Site subsoil class determinations in Tauranga

ABSTRACT:
The site subsoil classes used in Tauranga often rely on relatively shallow ground investigation data, and a site subsoil class C (shallow soil) is often used for seismic design outside of areas dominated by Holocene materials. In this study, active- and passive-source surface wave testing was undertaken at a number of sites around Tauranga to determine the shear wave velocity profile of the subsurface. The results were combined with the available geotechnical and geological information to define the site subsoil class of each site in terms of NZS1170.5 (SNZ 2004). While parts of Tauranga are underlain at relatively shallow depth by ignimbrites, site subsoil class C may not be an appropriate classification, as the ignimbrites may not classify as rock and are often underlain by older alluvial deposits due to the complex geological history of the area. The results of this preliminary study indicate that most of the sites within the Tauranga Basin are likely to have a site period greater than 0.6 seconds, and should therefore be classified as site subsoil class D (deep or soft soil) at a minimum, especially those more than a few hundred metres from the edge of the basin. Site subsoil class E (very soft soil) was also applicable for two sites that were located near the edge of the basin, due to the presence of greater than 10 m of material with a shear wave velocity less than 150 m/s.

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1. INTRODUCTION

Tauranga is the largest city in the Bay of Plenty, and one of the fastest growing areas in New Zealand. While most buildings are low-rise, several multi-storey office buildings have been constructed in recent years. Tauranga is in an area of moderate seismic hazard, with a hazard factor (Z) of 0.20 according to NZS1170.5:2004 (SNZ 2004). The Tauranga area has had an active seismological past, however the volcanic activity and active fault belt associated with the Taupo Volcanic Zone have now moved further towards the south-east.

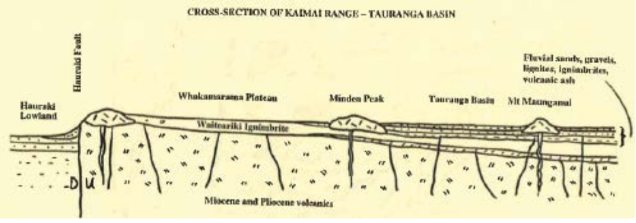

Figure 1: Geological cross section of Kaimai Range and Tauranga Basin (Briggs, 1997).

The geology around Tauranga is a complex mixture of estuarine, fluvial, volcanic flow and airfall deposits. The oldest materials in the Tauranga region are the volcanic and volcaniclastic rock of the Kaimai Subgroup, which form the Kaimai Range in the western limit of the Bay of Plenty. The bulk of the region was formed by a series of pyroclastic flows (ignimbrites), varying in age from Late Pliocene to Quaternary (Briggs et al. 2005). The ignimbrites have formed plateaus with a gentle dip towards the north or north-east, with Pleistocene and Quaternary volcaniclastic sediments infilling the north-eastern part of the Tauranga Basin, which also comprises Tauranga Harbour (refer Figure 1 and 2). There are also several localised lava domes and flows, which range in age from 2.9 to 1.9 Ma (Otawa Volcanics and Minden Rhyolite (R5-R6)), including the prominent Mount Maunganui dome.

Because of the complex geological setting and different interpretations on whether ignimbrite deposits should be considered bedrock, the aim of this preliminary study was investigate the site subsoil classification at a selection

SITE CLASS	GENERAL DESCRIPTION	TIME-AVERAGED SHEAR WAVE VELOCITY TO 30M (V_{s30}) (m/s)	UNCONFINED COMPRESSIVE STRENGTH (UCS) (MPa)	DESCRIPTION
A	Strong rock	> 1,500	> 50	Not underlain by materials with UCS < 18 MPa or *Vs* < 600 m/s.
B	Rock	> 360	1 - 50	Not underlain by materials with UCS < 0.8 MPa or *Vs* < 300 m/s. A weaker surface layer up to 3 m depth may be present.
C	Shallow soil sites	-	-	Not A, B or E and low-amplitude natural period · 0.6 s or soil depth less than Table 3.2 of NZS1170.5.
D	Deep or soft soil sites	-	-	Not A, B or E and low-amplitude natural period > 0.6 s or soil depth greater than Table 3.2 of NZS1170.5.
E	Very soft soil sites	-	-	> 10 m of soils with su < 12.5 kPa, N < 6 and/or *Vs* < 150 m/s.

