A Comparison of the Seismic Demands Calculated for Residential Buildings using DZ TS 1170.5 and NZS 3604

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ABSTRACT

Light timber-framed residential buildings designed using NZS 3604:2011 (SNZ, 2011) form a significant part of New Zealand's building stock. Seismic calculations in NZS 3604 are based on NZS 1170.5:2004 (SCNZ, 2004). The new draft Technical Specification DZ TS 1170.5:2024 (SNZ, 2024), which incorporates the new National Seismic Hazard Model, may replace NZS 1170.5. This paper compares seismic demand coefficients calculated using NZS 3604 and TS 1170.5 for residential buildings, assessing whether NZS 3604 will fall 'out-of step' with the general seismic design approach in New Zealand upon the adoption of TS 1170.5 and whether an urgent update is needed as a result.

TS 1170.5 and NZS 3604 differ in how seismic coefficients are calculated. As well as this, NZS 3604 uses simplified bounding for the hazard factor (Z) and TS 1170.5 introduces a default site class. Despite these differences, for most locations, TS 1170.5 produces design demand coefficients similar to or lower than those from NZS 3604. However, on rock sites, particularly in Wellington, TS 1170.5 results in demand coefficients up to 50% higher than NZS 3604.

Considering the good performance of NZS 3604 buildings during the Christchurch earthquakes, it is concluded that the seismic design approaches used in NZS 3604 and TS 1170.5 remain 'in-step' and NZS 3604 does not need urgent updating. However, based on damage observed in high-acceleration areas during the Christchurch earthquakes, it is recommended that heavy cladding should be avoided on residential buildings designed for rock sites with high accelerations, such as in Wellington.

1 INTRODUCTION

NZS 3604, the standard for timber-framed buildings, is used to design of the majority houses in New Zealand. The standard can be used without the need for specific structural engineering design and varies from other standards as it provides both demand and capacity for structural elements. The seismic demands presented in NZS 3604 are based on the current seismic actions standard, NZS 1170.5. However, a new draft technical standard, TS 1170.5, has been put forward for public consultation and may supersede NZS 1170.5.

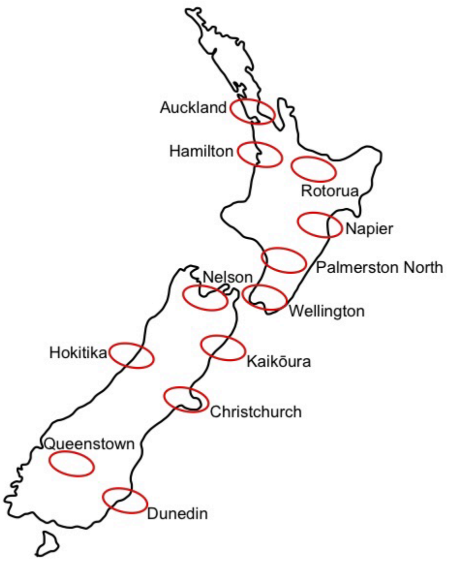

Figure 1: Locations considered.

The motivation for updating NZS 1170.5 is to include the new National Seismic Hazard Model, which is adopted in TS 1170.5. The new National Seismic Hazard Model significantly increases the anticipated seismicity of certain regions.

This paper considers whether NZS 3604 will fall 'out-of step' with the general seismic design approach upon the adoption TS 1170.5 and if NZS 3604 should therefore be urgently updated. To answer this question, seismic demand coefficients calculated using TS 1170.5 were compared with the coefficients used in NZS 3604. This comparison was carried out for light-timber framed buildings across 12 locations (Figure 1). These locations were chosen to represent a broad geographic spread across the country and a range of seismic hazard zones.

2 CALCULATION OF SEISMIC DEMAND COEFFICENTS

The seismic design characteristics of residential light timber-framed buildings within the scope of NZS 3604 are outlined in The Engineering Basis of NZS 3604 (Shelton, 2013). Consequently, the following assumptions were made for calculations when using TS 1170.5: a period of 0.4 s, a ductility of 3.5, an importance level of 2 and a design life of 50 years. No near fault effects were considered for any locations. While a period, T, of 0.4 s has been considered, the spectra in this paper were produced for the range $T \leq 4.5$ s to help better visualise the results.

