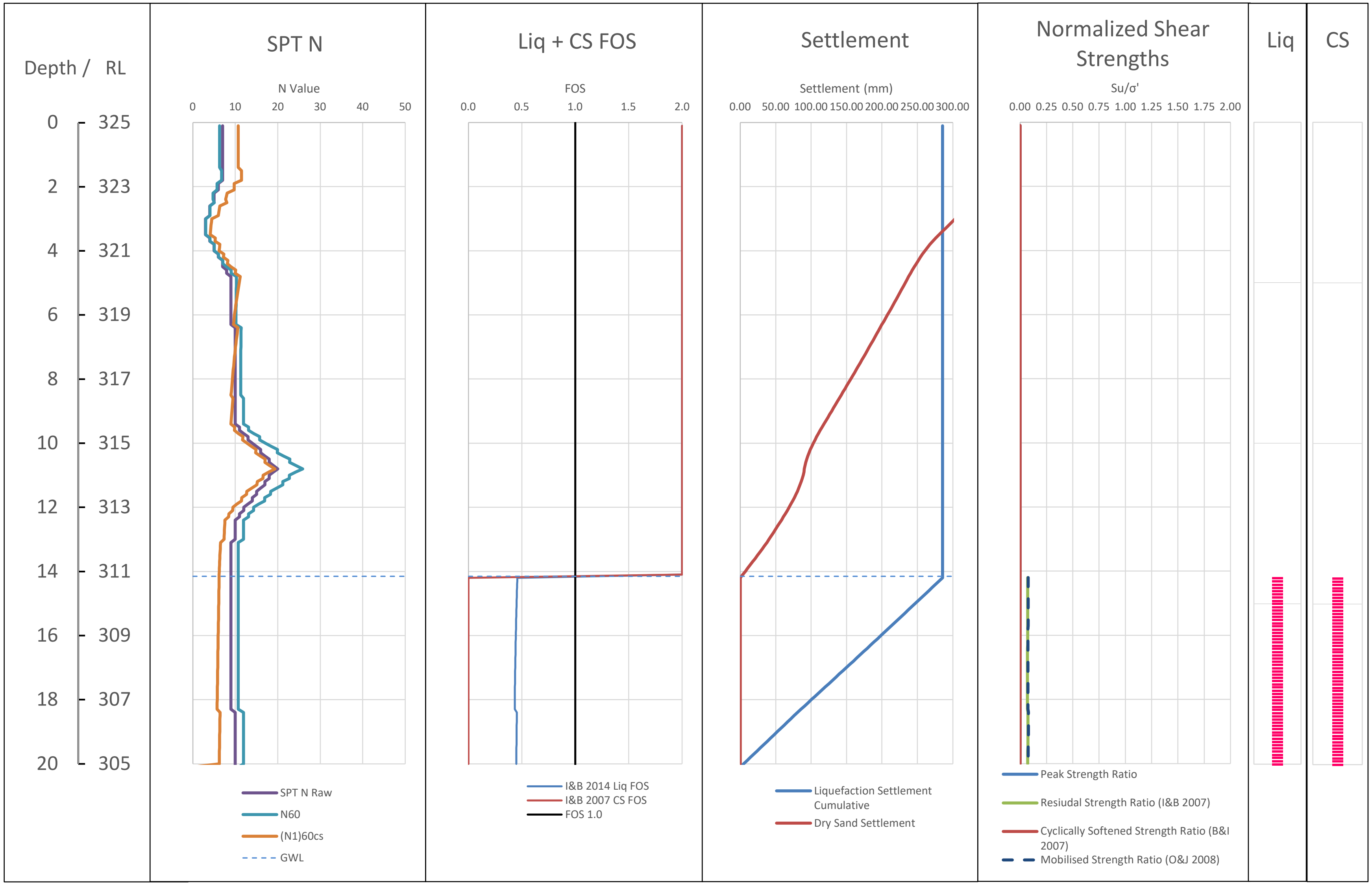
Peak Ground Acceleration (g) = 0.41

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
22BH01	User Input	48.75	14.15	0.41	6.5	285	381	666	236	3	42	1029.0

Made using data from 22BH01.ags

Project Summary	
Project Name	Tapuae/Southern Cor
Project Number	3161129
Unscaled PGA (g)	0.41
Magnitude	6.5
Liquefaction Settlement (mm)	285

Borehole Information	
BH ID:	22BH01
BH Depth (m):	20.0
Ground Level:	325
Water Level:	14.15
Fill:	0

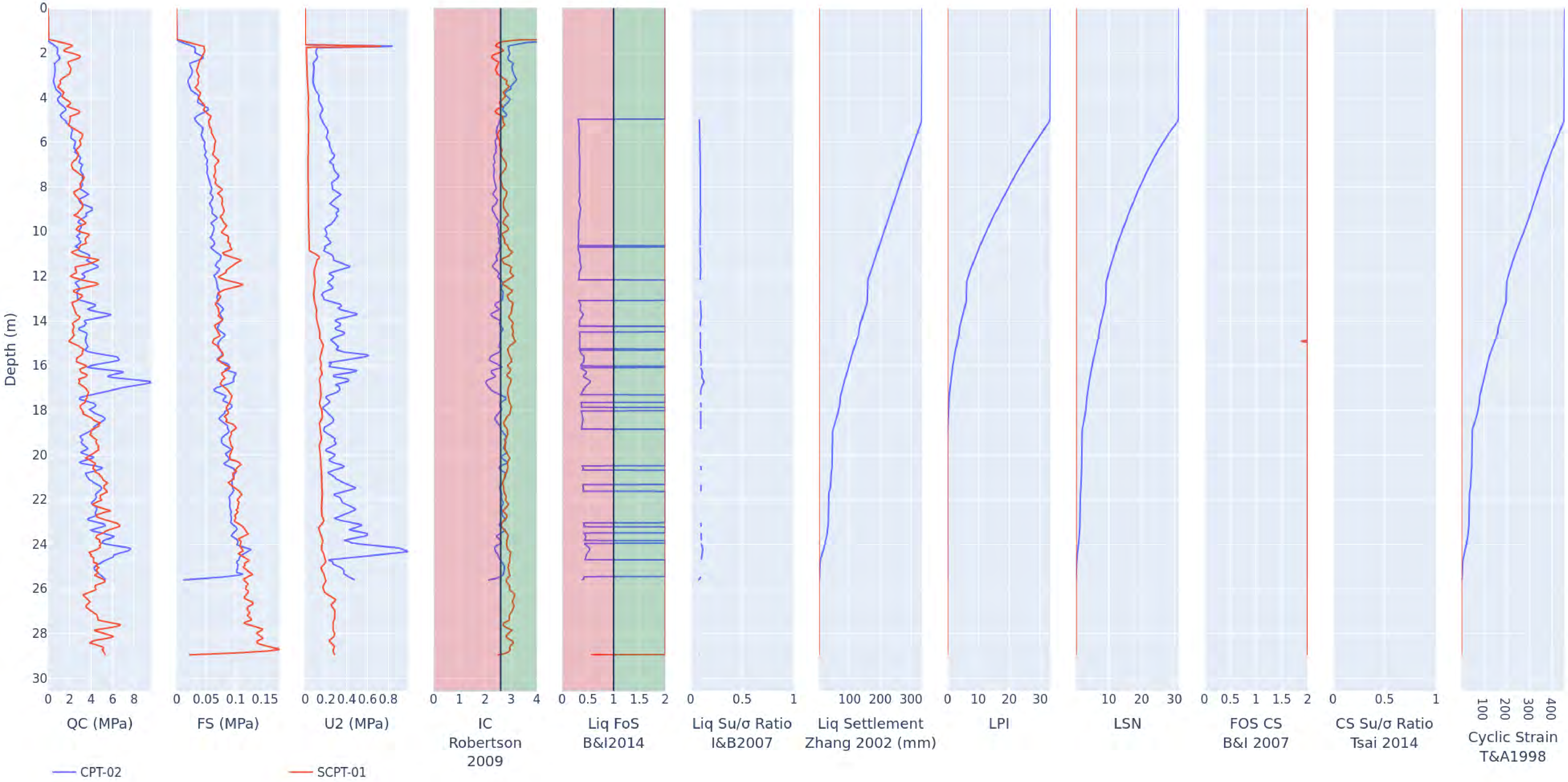


Beca SPT Seismic Analysis Spreadsheet v53

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
CPT-02	25.59	1.6	0.41	6.5	337	455	33	31
SCPT-01	28.95	13.0	0.41	6.5	1	1	0	0

Made using data from CPTs.ags

Liquefaction Standard Output

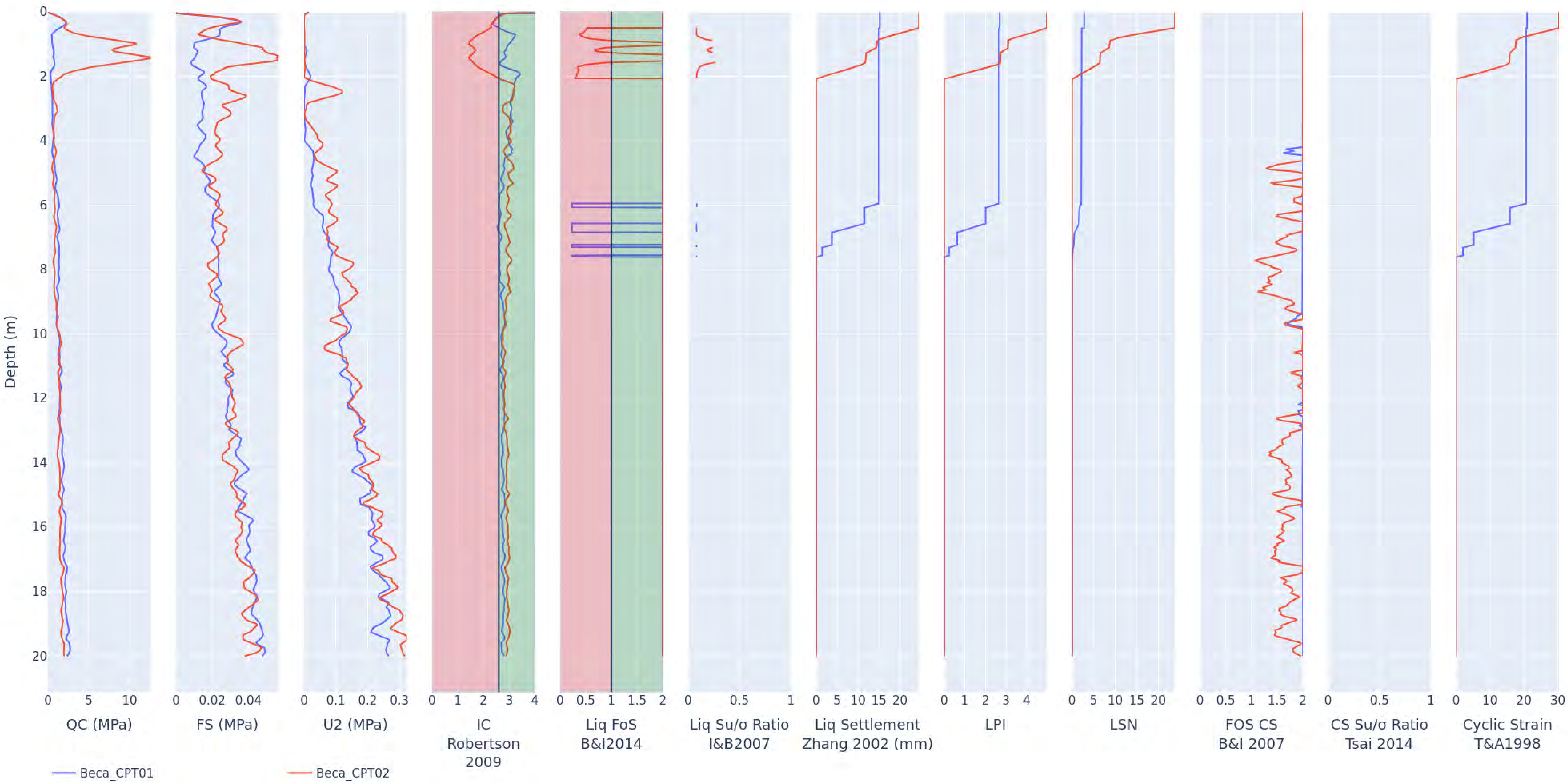


Made using data from CPTs.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
Beca_CPT01	20.0	0.5	0.41	6.5	15	21	3	3
Beca_CPT02	20.0	0.5	0.41	6.5	25	30	5	24

Made using data from Beca CPT - 2023.ags

Liquefaction Standard Output

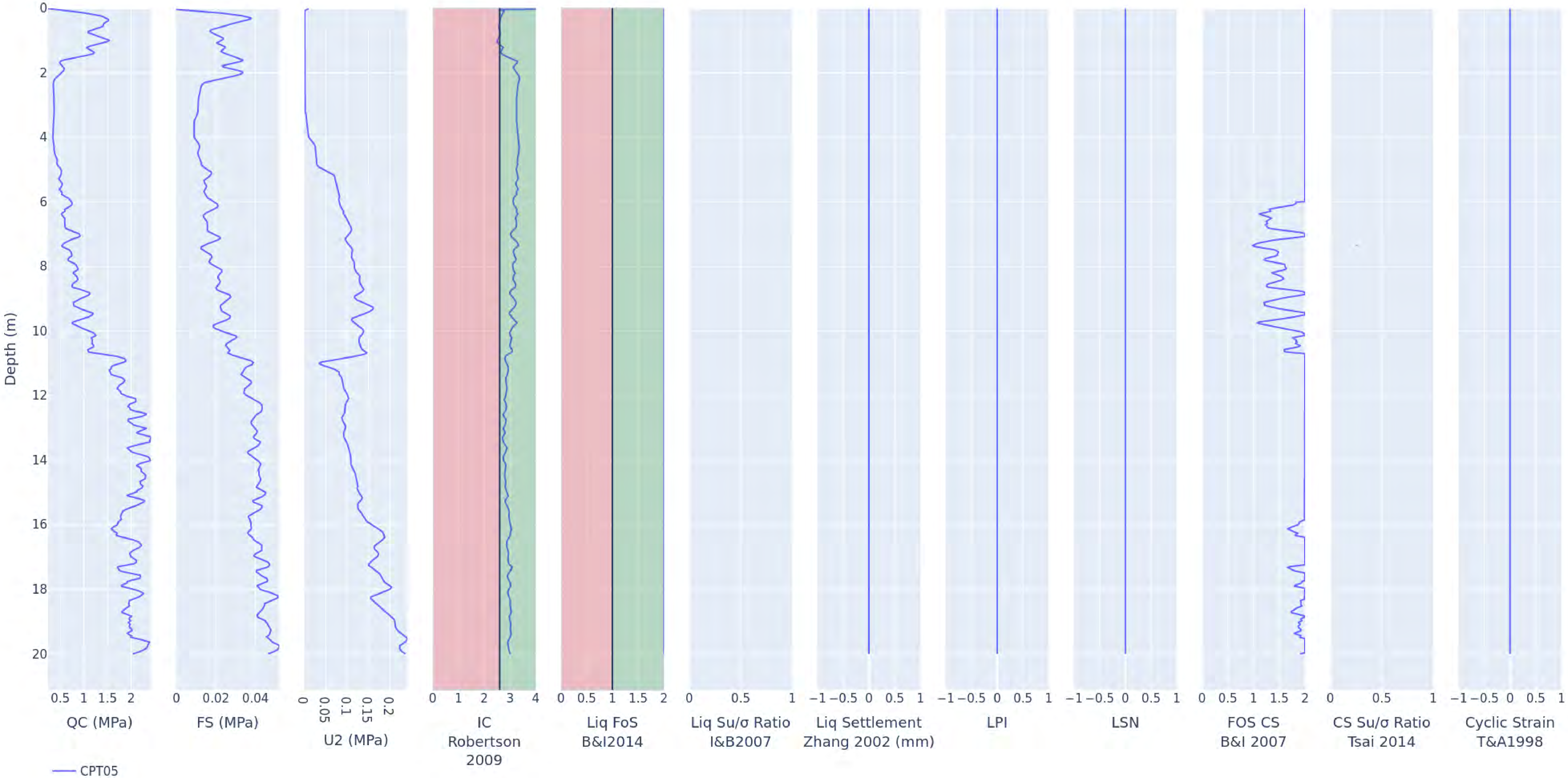


Made using data from Beca CPT - 2023.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
CPT05	20.0	6.0	0.41	6.5	0	0	0	0

