Applicability of Foreign Ground Motion Prediction Equations for New Zealand Active Shallow Crustal Earthquakes

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1. Background and Objective

The number of instrumental ground motion records in New Zealand (NZ) has increased significantly in recent years due to an increase in the number and quality of seismometer throughout NZ. Figure 1 provides a comparison between NGA ground motion database and the NZ database developed as part of this study. Despite this increase in instrumental data, it can be seen clearly in Figure 1 that there is a lack of empirical records from large magnitude events observed at near-source distances. This is even more clear in Figure 2, which plots the cumulative number of records exceeding specific PGA values in the NZ ground motion database. There are only a total of 66 ground motion records which have PGA values above 0.1g (28 crustal, 11 interface, and 27 slab). Furthermore, the maximum PGA values recorded are 0.39g, 0.31g, and 0.28g for crustal, interface, and slab events, respectively. This lack of ground motion records from large magnitude near-source records, which typically dominate seismic hazard analyses, makes it difficult to develop robust ground motion prediction equations used in seismic hazard analysis based on NZ data alone.

In this study an alternative approach to empirical ground motion prediction equation development was taken. Firstly, the applicability of various foreign ground motion prediction equations (derived using plentiful data) to NZ were considered. The consideration was based on both the dependence of the inter- and intra-event residuals as a function of several predictor variables, and also the general predictor variable scaling of the various models. Secondly, the model exhibiting the best applicability to NZ was modified based on theoretical and empirically-driven considerations to better represent the NZ data.

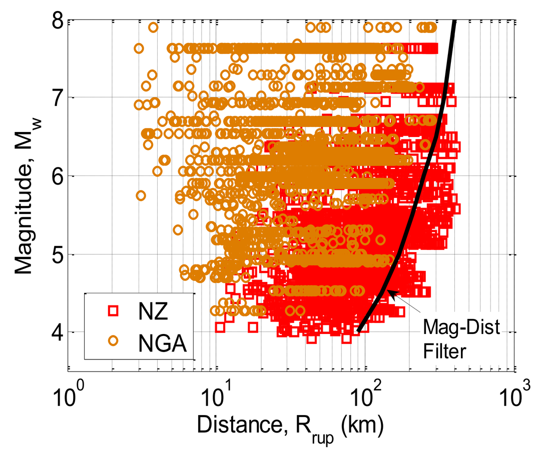

Figure 1: The NZ and NGA databases.

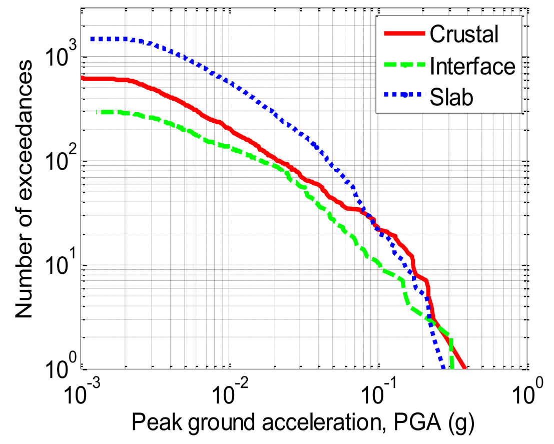

Figure 2: Number of observed PGA exceedances in NZ

2. Foreign Ground Motion Prediction Equations Considered

- McVerry et al. (2006) (McV06) — Based on NZ data from 1966-1995. It the conventional GMPE used in NZ at present.
- Zhao et al. (2006) (Z06) — Based on Japanese data.
- Boore and Atkinson (2008) (BA08) — A relatively simple model arising from the NGA project
- Chiou and Youngs (2008) (CY08) — A relatively complex model arising from the NGA project
- Chiou et al. (2010) (C10) — A modification of the CY08 model at small magnitudes

Figure 3 illustrates the general scaling with magnitude and distance of the five different ground motion prediction equations. Of particular note is the significant difference in the small and large magnitude scaling, and standard deviation of the various models.