2.1 NZS 3604

The tabulated seismic demands presented in NZS 3604 are based on values calculated using NZS 1170.5 (Shelton, 2013). These calculations use the horizontal design action coefficient, $C_d(T_1)$, as defined in NZS 1170.5. The equation for $C_d(T_1)$ is given as:

$$C_d(T_1) = \frac{C(T_1)S_p}{k_\mu} \tag{1}$$

where T_1= largest translational period in the direction under consideration; S_p = structural performance factor; k_μ = inelastic site spectrum scaling factor; and $C(T_1)$ = elastic site spectrum coefficient for horizontal loading, as defined in is Equation 2 below:

$$C(T_1) = C_h(T_1)ZRN(T,D) \tag{2}$$

where $C_h(T_1)$ = spectral shape factor; Z = hazard factor; R= the return period factor; and $N(T,D)$=near fault factor.

The value of S_p was taken as 0.7 for light timber-framed buildings with a ductility, μ, of 3.5. The values of $C_h(T_1)$ and k_μ for T_1=0.4 s are presented in Table 1. Based on these values the five soil classes are consolidated into three groups: A&B, C, and D&E. While the value of k_μ varies slightly for soil classes D and E, NZS 3604 groups their results together.

While NZS 3604 is based on NZS 1170.5, the Z factors used in each standard vary. NZS 3604 uses simplified bounding to group the NZS 1170.5 Z factors into four “zones” with set values (Table 2). The values for the “zones” used in NZS 3604 are always greater than the Z factors defined for each location in NZS 1170.5, except for Christchurch which was increased from Z = 0.22 to 0.3 following the Canterbury earthquake sequence.

Table 1: NZS 3604 soil class specific parameters.

Soil class	Soil type	k_μ	C_h(T=0.4 s) (g)
A	Rock	2.4	1.89
B	Rock	2.4	1.89
C	Shallow	2.4	2.36
D	Deep to very soft	2.4	3.00
E	Deep to very soft	2.3	3.00

Table 2: NZS 3604 and NZS 1170.5 hazard factors Z.

Location	NZS 3604	NZS 1170.5	Location	NZS 3604	NZS 1170.5
Auckland	0.20	0.13	Nelson	0.30	0.27
Hamilton	0.20	0.16	Kaikōura	0.46	0.42
Rotorua	0.30	0.24	Hokitika	0.46	0.45
Napier	0.46	0.38	Christchurch	0.30	0.30
Palmerston North	0.46	0.38	Queenstown	0.46	0.32
Wellington	0.46	0.40	Dunedin	0.20	0.13

2.2 TS 1170.5

Similar to NZS 1170.5, TS 1170.5 uses Equation 1 to calculate $C_d(T_1)$, with S_p set to 0.7. However, the inelastic site spectrum scaling factor is defined as:

$$k_\mu = \mu \tag{3}$$

The elastic site spectrum horizontal coefficient equation also varies from NZS 1170.5 and is given as:

$$C(T) = S_a(T)N(T,D) \tag{4}$$

where $S_a(T)$ = spectral acceleration and is defined by equations 5 to 8 below.

$$S_a(T) = PGA\ for\ T = 0\ s \tag{5}$$

$$S_a(T) = S_{as}\ for\ 0.1\ s < T < T_c \tag{6}$$

$$S_a(T) = S_{as}\frac{T_c}{T}\ for\ T_c < T < T_d \tag{7}$$

$$S_a(T) = S_{as}\frac{T_c}{T}\left(\frac{T_d}{T}\right)^{0.5}\ for\ T_d < T \tag{8}$$

where S_{as} = short-period spectral acceleration; T_c = spectral-acceleration-plateau corner period; and T_d = spectral-velocity-plateau corner period, taken as 3 s.

Values of S_{as} and T_c are provided in Table 3.3 and 3.4 of TS 1170.5 based on location, annual exceedance probability, and site class. TS 1170.5 has seven different site classifications (I-VII) which are based on the time-average shear velocity over a 30 m depth from the ground surface, $V_s(30)$. If insufficient soil properties are available to determine the site classification for a given site, a default site class may be adopted.

The default site class is expected to be widely used in residential design projects due to the availability and cost associated with obtaining the necessary geotechnical information needed to determine the specific classes. This paper uses a proposed revised default site class that defines the elastic site spectrum, C(T), as the envelope of the elastic site spectrum for site classes II - VI.

Elastic site spectra generated using the default site class are shown in Figure 2 for Christchurch and Wellington. The chosen period 0.4 s coincides with the corner period for site class II in Wellington, which governs the default site class at this location. The site class which governs the default site class at each test location for a period of 0.4 s is presented in Table 3. It is clear that for a period of 0.4 s, default site class can be governed by either stiff or softer soils, depending on the location.

