LETTER TO THE EDITOR

Dear Sir,

Re: Paper by Dhakal, Lin, Loye and Evans "Seismic Design Spectra for Different Soil Classes" in NZSEE Bulletin Volume 46, No. 2, June 2013, pp 79-87.

This article in the June 2013 edition of the *Bulletin* proposes significant alterations to the NZS1170.5 design spectra based on 1D nonlinear site response simulations. The authors suggest alterations to the spectral shape factors, $C_h(T)$, and a new intensity amplification factor, Z_{amp}, which depends on soil class and the Z factor. While the authors have correctly identified a shortcoming in the existing standards, the study has three major points of contention that adversely affect the conclusions:

1. The use of a class D suite of recordings as the bedrock motion input for the nonlinear site response analysis renders the results unreliable.
2. The fixed 30 m depth of profiles for the simulations are unlikely to be representative of an entire site class.
3. The proposed modifications are deterministic and do not account for the return period of the motions.

Firstly, the degree of nonlinear response of soils is related to the amplitude, duration and frequency content of the input motion. The study uses the Somerville *et al.* (1997) suite of recorded and simulated deep soil motions (i.e. NZS 1170.5 class D) as the input bedrock motion to their model, which will contain different amplitude, duration and frequency characteristics to recorded bedrock motions, even when the motions are scaled to different levels of peak ground acceleration (PGA). The assumption that the class D recordings are representative of bedrock with shear-wave velocity (V_S) of 1,500 m/s is questionable and will yield unreliable results.

Secondly, the adopted soil profiles for the simulations are all homogenous soil layers with a fixed depth of 30 m. Site effects for soil sites depend on V_S of the soil, the depth to bedrock, and the impedance contrast between the rock and the soil i.e.

$$\frac{\rho_{rock} V_{S,rock}}{\rho_{soil} V_{S,soil}}$$

The Dhakal *et al*. study varies neither the depth to bedrock nor the V_S of the underlying rock. This is particularly an issue for class C (shallow soil) and class D (deep or soft soil) sites, for which the soil depth has a large influence on the site period and therefore site response. The article does not mention the shear-wave velocities adopted for the simulated class D soil profile, however based on a fixed 30 m depth, the class D profile would need to have $150 < V_S \leq 200$ m/s, the lower bound being the boundary for class E based on V_S and the upper bound being the boundary for class C based on site period, T = 0.6 s. A single 30 m depth profile with an uncharacteristically low V_S range and a very high impedance contrast cannot be considered representative of all class D sites in New Zealand.

The issue of the fixed 30 m profile depth is not confined to the soil site modifications. Rock site effects are very complex to model, and the site amplification and diminution effects depend on the properties of the top few kilometres of the earth's crust. However, the Dhakal *et al*. results are based on modelling of only the top 30 metres. Therefore the proposed class A/B modifications are not theoretically justified and are likely an artefact of the single-layer velocity profile adopted for the simulations.

A further crucial point of contention with the study is that the modifications are deterministic (i.e. they are the same for all values of return period, R, and near-fault factor, $N(T,D)$), while the code spectra are the product of a probabilistic assessment. Nonlinear soil response will not be the same for design motions of different annual probabilities of exceedance, hence an across-the-board modification of the spectral shape factors cannot represent true site response or nonlinear behaviour. Modification of the Z factor (which the article proposes through the intensity modification factor, Z_{amp}) to account for nonlinear response cannot be made without consideration of the return period R. Best practice dictates re-modelling site effects in ground motion prediction equations (GMPEs), then recalculating $C_h(T)$ and Z factors in a new PSHA (probabilistic seismic hazard assessment).

The authors of this article are correct in their concerns that soil nonlinearity is not modelled well in NZS1170.5. Site effects in the current code spectra are modelled using the McVerry *et al*. (2006) GMPE [14]. This GMPE was derived from a relatively small dataset of strong motion recordings from between 1966 and 1995, and considered soil nonlinearity using one of the very early nonlinear soil response models [15, 16]. The New Zealand strong motion database is now much greater than it was at the time the McVerry *et al.* GMPE was derived, and more robust nonlinear models are now available in the literature [17, 18, 19, 20]. As such, there may be grounds for an update to the New Zealand seismic hazard model, incorporating new GMPEs derived from larger, more recent datasets. Including multiple, modern and New Zealand specific GMPEs in future iterations of the seismic hazard model will result in an improved model of nonlinear effects in the New Zealand dataset. Treating these effects probabilistically in the New Zealand seismic hazard model is significantly more robust than the proposed deterministic adjustments derived from single-layer site response simulations. The results of an updated PSHA for New Zealand may indicate that period-dependent Z factors are justified in a revision to NZS 1170.5, as implemented in U.S. building codes, however this remains to be seen.