Table 1: NZS1170 site subsoil classifications.

of sites across Tauranga using active- and passive-source surface wave testing. Testing was undertaken to determine the site period and shear wave velocity profile of the subsurface at locations outside regions dominated by Holocene deposits. The results were combined with details of the geotechnical/geological profile to define the NZS1170.5 site subsoil class at each test location.

2. SITE SUBSOIL CLASSIFICATION IN TAURANGA

NZS1170.5 uses five site subsoil classes, where A is strong rock, B is rock, C is shallow soil, D is deep or soft soil and E is very soft soil. Table 1: NZS1170 site subsoil classifications.1 summarises the site subsoil classes.

NZS1170.5 only classifies a site as site subsoil class B (rock) if it has:

1. a Vs30 greater than 360 m/s; **and**,
2. a compressive strength greater than 1 MPa; **and**,
3. is not underlain by material with a UCS > 0.8 MPa.

Site subsoil classes C and D are differentiated using the low-amplitude natural period (*T*) or descriptive definitions related to soil type and depth to bedrock. Depth limits of soil above bedrock for class C sites are given in Table 3.2 of the Standard, ranging from 0 m for very soft or very loose soil (s_u < 12.5 kPa or N < 6) to 60 m for very stiff/hard or very dense soil (s_u > 100 kPa or N > 50).

No definition is given as to what constitutes 'bedrock' in NZS1170.5. The criteria for site class B (rock) could be used to define bedrock, however a shear wave velocity of 360 m/s may be considered to be too low to constitute bedrock, with a value of 760 m/s often used internationally (BSSC 2015). The minimum compressive strength of 1 MPa for site subsoil class B includes very weak to extremely strong rock (R1 to R6) but excludes extremely weak rock (R0) (NZ Geotechnical Society Inc. 2005). The ignimbrites and lavas can generally be classified as rock, with the strength varying from very weak (R1) to extremely strong (R6), except for the Te Ranga Ignimbrite, which can be extremely weak (R0) (Briggs et al. 1996).

While the recommended method to determine the site subsoil class in NZS1170.5:2004 is related to the shear wave velocity of a profile, for most projects it is defined using the descriptive definitions in the Standard, which consider soil type and depth. This has led to some conflicting assessments around Tauranga, where ignimbrite or refusal in a CPT test is often considered to correspond to 'rock' in terms of NZS1170.5, often resulting in a site subsoil class C. This may not be appropriate in all locations, especially where the ignimbrite is underlain by sedimentary deposits or where the ignimbrite is not sufficiently strong to be classified as rock, in which case class D would be more appropriate.

Another way to explore this is that if these ignimbrites were present at the ground surface, the site should not be classified as site subsoil class B, as the ignimbrite deposits are underlain by alluvial material that would be unlikely to have a UCS > 0.8 MPa. Therefore, if these ignimbrites are unable to be classified as site class B at the ground surface, they should not be used to define the location of rock at depth when they still have alluvial material beneath them.

In 2002 a study was completed for the Western Bay of Plenty Engineering Lifelines Group (Opus 2002), which included maps showing the site subsoil classes in the study area. The assignment of site subsoil classes was based on geological mapping, with geological units older than Late Quaternary sediments being classified as either site subsoil class C or A. This resulted in the majority of the Tauranga urban area being classified as site subsoil class C without considering the depth of sediments, which is generally greater than the limit for site subsoil class C. While the maps were prepared for the attenuation model used in the study and were not intended to be used for building design, the lack of alternative published information has led to these maps being used as the first (and sometimes only) reference for determining the site subsoil class around Tauranga.