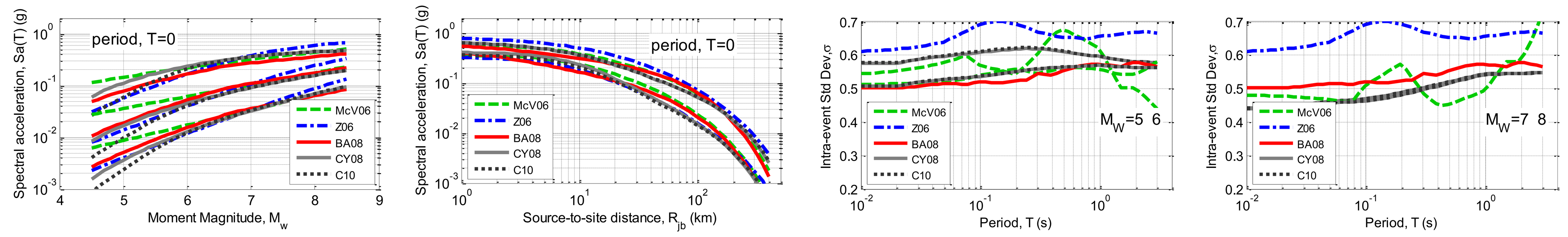

Figure 3: Magnitude, distance, and intra-event standard deviation scaling of the considered GMPEs.

3. Observed inter-and intra-event residuals from NZ database

With the insight obtained from examining the qualitative predictor variable scaling of the various GMPEs it is possible to thoroughly examine the statistics of the observed inter- and intra-event residuals of the NZ database. Such inter- and intra-event residuals were considered for vibration periods of 0.0, 0.2, 0.5, 1.0, and 5.0 seconds. It was found that the McVerry et al. (2006) model provided the poorest prediction of the NZ data based on the observed inter- and intra-event residuals. In particular, this was due to: (i) the large spectral amplitudes predicted for small magnitude events; (ii) the assumption that site response was equal for site classes A and B and site classes D and E; and (iii) an erratic variation in standard deviation with vibration period. The Chiou et al. (2010) modification of the Chiou and Youngs (2008) model provided the best prediction of the NZ data based on the observed inter- and intra-event residuals. The C10 model, in particular, did not exhibit the small magnitude bias that was apparent in all of the other four considered models. However, there was still some bias in the inter- and intra-event residuals using the C10 model which suggested that modifications of this model were required to provide an improved prediction for NZ-specific application. The modifications of the C10 model, which are based either on theoretical considerations, or can be adequately constrained from empirical data were:

- NZ-specific small magnitude scaling
- Scaling of normal faulting events
- Site response amplification for very hard rock (Site class A) sites
- NZ-specific anelastic attenuation
- Consideration of the additional anelastic attenuation in the Taupo Volcanic Zone (TVZ)

Worst GMPE

McVerry et al. (2006)