The potential ramifications of the Dhakal *et al*. modifications are large, particularly with the on going rebuild in Christchurch. **Table 6** shows that the authors are suggesting short-period (e.g. T = 0.4 sec) class D design motions, $C(T)$ (which will apply to many new structures in Christchurch) can be a factor of three lower than NZS 1170.5 levels, which could classify the new structures as 'earthquake-prone' under current guidelines.

Table 6. Comparison of design motions for T = 0.4 s, class D, Z = 0.3 (assuming R = 1 and $N(T,D)$ = 1).

	NZS1170.5	**Dhakal *et al*.**
Z	0.3	0.3
$C_h(T)$	3	2.03
Z_{amp}	-	0.46
$\boldsymbol{C(T)}$	**0.9**	**0.28**

The article raises important concerns, however the proposed modifications to the code spectra are not recommended for structural design purposes.

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17. Walling, M., W.J. Silva, N.A. Abrahamson (2008). "Nonlinear site amplification factors for constraining the NGA models". *Earthquake Spectra*, **24**(1), 243-255.

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19. Sandikkaya, M.A., S. Akkar, P.-Y. Bard (2013). "A Nonlinear Site-Amplification Model for the Next Pan-European Ground-Motion Prediction Equations". *Bulletin of the Seismological Society of America*, **103**(1), 19-32.

20. Kamai, R., N.A. Abrahamson, W. Silva (2013). "Nonlinear Horizontal Site Response for the NGA-West2 Project", *PEER Report 2013/12*.

AUTHORS' RESPONSE

We thank Van Houtte and Larkin (referred to as *the critics* hereafter) for their in-depth comments on our article ("Seismic design spectra for different soil classes" in NZSEE Bulletin Volume 46, No. 3, June 2013, pp 79-87). In their letter, the critics point out three major concerns; namely: 1) the use of ground motions recorded on a class D site as the input bedrock motion, 2) the fixed 30 m depth of all soil profiles used in the simulation, and 3) deterministic nature of the proposed modifications which do not account for the return period of the ground motions. Below, the authors try to address these concerns and other comments raised by the critics.

Firstly, to investigate the effect of ground motion records used (e.g. recorded on soft soil and those recorded on hard soil/rock) on the outcome, the authors have repeated the analyses with 10 ground motions recorded on rocky sites (taken from the PEER NGA database). These ground motions are listed in Table 1 and their response spectra are plotted in Figure 1. The results of the analyses using these ground motions are shown in Figures 2 and 3 (in the form of amplification/de-amplification of the intensity of the bed rock motions as they travel through the soil layers to the surface). The outcome is expectedly unchanged (compare these with Figures 10 and 11 in the original article). Regardless of the frequency content of the ground motions applied at the base, the maximum acceleration response at the surface is consistently less as the soil gets softer.

Table 1. Rock motions used in the investigation (taken from the PEER NGA database)

NGA#	Event	Year	Station	Vs30 (m/s)
284	Irpinia, Italy-01	1980	Auletta	1000
285	Irpinia, Italy-01	1980	Bagnoli Irpinio	1000
292	Irpinia, Italy-01	1980	Sturno	1000
296	Irpinia, Italy-02	1980	Bagnoli Irpinio	1000
297	Irpinia, Italy-02	1980	Bisaccia	1000
303	Irpinia, Italy-02	1980	Sturno	1000
455	Morgan Hill	1984	Gilroy Array #1	1428
765	Loma Prieta	1989	Gilroy Array #1	1428
957	Northridge-01	1994	Burbank-Howard Rd	821.7
1011	Northridge-01	1994	LA-Wonderland Ave	1222.5

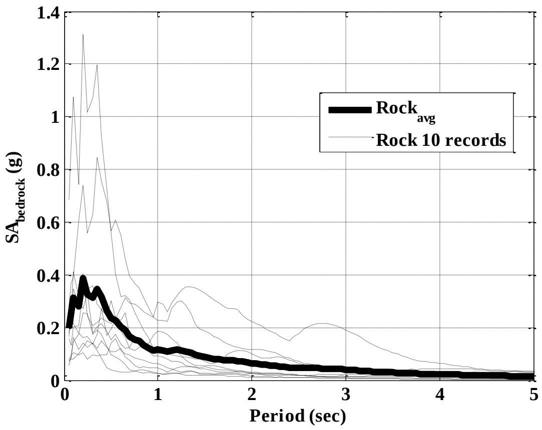

Figure 1: Response spectra of the 10 PEER rock motions.