3. SURFACE WAVE TESTING METHODOLOGY

Active- and passive-source surface wave tests were undertaken at nine sites around Tauranga. All available subsoil data near the test locations was collated and used to interpret and constrain the test results. The test locations are shown on Figure 2: Test locations (square: H/V only, circle: H/V and active source) and approximate extents of Tauranga suburbs (dash-dot line) on geological map (after Leonard et al. 2010).2. The test locations were chosen using the following criteria:

- Good availability of nearby subsurface investigation data;
- Relatively level ground, away from nearby steep slopes;
- Proximity to main areas of development or strong motion stations (e.g. Tauranga Boys College);
- Spatial distribution around Tauranga;
- Covering different geological units (apart from Holocene materials).

On the background geological map (Leonard et al. 2010), different shades of pink represent various pyroclastic flows (ignimbrites), purple and red are lava domes and flows, dark yellow is a group of fluvial, lacustrine and estuarine deposits (Matua Subgroup), and light yellow represents all Holocene sediments. The approximate extent of Tauranga urban area is indicated by the dash-dot line, with the central business district north of Tauranga Primary and east of Wharepai Domain.

3.1 Active Source Testing

Active source surface wave testing was undertaken using a linear array of 24 vertical 4.5 Hz geophones with a 2.0 m spacing. Active-source methods included a combination of the Spectral Analysis of Surface Waves (SASW) (Nazarian & Stokoe 1984, Stokoe et al. 1994) and the Multi-channel Analysis of Surface Waves (MASW) (Park et al. 1999). The source used in this testing was a 5.4 kg sledgehammer on a steel strike plate with a rubber pad. Figure 3 shows a typical test set-up. Three different source offsets (5, 10 and 20 m) were used from both ends of the array to account for lateral variability along the lines and for near source effects that may contaminate the results. Ten sledgehammer impacts were recorded at each offset, with stacking of the records used to reduce the background noise and thus improve the signal to noise ratio. P-wave refraction testing was also undertaken to identify the depth to saturation in the soil profile.

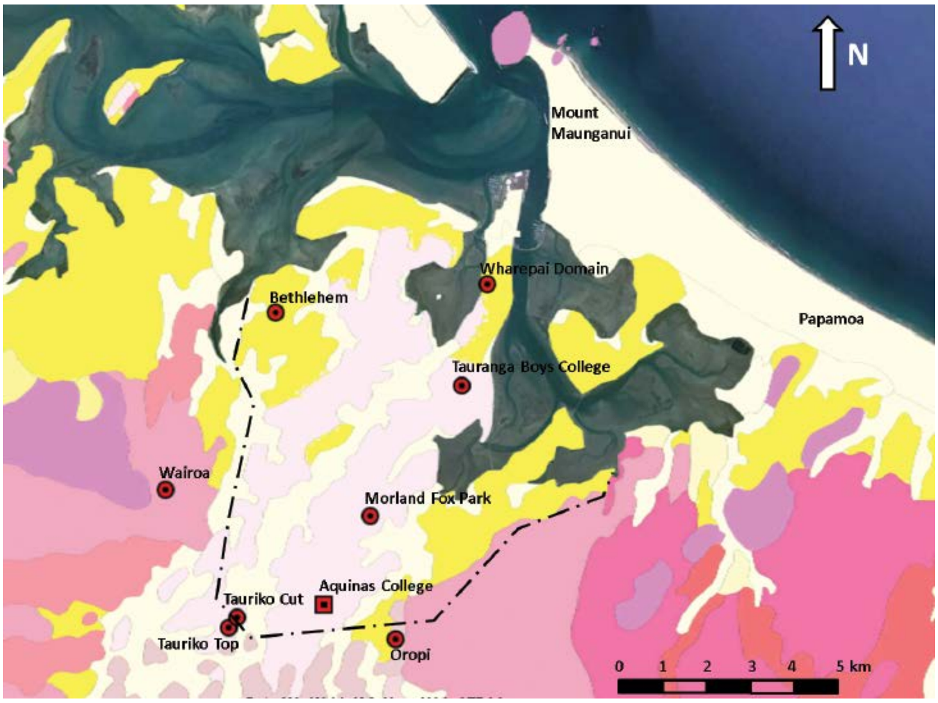

Figure 2: Test locations (square: H/V only, circle: H/V and active source) and approximate extents of Tauranga suburbs (dash-dot line) on geological map (after Leonard et al. 2010).