Table 3: Site class which is governing the default site class at T=0.4 s for each location.

TS 1170.5 site class	Description of site class	Locations
II	Very stiff soil, very dense soil or soft rock	Napier, Palmerston North, Wellington, Kaikōura
IV	Moderately stiff or medium dense soil	Hokitika
VI	Very soft or very loose soil	Auckland, Hamilton, Rotorua, Queenstown, Nelson, Christchurch, Dunedin

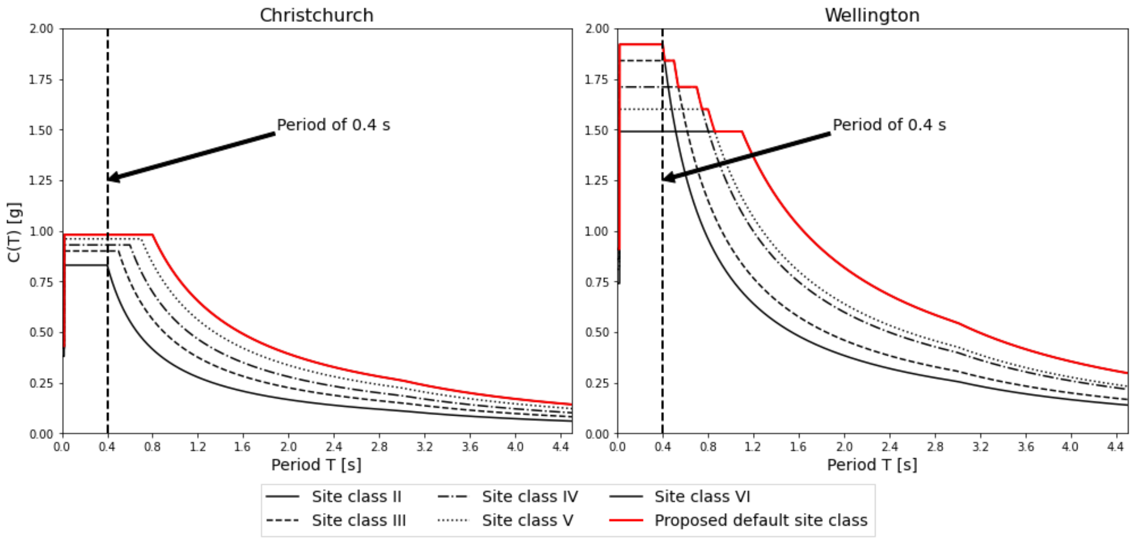

Figure 2: Elastic site spectra from TS 1170.5 for Christchurch (left) and Wellington (right) showing site classes II- VI and the default site class.

3 COMPARISON OF SEISMIC DEMAND COEFFICENTS

For the remainder of this paper $C(T_1)$ will be referred to as the elastic spectrum coefficient and $C_d(T_1)$ will be referred to as the design demand coefficient. Together, $C(T_1)$ and $C_d(T_1)$ will be referred to as seismic demand coefficients. The comparison of seismic demand coefficients in this paper focuses on how values calculated using TS 1170.5 compare with values used in NZS 3604. The values used in NZS 3604 are produced using NZS 1170.5 for buildings within the scope of NZS 3604, mostly residential buildings.

3.1 Elastic site spectra

Elastic spectrum coefficients, $C(T_1)$, were calculated for each location using the TS 1170.5 default site class. These values were compared with coefficients used in NZS 3604. Based on the trends observed, locations were divided into two groups (Figure 3). Group 1 is locations where the default site class produces both higher and lower values of $C(T_1)$ depending on which NZS 3604 soil class it is being compared to. Group 2 is locations where the default site class produces $C(T_1)$ values which are all higher than those used in NZS 3604.

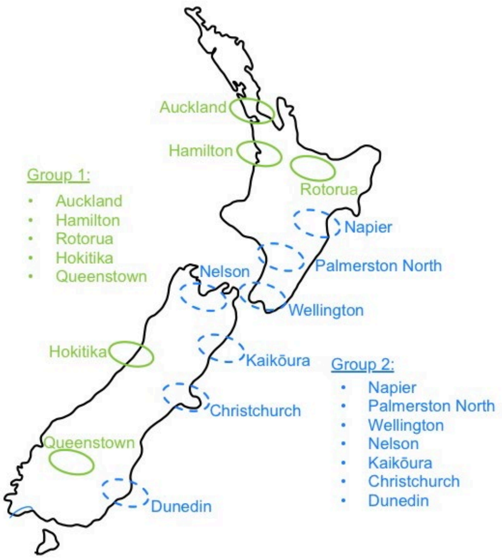

Figure 3: Grouping of locations based on trends.

