Liquefaction assessment for an urban roading project in the Bay of Plenty

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ABSTRACT

The NZ Transport Agency Baypark to Bayfair link upgrade project will provide improvements to two key intersections on State Highway 2 in the east of urban Tauranga in the Bay of Plenty. The project will be constructed in an area which is susceptible to liquefaction and cyclic strain softening. The ground conditions comprise Holocene beach deposit sands overlying swamp deposits, underlain by Pleistocene age volcanically derived alluvium. Preliminary analyses using CPT based methods indicated potential widespread liquefaction (and associated effects) in a 1/2500 APE event. This represented a significant risk to the project and it was recognised that a robust and considered assessment of the liquefaction hazard was necessary. This paper describes the investigation techniques used and the approach taken to undertake that assessment. The assessment was based on an extensive investigation programme comprising boreholes, Cone Penetration Tests (CPTs), seismic CPTs, seismic Dilatometer tests, downhole (Geonor) Shear Vane tests and laboratory testing. The investigation highlighted the importance of, and difficulties with, obtaining good quality data in the field. Both CPT and shear wave velocity based methods were used in the liquefaction assessment with a particular emphasis on the liquefaction potential of the Pleistocene aged soils. Findings from the liquefaction assessment showed good agreement with other recent liquefaction studies carried out within volcanic soils in the central North Island.

1 INTRODUCTION

The NZ Transport Agency Baypark to Bayfair link upgrade project will provide improvements to the Te Maunga intersection at Baypark and to the Maunganui Road/Girven Road intersection at Bayfair, in Tauranga, Bay of Plenty. The project lies at the northern terminus of the Tauranga Eastern Link (TEL) which was completed in 2015. The TEL is located to the east of Tauranga and is a key freight route for transporting goods from the Eastern Bay of Plenty agricultural and forestry areas to the Port of Tauranga and wider markets.

The project layout is shown in Figure 1. The project features a 3 span flyover at the Maunganui/Girven intersection and 2 single span bridges at the Te Maunga intersection, with significant lengths of MSE type approach embankment. The estimated project cost is $100m.

The project will be constructed in an area which is susceptible to liquefaction and cyclic strain softening. Seismic stability of the up to 8m high approach embankments and abutments under the various design events was a key consideration. Preliminary analyses indicated that liquefaction could be initiated in events with an Annual Probability of Exceedance (APE) of as little as around 1/100 (equivalent to a Minor earthquake), with widespread liquefaction (and associated effects) indicated in a 1/2500 APE (Design earthquake) event. This represented a significant risk to the project.