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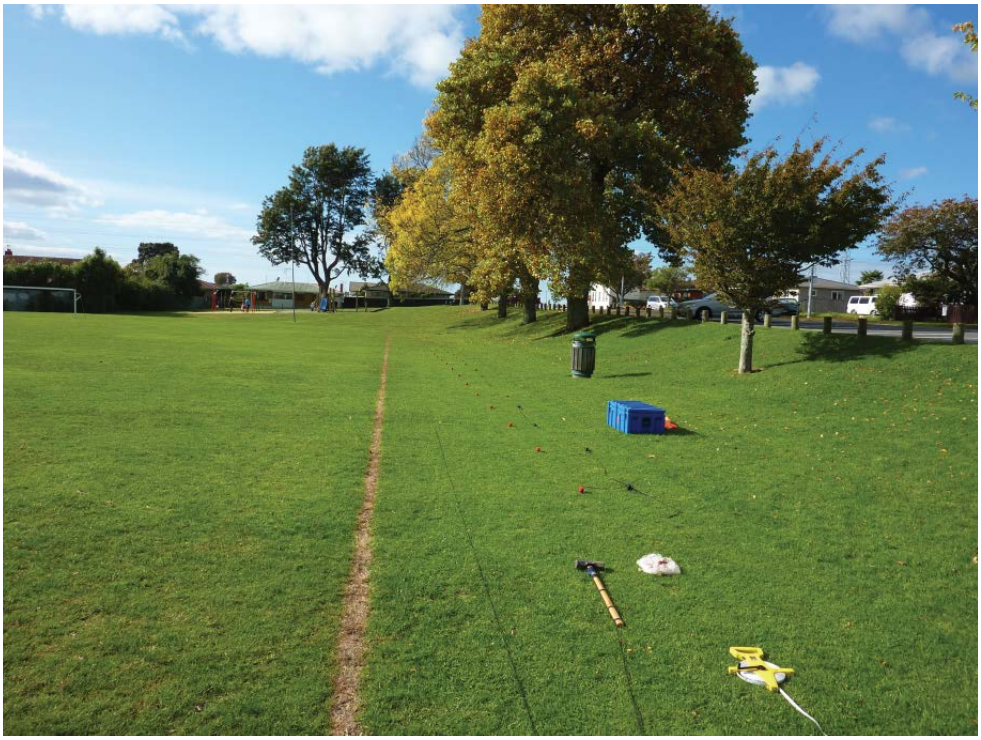

Figure 3: Typical active source test set-up, showing array of geophones, sledgehammer and pad.

The open-source software package Geopsy (www.geopsy.org) was used to develop the shear wave velocity profiles at each site using the field test data (experimental dispersion curves). To provide the best representation of the shear wave velocity profile at each site the layering and limits on soil properties were defined using information from nearby subsurface geotechnical investigation data. The shear wave velocity was generally constrained to increase with depth, except where a strength reduction between layers was observed in the geotechnical data (for example at the top of the Matua Subgroup deposits).

The period of the soil profile down to the maximum depth of the shear wave velocity profiles was estimated at each site, and where a significant impedance contrast was evident at sites (a contrast in stiffness and density from one layer to the next), the period of the profile above the depth of the impedance contrast was also calculated. The travel time in the measured (layered) profile is used to determine the average shear wave velocity (VSavg) of an equivalent uniform profile with the same overall thickness as the measured profile using:

$$V_{Savg} = \frac{\sum_i h_i}{\sum_i \frac{h_i}{V_{Si}}} \qquad (1)$$

where h_i is the thickness and V_{Si} the shear wave velocity of each layer. The period of the equivalent uniform profile (*T*) was then calculated using:

$$T = \frac{4}{V_{Savg}} \sum_i h_i \qquad (2)$$

As none of the shear wave velocity profiles presented here extended down to bedrock, the true natural site period (as required by NZS1170.5) will be larger than the periods presented herein.