Values of $C(T_1)$ calculated using the default site class for Wellington (red line in Figure 4, left) showed the most drastic increase when compared to NZS 3604 values. Values of $C(T_1)$ were 120% higher than values used for NZS 3604 soil class A&B, 80% higher compared to class C values and 40% higher compared to class D&E values (blue lines in Figure 4). On average, for the other six locations in Group 2 the default site class produced $C(T_1)$ values that were 80% higher than values used for soil class A&B, 40% higher compared to soil class C, and 10% higher compared to soil class D&E. For locations in Group 1, the $C(T_1)$ values calculated using the default site class, on average, were 30% higher compared to soil class A&B and 10% higher compared to soil class C. However, in comparison to soil class D&E values, default site class values were 20% lower. The results for Auckland are representative of these trends (Figure 4, right).

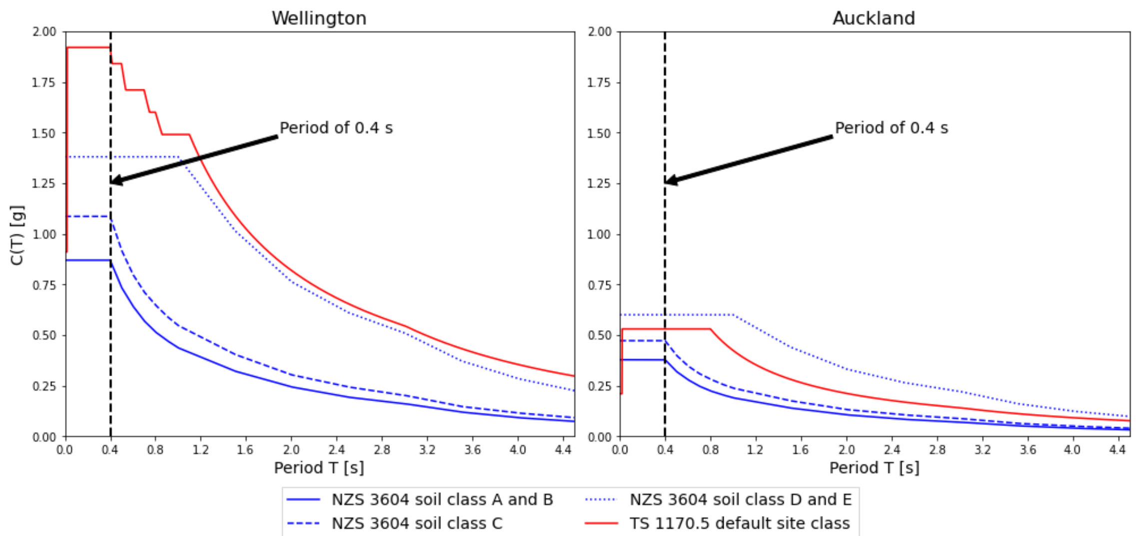

Figure 4: Elastic site spectra from NZS 3604 for Wellington (left) and Auckland (right) showing all NZS 3604 soil classes and the TS 1170.5 default site class.

3.2 Design Spectra

TS 1170.5 and NZS 1170.5 have different design approaches when considering the effect of inelastic response on seismic demand. TS 1170.5 assumes that k_μ is independent of the period, meaning for buildings within the scope of NZS 3604, k_μ is always equal to 3.5. The values of k_μ used in NZS 3604 (Table 1) are all lower than 3.5.

The values of the inelastic design demand coefficient, $C_d(T_1)$, were calculated using the default site class. Based on trends observed, the 12 locations were divided into the same groups as shown in Figure 3. For

Group 1, $C_d(T_1)$ values calculated using the default site class (red line in Figure 5) were lower than values used in NZS 3604 (blue lines) for all soil classes. On average, default site class $C_d(T_1)$ values were 10% lower than NZS 3604 values for soil classes A&B, 30% lower for soil class C, and 40% lower for soil classes D&E. Results for Queenstown (Figure 5, left) represent these trends, but with different percentages than the average figures quoted above.

