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NEW ZEALAND SOCIETY FOR
EARTHQUAKE ENGINEERING

Multiple approaches toward floor shaking predictions for a Wellington building

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ABSTRACT

Resilience to seismic hazard in New Zealand (NZ) relies on better understanding and quantifying earthquake impact on building performance. The acceleration response of a building is influenced by the earthquake characteristics, its own structural characteristics and secondary components. More specifically, the extent of non-structural damage caused by the 2013 M6.6 Cook Strait and 2016 M7.8 Kaikōura earthquakes highlighted the importance of gaining a better understanding of the seismic demands imposed on the parts and components of buildings.

In this study we compare and quantify the floor performance of one of the buildings at Te Puni Village (instrumented by GeoNet) using NZ specific approaches including: i) NZS1170.5:2004 Section 8: Parts and Components (the current National loadings Standard), ii) The recommended mode-based approach by Haymes et al. (2025), Floor amplifications obtained from an engineering desktop analytical building model, and iii) behaviour derived from seismological methods applied to the building seismic array data.

This comprehensive building specific analysis provides quantitative comparison between the four methods in detail for a medium height NZ building that has been exposed to moderate level of shaking. The analysis supports building stakeholders and engineering communities in fine tuning future resilient design and assessment procedures.

1 INTRODUCTION

The extent of non-structural damage caused by the 2013 M6.6 Cook Strait and 2016 M7.8 Kaikōura earthquakes highlighted the importance of gaining a better understanding of the seismic demands imposed on the parts and components of buildings.

New recommendations proposed for NZS1170.5 (Haymes et al. (2025)) provide an updated approach for NZ practitioners for determining the seismic demands on parts and components and is the basis of the method included in TS1170.5, a proposed Technical Specification released for public comment in February 2024.

Seismic data from instrumented buildings can offer valuable insights into the dynamic behaviour of structures. The Te Puni central building in Wellington, equipped with seismic instruments on nearly every floor by GeoNet since 2009, has experienced a wide range of low to moderate levels of shaking, thus producing a comprehensive spectrum of structural response records for research.

Four approaches (two heuristic-based, direct measurements and engineering models) are currently available to estimate floor vibration amplification. It remains uncertain how these approaches compare and what inherent uncertainties they carry. This study presents a quantitative floor acceleration analysis using the latest recommendations, robust seismological analysis and data from the finite element model used by the building's engineers during design. This case-specific study provides important insights into the draft TS1170.5 methodology which is intended to form the basis of an update to the current National Standard. This study complements the work done by Haymes et al. (2025) by including data from the Te Puni building (described below), ground shaking from over 100 earthquakes and an engineering desktop software analysis.

2 FLOOR AMPLIFICATION APPROACHES

2.1 The GeoNet Te Puni building array

Te Puni Village is a facility which provides student accommodation for the University of Wellington. The central building considered in this study is a 10-storey rocking steel moment frame built in 2009 and instrumented by GeoNet in 2009 (Gledhill et al., 2013). Te Puni is an IL2 building located on site class B equivalent ground condition in Wellington.

The seismic array consists of 12 stations distributed across all floors including a vertical array of 8 sensors. The location and distribution of instruments are illustrated in Figure 1.