Made using data from CPT05.ags

Liquefaction Standard Output

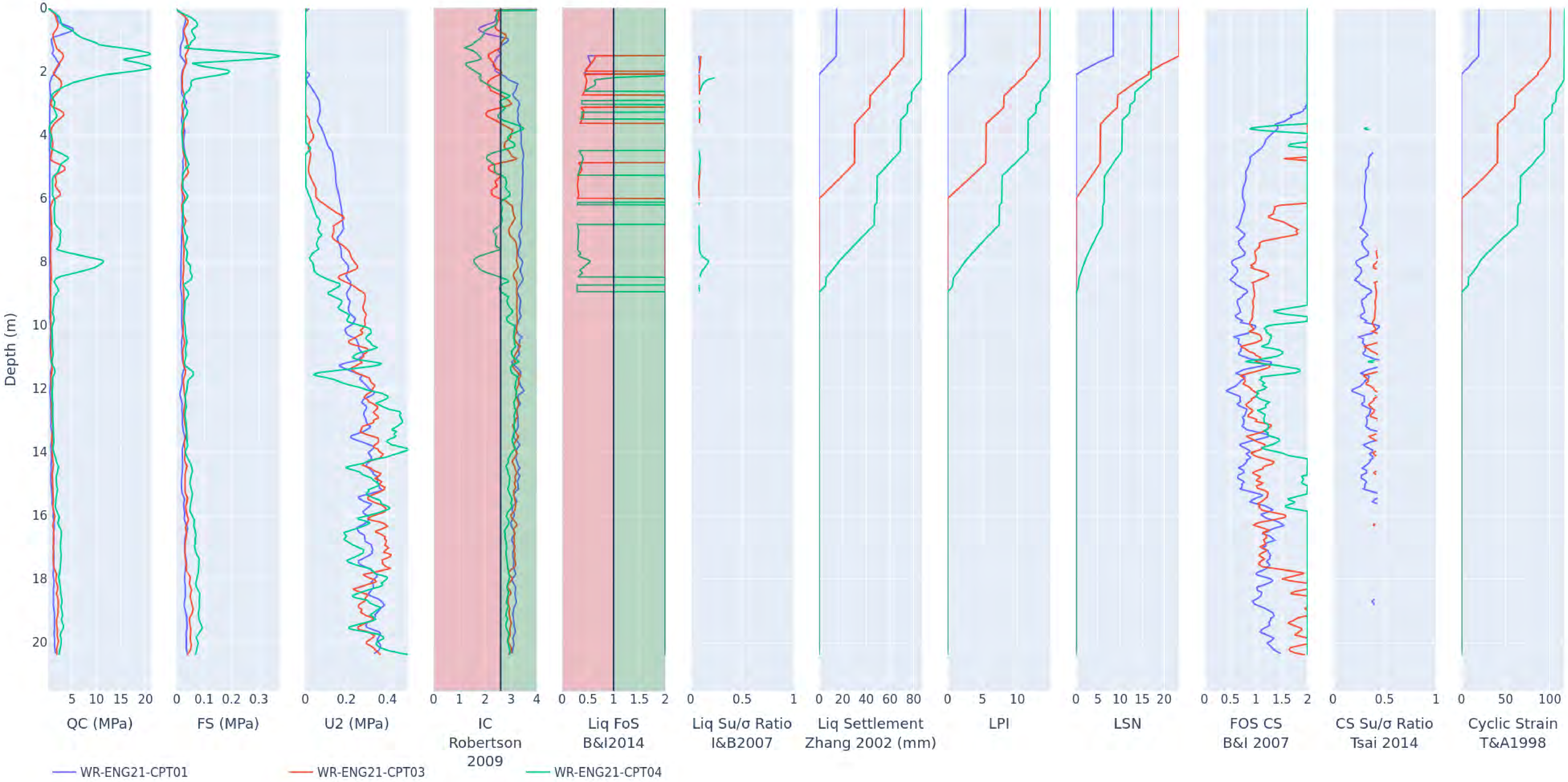


Made using data from CPT05.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
WR-ENG21-CPT01	20.35	1.5	0.41	6.5	15	20	3	8
WR-ENG21-CPT03	20.39	1.5	0.41	6.5	72	101	13	23
WR-ENG21-CPT04	20.38	1.5	0.41	6.5	87	117	15	17

Made using data from WR-ENG21-CPT01-03-04.ags

Liquefaction Standard Output

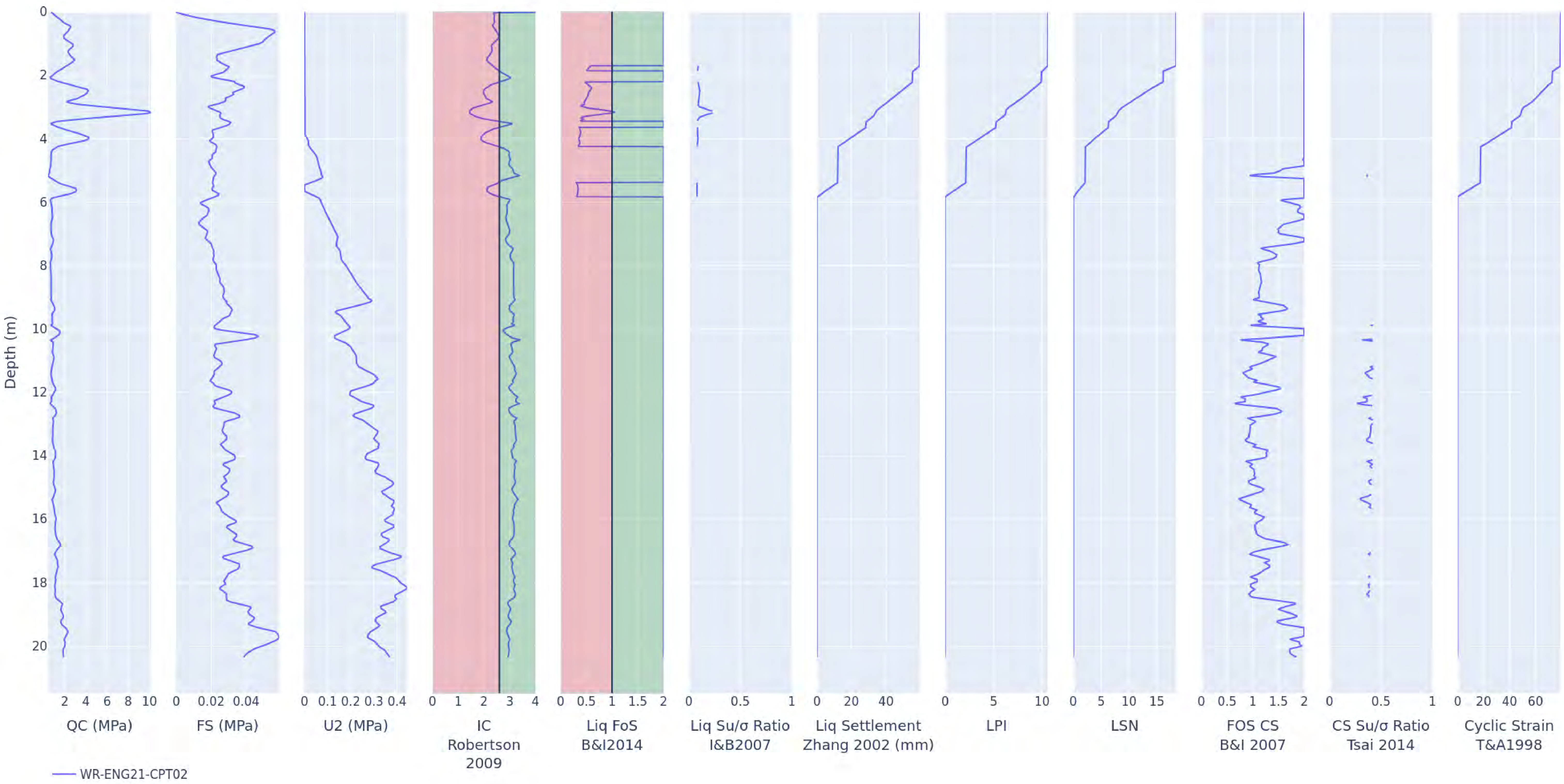


Made using data from WR-ENG21-CPT01-03-04.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
WR-ENG21-CPT02	20.35	1.7	0.41	6.5	60	79	11	18

Made using data from WR-ENG21-CPT02.ags

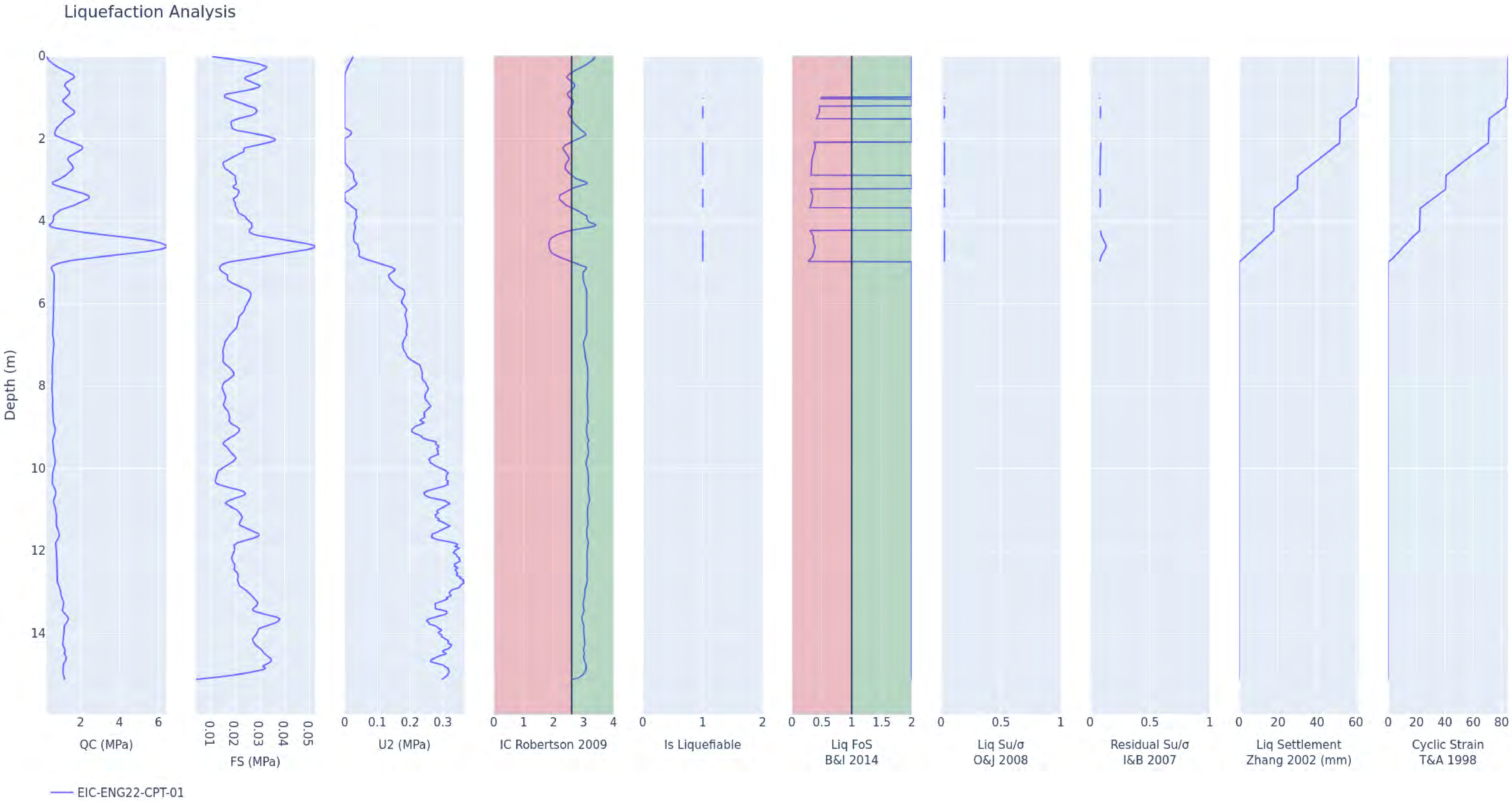
Liquefaction Standard Output



Made using data from WR-ENG21-CPT02.ags

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
EIC-ENG22-CPT-01	User Input	15.12	1.0	0.41	6.5	62	0	62	84	13	24	54.0