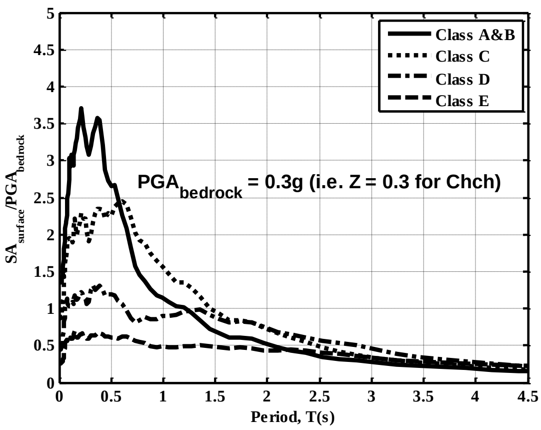

Figure 2: Average spectral shape curves for different soil classes when using rock motions.

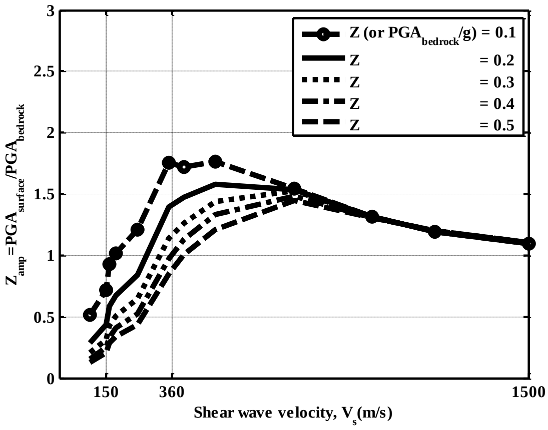

Figure 3: Relationship between normalised PGA and shear wave velocity for various Z factors (i.e. input motion intensity) when using rock motions.

Secondly, the effect of soil profile, namely single-layer vs. multi-layer soil deposits and soil properties is already discussed in the original article (in the parametric analyses section). To further investigate the influence of soil depth, in particular for class D soil, the authors have conducted more analyses with deeper soil profiles. Table 2 shows a comparison between two class D soil profiles (which were originally used in the analyses) and two modified soil profiles (which is intended to reflect the deeper soil deposits covered by class D soil as defined in NZS1170.5).

Table 2. 30 m and deeper soil (class D) soil profiles used in the analyses

Category	Soil Model Parameters
Original	Depth = 30m, Vs = 160 m/s, Period = 0.75s
	Depth = 30m, Vs = 180 m/s, Period = 0.66s
Modified	Depth = 52m, Vs = 180 m/s, Period = 1.16s
	Depth = 75m, Vs = 180 m/s, Period = 1.67s

Figures 4 and 5 show the results (i.e. normalised response spectra and the PGA amplification/de-amplification vs. shear wave velocity curves) using modified class D soil profile and the PEER rock motions listed in Table 1. As can be seen in the figures (comparing with figures 2 and 3), the bed rock motions are slightly less amplified by deeper soil columns in the short period range; but this minor change is far from that required to alter the hierarchy. For the same bed rock motion the intensity of the resulting surface motion invariably increases as the soil gets stiffer; this trend is not affected at all by the depth of soil layers within the range permitted for different soil classes by NZS1170.5. Hence, the qualitative findings (i.e. hierarchy of the surface motion intensities for different soil classes) presented in the article are very much valid.

Regarding the quantitative conclusions though (i.e. exact values of the $C_h(T)$ and Z_{amp} factors), the authors recognise that the assumption of bedrock at a depth of 30 m (or even the 75 m in the modified soil class D model) limits the varieties of real soil profiles represented in this study. Deeper soil deposits in other (than class D) soil classes might not necessarily exhibit similar acceleration response to the 30 m soil deposits used in the study. Therefore, further comprehensive investigation using a wide range of soil profiles for different soil classes is needed to check if the factors proposed in this study need to be amended to ensure consistently reliable and conservative design across all soil profiles commonly found in NZ.