3.2 Horizontal-to-vertical spectral ratio method (H/V method)

The horizontal-to-vertical spectral ratio method (H/V method) has been used in a large number of studies to characterise soil profile characteristics, with the peak (or peaks) in the H/V ratio used to estimate the fundamental period (overall profile to bedrock), or the period of the soil profile above a shallower impedance contrast. A more detailed overview of this method can be found in Nakamura (1989), Field et al. (1990), Field & Jacob (1993) and Sánchez-Sesma et al. (2011).

In this preliminary study a short period 3D geophone (2 Hz) was used to record the background ambient noise (microtremors) with an acquisition duration of 20 minutes. H/V data were processed using the Geopsy software. The data was split up into time windows, windows that were overly noisy were removed, and the remaining windows used to develop the spectral average at each location. The geometric mean of the horizontal-component Fourier spectra were used to develop the H/V spectral ratios, and a smoothing function was applied. The H/V spectral ratios from a range of time window lengths were compared during processing to determine the influence of window lengths on the estimated spectral peak(s) and to estimate the uncertainty associated with the spectral peak(s).

4. RESULTS

Examples of the shear wave velocity profiles from the active source testing at three of the sites are shown in Figures 4 to 6. They show the best (lowest misfit) profile, which is the profile that best fits the experimental data, as well as the best 50 and 1000 best profiles to provide an indication of the uncertainty in the measurements. At all locations the uncertainty generally increases with depth. A simplified representation of the layering at each site from subsurface investigation data is indicated in each figure.

At Oropi, the profile in Figure 4 shows surface layers of volcanic ashes and the Matua Subgroup with low V_s (<150 m/s) down to 15m depth, where there is an increase in V_s corresponding with the top of the Te Ranga Ignimbrite. The Tauranga Boys College profile in Figure 5 shows a gradual increase in Vs with depth through the Older Ashes or Matua Subgroup deposits from 5 to 13m depth. The V_s at the top of the Te Ranga Ignimbrite deposits is similar to the layers above. The Wharepai Domain profiles in Figure 6 show a reduction in V_s around 5m depth, at the base of the Holocene volcanic ash layers, corresponding to reduction in CPT tip resistance in this layer. The Te Ranga Ignimbrite below this shows a gradual increase in V_s with depth. Across all sites the best profile in the Te Ranga Ignimbrite does not have a V_s greater than 360 m/s down to a depth of 25 m.

Figures 7 to 9 summarise H/V spectral ratio data obtained from the microtremor recordings at three sites around the edge of the Tauranga Basin, showing the mean and plus/minus 1 standard deviation spectra. Clear peaks were evident at each of these locations (within 2 km of the exposed ignimbrite plateaus) at periods of between 0.8 and 1.05 seconds, which may correspond to the period of the entire profile to rock. Further investigation would be required to confirm this, however even if this was the response above a shallower impedance contrast, the site period at these locations are all greater than 0.6 seconds.

Although not summarised here, weak peaks in the H/V spectral ratio data were evident at locations from Tauranga Boys College north. The values of these peaks were at periods of 1.5 seconds and greater, indicating an increase in period heading away from the basin edge. Given the limitations of the equipment used for this testing there is some uncertainty in these measurements, however the longer periods agree with the general trend of an increasing depth to rock further away from the basin edges.