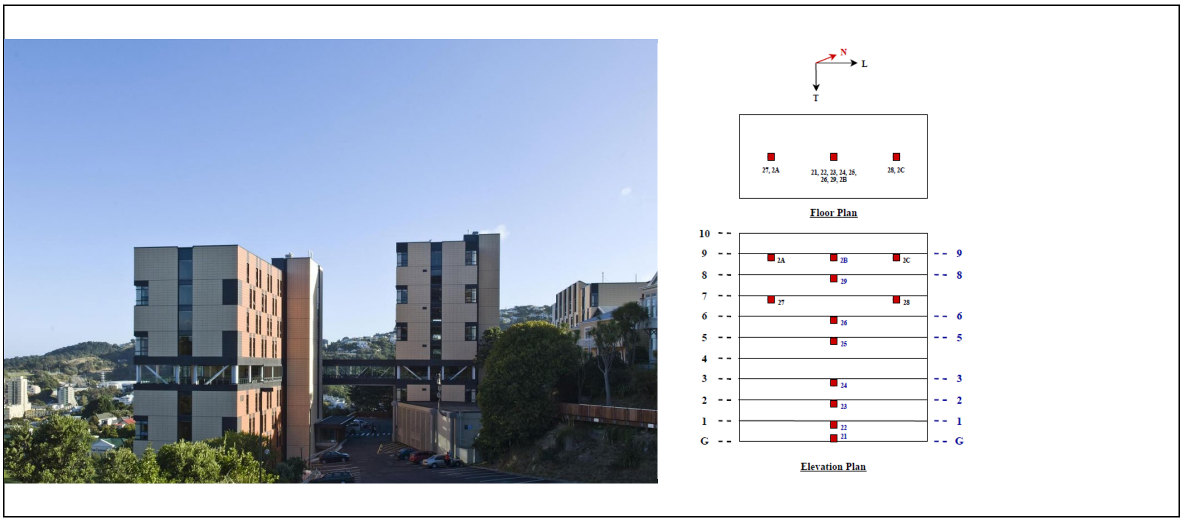

Figure 1: The instrumented central tower of the Te Puni building and detailed floor plan of the seismic array (adapted from Gawne (2025) and Gledhill et al. (2013)).

2.2 NZS1170.5:2004

NZS1170.5:2004 provides methods for the determination of design earthquake actions on structures in New Zealand. In particular NZS1170.5:2004 Section 8: Parts and Components (the current National loadings Standard) describes equations and parameters for calculating floor amplification. Key controlling parameters are input peak ground acceleration (PGA) and the ratio of floor height to total building height.

2.3 TS1170.5:2024

New recommendations proposed for NZS1170.5 (Haymes et al. (2025)) provides an updated approach for New Zealand practitioners for determining the seismic demands on parts and components and is the basis of the method included in TS1170.5.

Regarding parts and components, important changes from NZS1170.5:2004 include new equations for floor height contribution, nonlinear response, and dynamic amplification for flexible parts dependent of structural modes (Haymes et al., 2025). Parameters and related equations chosen to represent the Te Puni building are presented in Table 1.

Table 1: Te Puni specific parameters as required for TS1170.5 2025 calculations.

Total Floor height	**Structural ductility factor**	**$T_{p,long}$ (per eq. 8.2 in TS1170.5:2025)**	**Type of components**
31 m	1	2.2sec	Rigid

2.4 ETABS model

ETABS is a full 3D engineering desktop analytical building software. Aurecon New Zealand Ltd currently have an existing dynamic ETABS models of the building, updated for the C5 assessment guidelines, which provide the base information for the study.

Our team developed a virtual seismic sensor network to match the Te Puni GeoNet seismic array, generated synthetic seismic datasets and validated the virtual ETABS model against the as-recorded behaviour. Through the fidelity of the virtual model, we extracted floor amplification readings for 100+ selected earthquake events.

Inferred ETABS fundamental periods for longitudinal and transverse directions are presented in Table 2.

3 RESULTS AND PRELIMINARY CONCLUSIONS

3.1 Lessons from structural monitoring studies

Based on a comprehensive GeoNet catalogue from 2009 to 2021, Sklodowska et al. (2021) measured the dominant period of the building (Figure 2). For clarity this period derived from small vibrations is T_0 in the rest of the paper and is different from T1 the true period of the building. Sklodowska et al. (2021) showed that, for both the transverse and longitudinal directions, T_0 is:

- constant over a period of regular background seismic activity,
- smaller than the empirically derived and ETABS derived values (Table 2),
- increasing with increased earthquake loading,
- permanently larger and getting closer to T_1 ETABS following intense earthquake mainshock-aftershock activities (the Te Puni building has experienced 3 major earthquake sequences: the 2013 Cook Strait, 2013 Lake Grassmere, and the 2016 Kaikōura earthquakes).

Table 2: Dominant period of the building as measured by Sklodowska et al. (2021) and the ETABS model.

Quantity	Structural period (s)	
	Transverse direction	Longitudinal direction
T_0 Measured 2010	0.65	0.70
T_0 Measured 2025	0.70	0.81
T_1 ETABS model	1.12	1.60

Key conclusions are that during the building's lifetime, it has mainly behaved under small vibration level conditions. Observed discrepancies between measured T_0 periods and the ones from the ETABS model are generally considered due to:

- Observed measurements include not only the contribution of the main structure but also that of non-structural elements not included in the ETABS model. (ie the initial stiffness of internal partitions, façade etc)
- Linear input vibrating conditions: small vibration measurements mostly capture T_1 in the linear elastic range. The engineered building models include an account of cracked section properties considered representative of the main member states during Ultimate Limit State (ULS) shaking.
- The modelled seismic mass may not match that which the building generally supports. In particular, the Live Load and Superimposed Dead Load (SDL) components considered in the analytical model may be greater than that generally supported by the building.