Made using data from 10 EIC-ENG22-CPT-01.ags

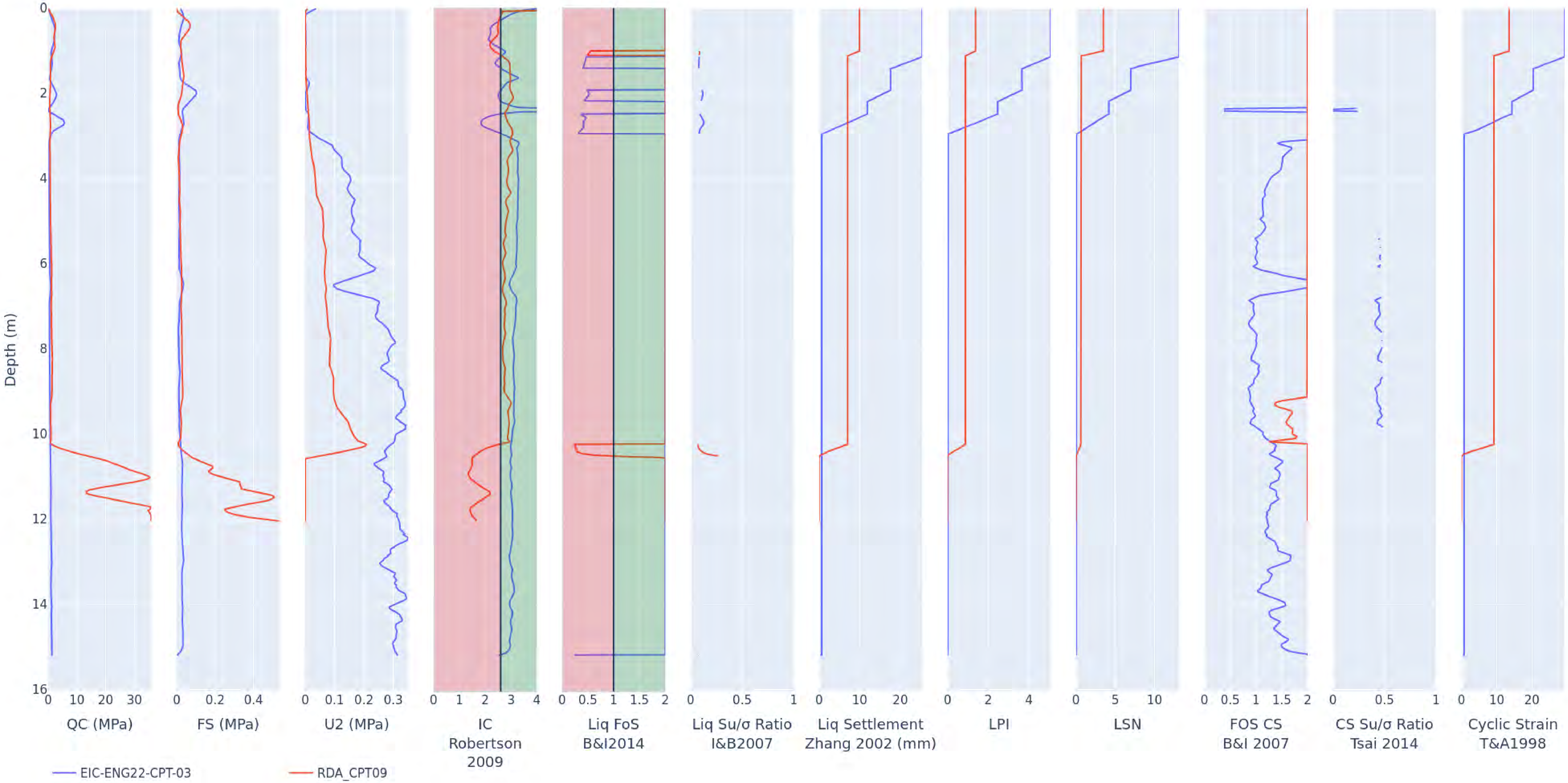


Made using data from 10 EIC-ENG22-CPT-01.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
EIC-ENG22-CPT-03	15.2	1.0	0.41	6.5	25	29	5	13
RDA_CPT09	12.04	1.0	0.41	6.5	10	14	1	3

Made using data from RDA CPT - 09 - EIC-ENG22-CPT-03.ags

Liquefaction Standard Output

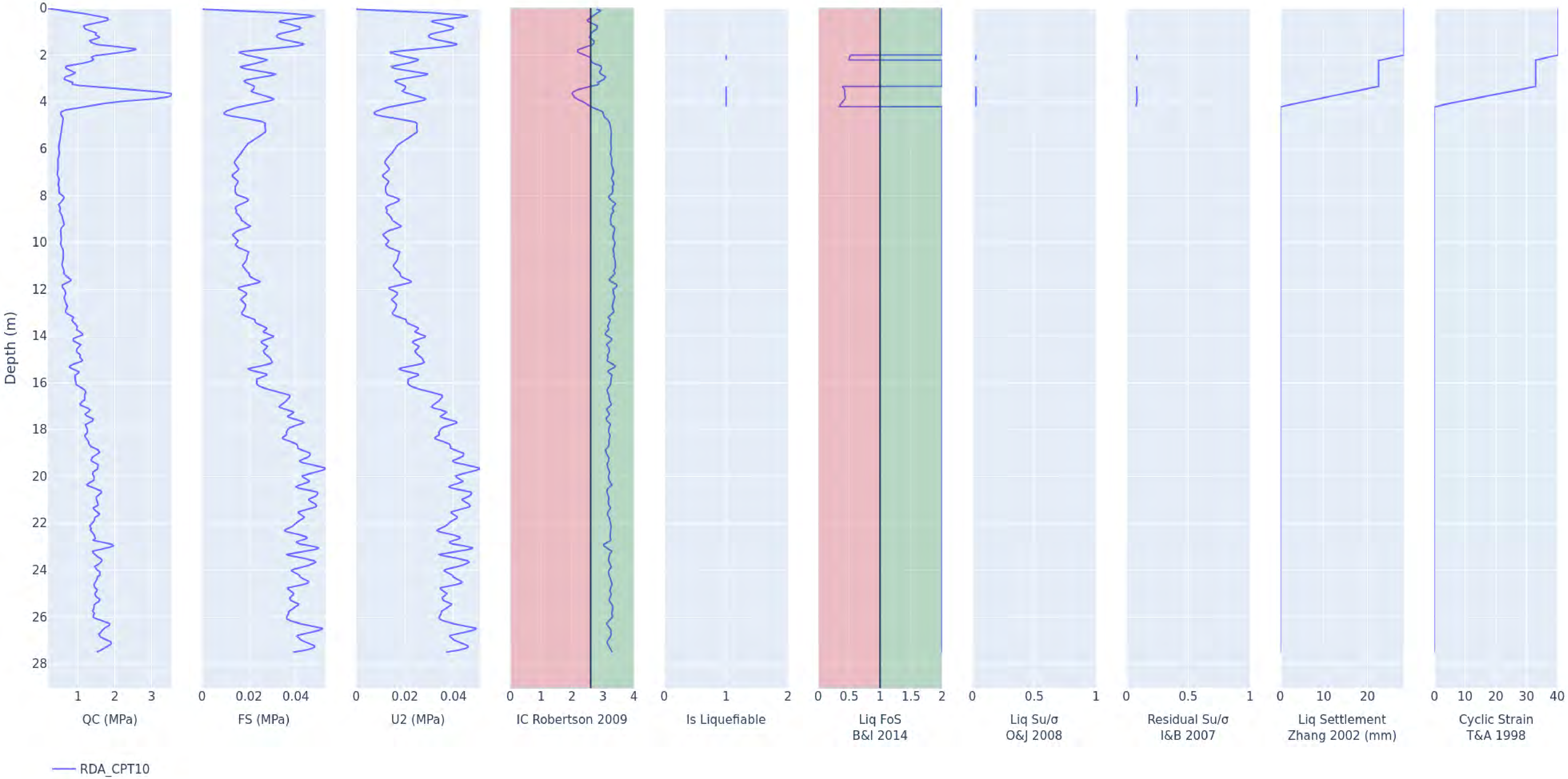


Made using data from RDA CPT - 09 - EIC-ENG22-CPT-03.ags

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
RDA_CPT10	User Input	27.5	2.0	0.41	6.5	29	0	29	40	5	9	28.0

Made using data from 13 RDA - CPT10.ags

Liquefaction Analysis

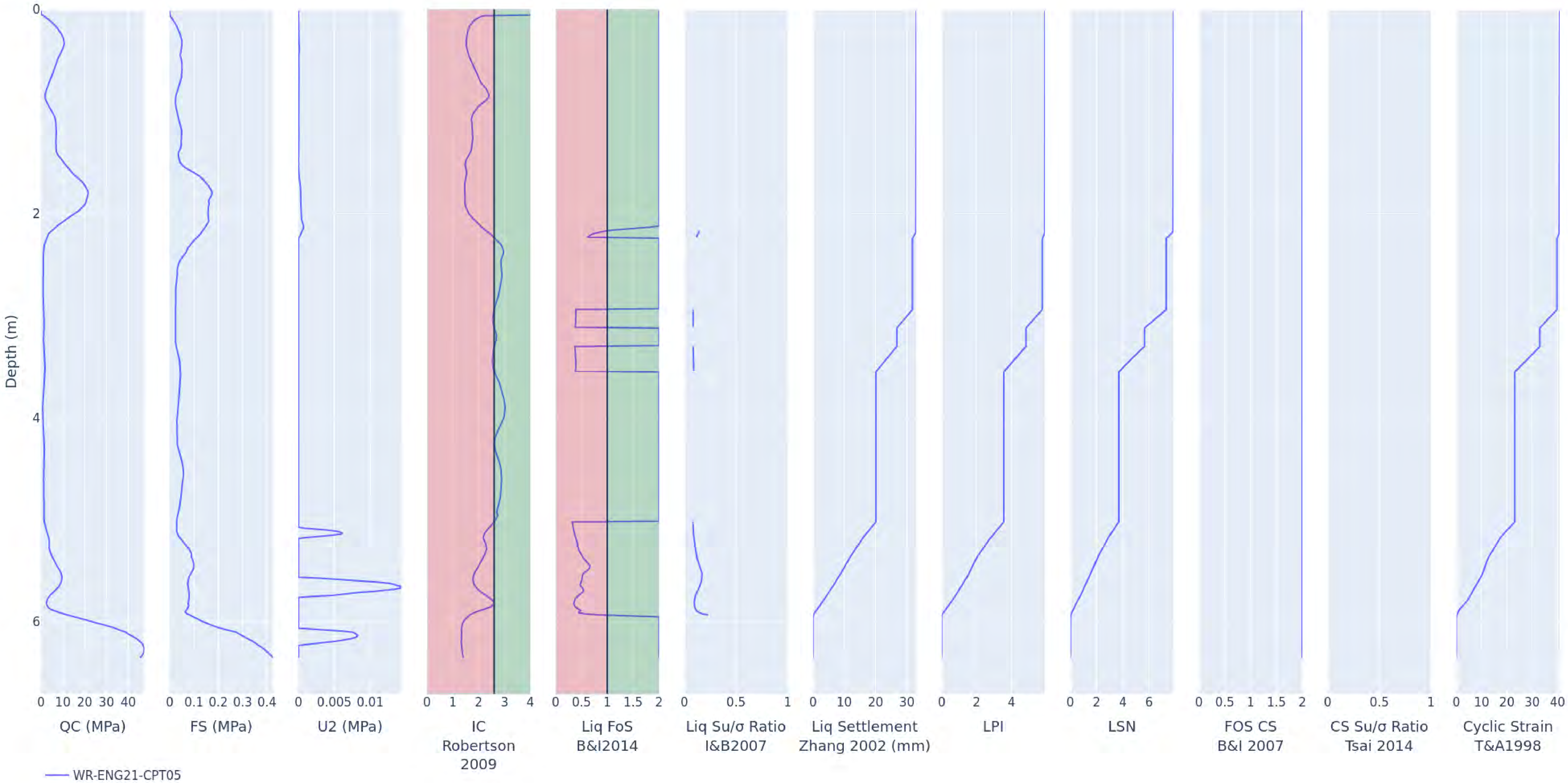


Made using data from 13 RDA - CPT10.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
WR-ENG21-CPT05	6.35	1.6	0.41	6.5	33	41	6	8

Made using data from WR-ENG21-CPT05.ags

Liquefaction Standard Output

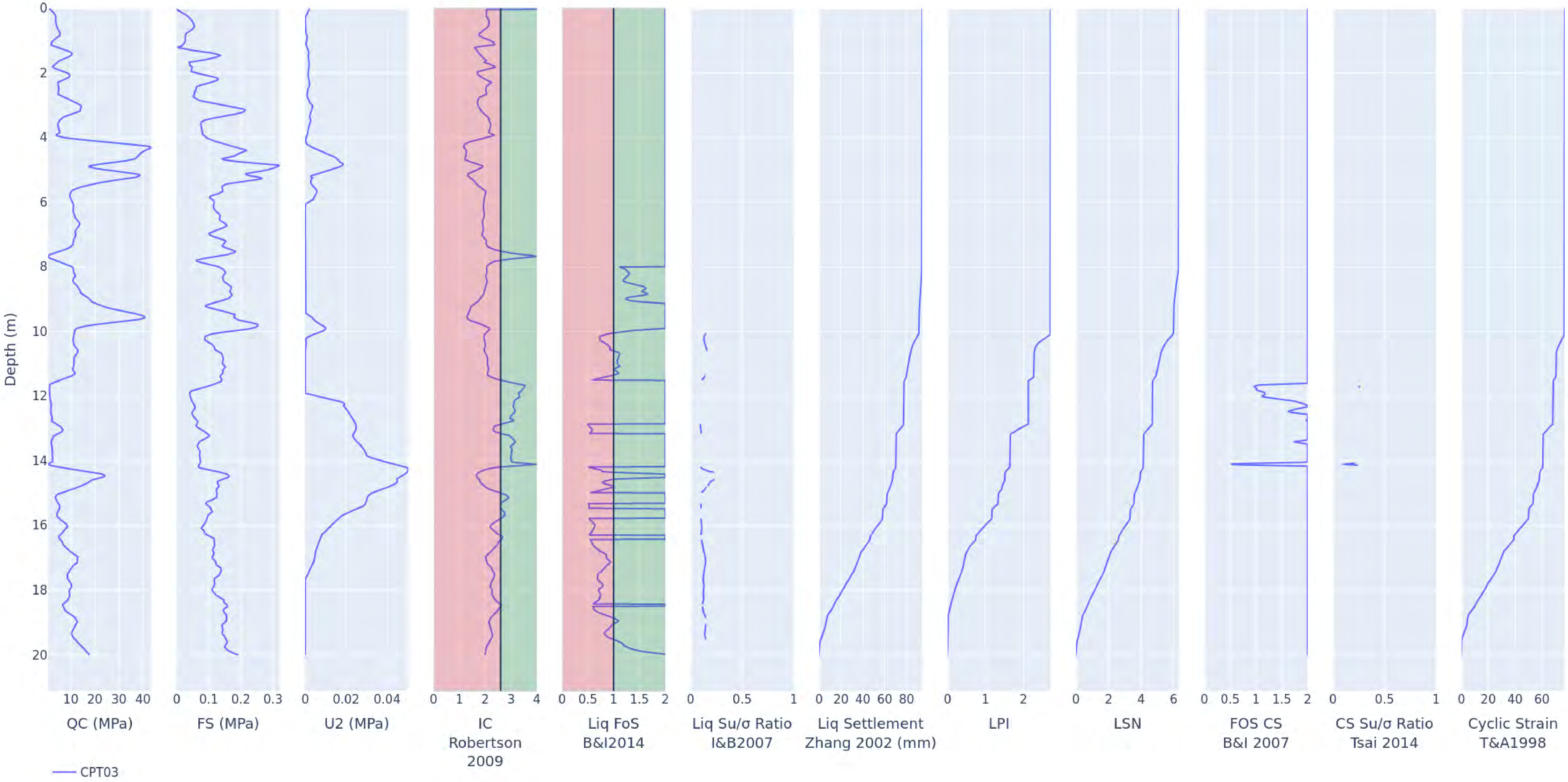


Made using data from WR-ENG21-CPT05.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
CPT03	20.0	8.0	0.41	6.5	94	77	3	6