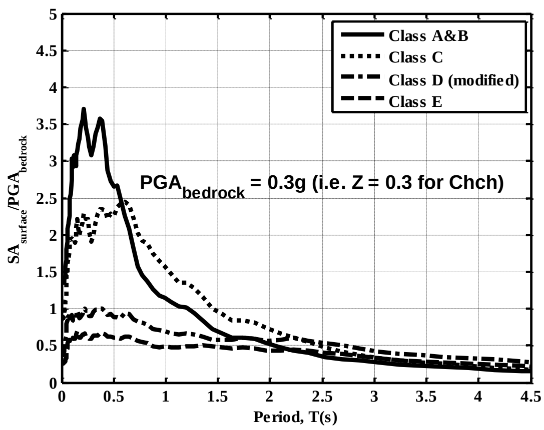

Figure 4: Average spectral shape curves for different soil classes when using rock motions.

Regarding the deterministic approach used in the paper, the authors fail to see much problem associated with it. Seismologists use probabilistic calculations (PSHA) to obtain Z factors which indirectly represent bedrock PGAs that have 10% probability in 50 years; but it is a well-accepted practice to use the local Z factor to calculate the seismic design actions on a building and its components deterministically. The Z factor provided in the code does not account for local site effect; otherwise five different Z factors would be required for the same site corresponding to the five different soil types. Instead, different spectral shape factors $C_h(T)$ are provided to account for the local soil effects. Nevertheless, the shape factors for different soil classes currently provided in the code appear to violate the simple rule that softer systems deform more but accelerate less than stiffer systems.

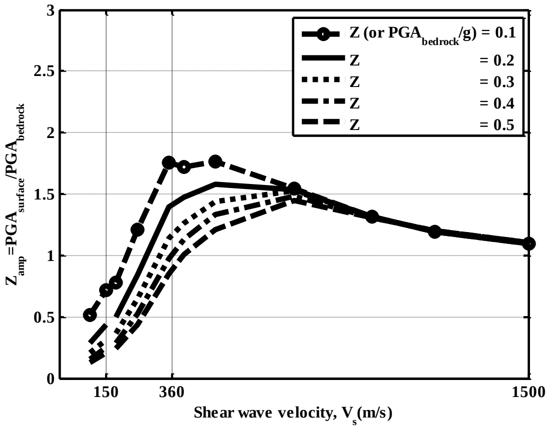

Figure 5: ***Relationship between normalised PGA and shear wave velocity for various Z factors when using rock motions.***

In the authors' opinion, site effect cannot be appropriately modelled in ground motion prediction equations (GMPE). Even if we ignore the inevitable variation in the path characteristics, it is very difficult to get a unique attenuation relationship that confirms to the complex seismological signature of a region. How/where do we get reliable GMPEs that correctly predict different ground motion intensities at sites with different soil types but at similar distance from a source? The authors do not believe that the complex nature of local soil effect can be reliably modelled in a certain GMPE.

As stated in the original article, the intention of this study is to investigate if the consideration of effect of soil on seismic demand as currently used in NZS1170.5 is indeed flawed and if so, to propose a more logical approach that is in line with the findings. The extensive analytical investigation presented in the paper proves beyond doubt that the current approach is flawed, and hence the paper proposes a modified approach to account for the local soil effect. Although the analysis is rigorous despite being simple (understand that complex and accurate are not synonymous) and the nonlinear soil models used are the state of the art models, the proposed alternate method may not necessarily be the most accurate (in quantitative sense), but it is definitely an improvement over the status quo.

As the critics have pointed out, the potential ramifications of the conclusions are large; and that is precisely the reason why these conclusions were made. It is true that the proposed method significantly reduces the seismic demand for buildings on soft soil; this is because the currently specified spectral acceleration demand on soft soil (especially classes D and E) is unnecessarily over-conservative. On the other hand, the authors would like to point out that the status quo significantly undermines the seismic demand for buildings on stiff soil; thereby endangering the users of such buildings. Hence, this flawed practice needs to be stopped as soon as possible.

Note that the finding of this research is in line with the nature/extent of damage observed in residential houses in different suburbs in Christchurch (with distinctly different soil classes) during the recent Canterbury earthquakes. After the publication of this paper, the authors have been contacted by multiple practitioners who have admitted that the pattern of building damage they observed on different soil types in Christchurch is in contrast with the current NZS1170.5 approach but in line with the conclusions of the paper.

The authors would like to make a strong case (through the evidences provided in the paper) that there is an urgent need to change the consideration of soil effect in our current loading standard for seismic actions (i.e. NZS1170.5). As explained earlier, further investigation using different soil profiles and ground motions to better represent NZ geology and seismology, different analytical tools, and more extensive verification using more extensive building damage data on different soil types will provide the basis for amendment of the proposed factors. However, the approach and factors currently proposed in the paper could be used to amend NZS1170.5 in the interim until further research is accomplished.

R.P. Dhakal, S-L. Lin, A.K. Loye and S.J. Evans.