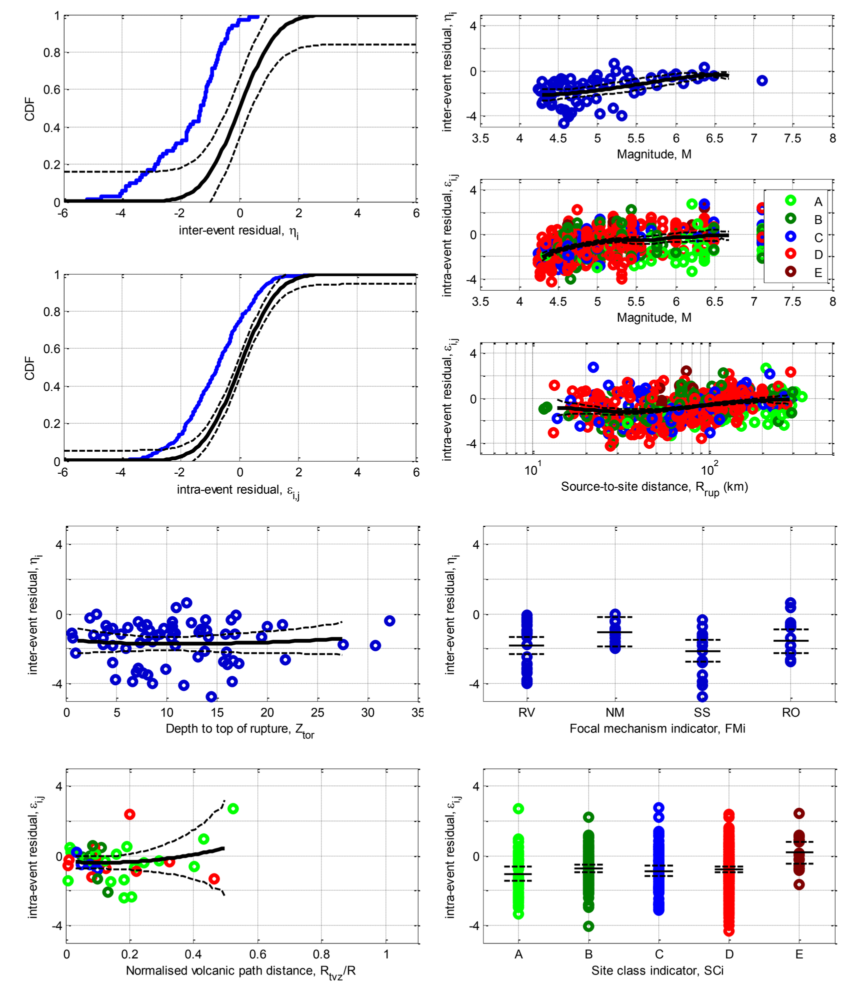

Figure 4: Residuals using McV06

Best GMPE

Chiou et al. (2010)