For locations in Group 2, $C_d(T_1)$ values calculated using the default site class were higher compared to some soil classes and lower compared to others. Figure 5 (right) shows that values of $C_d(T_1)$ for Wellington calculated using the default site class (red line) were 50% higher than the NZS 3604 values for soil class A&B and 20% higher for soil class C (blue lines). However, in comparison to soil class D&E, values using the default site class were 10% lower than the NZS 3604 values (top blue line). On average, for the other six locations in Group 2, $C_d(T_1)$ values calculated using the default site class were 20% higher than values used for soil class A&B, 30% higher for soil class D&E and showed no difference for soil class C.

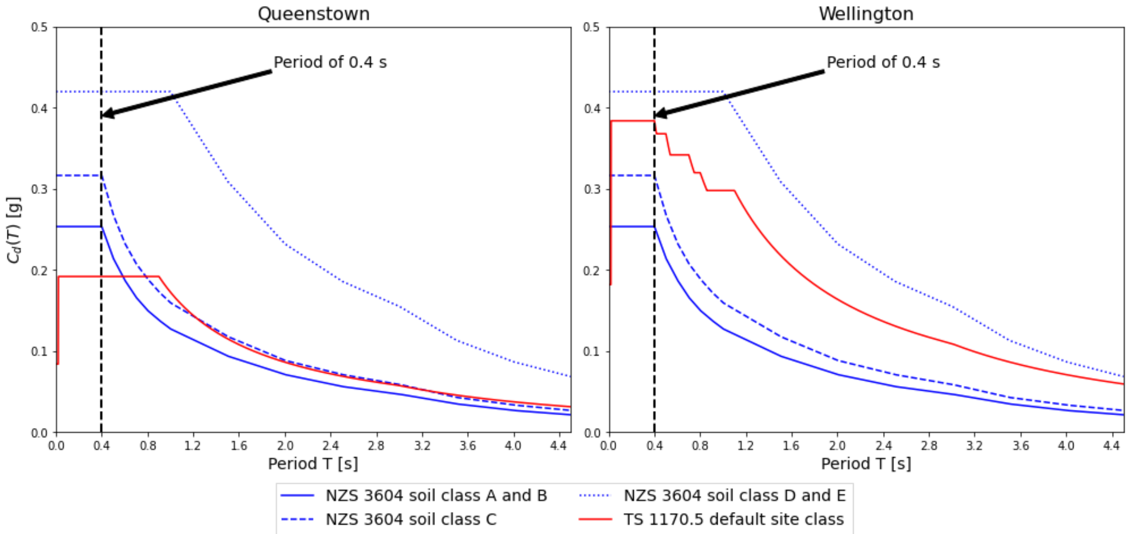

Figure 5: Inelastic design spectra for Queenstown (left) and Wellington (right) showing all NZS 3604 soil classes and the TS 1170.5 default site class.

4 DISCUSSION

4.1 Key differences in the calculation of seismic demand coefficients

There are two key differences between TS 1170.5 and NZS 3604 in the calculation of the seismic demand coefficients. The first is the generation of the elastic site spectrum. When generating $C(T_1)$ values, NZS 3604 uses the Z factor to account for location and $C_h(T)$ to account for soil class. TS 1170.5 instead uses $S_a(T)$ which is a function of S_{as}, T_c and T_d, where S_{as} and T_c are dependent on both site class and location. The second difference is the definition of k_μ. TS 1170.5 defines k_μ as independent of period, meaning for buildings within the scope of NZS 3604 the k_μ values used in TS 1170.5 will always be higher than those used in NZS 3604.

It is apparent that the seismic demand calculations used in the design approaches of NZS 3604 and TS 1170.5 are different. However, for the majority of locations considered in this paper, TS 1170.5 produces design demand coefficients which are similar or lower in value to the coefficients used in NZS 3604. As discussed in the subsequent sections, coefficient values are also influenced by the default site class used in TS 1170.5 and the simplified bounding used in NZS 3604.

4.2 The default site class used in TS 1170.5

The default site class takes the envelope of elastic site spectra generated for site classes II – VI. This means that for a given period, the site class which produces the largest $S_a(T)$ value governs the value of the elastic spectrum coefficient. When looking at a period of 0.4 s, the site classes which govern the default site class of each location are predominantly site class II (very stiff soil, very dense soil or soft rock) and site class VI (very soft or very loose soil).