Made using data from CPT03.ags

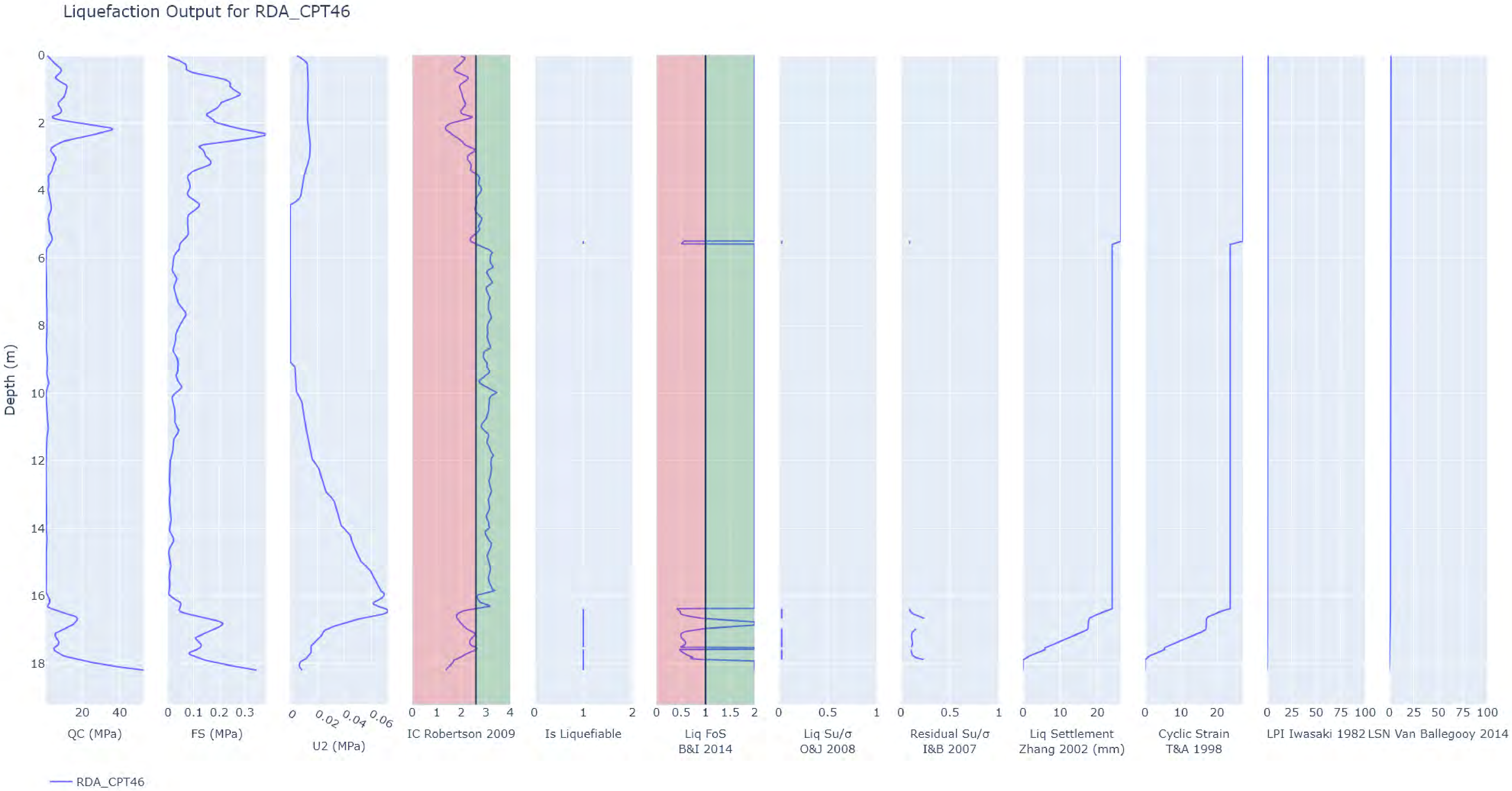
Liquefaction Standard Output



Made using data from CPT03.ags

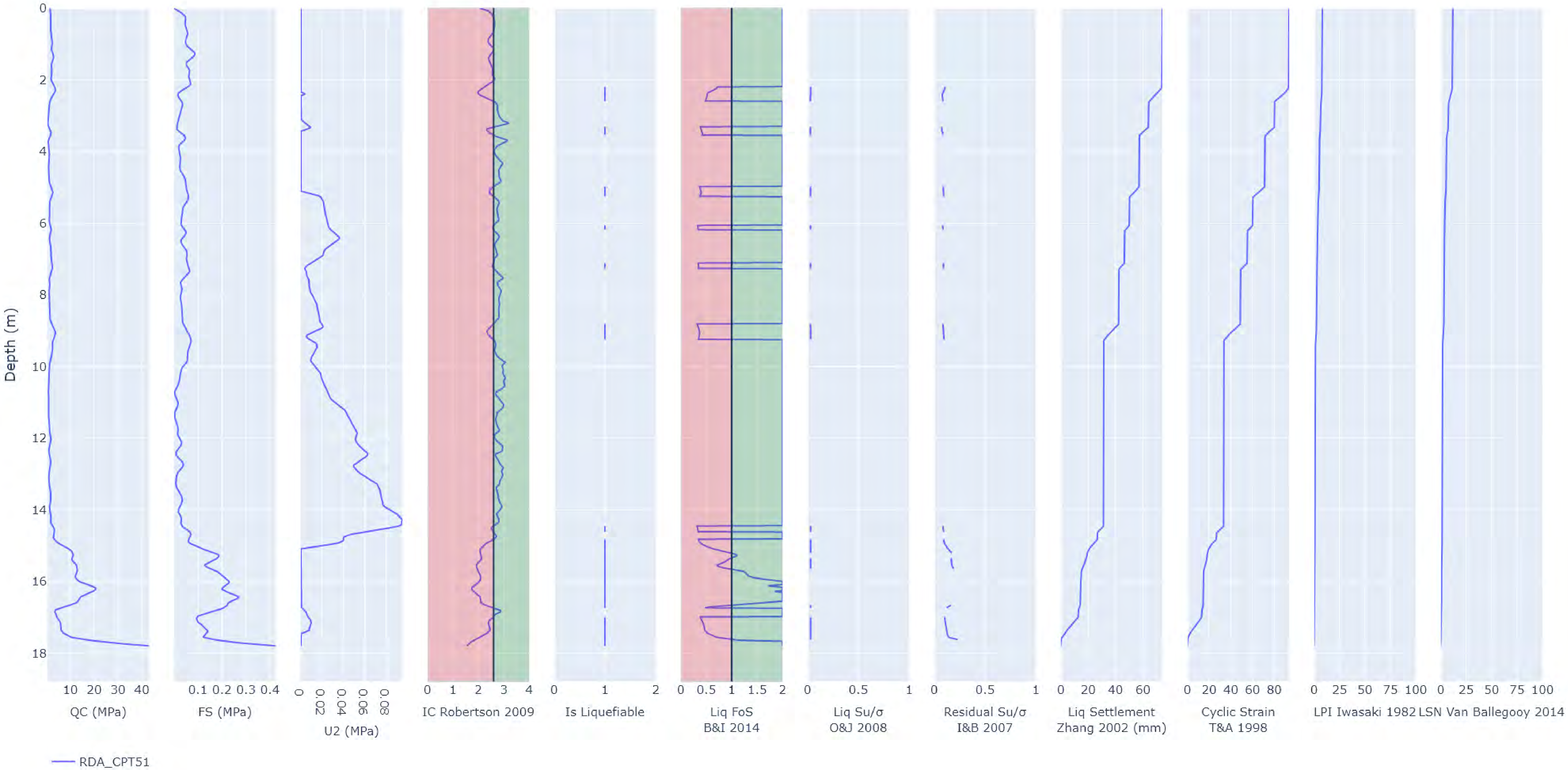
ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
RDA_CPT46	User Input	18.2	5.5	0.41	6.5	27	0	27	27	1	2	5.0
RDA_CPT51	User Input	17.8	2.2	0.41	6.5	75	0	75	94	8	12	47.0
RDA_CPT52	User Input	14.02	4.0	0.41	6.5	40	0	40	52	3	3	30.0
RDA_CPT61	User Input	11.02	4.0	0.41	6.5	18	0	18	23	2	2	12.0

Made using data from RDA CPT-43-51-52-61.ags



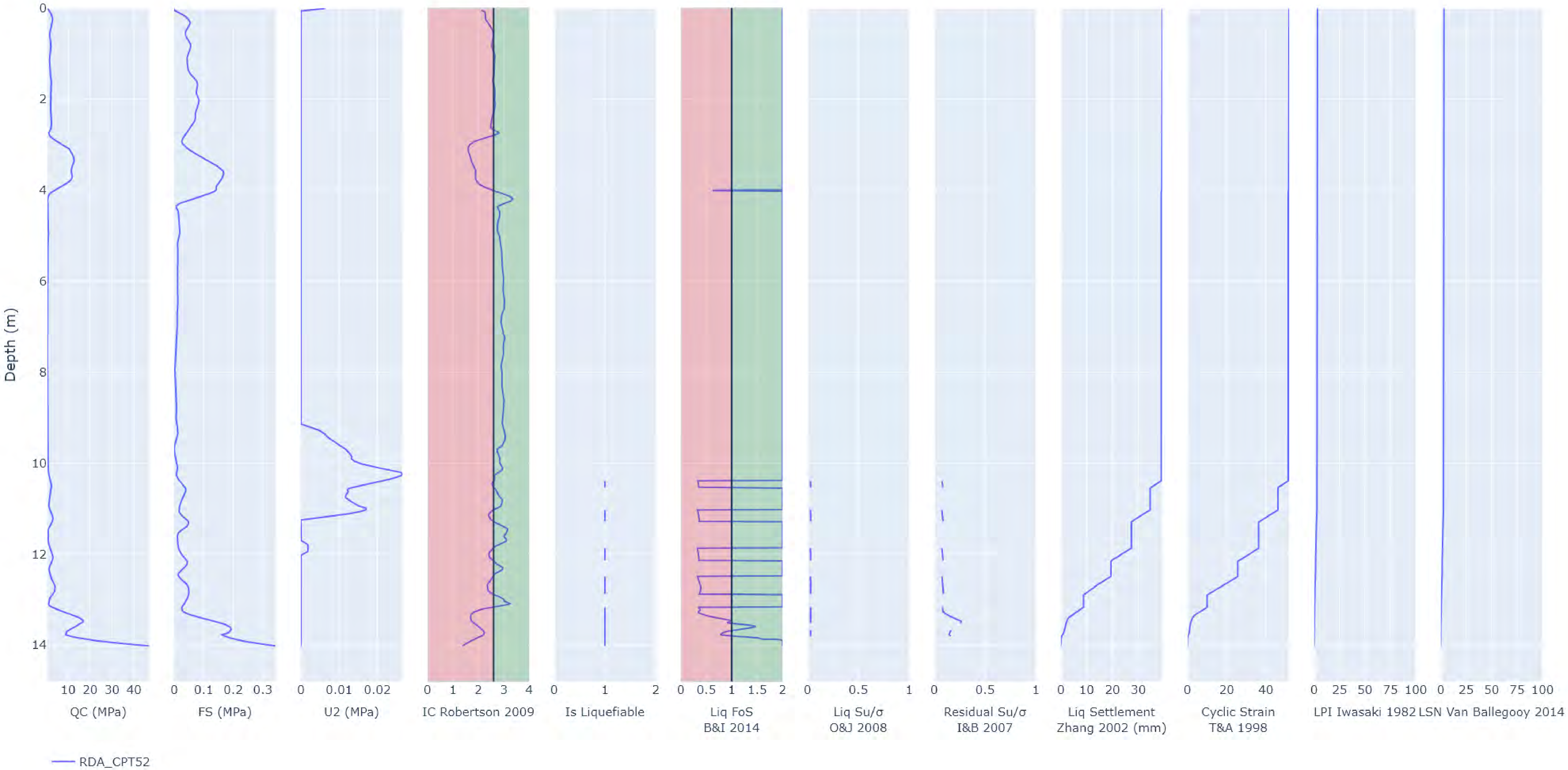
Made using data from RDA CPT-43-51-52-61.ags

