An Improved Understanding of Earthquake Ground Motion in Australia

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ABSTRACT

In the past two years, Geoscience Australia has made significant progress in improving our understanding of earthquake ground-shaking in Australia. This research has culminated in the development of an Australian-specific ground-motion attenuation model and the first national-scale site classification map of Australia.

Using a scenario based around the 1989 Newcastle earthquake, we demonstrate how these new products can refine our estimates of ground-shaking in Australia compared to what could be achieved in the recent past. In particular comparisons are drawn against the previous practice of employing ground-motion models derived elsewhere (primarily North America) without any consideration of site response.

These models, and in particular, the site classification map, will assist in identifying regions that may be more vulnerable to severe earthquake ground-shaking. These capabilities are important in aiding land use planning and building code development, and, following a large earthquake, the rapid assessment of affected areas for prioritisation of emergency response. The products will also assist risk modellers to produce more reliable loss and damage estimates for scenario events.

INTRODUCTION

The devastating 1989 Newcastle earthquake, which claimed 13 lives and caused over $4.3 billion damage (IDRO, 2006), poignantly demonstrated that Australian communities are not immune to the effects of earthquakes. Ironically, our comparatively stable tectonic setting means that, for a given sized event, earthquake impact in Australia has the potential to be greater than in more active regions since both communities and engineered structures are more vulnerable to strong ground shaking.

Predicting the level of ground shaking at a given distance from an earthquake rupture is dependent upon three key elements; (1) the magnitude and frequency content of the earthquake source; (2) how earthquake energy attenuates through the crust; and (3) how near-surface regolith modifies the observed ground motions. The first two of these elements are integrated in a ground motion *attenuation* model, while the third is represented in 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, development of improved numerical simulation techniques and the first national-scale Australian site response model now permits Australian-specific earthquake hazard analyses. Improved prediction of earthquake ground shaking potential in Australia provides critical decision support information for planners and emergency managers involved in disaster mitigation. It also has potential implications for Australian Standards and Building Codes.

GROUND-MOTION

A new ground-motion attenuation model has been derived for the southeastern Australian crust, obviating or reducing the need to invoke analogues from other settings e.g. eastern North America (ENA). The new model is based on finite-fault stochastic simulations of ground-motion, calibrated by earthquake source and path characteristics from recorded Australian ground motions. These numerical methods have particular utility in stable continental regions such as Australia, where records from larger magnitude earthquakes are not available to develop empirical attenuation models.

The new Australian ground-motion model is 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. Inputs to the stochastic simulations employ source and path parameters derived from the empirical studies of Allen *et al*. (in review). The stochastic finite-fault software package, EXSIM, (Motazedian & Atkinson, 2005) is used to simulate ground-motion for moment magnitudes over a range of **M** 3.0 to 7.5, with the resulting time histories then regressed to obtain model coefficients (Allen *et al.*, in prep.).

SITE RESPONSE

Regolith, the layer of weathered rock, unconsolidated sediments and/or soils that overlie bedrock, can contribute significantly to the 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 the behaviour of the regolith when subjected to ground-shaking. Significantly, many of Australia's major urban population centres are built on alluvial plains or coastal margins; environments characterised by appreciable thicknesses of regolith. In general such areas can be considered to have a comparatively high vulnerability to earthquake ground-shaking; and in these environments where outcropping bedrock does not predominate, earthquake hazard determined as ‘hazard on rock’ is of limited applicability.

A first generation national scale site classification map based on modified National Earthquake Hazard Reduction Program (NEHRP) site classes (Building Seismic Safety Council, 2004; Wills *et al.*, 2000) has been developed for Australia (McPherson & Hall, 2006) (Fig. 1). The map uses surficial geology and other available geoscientific data at a variety of scales to identify and group regolith materials likely to exhibit a similar response to earthquake ground-shaking. Shear wave velocity, the key geophysical variable for assessing the response of regolith materials, is inferred from relationships between measured shear wave velocity and geological materials in California (Wills *et al.*, 2000). There is a paucity of data available in Australia to quantify the regolith in three dimensions, particularly with respect to thickness and key geophysical properties. Thus mapped Australian geological information is used as a proxy for shear wave velocity, and therefore to approximate the physical behaviour of materials in each site class. Modifiers for the classification have been developed to provide an estimate of the thickness and degree of weathering in bedrock-dominated units and the degree of consolidation in sedimentary deposits.