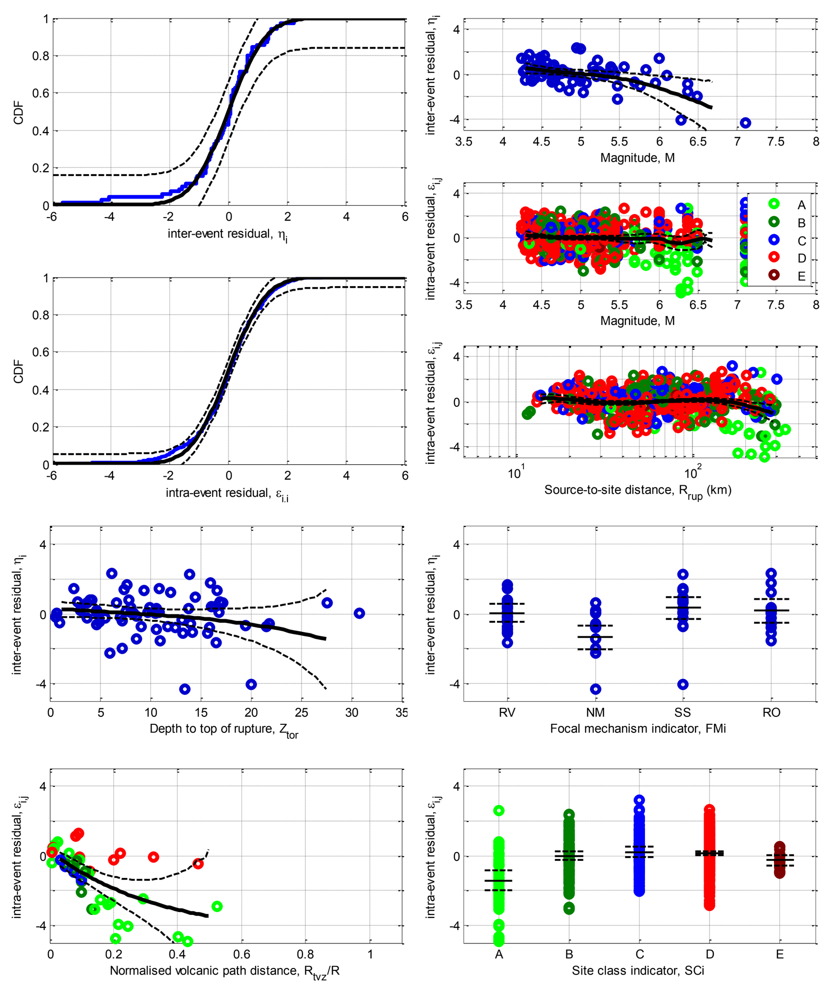

Figure 5: Residuals using C10

Modifications for improved prediction

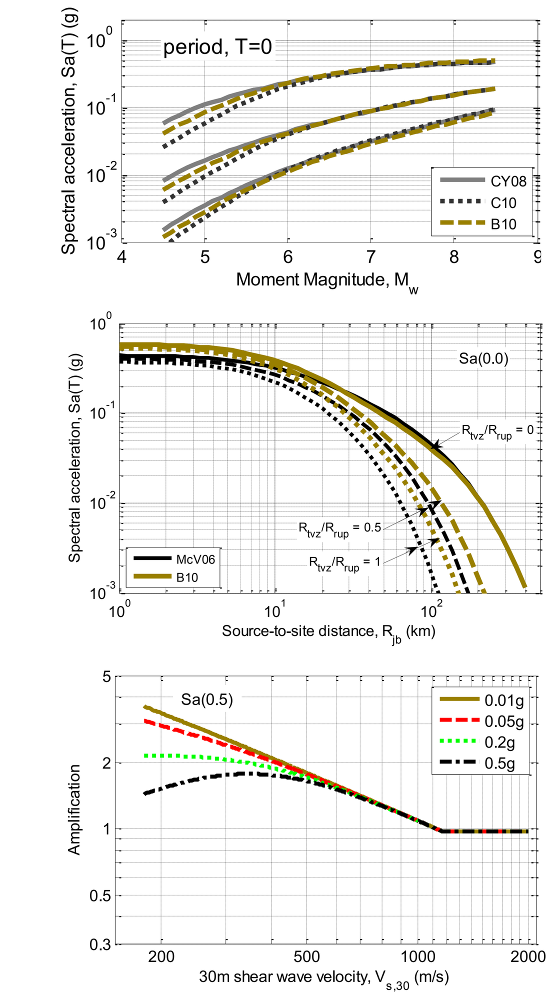

Figure 6: Modifications to the C10 model

4. NZ-Specific Ground Motion Prediction Equation

Figure 6 illustrates the modifications of the C10 model to develop the NZ-specific Bradley (2010) GMPE (B10). It can be seen that the small magnitude scaling of the B10 model is similar to the C10 model both with magnitude and also as a function of vibration period.

Because normal faulting events in NZ occur in the Taupo Volcanic Zone (TVZ) it was found that the short period spectral amplitudes from such events were systematically lower than those predicted by the C10 model. This could be the result of lower stress drops for such volcanic events. The increased anelastic attenuation in the TVZ is also a significant contributor in reducing the spectral amplitudes of ground motions which pass through this region, and was included in the B10 model.

Finally, Site class A sites in NZ are very hard rock sites and the short period spectral amplitudes on such sites was observed to be systematically less than that predicted by the CY08 model. The B10 model considered this by relaxing the C10 constraint that the site amplification be limited to 1.0 for sites with $V_{s,30}$ > 1130 m/s.

Figure 7 illustrates the observed inter- and intra-event residuals obtained from the NZ database using the B10 model. It can be seen that that the biases in the C10 model are not present in the B10 model due to the aforementioned changes. In particular, none of these changes have affected the large magnitude and near-source scaling of the B10 model (which gives predictions similar to the C10 and CY08 models).

Recognising the importance of the standard deviation of GMPEs, Figure 8 illustrates that the standard deviation of the (normalised) inter- and intra-event residuals is also not statistically different from one.