Liquefaction Output for RDA_CPT51



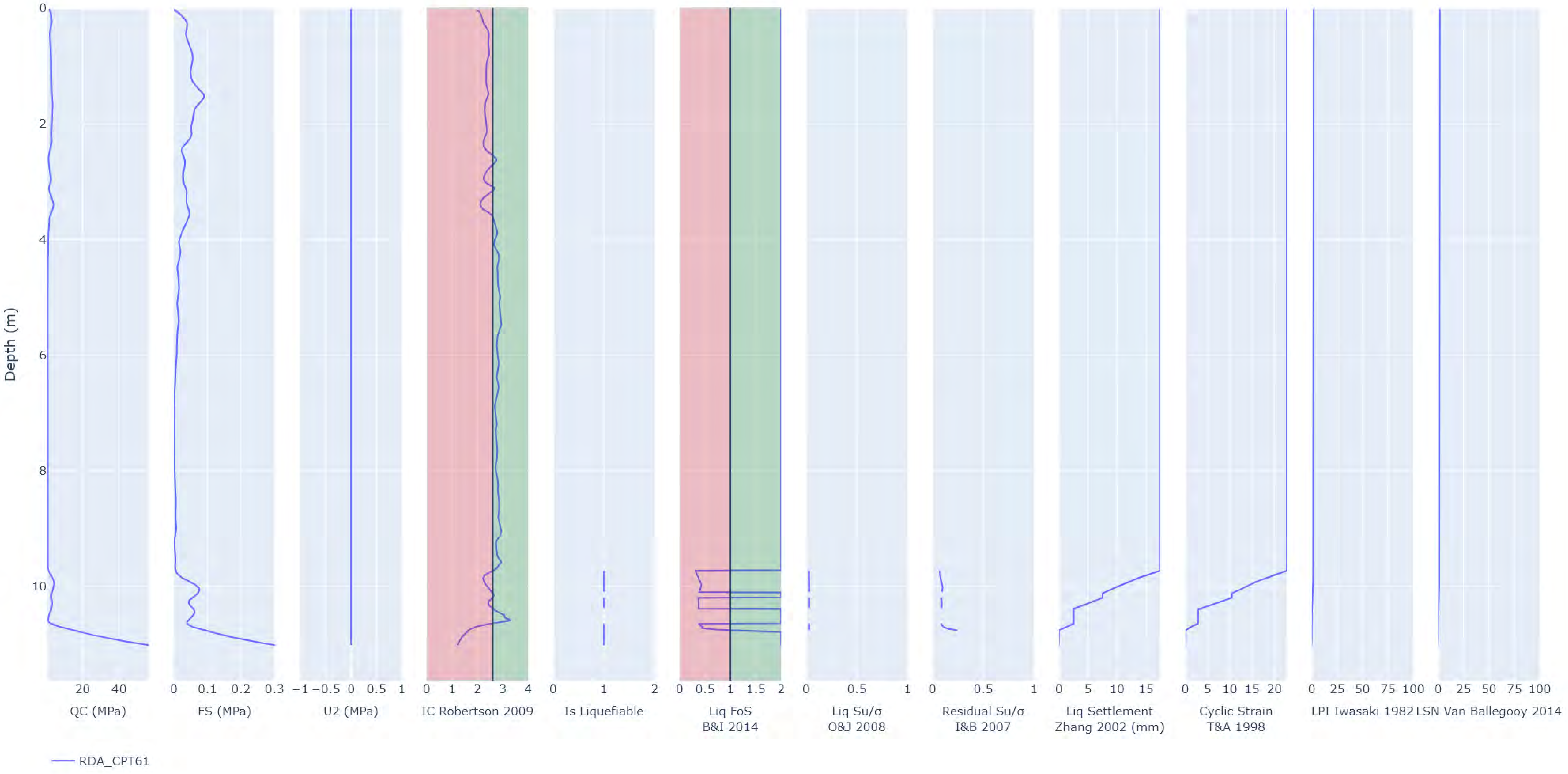
Made using data from RDA CPT-43-51-52-61.ags

Liquefaction Output for RDA_CPT52



Made using data from RDA CPT-43-51-52-61.ags

Liquefaction Output for RDA_CPT61

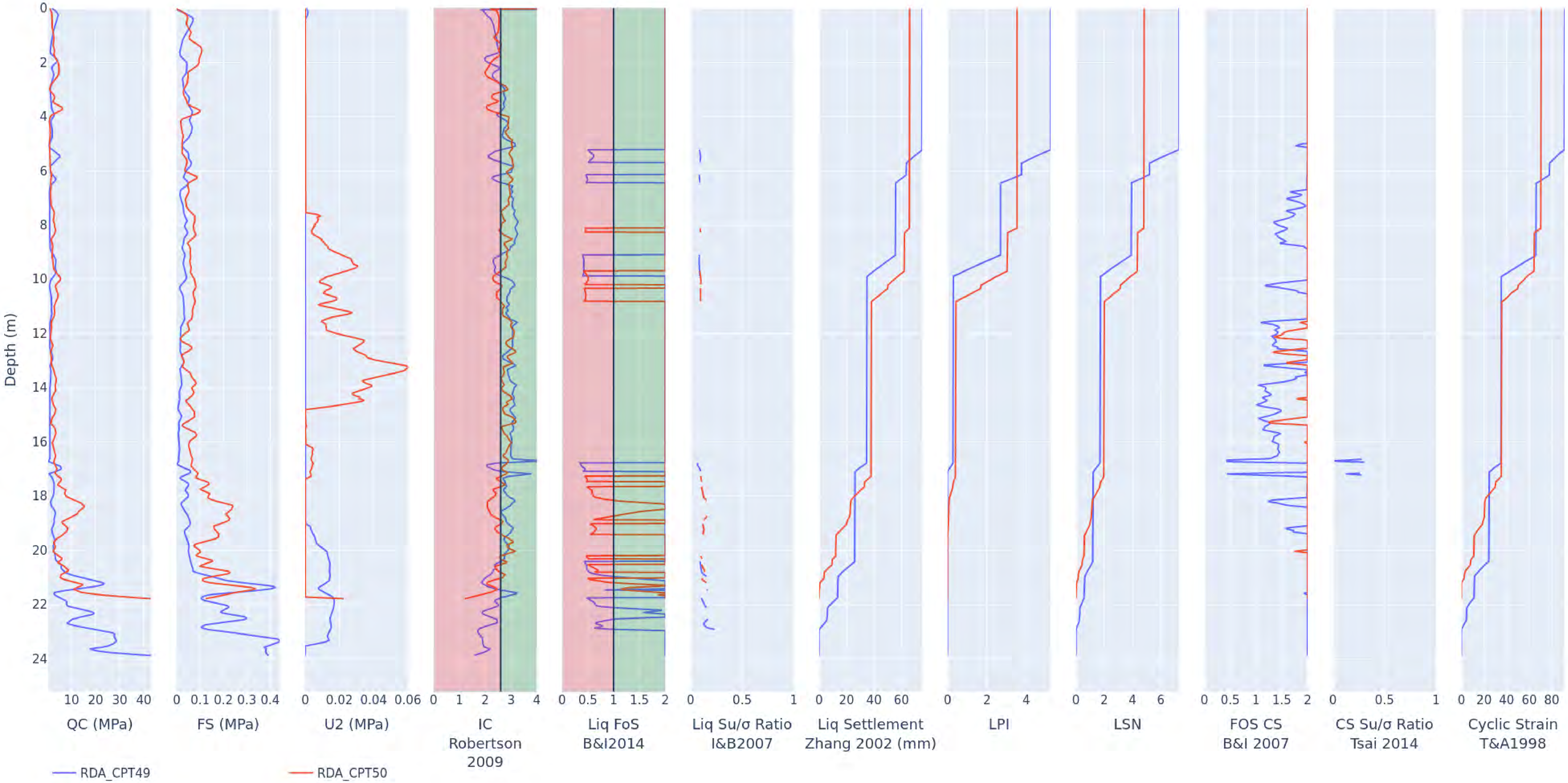


Made using data from RDA CPT-43-51-52-61.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
RDA_CPT49	23.88	5.0	0.41	6.5	75	91	5	7
RDA_CPT50	21.78	5.0	0.41	6.5	66	71	4	5

Made using data from RDA - CPT49-50.ags

Liquefaction Standard Output

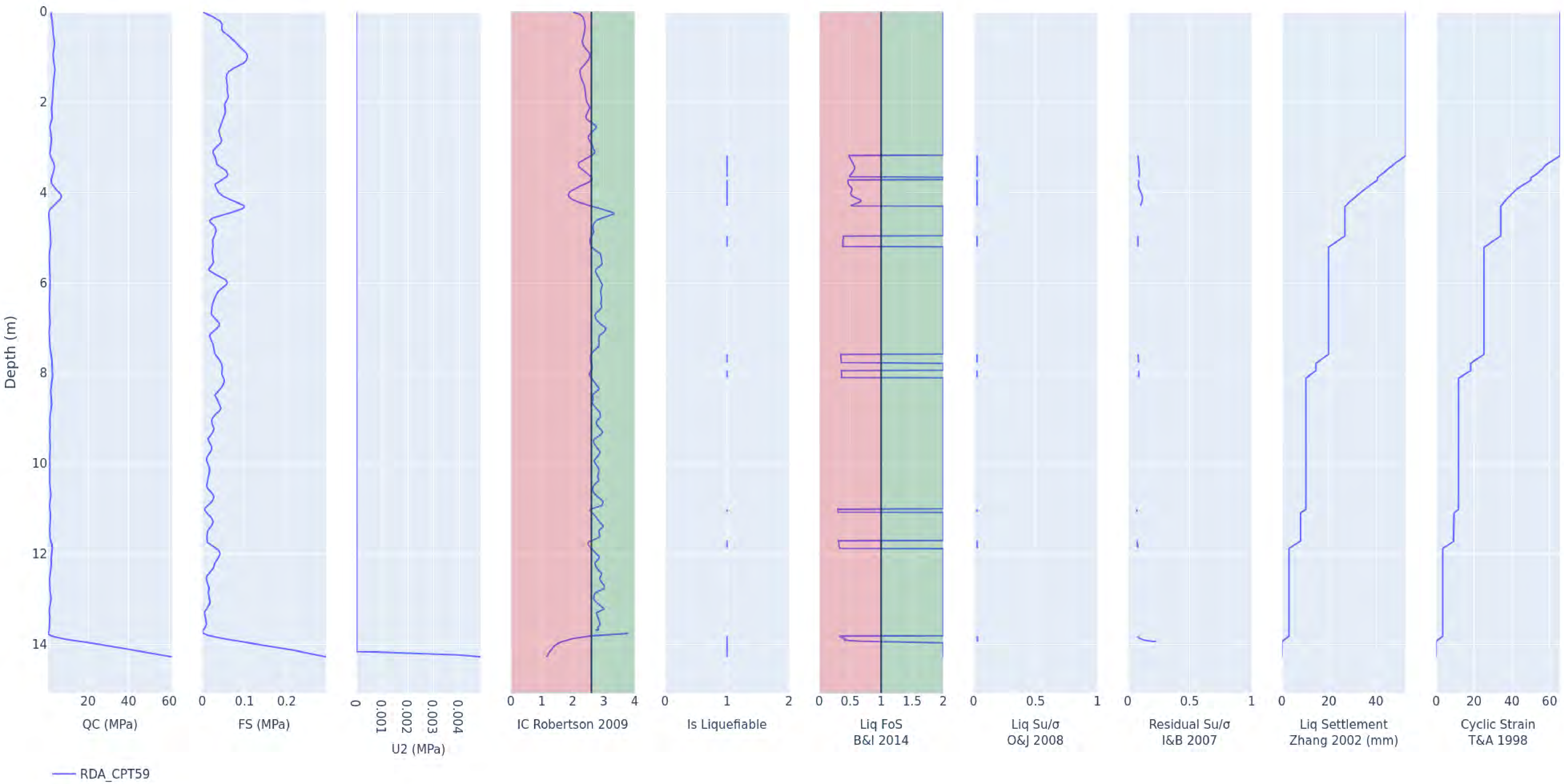


Made using data from RDA - CPT49-50.ags

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
RDA_CPT59	User Input	14.28	3.0	0.41	6.5	53	0	53	66	7	10	44.0
RDA_CPT60	User Input	23.74	3.0	0.41	6.5	149	0	149	181	14	16	83.0

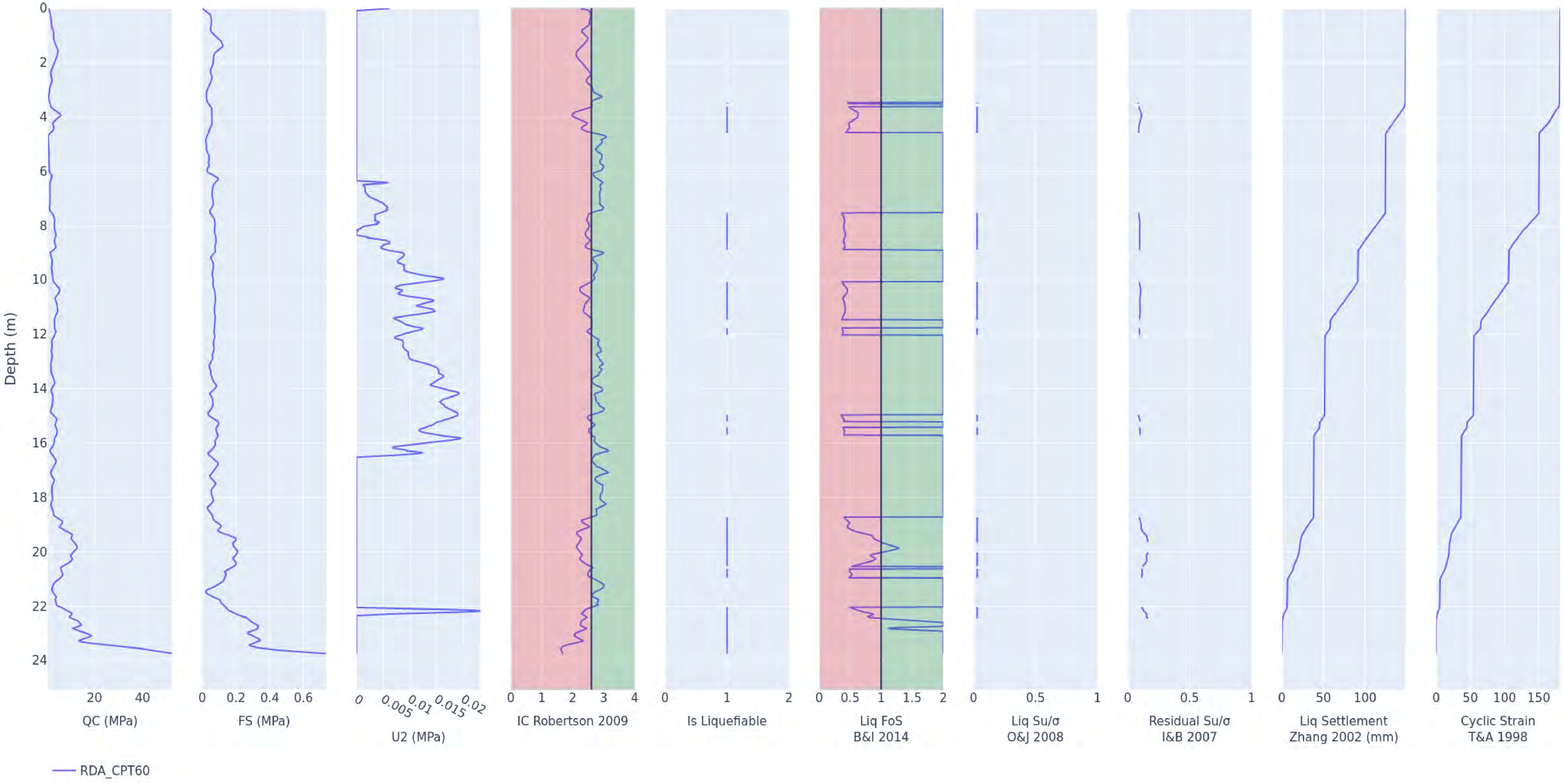
Made using data from 22-23 RDA-CPT 59-60.ags