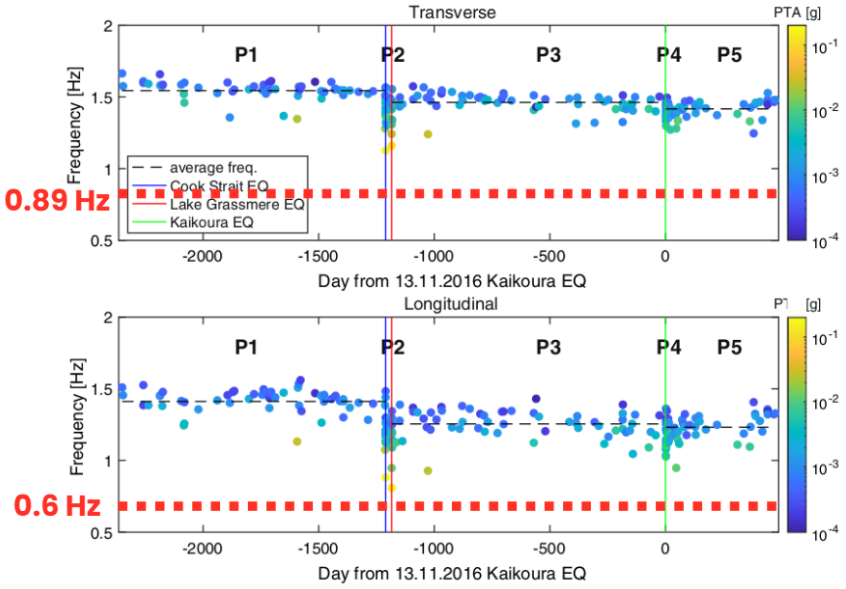

Figure 2: Measured dominant frequency for the Te Puni building as a function of days from the M7.8 2016 Kaikōura earthquake and peak top acceleration. The red dotted line indicates dominant frequency as per the ETABS model of the building (see Table 2). (Adapted from Figure 7b of Sklodowska et al. (2021))

In this study, to compare code relevant amplification factors, we favour the T_1 value derived from the ETABS model as a more appropriate input parameter to the TS1170.5 2025 model.

3.2 Comparison of the 4 amplification methods

3.2.1 Data selection

Over 30,000 earthquakes were recorded at Te Puni during the period 2010-2024 (M>3) (Gawne 2025). Gawne (2025) subsequently selected 591 sets of high quality data. We further filtered the data by excluding earthquakes producing peak pseudo-spectral acceleration lower than 0.01g at the top floor. This is to ensure the relevance of our study to the engineering community while retaining enough data to be statistically meaningful. A final suite of 103 earthquakes was utilised including three large events detailed in Table 3.

Table 3: characteristics of the largest three events recorded at the Te Puni array

Event name	Magnitude	Date	PGA Transverse (VUWB)	PGA Longitudinal (VUWB)
Cook Strait earthquake	6.5	21 Jul. 2013	0.12g	0.12g
Lake Grassmere earthquake	6.6	16 Aug. 2013	0.11g	0.09g
2024 earthquake near Wellington	5.7	6 Oct. 2024	0.15g	0.1g

3.2.2 Single floor comparisons

Figure 3 presents the 5% damped response spectra for the top floor of the building in the transverse and the longitudinal directions, for the four different approaches and for the largest three events.

NZS1170.5 2004 (magenta) is found to be overconservative as expected. The fit between the ETABS model (black) and the recorded data (red) is very good in terms of peak amplitudes and the main periods of resonance. Both methods indicate the presence of a higher modal period of 0.3 seconds in both directions, as well as, on a first mode period of approximately 1.2 seconds in the transverse direction. However, ETABS data suggests a longer first mode period of 1.6 seconds in the longitudinal direction, where the recorded data peaks at 1 seconds.

Figure 3 also shows that the second mode shape has a stronger contribution in the transverse component than the first mode. This shows that the complexity of a building like Te Puni cannot completely be captured by a simplified approach.

