



# ON *shaky ground? Understanding earthquake ground-shaking in Australia*

*New prediction equations and Australia's first site-response model to aid earthquake disaster planning*



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The devastating 1989 Newcastle earthquake, which claimed 13 lives and caused over \$800 million in insured losses, showed that Australian communities are not immune to the effects of earthquakes.

New ground-motion prediction equations integrated with the first site-response model for Australia can refine our estimates of earthquake ground-shaking, providing the potential to rapidly assess earthquake impact for disaster response.

Predicting the level of ground-shaking at a given distance from an earthquake rupture depends on three key elements:

- the magnitude and frequency content of the earthquake source
- how earthquake energy decays as it propagates through the Earth's crust
- how near-surface regolith modifies the observed ground motions.

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For a specific earthquake (e.g. Newcastle 1989) the first of these are estimated from the recorded seismograms. The second of these elements are modelled using ground-motion prediction equations, while the third is represented by a site-response model. The combination of these two models provides a fundamental tool for assessing earthquake hazard.

The acquisition of high-quality Australian earthquake ground-motion data, and the development of improved numerical simulation techniques and the first national-scale Australian site-response model, now permit Australian-specific earthquake hazard analyses.

## **Ground motion**

New ground-motion prediction equations have been derived for the southeastern Australian crust, obviating or reducing the need to invoke analogues from other settings, such as eastern North America

(ENA). The new equations are based on numerical simulations, calibrated by data recorded from small-to-moderate sized Australian earthquakes. These numerical methods have particular utility in stable continental regions such as Australia, where records from larger magnitude earthquakes are simply not available to develop predictive ground-motion models for large earthquakes.

The new ground-motion prediction equations are based on recorded data from southeastern Australia (SEA) where, due to the development of much of the nation's infrastructure and higher than average earthquake activity, the seismograph network is well developed. Earthquake source and seismic wave travel path parameters are used to simulate ground-motions over a magnitude range of M 3.0 to 7.5, with the resulting simulated data regressed to obtain model coefficients.

## **Site response**

Regolith, the layer of weathered rock, unconsolidated sediments and/or soils that overlies fresh bedrock, can contribute significantly to the modification

(amplification or de-amplification) of earthquake ground-motions. Modelling and predicting the potential impact of earthquakes on the built environment therefore requires an understanding of how the regolith behaves during an earthquake.

A first-generation national-scale site classification map based on modified US National Earthquake Hazard Reduction Program site classes has been developed for Australia (figure 1). The map uses surficial geology and other available geoscientific data at a variety of scales to identify and group regolith materials into classes likely to exhibit a similar response to earthquake ground-shaking. The paucity of data available in Australia to quantify this physical behaviour means that geology has to be used as a proxy for shear wave velocity—a key variable for modelling the potential response of structures at the surface. Accordingly, shear wave velocity values for mapped Australian geological units are inferred from available relationships between measured shear wave velocity and geological materials in California.

For areas of Australia where local-scale geophysical and geological data are available, more detailed site classification and site response assessment can be achieved. However, in the absence of these data, the national site classification map now provides a first-pass estimate of regolith site amplification anywhere in Australia.

### **Modelling the Newcastle 1989 earthquake**

Using the M 5.4 Newcastle 1989 earthquake as a scenario, we demonstrate:

- differences in calculated ‘hazard on rock’ using an ENA ground-motion model versus the new SEA ground-motion model

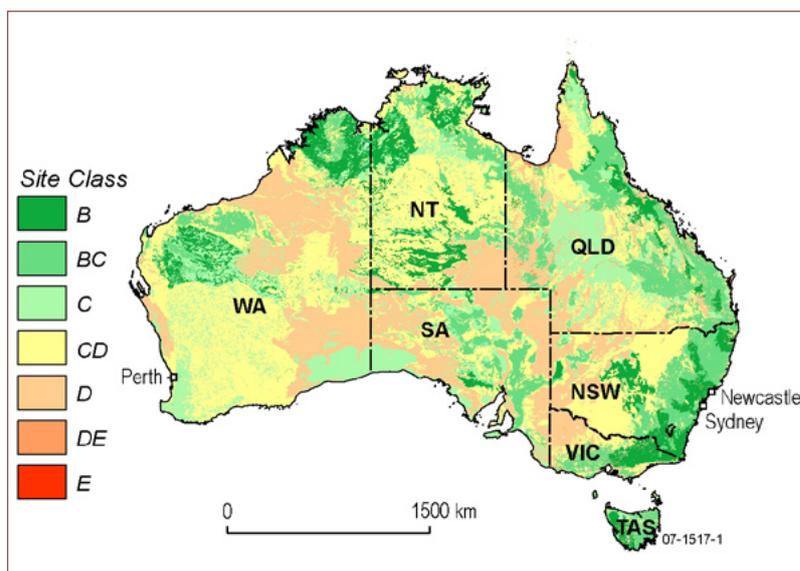


Figure 1. First-generation national site classification map of Australia based on modified US National Earthquake Hazard Reduction Program site classes.

- the significance of resolving earthquake hazard with and without the incorporation of site response information.