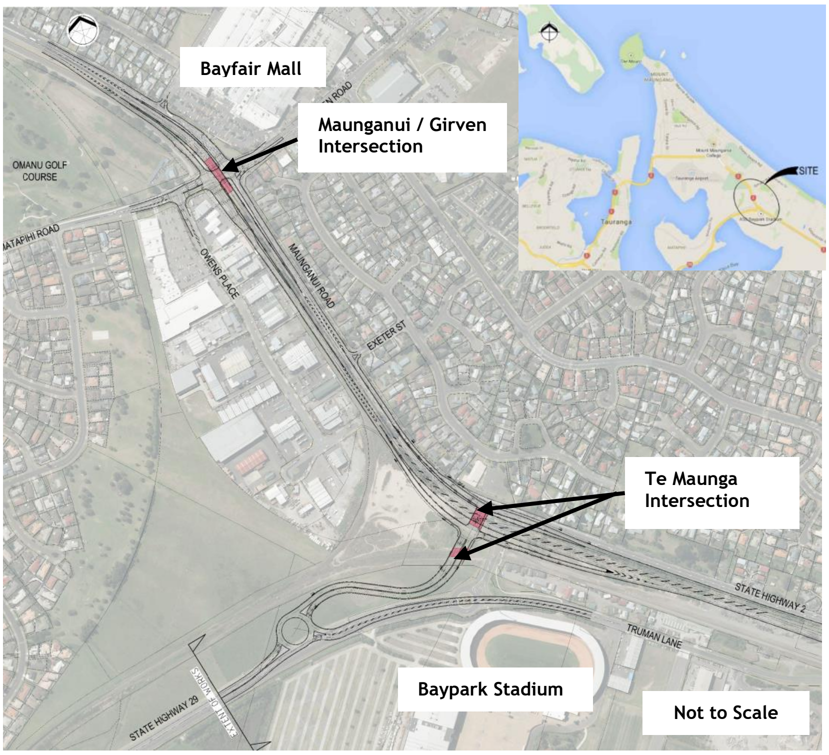

Figure 1: Project layout plan

2 GEOLOGY, GROUNDWATER AND SEISMICITY

2.1 Geology

The site is relatively flat and sits between the coastal barrier system at Omanu Beach to the northeast and the Matapihi peninsula to the southwest. The Tauranga Harbour and associated estuarine environment extends to the south of the site at Rangataua Bay. The city of Tauranga is located almost completely within the Tauranga Basin, a Pleistocene to Holocene (about 2 million years to the present) tectonic sedimentary basin up to 150m thick (Briggs et al, 1996). The basement of the Tauranga Basin consists of variably welded ignimbrites of Upper Tertiary age.

Deposits infilling this basin are termed Tauranga Group and consist of a basal Pleistocene sequence and an upper Holocene unit. The Pleistocene sequence comprises mainly alluvial deposits interbedded with unwelded ignimbrites and tephras, and is commonly referred to as the Matua Subgroup. The Holocene sediments include estuarine (swamp), alluvial, beach and dune deposits. The most recent geological map covering the area (Leonard et al, 2010) shows that the low lying areas of Tauranga and Mount Maunganui, where the site is located, are underlain by Beach Deposits and Swamp Deposits. The Matapihi peninsula, close to the southwest limit of the site, is underlain by the Matua Subgroup. These three units were of particular significance to the study and are described below in stratigraphic order:

2.1.1 Holocene beach deposits

The beach deposits are composed mainly of sands with little fines. Most of these deposits consist of loose to medium dense, fine to coarse-grained sands, composed largely of quartz and, subordinately, of shells and pumice. Trace silt was frequently observed, whilst minor pumice gravel occurs locally.

The sands extend across the whole site with relatively uniform thickness, to depths of about 10m below ground level (bgl). In the southeastern part of the site, a dense to very dense bed of gravelly sands was encountered at the base of the beach deposits. A number of Cone Penetration Tests (CPTs) refused on this bed.

2.1.2 Holocene swamp deposits

The swamp deposits consist of a sedimentary package of clays and silts interbedded with lenses/beds of sands. These deposits are estuarine in nature but the “swamp deposits” terminology was adopted to follow the QMAP series units. The swamp deposits occur throughout much of the site, immediately below the beach deposits, from a depth of about 10m bgl. Apart from the edges where the unit thins out, the thickness of the swamp deposits is reasonably regular, varying between 4 and 8m. The swamp deposits were classified into cohesive and granular sub-units. The cohesive sub-unit was typically described as a soft to firm sensitive clayey silt of high plasticity, the granular sub-unit as loose to medium dense sands with some silt.

2.1.3 Matua Subgroup

This Pleistocene deposit is composed mainly of loose to dense silty sand alluvium and is occasionally pumiceous. In addition to the sands, beds or lenses of fine-grained soils are frequently distributed throughout the unit and are interpreted as likely tephras.

A cross section that presents the typical geology of the site is shown in Figure 2.

2.2 Groundwater

The groundwater level is typically encountered at around 2.5m bgl across much of the site.