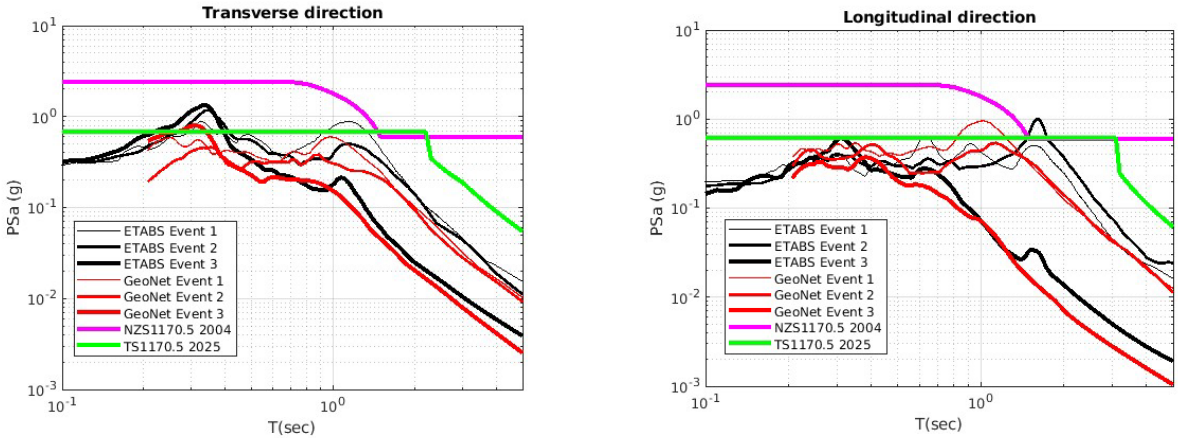

Figure 3: Response spectra (5% damping) for the top floor of the Te Puni building for the transverse and longitudinal directions and four approaches: recorded data (red), ETABS model data (black), NZS1170.5 2004 (magenta) and TS1170.5 2025 (green). The recorded and ETABS dataset are observed/computed for the three largest earthquakes (Table 3).

3.2.3 Multi-floor comparisons

We compare the amplification factors for all instrumented floors using the four approached described above, including various input T_1 values to the TS1170.5 2025 calculations (Table 2).

We first compare floor amplification for earthquakes with relatively low peak ground acceleration input (0.01-0.08g) as presented in Figure 4. For low levels of input shaking, the ETABS data (black) presents a very good fit to the recorded data (red). This could be explained by: the building response occurring in the linear vibration domain but also perhaps by the very low amplification at these levels of input shaking (note that the amplification curves are very close to 1 throughout the building). For these low levels of input shaking, the TS1170.5 2025 amplification factors are generally conservative (apart from the two lower levels), for all T_1 values considered. While the TS1170.5 2025 predictions based on the ETABS-derived T_1 period provides a better envelop to the data, the values based on the recorded periods generally appear reasonable for use in design and assessment by practitioners.

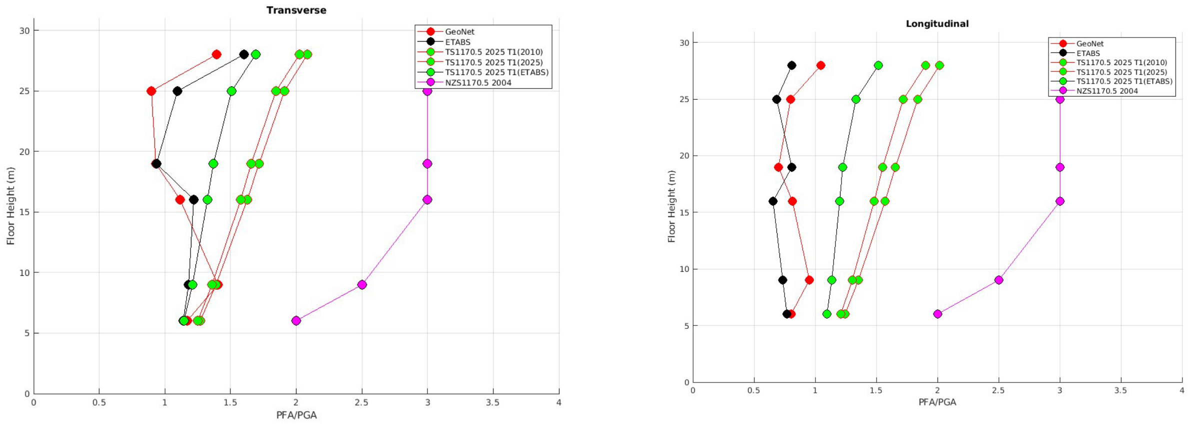

Figure 4: PFA/PGA across the Te Puni floor levels for the 4 different approaches using acceleration input between 0.01 and 0.08g: recorded data (red), ETABS model (black), NZS1170.5 (magenta), TS1170.5 using measured T0 in 2010 (green with red line), measured T0 in 2025 (green with red line) and measured T1 from

ETABS model (green with black line). Recorded and ETABS data points are the median value for events with PGA inputs ranging 0.01-0.08g.