Liquefaction Output for RDA_CPT59



Made using data from 22-23 RDA-CPT 59-60.ags

Liquefaction Output for RDA_CPT60

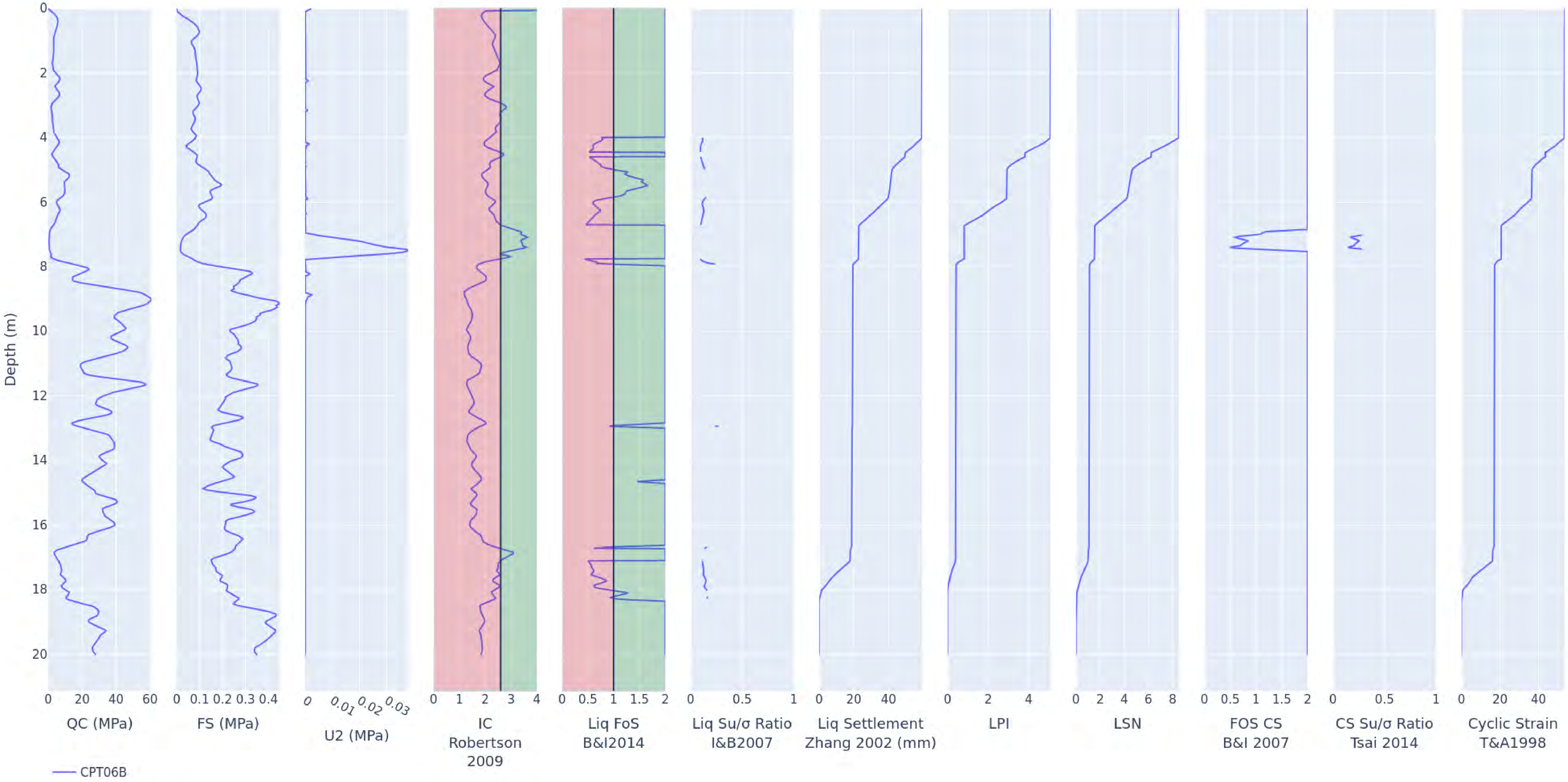


Made using data from 22-23 RDA-CPT 59-60.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
CPT06B	20.02	4.0	0.41	6.5	59	53	5	9

Made using data from CPT6.ags

Liquefaction Standard Output

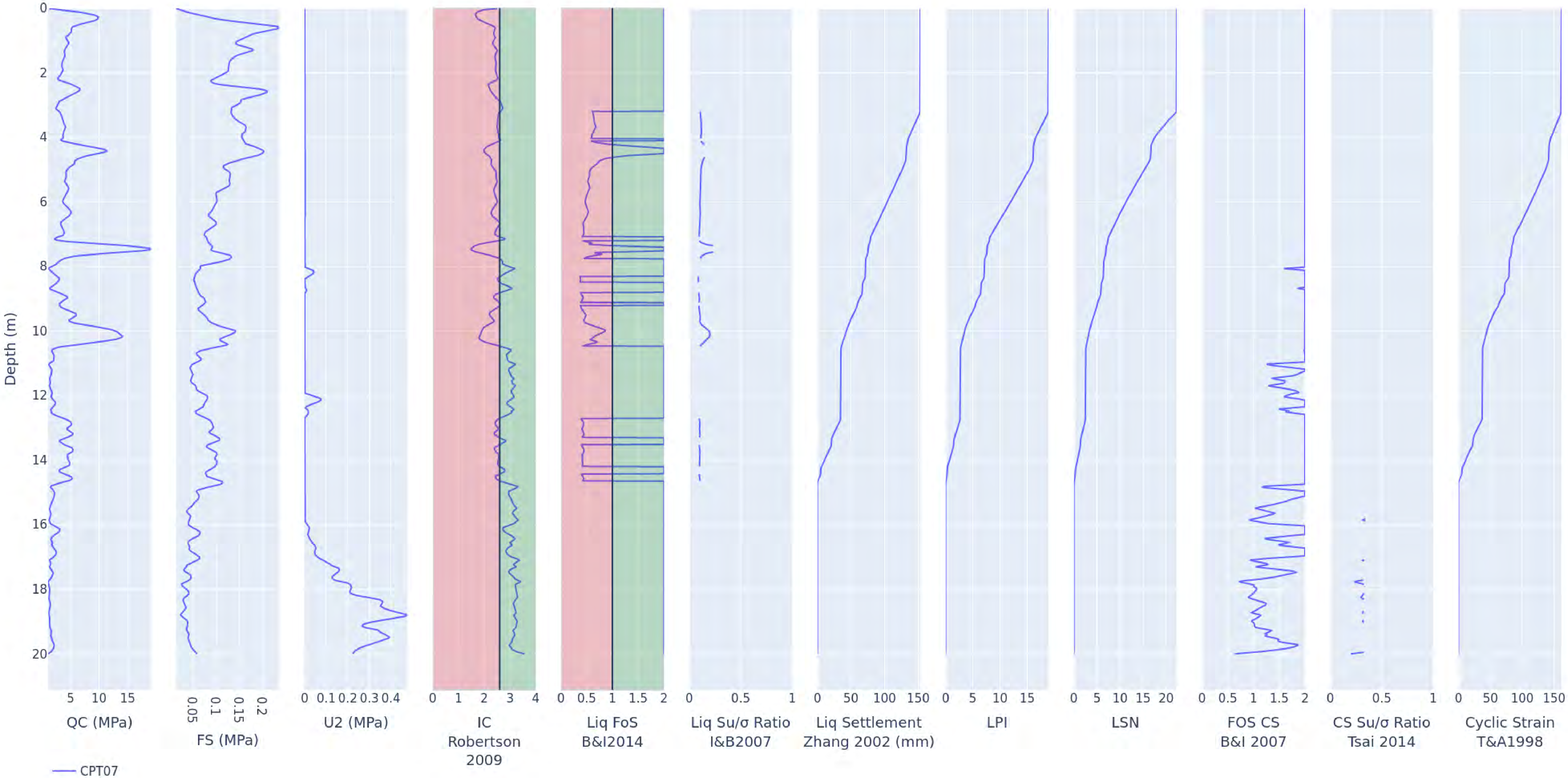


Made using data from CPT6.ags

ID	Max Depth (m)	Groundwater Level (m)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Cyclic Strain (mm)	LPI	LSN
CPT07	20.0	3.0	0.41	6.5	153	162	19	22

Made using data from CPT07.ags

Liquefaction Standard Output

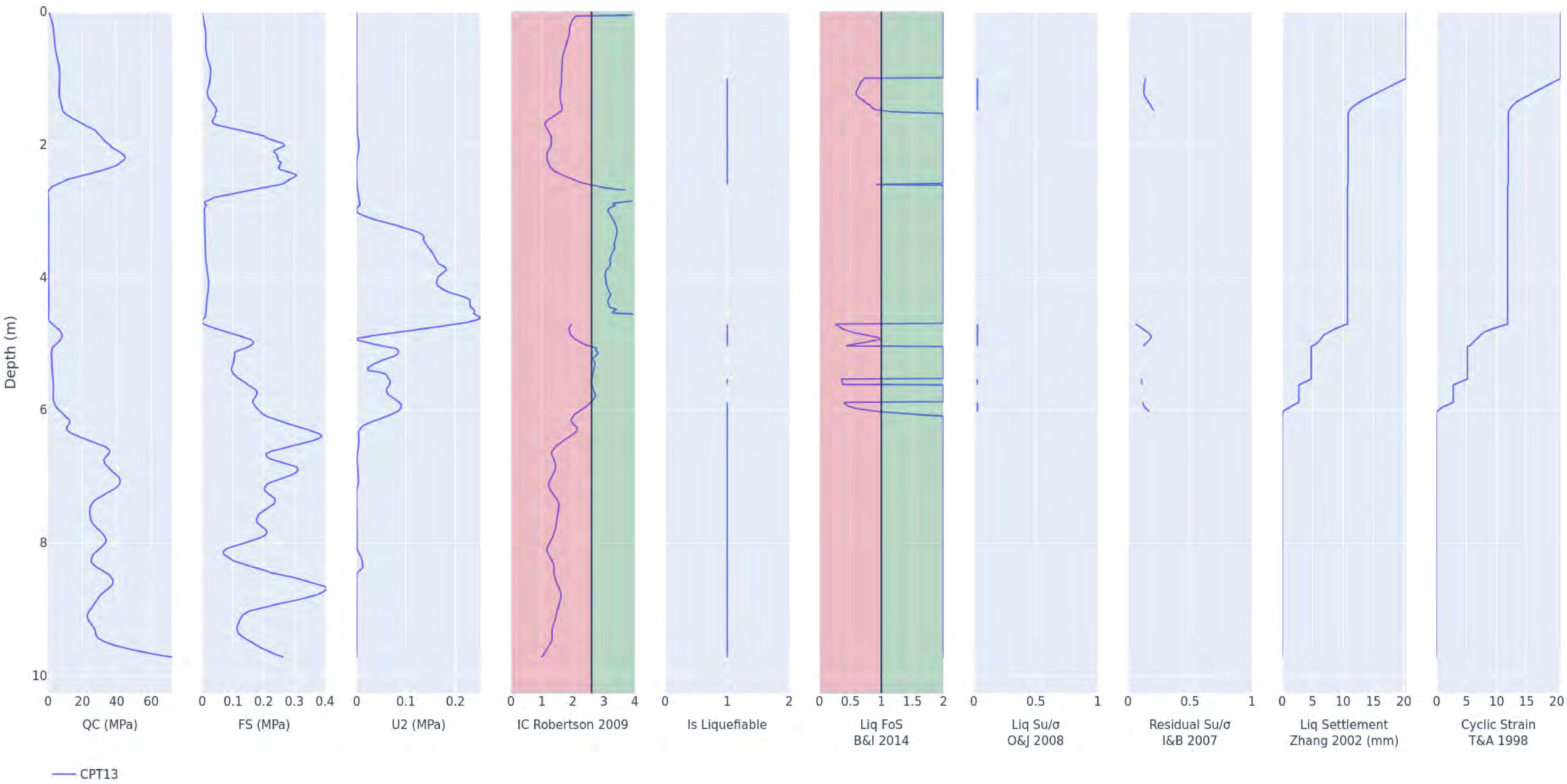


Made using data from CPT07.ags

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
CPT13	User Input	9.72	1.0	0.41	6.5	21	0	21	21	3	10	3.0