A summary of the period estimates at each location and their corresponding site subsoil class is provided in Table 2. The depth of the V_s profile developed at each site and the period above the base of this profile calculated using Equation 1 and 2 are summarised. While all sites had a period above the base of the V_s profile of less than the limit of 0.6 s, a site subsoil class could not be defined using this

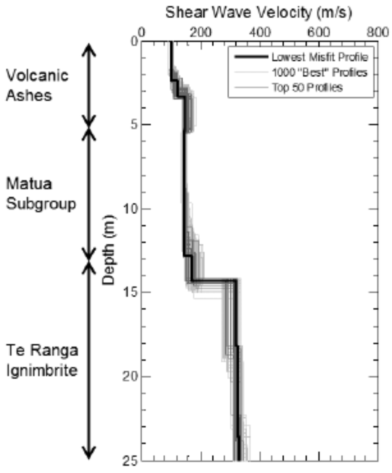

Figure 4: Shear wave velocity profile and geotechnical units from subsurface investigation at Oropi.

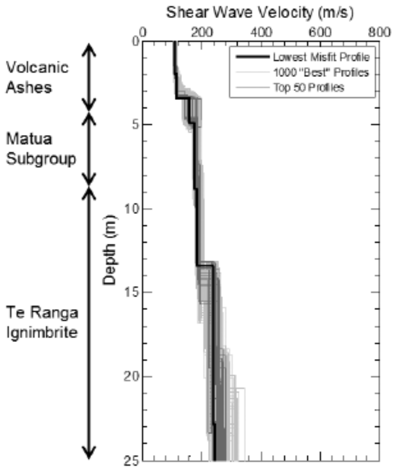

Figure 5: Shear wave velocity profile and geotechnical units from subsurface investigation at Tauranga Boys College.

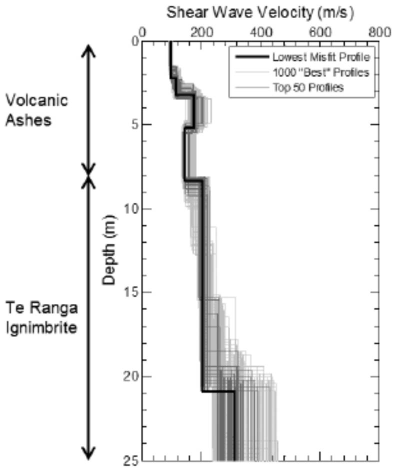

Figure 6: Shear wave velocity profile and geotechnical units from subsurface investigation at Wharepai Domain.

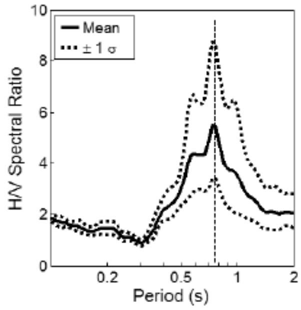

Figure 7: H/V spectral ratio data at Bethlehem.

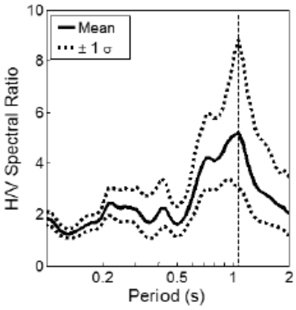

Figure 8: H/V spectral ratio data at Tauriko Cut.

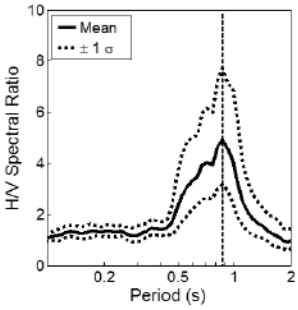

Figure 9: H/V spectral ratio data at Aquinas.

information alone as bedrock was not encountered at any of these locations. This was due to the limitation of energy provided by the sledgehammer impacts, with a larger energy source needed to profile deeper at these locations.

When taking the limited investigated depth, shear wave velocity of the deepest layer and likely depth to rock into account, most of these sites should have a site period in excess of 0.6 seconds. This is confirmed by the H/V spectral ratio data results, which identified spectral peaks of greater than 0.6 s at all locations around the basin edge apart from Wairoa and Oropi. Considering that near the edge of the basin the H/V spectral ratio peaks were greater than 0.6 s, this suggests that all sites in the main urban area of Tauranga to the north would have site periods to rock greater than 0.6 seconds.