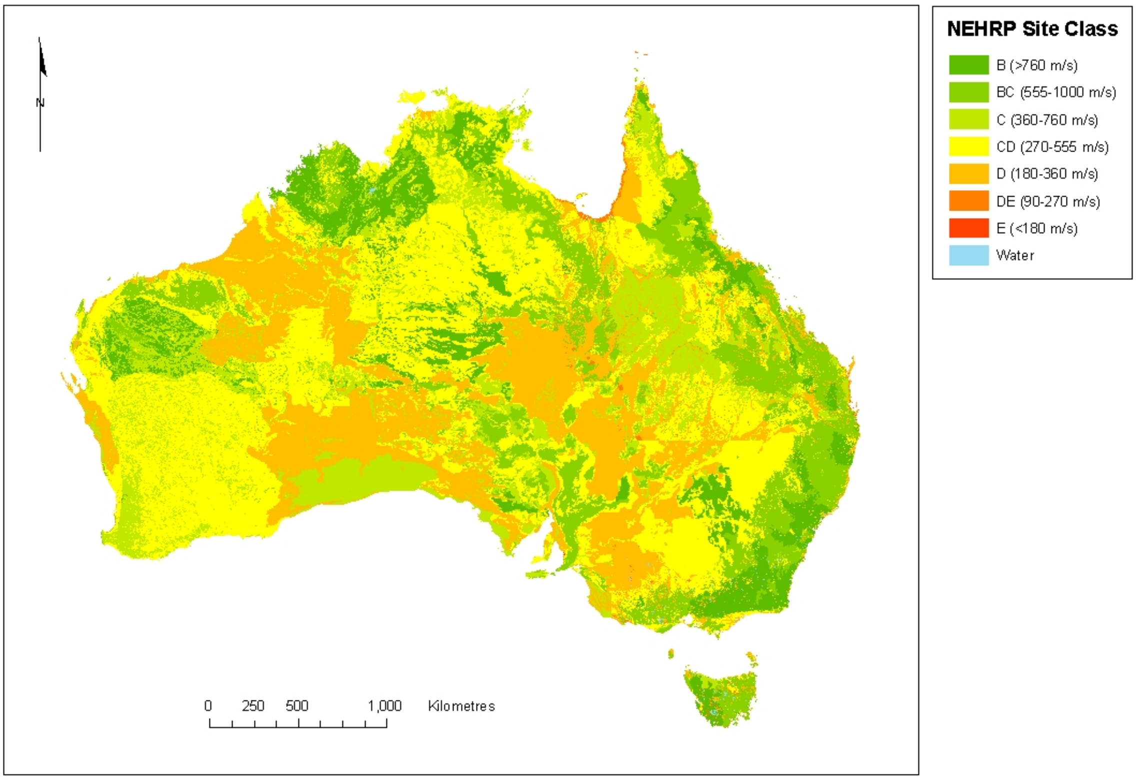

Figure 1. First generation national site classification map of Australia based on modified NEHRP site classes.

A series of generic geotechnical profiles from the Next Generation Attenuation Program in the USA (Silva, 2005) are applied to each site class in order to model and generate amplification factors for each site class.

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

MODELLING SCENARIO - NEWCASTLE 1989 EARTHQUAKE

Using the moment magnitude **M** 5.4† Newcastle 1989 Earthquake as a scenario, we will demonstrate:

- differences in calculated 'hazard on rock' using an ENA ground-motion model versus the new SEA ground-motion model;
- the significance of resolving earthquake hazard with and without the incorporation of site response information.

† Moment magnitude based on the empirical M_L to **M** relations of A.C. Johnston (pers. comm., 2000).

Eastern North America (ENA) versus South-eastern Australia (SEA) Ground-Motion Models

Until recently, predicting earthquake ground-motions in Australia relied on the application of models from elsewhere – principally the United States. Australia's first spectral ground-motion model (Allen *et al.*, in prep.) has been developed using data from south-eastern Australia, an area previously considered by many to be analogous to the tectonically stable intra-plate setting of eastern North America (e.g. Dhu & Jones, 2002). Recent comparisons of recorded ground-motion data from each of these regions indicates that this assumption may not be so far from reality for short hypocentral distances less than approximately 100 km (Allen & Atkinson, 2006). However, following reinterpretation of ground-motion data in ENA, new ground-motion equations are now predicting higher attenuation for sites in this distance range (Atkinson, 2004; Atkinson & Boore, in review). Consequently, hazard and risk modellers should exercise caution when applying first generation ENA models to the Australian context.

The new SEA model (Allen *et al.*, in prep.) compares favourably against new ENA models (Atkinson & Boore, in review), demonstrating similar long-period ground-motions at short distances from the earthquake rupture. The SEA model, however, predicts lower levels of short-period motion (and PGA) relative to the new ENA model (Fig. 2) (e.g. Allen & Atkinson, 2006).