Until recently, predicting earthquake ground-motions in Australia relied on the application of models from elsewhere—mainly the United States. Australia’s first ground-motion model that considers different frequencies of earthquake wave energy has been developed using data from SEA, an area previously assumed by many to be analogous to the tectonically stable intra-plate setting of ENA.

Recent comparisons of recorded ground-motion data from ENA and SEA indicate that this assumption may hold true for distances less than 100 kilometres from a fault. However, following reinterpretation of ground-motion data from ENA, new ground-motion equations developed in the United States are now predicting higher attenuation for sites in this distance range.

The new SEA model compares favourably against new ENA models, demonstrating similar low-frequency ground-motions at short distances from the earthquake rupture. The SEA model, however, predicts lower levels of high-frequency energy and peak ground acceleration relative to the new ENA model (figure 2).

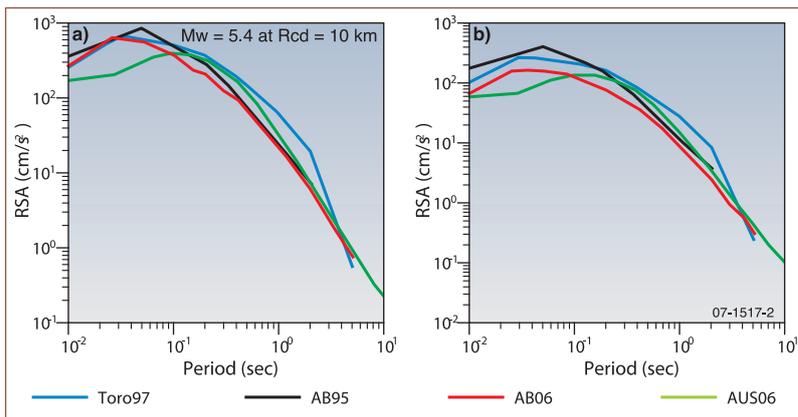


Figure 2. Comparison of the new SEA (AUS06) model against several North American ground-motion attenuation models. Estimated response spectral accelerations (RSAs) are calculated over a range of periods of ground-shaking at (a) 10 and (b) 20 kilometres. The new SEA model demonstrates lower ground-motions over most periods relative to pre-2006 models, and compares favourably with the latest ENA model (AB06) at longer periods, but with lower levels of short-period (and peak ground acceleration) motion.

## Then and now: the current Australian earthquake hazard model

Figure 3 demonstrates our capabilities before and after the development of Australian-specific ground-motion prediction equations and the national site response model. Figure 3a compares modelled earthquake ground-shaking potential employing the ENA ground-motion attenuation model of Toro et al (1997) against the latest revision of the Australian hazard model (figure 3b) for a scenario earthquake in the Newcastle region.

The SEA ground-motion prediction equations predict significantly lower ground-motions than those produced using the ENA model, and also demonstrate the significance of incorporating regolith site response into earthquake hazard assessment.

The addition of modelled site response information significantly enhances our ability to predict spatial variation in strong ground-shaking, a key factor in understanding and modelling the distribution of damage and loss. Despite allowing for increased amplification due to site response, we predict lower overall ground-shaking.

## Conclusion

A comparison of SEA and ENA ground-motion prediction equations demonstrates the importance of recording and modelling Australian-specific earthquake data. We observe that the SEA attenuation model predicts significantly lower ground-motions than the first generation of ENA attenuation models (e.g. Toro et al 1997). The application of a national-scale site response model that provides broad-scale characterisation of the potential response of the regolith to ground-shaking anywhere in Australia further refines our estimates of earthquake hazard.

Products from this current methodology for earthquake hazard assessment in Australia are of particular interest to emergency

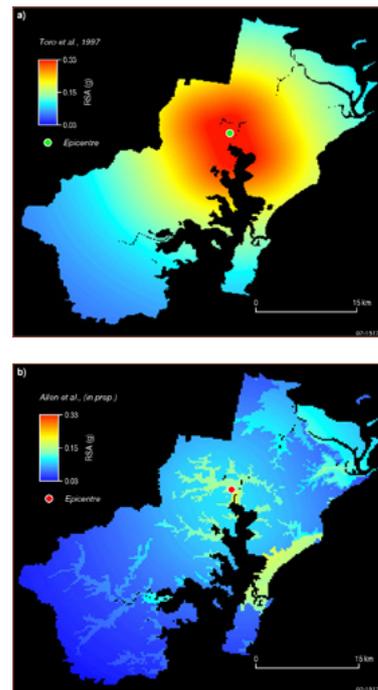


Figure 3. Comparison of earthquake hazard model output for the Newcastle region showing (a) previous capability employing an ENA attenuation model; and (b) present capability for SEA, employing the new southeast Australian ground-motion model in combination with the new national site response model.

managers involved in disaster planning, and have possible implications for revision of the Australian Building Code and earthquake loading standard. They also have significant potential application in decision-support tools for rapid post-event assessment of earthquake-affected areas for prioritisation of emergency response.

### For more information

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### Reference

Toro GR, Abrahamson NA & Schneider JF. 1997. Model of strong ground motions from earthquakes in central and eastern North America: best estimates and uncertainties. *Seismological Research Letters* 68(1):41–57.