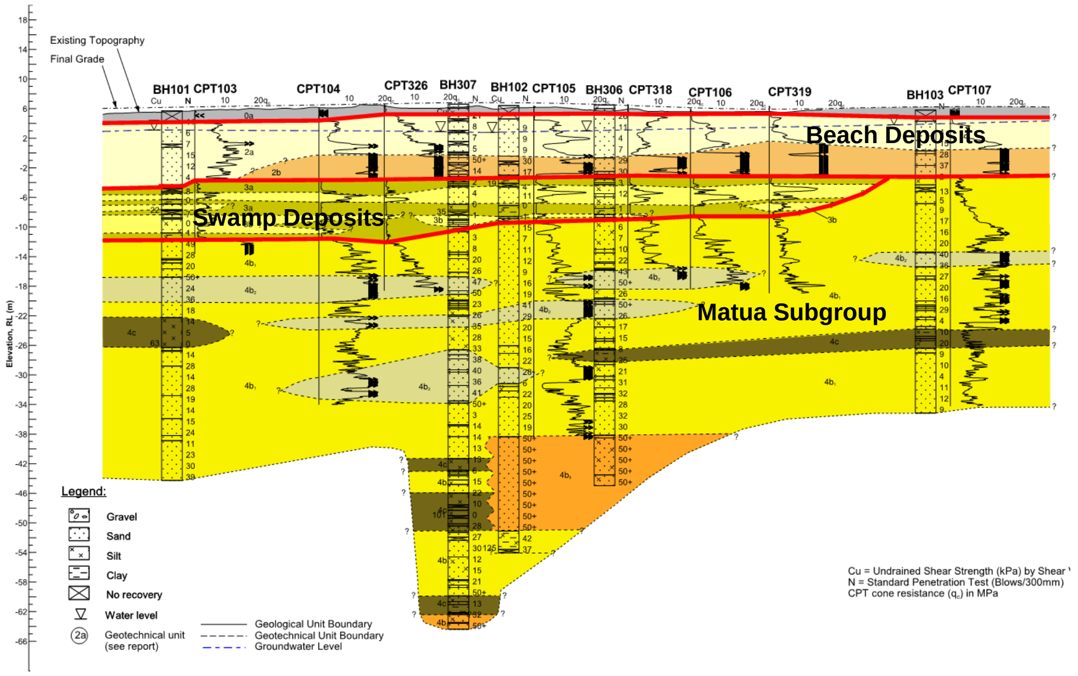

Figure 2: Typical geological section

2.3 Seismicity

The Tauranga area is located to the north of the Taupo Volcanic Zone (TVZ) and to the east of the Hauraki Rift. Active faults associated with both the TVZ and the Hauraki Rift occur in the region. However no active faults are known to exist within a 20km radius from the site (New Zealand Active Faults Database, 2015). The closest faults to the site are the Kerepehi Fault (38km to WSW) and, possibly, some offshore faults close to Motiti Island (22km to ENE).

The Peak Ground Accelerations (PGAs) and corresponding Representative Magnitudes recommended in the Site specific Seismic Hazard Assessment (SSHA) were used as inputs to the detailed liquefaction assessment (refer Table 1).

Table 1: SSHA Peak Ground Acceleration & corresponding Representative Magnitudes

Design Event	Annual Probability of Exceedance (APE)	PGA (g)	Representative Magnitude
Minor / Operational Continuity	1/100	0.15	5.9
Design Level	1/2500	0.42	5.7
MCE	-	0.46	6.9

Note. MCE = Maximum Considered Earthquake

3 LIQUEFACTION ASSESSMENT CHALLENGES

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3.1 Pleistocene age volcanogenic soils

A number of researchers and recent studies (refer Clayton et al, 2017) have highlighted challenges with undertaking liquefaction assessment in volcanically derived soils of the central North Island of New Zealand. It is widely considered that conventional penetrometer based liquefaction assessment methods in these soils can over predict liquefaction triggering in these unusual soils. The over-prediction is thought to result from the presence of crushable pumice grains and/or age effects. Where particle crushing occurs during a static Cone Penetration Test (CPT) the relative density of a soil can be under-estimated. Older deposits (such as the Pleistocene age Matua Subgroup) are considered to exhibit some cementation which are only partially recognised using large strain investigation techniques such as a CPT. Shear wave velocity based liquefaction assessment methods have been suggested as being more appropriate for such soils – refer to Clayton et al (2017) for further discussion.

3.2 Residual shear strength

Correlations associated with conventional penetrometer based methods may under-estimate the undrained and residual shear strength of young sensitive soils, such as the Holocene swamp deposits. This can result in the resistance to cyclic strain softening being under-estimated. Cyclic strain softening was an important consideration for stability given the extent of embankments on the project.

4 INVESTIGATION METHODS

4.1 Shear wave velocity

Paired seismic CPT (sCPT) and seismic Dilatometer (sDMT) direct push tests were carried out to provide down-hole shear wave velocity (Vs) data at five key locations. This enabled a comparison to be made between pseudo interval and true interval methods and gave confidence in the quality of the data obtained. Figure 3 shows the typical setup for the sCPT and sDMT testing.

Some challenges had been experienced with obtaining good quality shear wave velocity data during the initial investigations, particularly in locations where there was significant background noise, such as near the East Coast Main Trunk (ECMT) nearby. Within this investigation close collaboration between the consultant, the investigation contractor (Perry Geotech Ltd) and their specialist geophysics supplier (Baziw Consulting Engineers Ltd) was found to be beneficial as rapid evaluation and interpretation of test results allowed changes in investigation scope to suit conditions identified and evaluation of data reliability allowed interpretation to place appropriate levels of confidence on results.