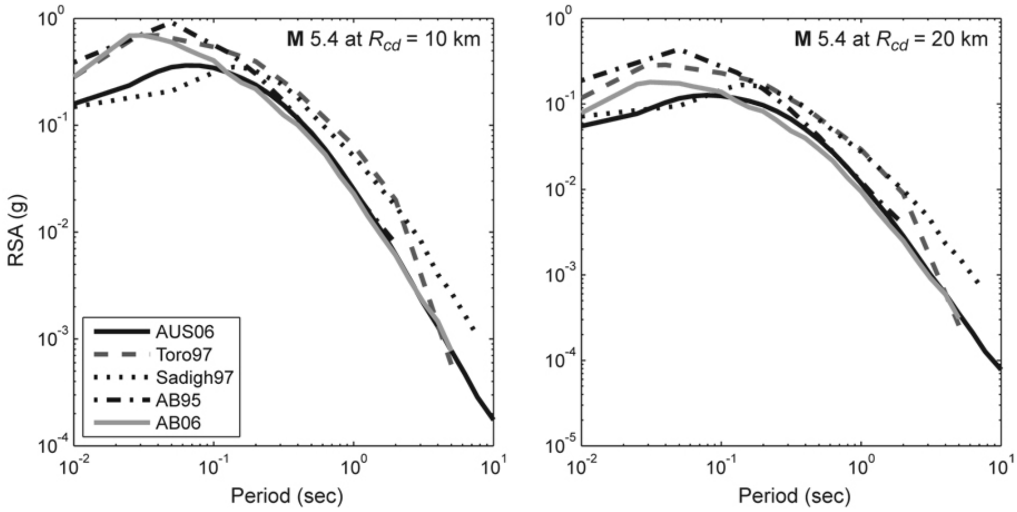

Figure 2. Comparison of the new SEA (AUS06) against several North American ground-motion attenuation models. The new SEA model demonstrates lower ground-motions over most periods relative to pre-2006 models. The new model compares quite well to the Atkinson & Boore (in review; AB06) model at longer periods, but with lower levels of short-period (and PGA) motion.

Figure 3 compares earthquake ground-shaking potential for a scenario earthquake in the Newcastle region employing the ENA ground-motion attenuation model of Toro *et al.* (1997) (Fig. 3a) against the state-of-the-art Australian hazard model (Fig. 3b). The SEA attenuation model underpinning the latter model indicates significantly lower ground-motions relative to the ENA model, but also demonstrates 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 observe lower overall ground-shaking.

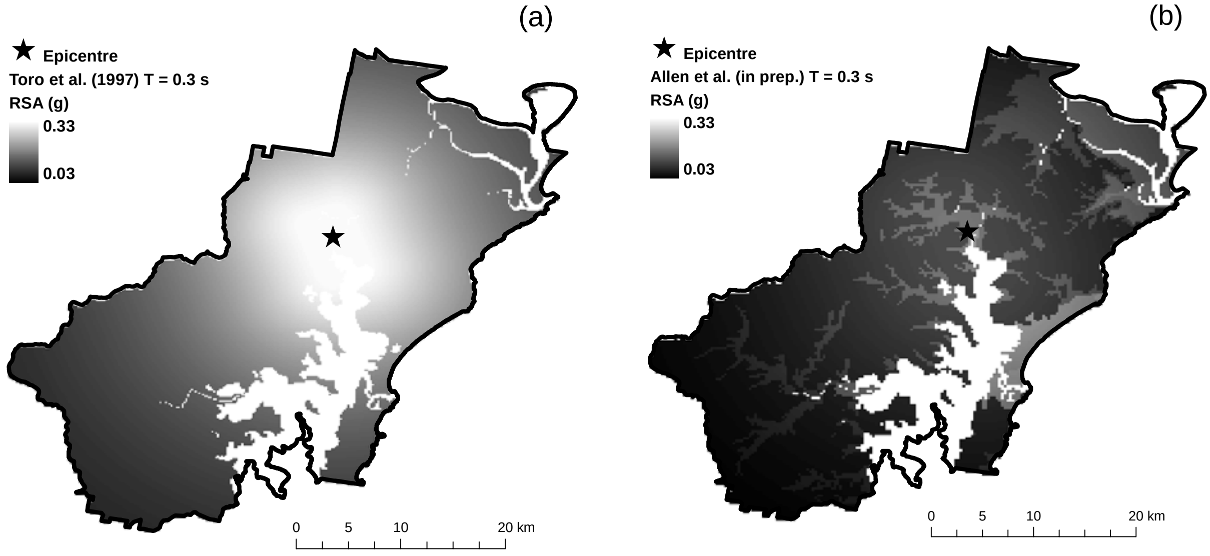

Figure 3. Comparison of earthquake hazard model output for the Newcastle region showing (a) previous capability employing an ENA attenuation model; and (b) present capability for SEA, employing a local ground-motion model combined with the new national site response model.

SUMMARY

A comparison of SEA and ENA ground-motion attenuation models clearly demonstrates the importance of recording and modelling Australian-specific earthquake data. We observe that the SEA model predicts significantly lower ground-motions than the first generation of ENA attenuation models (e.g. Toro *et al.* 1997). At present the underpinning ground-motion model is strongly biased towards eastern Australia, and, as such, application of this method to the western and central regions of the continent would not be advised based on recent empirical ground-motion studies in Western Australia (Allen *et al.*, 2006). However, the application of a national-scale site response model that can characterise the potential response of the regolith to ground-shaking anywhere in Australia further enhances our estimates of earthquake hazard. In some circumstances invoking models from ‘analogous areas’, such as the ENA, may be unavoidable due to a lack of Australian data. However, as demonstrated above, there is inherent risk in applying such models inasmuch as they may not accurately reflect Australian conditions.

We have presented the state-of-the-art in Australian earthquake hazard assessment. These products have particular application to emergency managers and planners for the purposes of disaster planning and potential implications for revision of the Australian Building Code and earthquake loading standard. They also have significant potential application in decision support tools for the rapid post-event assessment of earthquake-affected areas for prioritisation of emergency response.

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