At Wairoa and Oropi the peaks in the H/V spectral ratio data correspond well with the geotechnical data and shear wave velocity profiles. At Oropi, there is a doubling of the Vs at approximately 14 m depth as indicated in Figure 5. The estimated period of the shear wave velocity profile above this depth is equal to 0.42 seconds, similar to the 0.45 second estimate from H/V spectral ratio testing. Similar to this, at Wairoa, near the edge of the Tauranga Basin, the period estimate from H/V spectral ratio testing of 0.3 seconds was similar to the period of the shear wave velocity profile above an impedance contrast at 10 m depth.

At Wairoa a site subsoil class C could be applicable if rock is present at the site within approximately 40 m depth. This location has been given a C/D classification, and the final site subsoil class would need to be confirmed using additional investigations. At Oropi, the upper 12.8m of soil had a V_s of less than 150 m/s. At Tauriko Top the depth of soil with a V_s of less than 150 m/s was 11.1 m, therefore both Oropi and Tauriko Top should be classified as site subsoil class E. At all other sites the Vs profile did not meet the site class E limits, and therefore based on

SITE	V_S PROFILE DEPTH (m)	PERIOD ABOVE BASE OF V_S PROFILE (s)	PERIOD (FROM H/V DATA) (s)	PERIOD ABOVE SHALLOW IMPEDANCE CONTRAST	NZS1170.5 SITE SUBSOIL CLASS
Aquinas	-	-	0.85	-	D
Bethlehem Country Club	23	0.53	0.80	-	D
Morland Fox Park	23	0.47	1.05	-	D
Oropi	25	0.55	0.45	0.42	E
Tauriko Cut	16	0.37	1.05	-	D
Tauriko Top	25	0.53	-	-	E
Tauranga Boys	25	0.54	-	-	D
Wairoa	23	0.45	0.30	0.25	C or D
Wharepai Domain	22	0.52	-	-	D

Table 2: Estimates of site period or period of reduced profile depth and NZS1170.5 site subsoil class

the site period estimates they should be classified as site subsoil class D.

5. CONCLUSIONS

Based on active surface wave testing, H/V spectral ratio measurements, and knowledge of regional geology, this preliminary study has provided site subsoil classifications that should be used in locations not dominated by surface Holocene deposits across Tauranga.

While several of the sites tested are underlain at relatively shallow depth by ignimbrites, these sites should not be classified as site subsoil class C, as the ignimbrites do not classify as rock and are often underlain by older alluvial deposits due to the complex geological history of the area. The results of this preliminary study indicate that most of the sites within the Tauranga Basin are likely to have a site period greater than 0.6 seconds, and should therefore be classified as site subsoil class D (deep or soft soil) at a minimum, especially those more than a few hundred metres from the edge of the basin.

Two of the sites (Tauriko Top and Oropi) should be classified as site subsoil class E, with over 10 m of material with V_s less than 150 m/s. One site near the edge of the Tauranga Basin (Wairoa) would need further investigations to confirm the depth to rock and determine the rock properties, which may result in a site subsoil class C classification if favourable.

It is recommended that the local community of geotechnical and structural engineers consider the overall geological setting when using relatively shallow investigation data to determine the appropriate site subsoil class for seismic design of buildings.

6. FUTURE RESEARCH

Additional testing H/V spectral ratio testing across the region, combined with the available subsurface data, could be used to develop a detailed map of site periods in the region, which should help to standardise the subsoil class used in building design. This future testing should utilise broadband seismometers and longer duration records so that the period of the overall soil profile to bedrock can be characterised.

Testing should include both shear wave velocity measurements and UCS tests on potential bedrock, and testing in areas underlain by alluvial deposits. Once the shear wave velocity profile is well understood, a 1D site response analysis could be undertaken to establish how the response spectrum compares to those given in the Standard.

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