Made using data from CPT13.ags

Liquefaction Analysis



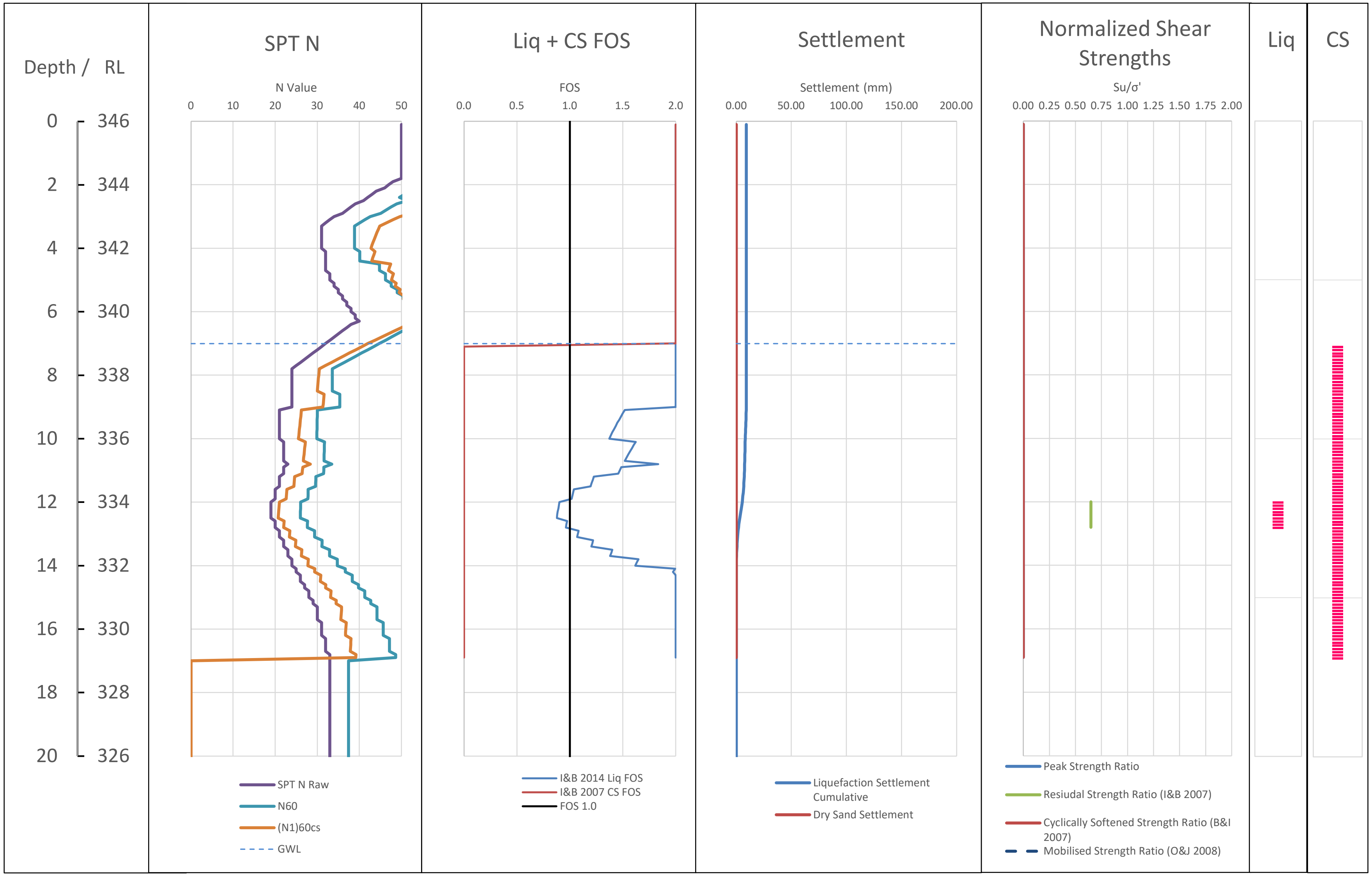
Made using data from CPT13.ags

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
BHLQ_04	User Input	17.25	7.0	0.41	6.5	9	0	9	12	3	9	3.0
BHLQ_09	User Input	12.5	7.0	0.41	6.5	0	0	0	0	0	0	0.0

Made using data from BHLQ_4-9.ags

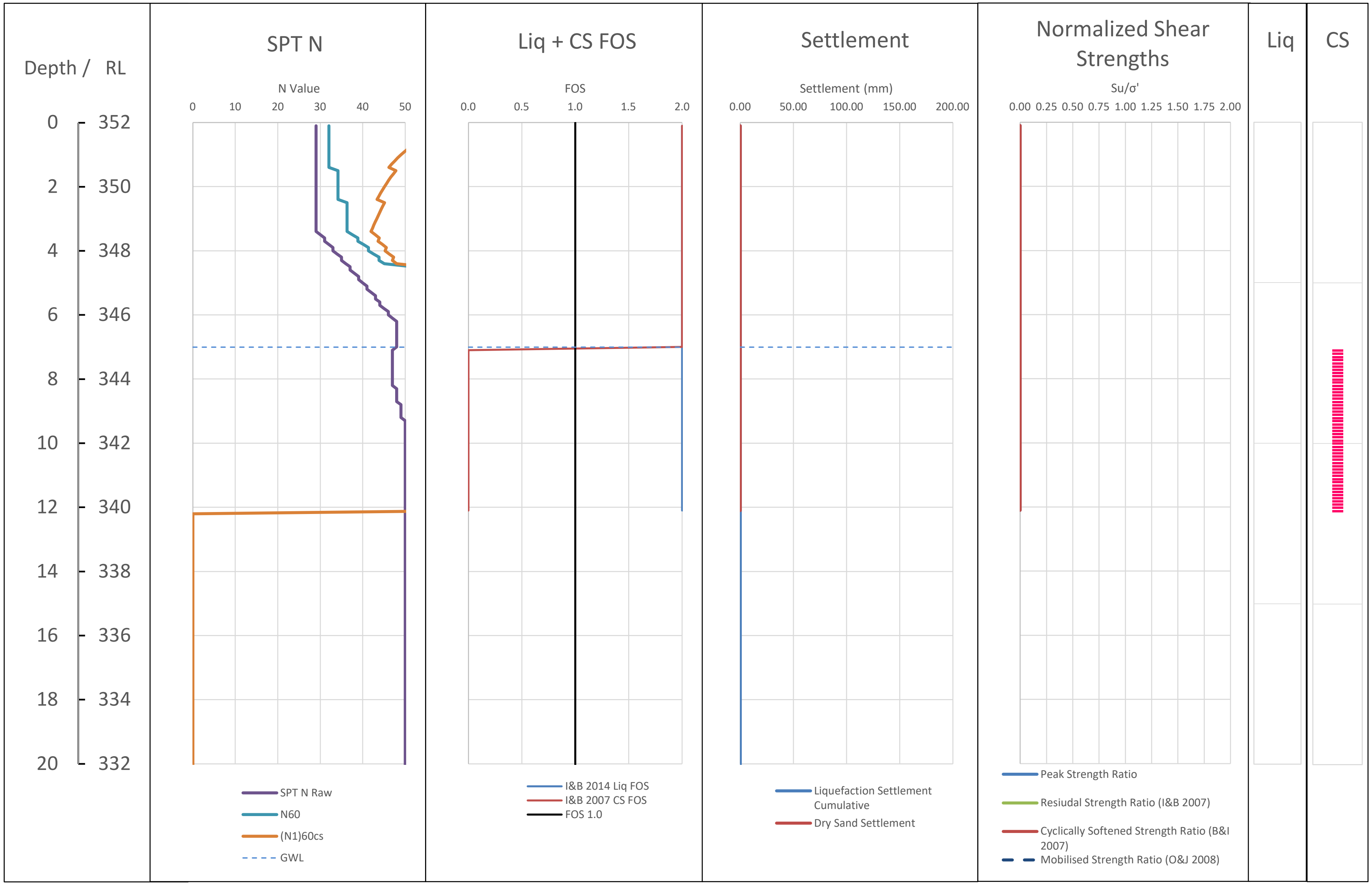
Project Summary	
Project Name	Tapuae/Southern Corri
Project Number	3161129
Unscaled PGA (g)	0.41
Magnitude	6.5
Total Settlement (mm)	9.07

Borehole Information	
BH ID:	BHLQ_04
BH Depth (m):	17.0
Ground Level:	346
Water Level:	7
Fill:	0



Project Summary	
Project Name	Tapuae/Southern Cor
Project Number	3161129.0
Unscaled PGA (g)	0.41
Magnitude	6.5
Total Settlement (mm)	0.00

Borehole Information	
BH ID:	BHLQ_09
BH Depth (m):	12.2
Ground Level:	352
Water Level:	7
Fill:	0

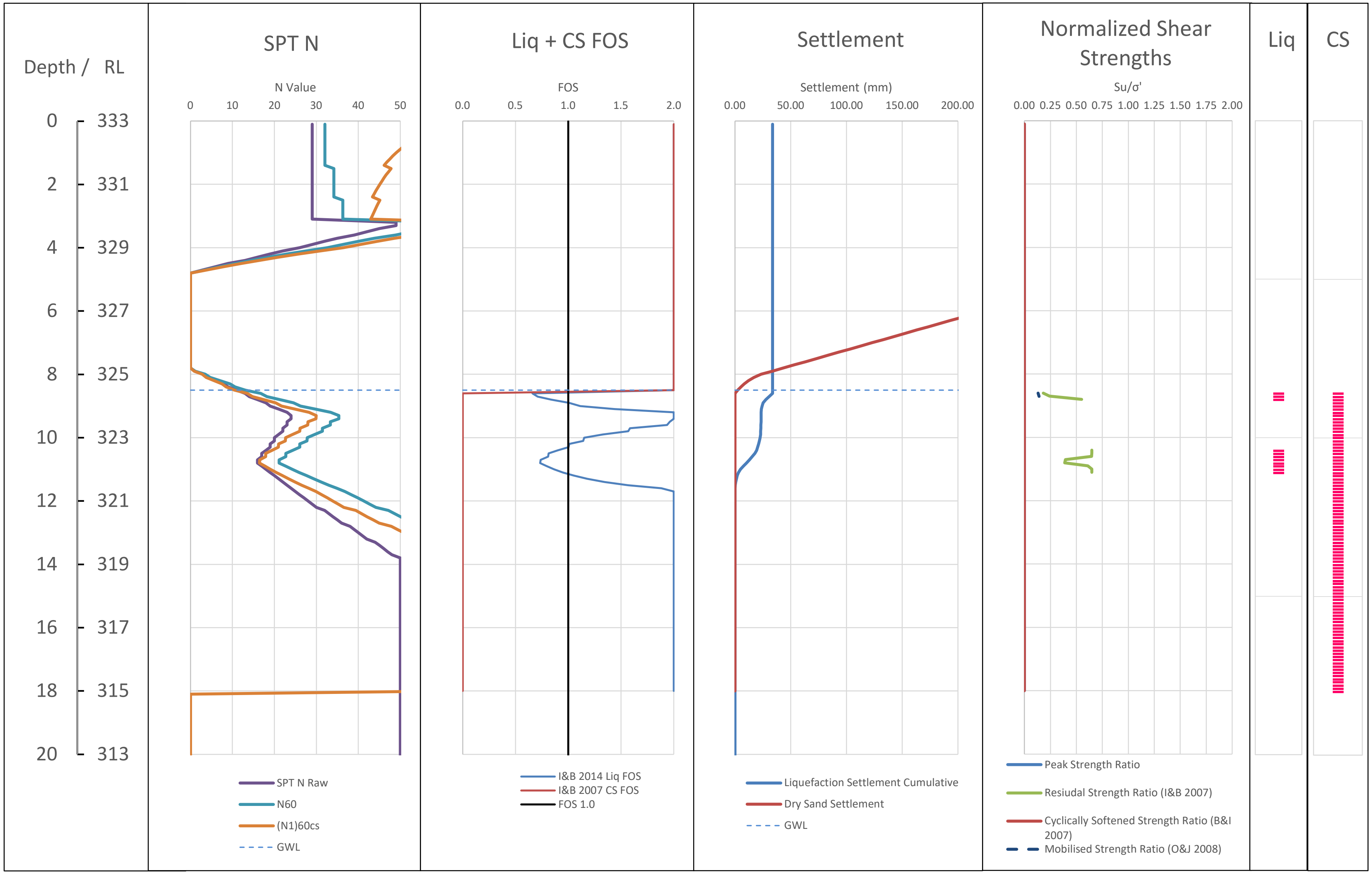


ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
BHLQ_11	User Input	18.3	8.5	0.41	6.5	34	355	389	22	1	3	7.0

Made using data from BHLQ_11.ags

Project Summary	
Project Name	Tapuae/Southern Corr
Project Number	3161129
Unscaled PGA (g)	0.41
Magnitude	6.5
Liquefaction Settlement (mm)	34

Borehole Information	
BH ID:	BHLQ_11
BH Depth (m):	18.0
Ground Level:	333
Water Level:	8.5
Fill:	0

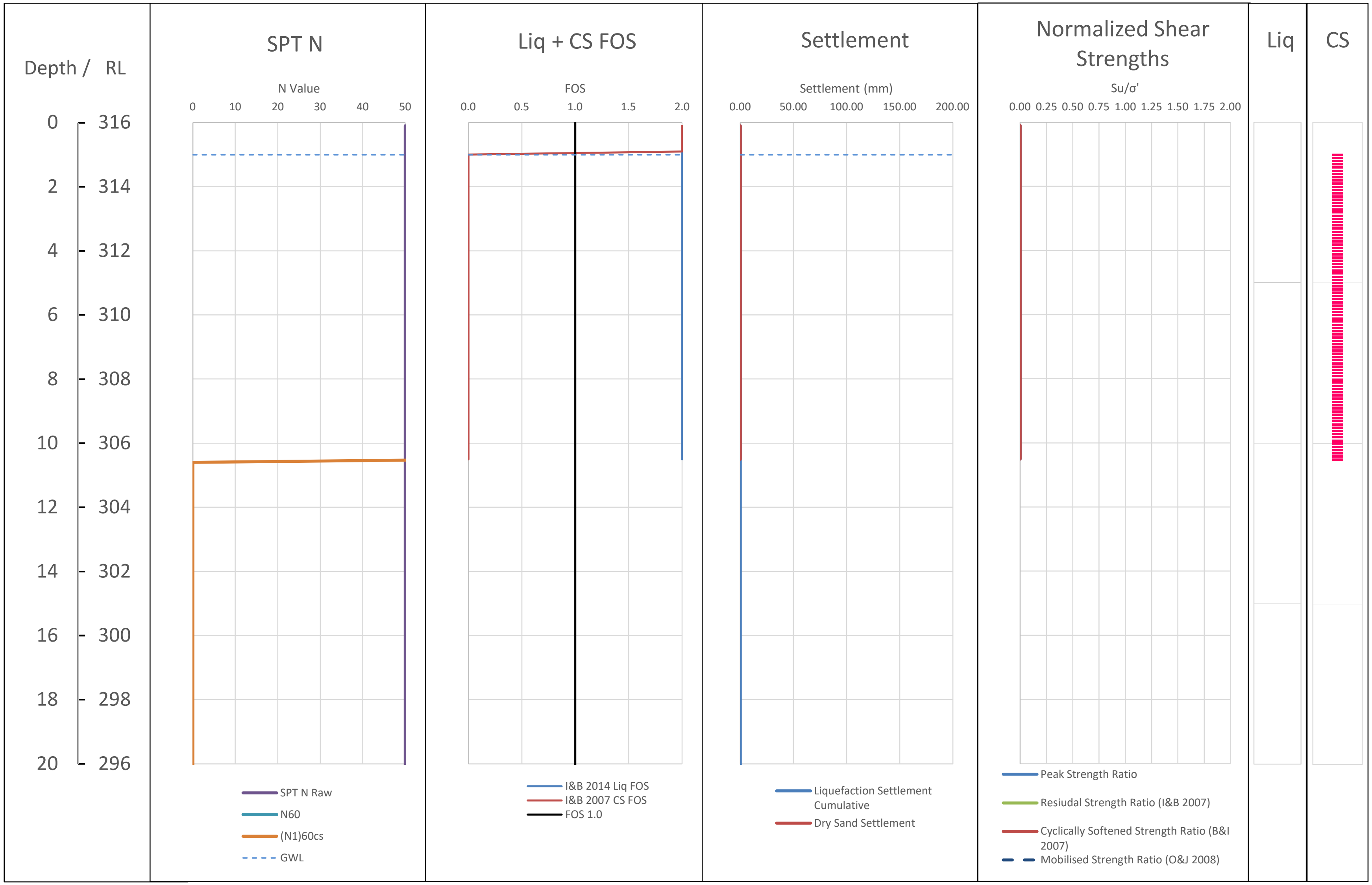


ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
BHLQ_16	User Input	10.81	1.0	0.41	6.5	0	0	0	0	0	0	0.0