Elastic site spectra generated using the default site class overpredict values for site classes which are not governing. This means for locations such as Napier and Wellington, the default site class overpredicts seismic coefficient values for soft and loose sites. For locations such as Auckland and Christchurch, the default site class overpredicts coefficient values for rock or very dense sites. For sites where the default site class overpredicts seismic demand coefficients, the comparison of these coefficients with those used in NZS 3604 may be influenced by the overprediction.

4.3 Simplified bounding used in NZS 3604

NZS 3604 uses simplified bounding to group locations by seismic hazard factor, Z. The nature of the simplified bounding means that, for all locations except Christchurch, NZS 3604 uses seismic coefficients which have higher values than if individual factors from NZS 1170.5 were used.

For sites where TS 1170.5 produces seismic demand coefficient values which are higher than the values used in NZS 3604, the simplified bounding means that the NZS 3604 and TS 1170.5 values are closer than if the simplified bounding was not used. Conversely, for sites where TS 1170.5 produces lower seismic demand coefficient values than NZS 3604, the increase in NZS 3604 coefficient values due to simplified bounding amplifies the disparity in coefficient values.

Due to the simplified bounding, NZS 1170.5 produces $C_d(T_1)$ values which are lower than those used in NZS 3604. For the majority of locations considered in this paper TS 1170.5 continues this trend. However, unlike NZS 1170.5, there are some locations where TS 1170.5 produces design demand coefficients which are higher than those used in NZS 3604. To understand if NZS 3604 requires an urgent update and potentially creates a life safety risk, a better understanding of the increases in design demands in TS 1170.5 is required.

4.4 Outcomes for locations with increased demands

Figure 6: Damage to heavy cladding due to high accelerations during the Christchurch earthquakes (courtesy of Andy Buchanan)

Light timber-framed buildings generally performed well in the 2011 Christchurch earthquakes (Buchanan et al., 2011). Timber framing and diaphragms were able maintain structural integrity, the vast majority of which would have been designed using NZS 3604. Where TS 1170.5 does produce increased design demand coefficients, for all locations other than Wellington, the increases are in the order of 10% to 30% higher than NZS 3604 values. Based on the performance of light timber-framed buildings in the Christchurch earthquake and the inherent robustness of this form of construction (Carradine et al., 2018), increases of 10% to 30% are not expected to result in significant increases in damage or threats to life safety.

According to TS 1170.5, rock sites in Wellington are expected to experience a 50% increase in seismic demands due to increased ground accelerations. There were a number of areas which experienced high accelerations in the 2011 Christchurch earthquakes such as Huntsbury, Mount Pleasant, and Sumner (Buchanan et al., 2011). While light timber-framed buildings in these locations still performed well, buildings with heavy cladding, such as brick and masonry wall cladding and concrete tile roofs, had increased levels of damage compared to buildings with light cladding (Figure 6). Some of the poor performance can be attributed to poor connections between the facade and timber framing, however, incompatibility of the systems due to differential movement and the high accelerations at low period during an earthquake is also to blame. To avoid poor performance with no changes in NZS 3604 but in light of the modified demands from TS 1170.5, it is recommended that heavy cladding should be avoided on residential buildings on rock sites where high intensity shaking is expected, especially in Wellington.

5 CONCLUSIONS

The purpose of this paper is to consider if NZS 3604 will fall 'out-of step' with the general seismic design approach in New Zealand after the adoption of TS 1170.5, and whether NZS 3604 should be urgently updated as a result. While the seismic design calculations used in NZS 3604 and TS 1170.5 are different, it was found that for most locations TS 1170.5 produces smaller design demand coefficient values than those used in NZS 3604. However, for rock sites in some locations TS 1170.5 produces higher design demand coefficient values, the most extreme case being Wellington where TS 1170.5 produces values which are 50% higher than those used in NZS 3604.

Based on these findings the following conclusions and recommendations are made:

- Considering the general trends in TS 1170.5 values when compared with NZS 3604 values and the generally good performance of NZS 3604 buildings in the Christchurch earthquakes, the seismic design approaches used in NZS 3604 and TS 1170.5 remain 'in step'.
- While future revisions of NZS 3604 should consider updating the seismic design calculations to produce seismic demand coefficients aligned with TS 1170.5, the need for such an update is not urgent.
- Based on the poor outcomes for houses with heavy cladding which experienced high ground accelerations in the Christchurch earthquakes, residential buildings designed for rock sites where high intensity shaking is expected, such as Wellington, should avoid the use of heavy cladding.

6 REFERENCES

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