Figure 3: sCPT / sDMT field testing

The approach followed, for obtaining good quality data with the sCPTs, was to establish suitable controls during data acquisition. The Vs data was captured using specialist software (SC3-DAC Pro™) that allowed field checking of the data during acquisition. For example, the operator was able to check the signal to noise ratio as the data was acquired and assess the quality of the data 'on the fly'. If poor quality data was acquired then the test could be repeated at that depth, until an acceptable data quality was achieved, before advancing the CPT probe further. Another control put in place was to observe potential sources of interference during testing, e.g. from heavy vehicles on the highway or trains passing nearby. Testing could be halted, repeated or rescheduled if necessary.

Tests using the sCPT were undertaken at 1.0m intervals typically, reducing to 0.5m intervals as the soil profile transitioned into the top of the Matua Subgroup. This was done to provide a clear indication of the Vs profile through the transition. Seismic readings were obtained at 0.5m intervals using the sDMT.

4.2 Geonor vane testing

Down-hole Geonor vane testing was carried out at five locations at various depths to obtain direct measurements of the peak and residual shear strength of the Holocene swamp deposits. The testing was carried out by Perry Geotech Ltd using an electronic Geonor vane. The vane test locations were paired with an existing CPT, to enable the required test depths within the target cohesive materials to be identified, and to allow calibration of N_{kt} and evaluation of sleeve friction (fs) as a measure of remoulded shear strength for the site soils.

5 ANALYSIS OF RESULTS

5.1 Comparison of shear wave velocity

5.1.1 Velocity Comparison

Comparison was undertaken of co-located Vs and correlated Vs from CPT testing. sDMT (true interval) and sCPT (pseudo interval) results correlate well with the exception of a zone approximately corresponding with the dense/weakly cemented zone at the base of the beach deposits and the top of the swamp deposits, in this zone limitations in the quality of data is apparent (402 to 404) indicated by the averaging of results (constant velocity/depth over >0.5m).

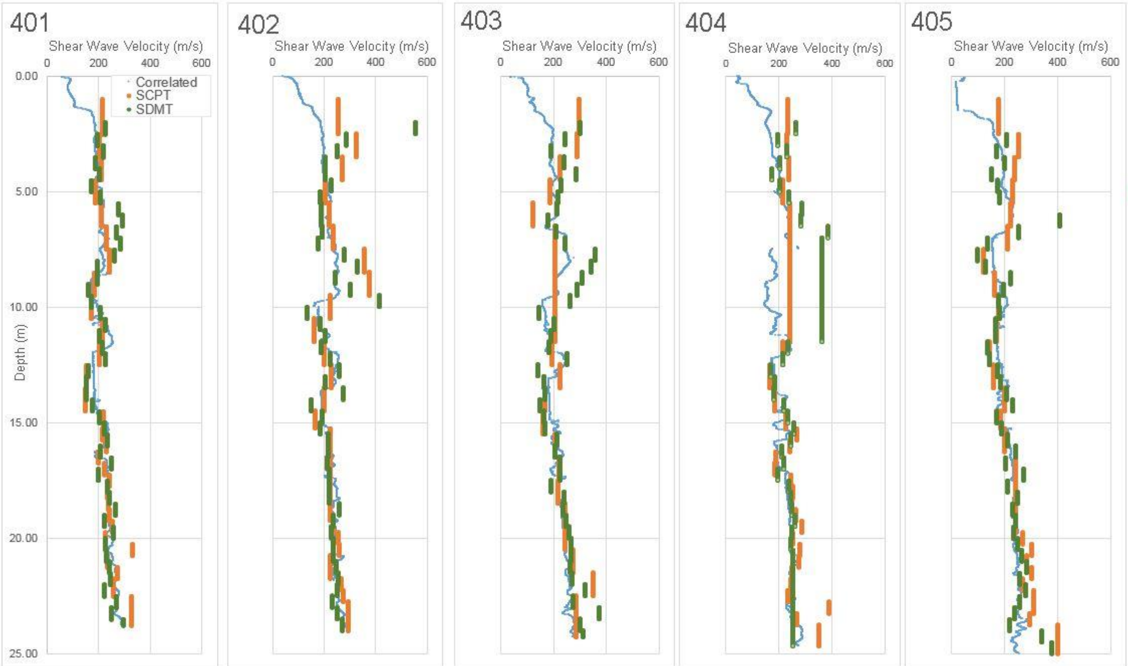

Figure 4: Comparison of co-located CPT derived and sDMT derived shear wave velocities