Made using data from BHLQ_16.ags

Project Summary	
Project Name	Tapuae/Southern Corr
Project Number	3161129
Unscaled PGA (g)	0.41
Magnitude	6.5
Liquefaction Settlement (mm)	0.00

Borehole Information	
BH ID:	BHLQ_16
BH Depth (m):	10.5
Ground Level:	316
Water Level:	1
Fill:	0

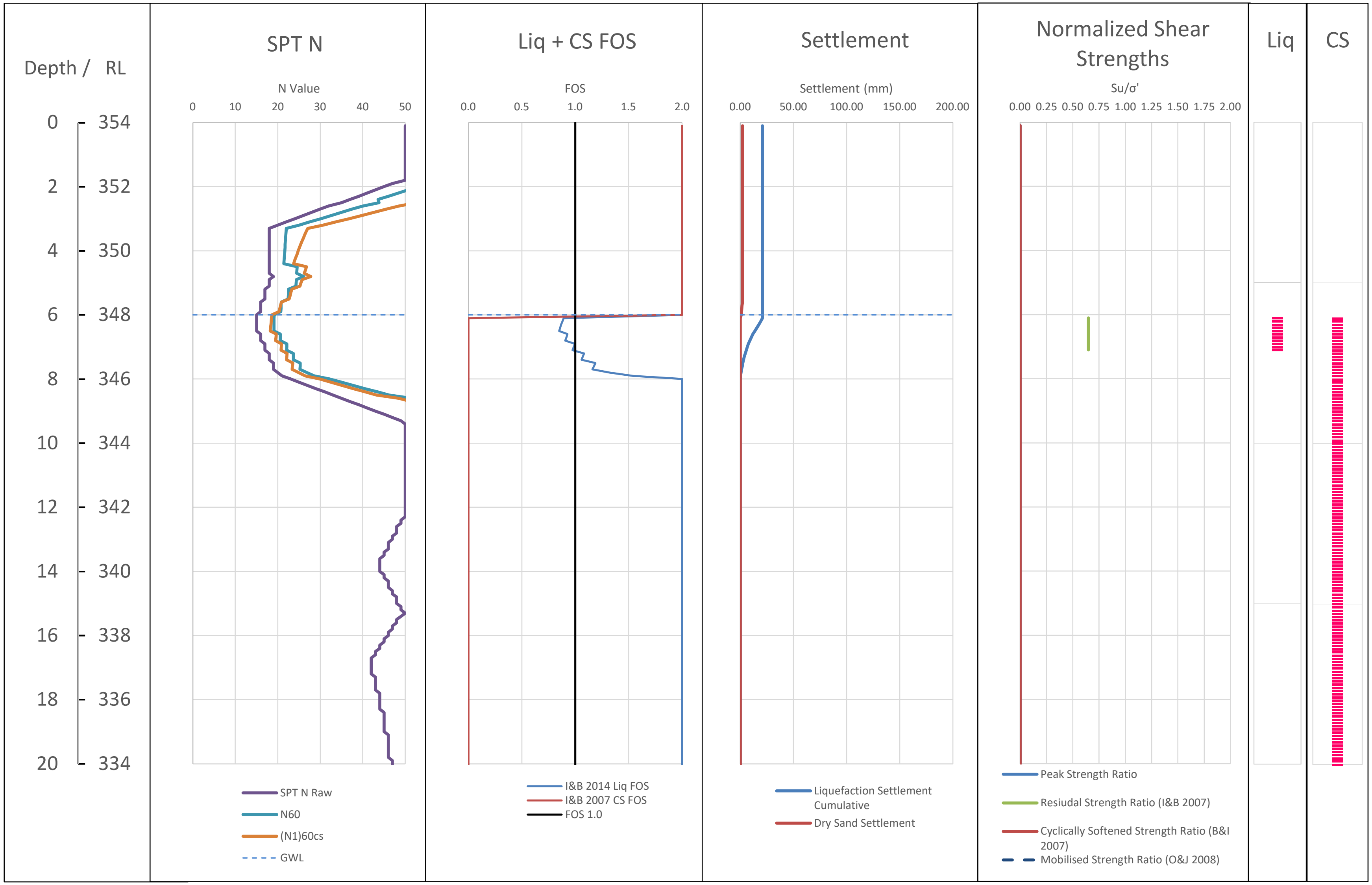


ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
BH01 Geosolve 2022	User Input	30.43	6.0	0.41	6.5	21	2	23	16	4	5	167.0

Made using data from BH01 Geosolve 2022.ags

Project Summary	
Project Name	Tapuae/Southern Corr
Project Number	3161129
Unscaled PGA (g)	0.41
Magnitude	6.5
Liquefaction Settlement (mm)	21

Borehole Information	
BH ID:	solve 2022
BH Depth (m):	30.1
Ground Level:	354
Water Level:	6
Fill:	0



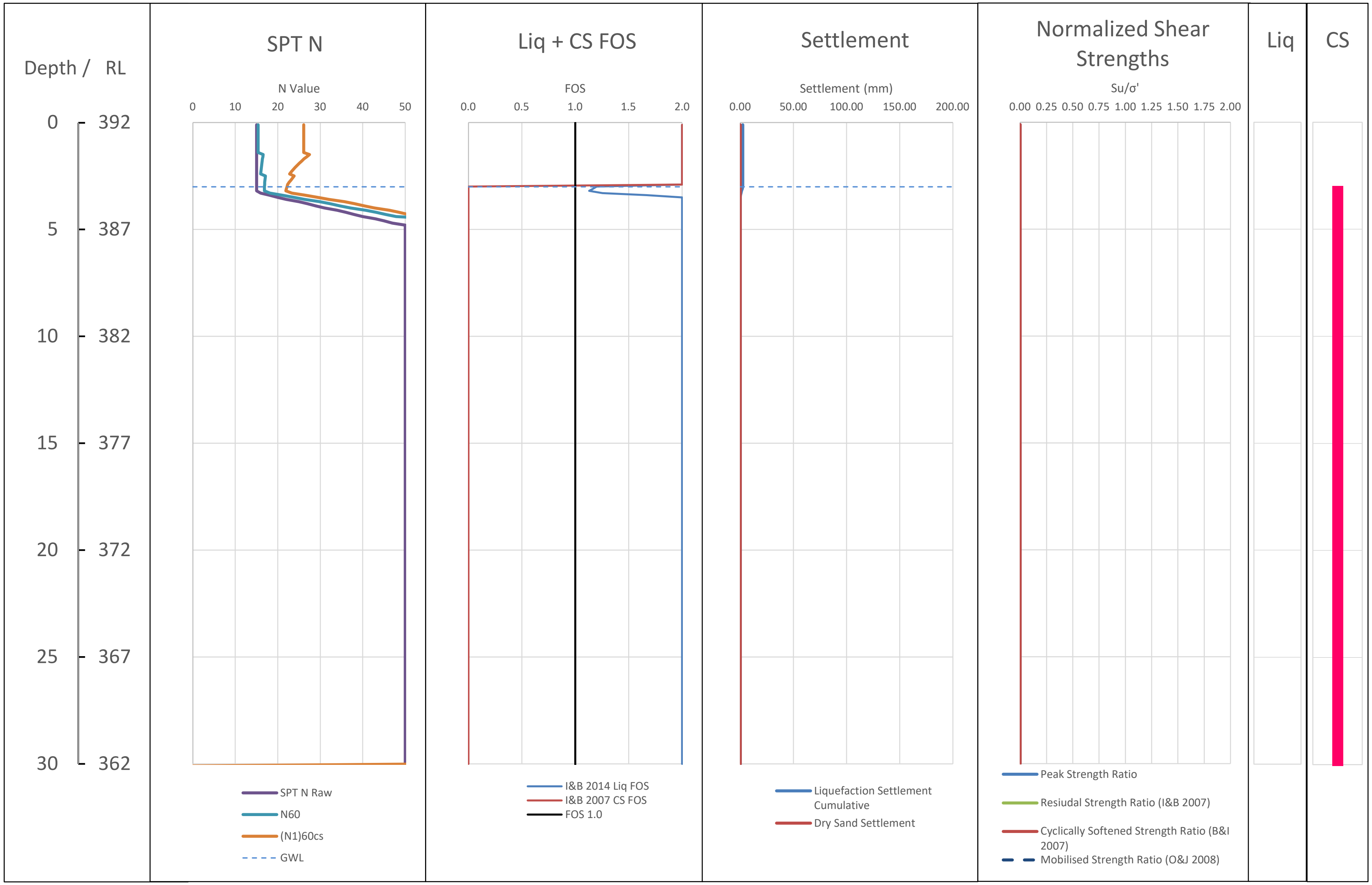
Beca SPT Seismic Analysis Spreadsheet v53

ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
BH02 Geosolve 2022	User Input	30.3	3.0	0.41	6.5	2	0	2	0	1	5	0.0

Made using data from BH02 Geosolve 2022.ags

Project Summary	
Project Name	Tapuae/Southern Corr
Project Number	3161129
Unscaled PGA (g)	0.41
Magnitude	6.5
Liquefaction Settlement (mm)	2

Borehole Information	
BH ID:	solve 2022
BH Depth (m):	30.0
Ground Level:	392
Water Level:	3
Fill:	0

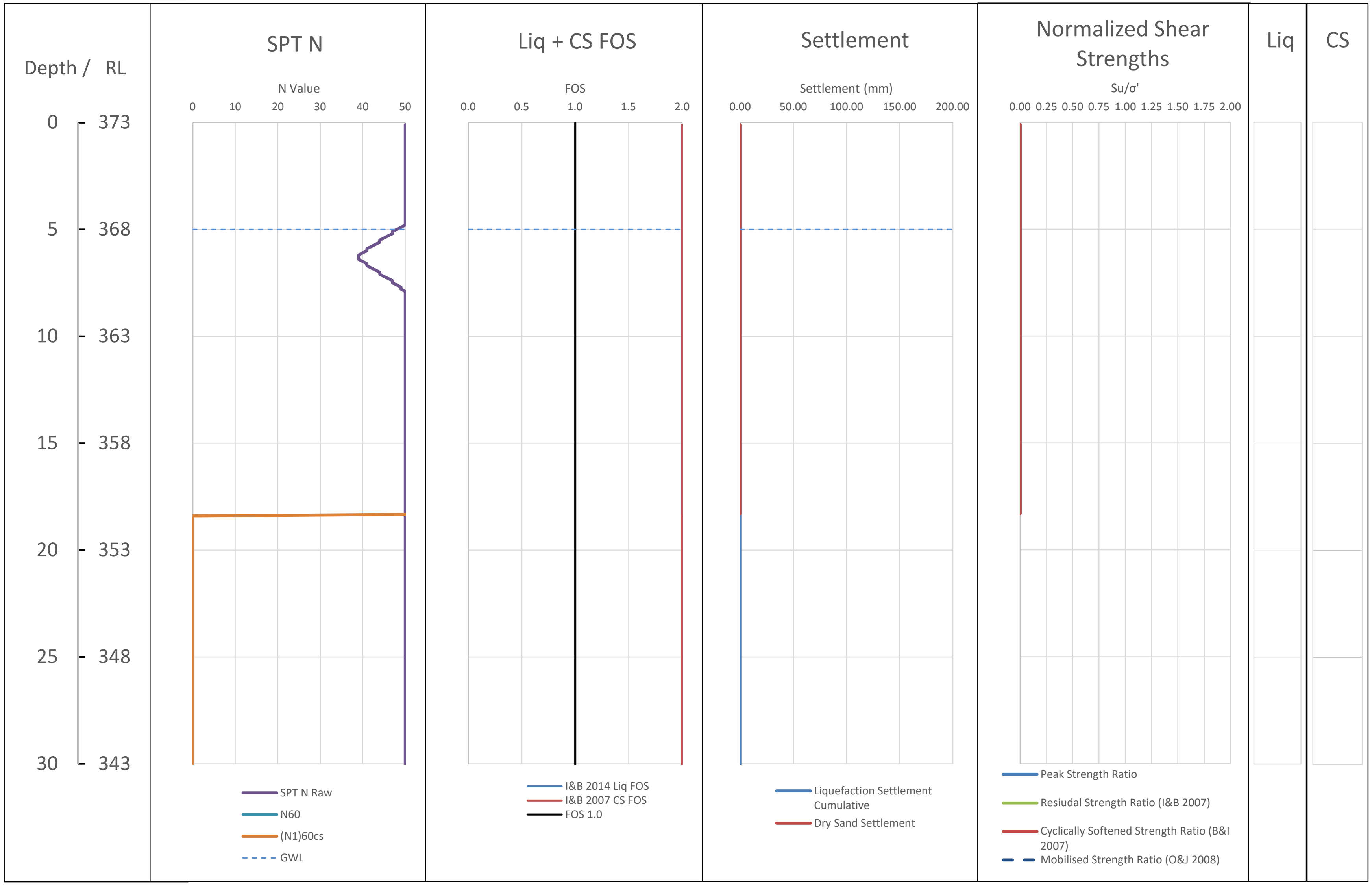


ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
BH03 Geosolve 2024	User Input	20.11	5.0	0.41	6.5	0	0	0	0	0	0	0.0

Made using data from BH03 Geosolve 2024-1.ags

Project Summary	
Project Name	Tapuae/Southern Corr
Project Number	3161129.0
Unscaled PGA (g)	0.41
Magnitude	6.5
Liquefaction Settlement (mm)	0.00

Borehole Information	
BH ID:	solve 2024
BH Depth (m):	18.3
Ground Level:	373
Water Level:	5
Fill:	0



ID	PGA Case	Max Depth (m)	Groundwater (mbgl)	PGA (g)	Magnitude	Liquefaction Settlement (mm)	Dry Sand Settlement (mm)	Total Settlement (mm)	Cyclic Strain (mm)	LPI	LSN	Vs Liquefaction Settlement (mm)
BH01 Geosolve 2024	User Input	20.25	2.0	0.41	6.5	31	34	65	91	16	12	47.0

Made using data from BH01 Geosolve 2024 -1.ags

Project Summary	
Project Name	Tapuae/Southern Corr
Project Number	3161129
Unscaled PGA (g)	0.41
Magnitude	6.5
Liquefaction Settlement (mm)	31

Borehole Information	
BH ID:	solve 2024
BH Depth (m):	20.0
Ground Level:	374
Water Level:	2
Fill:	0