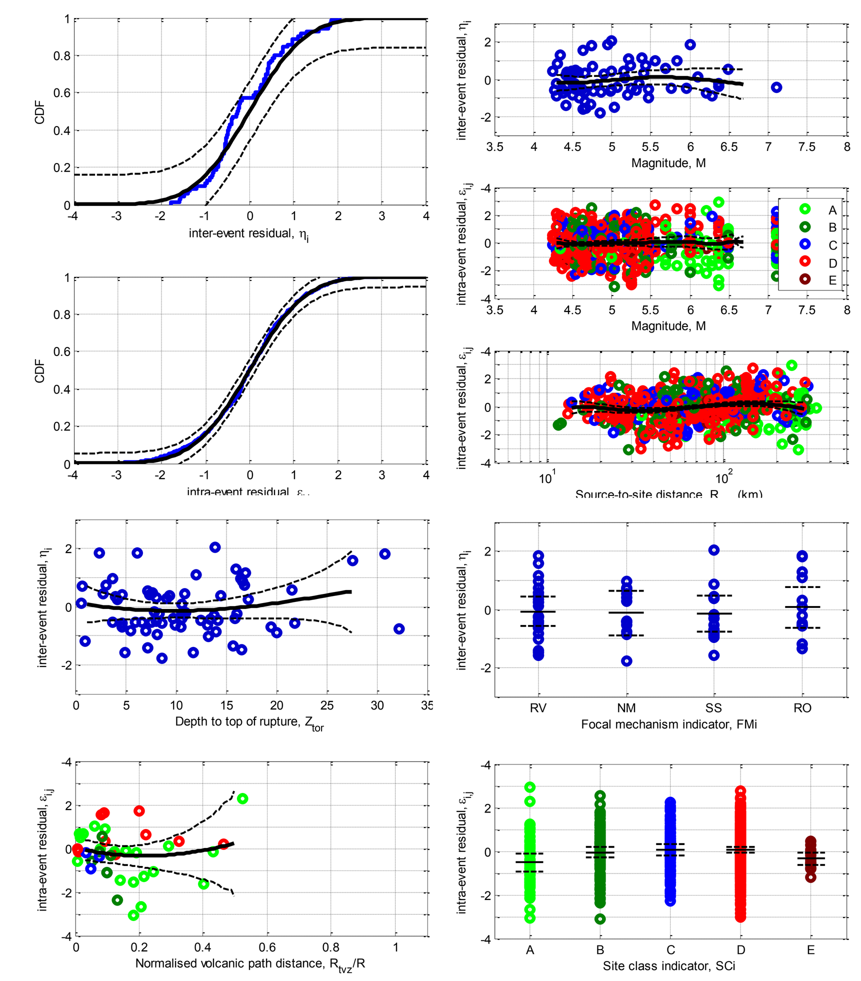

Figure 7: Residuals using B10

5. Implications

The NZ-specific GMPE developed as part of this study exhibits large magnitude and near-source scaling based on global ground motions, and small magnitude and large distance scaling constrained by the NZ ground motion database. The developed model is also applicable for 23 vibration periods from 0.01 to 10 seconds making it applicable for emerging displacement-based design procedures.

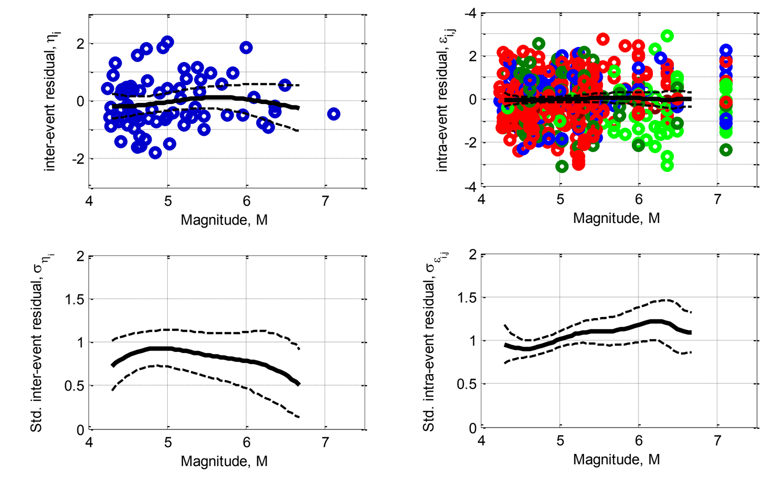

Figure 8: Standard deviation of the B10 residuals

6. References

Bradley, B.A. (2010) NZ-Specific pseudo-spectral acceleration ground motion prediction equations based on foreign models. *University of Canterbury Report.*