5.1.2 Liquefaction potential comparison

The measured and correlated Vs profile presented in Figure 4 are then utilised to prepare FOSliq under ULS shaking for further comparison in Figure 5. The nonlinear relationship between CRR and Vs is illustrated by the significantly greater apparent variation in the test results. Another noteworthy aspect of the plots in Figure 5 is the significantly higher FOSliq indicated by the Vs based analysis compared to the CPT based analysis in the older soils, particularly Matua Subgroup (typically around a depth of 15m).

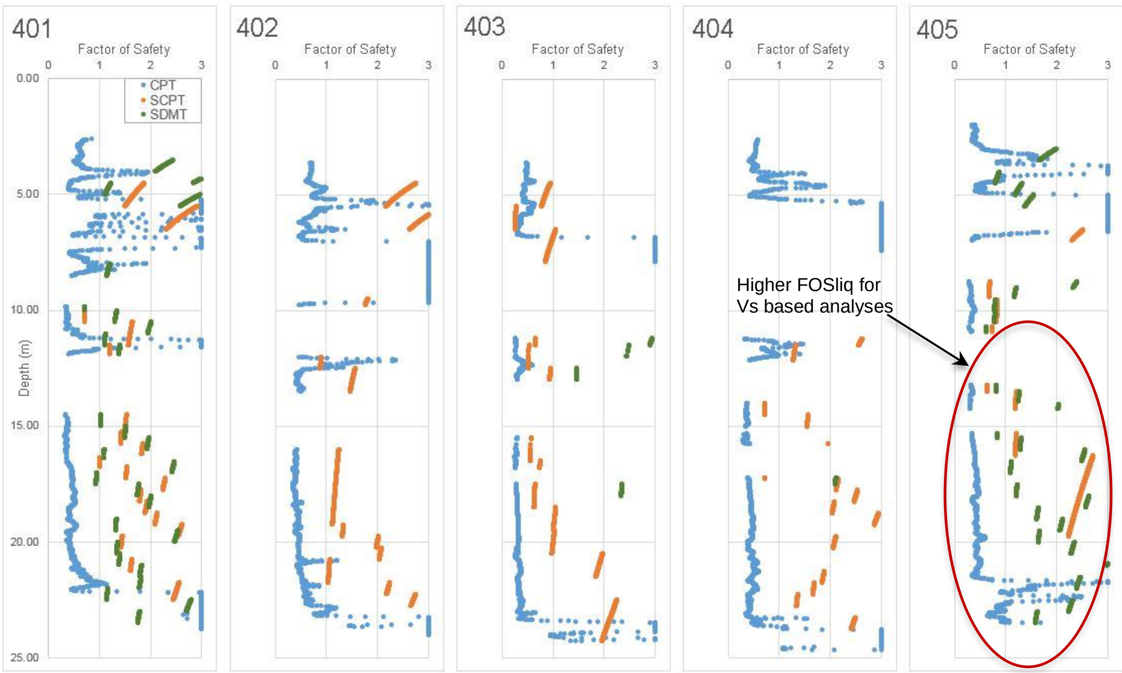

Figure 5: Comparison of CPT, Vs (sCPT) and Vs (sDMT) FOSliq for co-located tests

5.2 Comparison of shear strengths

Comparison was also made of peak and residual Cu measured from vane tests against peak Cu derived by correlation to CPT (CuNkt), (CuNk) and residual Cu based on CPT sleeve friction (Figure 6A and 6B). Correlated peak/residual Cu would commonly be applied while assessing the potential for and consequences of cyclic softening.