We then compare amplification factors for the three larger levels of input acceleration (PGA values of 0.12, 0.11 and 0.15g for the transverse direction and 0.12, 0.09 and 0.10g for the longitudinal direction). Figure 5 shows that all models somewhat overestimate amplitudes for the transverse direction. The ETABS model is particularly large for the upper levels, which is expected based on the strong contribution of the second mode that is not indicated as strongly in the recorded data and not included in the TS1170.5 2025 calculation method. For the longitudinal component, Figure 5 shows that ETABS matches the recorded data particularly well for the top floors, and all models (except NZS1170.5 2004) underestimate the amplification factors for the lower floors. At all levels of input shaking, the current NZS1170.5 2004 amplification prediction are noted to be quite over conservative.

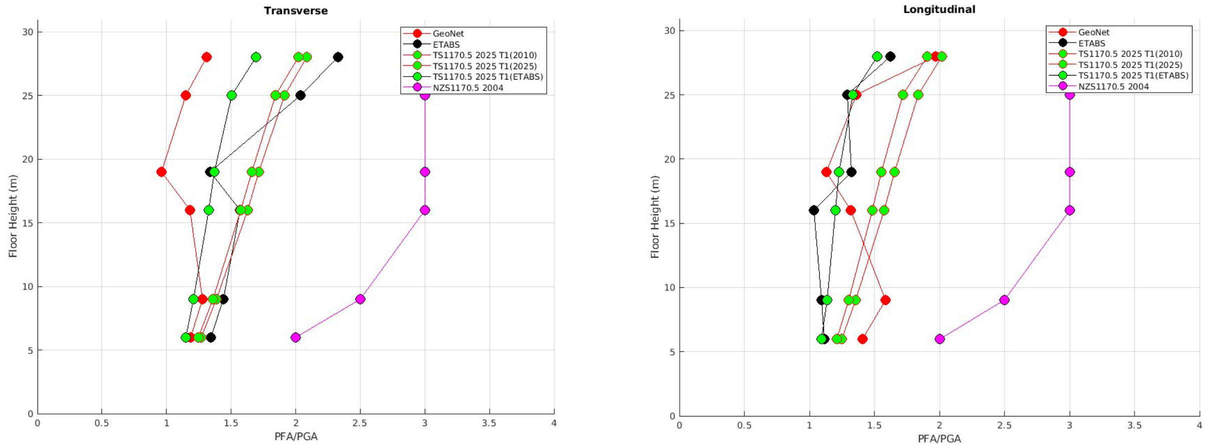

Figure 5: PFA/PGA across the Te Puni floor levels for the 4 different approaches using acceleration inputs ranging from 0.12 to 0.15g for the transverse direction and 0.09 to 0.12g for the longitudinal direction: recorded data (red), ETABS model (black), NZS1170.5 (magenta), TS1170.5 using measured T0 in 2010 (green dots with red line), measured T0 in 2025 (green dots with red line) and measured T1 from ETABS model (green dots with black line). Recorded and ETABS data points are the median value for the largest three recorded earthquakes (Table 3).

As shown on Figure 2 and Table 3, our dataset does not capture events that are likely to push the structure into the non-linear range. However, it appears that the models do have a better fit to the recorded data for larger earthquake input loading.

4 PRELIMINARY CONCLUSIONS

Using four different approaches for calculating floor amplifications, and a comprehensive earthquake catalogue for a densely instrumented building this study has shown that overall, the newly proposed approach in TS1170.5 2025 provides significantly better envelopes to the floor amplification than the current NZS1170.5 2004 method which appears overly conservative. However, TS1170.5 2025 is a simplified approach that will not fully capture building complexities inherent to structures like the Te Puni building. For instance, this building exhibits a strong secondary mode shape on the transverse component as shown by the recorded and the ETABS model data.

Recorded data are extremely valuable to validate models. However, their interpretation should be taken with caution. For example, the robust measure of the dominant period T0 from the 30,000-earthquake data at Te

Puni is different from the period T1 derived from analysis and used in the TS1170.5 2025 method. The period relevant to the building design should be derived from measures based on larger earthquake loadings.

Some questions remain on whether T1 can actually be extracted from the seismic data recorded for smaller events and what model is represented by the T0 value. As floor amplification is controlled by earthquake loading and frequency content, in a similar approach to Hayme et al. (2023) we are working toward developing Fourier and amplitude-based amplification factors to follow on the work by Gawne (2025).

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