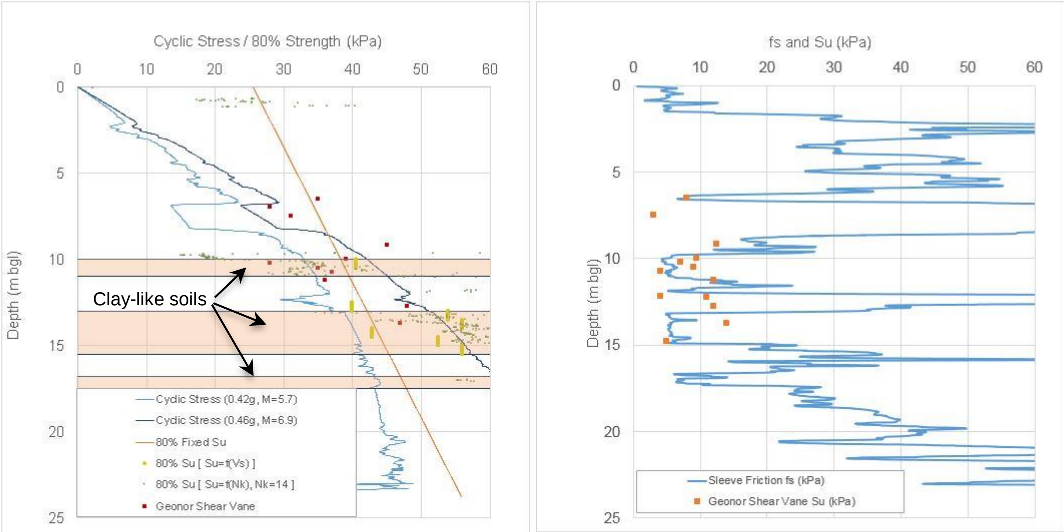

Figure 6A and 6B: Depth vs measured and correlated strength.

6 DISCUSSION

6.1 Shear wave velocity testing

The execution of a number of side by side Vs and CPT tests has allowed comparison of both true and pseudo interval downhole Vs measurements and the correlated Vs from CPT. In general very good correlations were present between all three, with two exceptions:

- sDMT (true interval) and SCPT (pseudo interval) results correlate well with the exception of a zone corresponding with the dense/weakly cemented sands at the base of the beach deposits and the top of the swamp deposits. Limitations in the quality of data is apparent (esp 402 to 404) indicated by the averaging of results (constant velocity/depth over >0.5m). This is likely associated with the large velocity contrast and inverted velocity profile between the base of the beach deposits and the swamp deposits.
- The ratio between measured and estimated (from CPT) Vs (MEVR) was noted to be greater at depth, in particular within the Matua Subgroup. This is likely associated with age related effects (or less likely, particle crushing).

The above findings have a number of implications for design. Firstly that shear wave velocity measurement can provide consistent results independent of method, but that care is required to assess the quality of data prior to application. To that end contractors undertaking investigation and practitioners utilising Vs testing should communicate about the level of uncertainty in individual test results, including flagging areas of uncertainty such as where data must be averaged over a greater interval or where there is a large difference between polarised results. Secondly, higher MEVR are noted within older deposits in this location, in particular the Matua Subgroup, indicative of comparatively higher age related liquefaction resistance not identified in the penetrometer based (CPT) liquefaction assessment.

Although the CPT derived Vs correlation used showed good agreement with the Vs measurements in this instance, in the authors' experience elsewhere there is typically a bias with the particular correlation that results in correlated Vs higher than measured. This bias is reflected in the variance shown in FOSliq (Vs/qc) in Figure 5.

6.2 Shear Strength

Comparison of measured and correlated peak and residual undrained shear strength determined utilising correlations of Cu (peak) = qt *Nkt and Cu (residual) = fs based on Robertson (2015) were found to show good agreement with shear strength as measured using a large vane test (LVT). This finding validates the ongoing use of CPT based cyclic softening assessment.

7 CONCLUSIONS

The execution of five sets of side by side true and pseudo interval Vs and paired CPT tests through Holocene and Pleistocene alluvial and airfall deposits has allowed comparison of both Vs from two different methods and CPT. This comparison has lead to the following conclusions:

- Downhole Vs testing, either true or pseudo interval, can give good repeatability of results.
- Under certain ground conditions, in this case likely associated with an inverted velocity profile, shear wave test results may be less reliable/more challenging to interpret.
- An appreciation for reliability of data can be gathered from close attention to the difference between polarised results and where velocity is averaged over an interval.
- Consistent with observations from a number of other studies (Clayton et,al (2017), Clayton & Johnson (2013)) measured to estimated velocity ratio (MEVR) is typically higher in older deposits (in this case the c. 1.8Ma to 0.1Ma Matua Subgroup) indicating age related liquefaction resistance is not identified by CPT based assessments.

LVT were also carried out to validate CPT based correlation to peak and residual undrained shear strength. These tests identified a good correlation between correlations of qt and fs to peak and residual shear strength for use in assessing the risk, and consequences of cyclic softening.

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