An improved understanding of earthquake ground-shaking 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 two preliminary products - an Australian-specific Ground-Motion Prediction Equation (GMPE) 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 GMPEs derived elsewhere (primarily North America) without any detailed 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 Prediction Equation (GMPE), 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 revisions of Australian Standards and Building Codes.

Ground-motion

A new ground-motion attenuation model has been derived for the southeastern Australian (SEA) 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 GMPEs.

The new Australian GMPE is based on recorded data from southeastern Australia, where, due to the development of much of the nation's infrastructure and higher than average seismicity, 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 spectral ground-motions for moment magnitudes over a range of M 3.0 to 7.5. The simulated spectra are 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 the potential impact of earthquakes on the built environment therefore requires an understanding of the behaviour of the regolith when subjected to an input bedrock motion. 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 relatively high vulnerability to earthquake ground-shaking when compared to bedrock sites. 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 in the upper 30 m (Vs30), 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 key geophysical properties. Thus mapped Australian geological information is used as a proxy for Vs30, 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.

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.

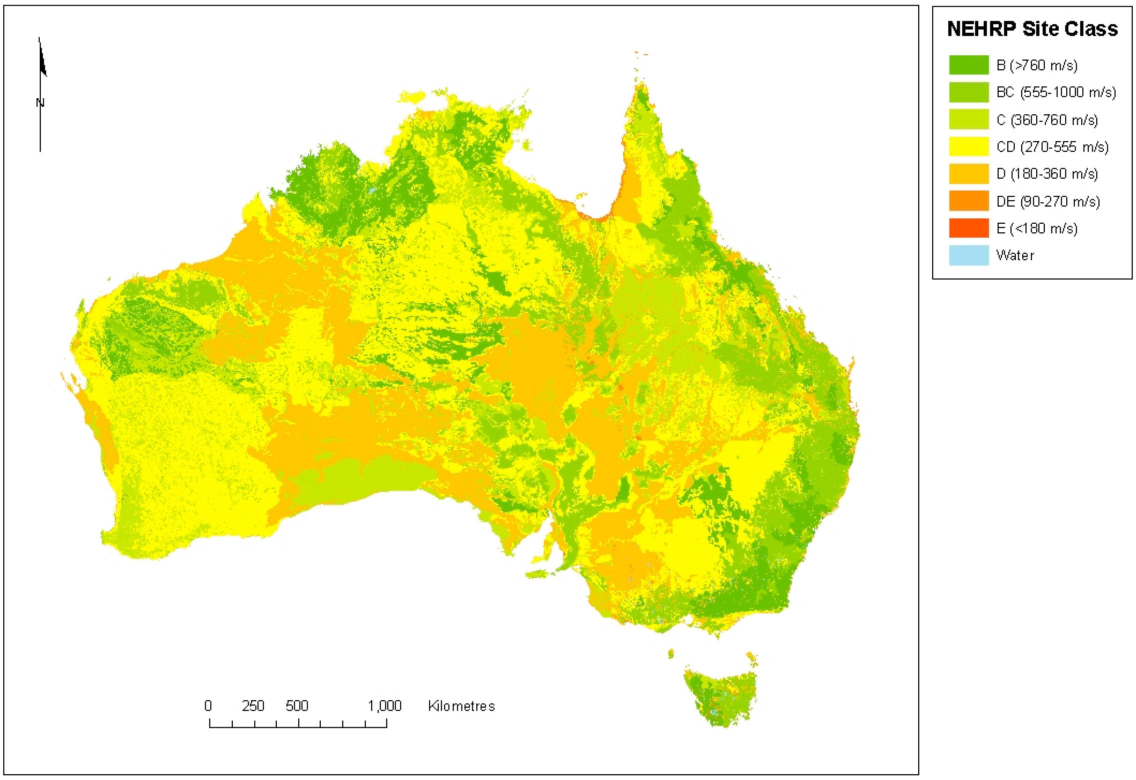

Figure 1. First generation national site classification map of Australia based on modified NEHRP site classes.

Modelling scenario - Newcastle 1989 earthquake

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

- differences in calculated ground-motion between ENA and SEA GMPEs; and
- the significance of modelling earthquake ground-shaking with and without the incorporation of site response information.

† Moment magnitude based on the empirical ML to M relations of AC 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 GMPEs from elsewhere – principally the United States. Australia's first spectral GMPE (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 indicate 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 from ENA, new ground-motion equations are now predicting lower ground-shaking 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 GMPEs to the Australian context.

The new SEA model (Allen et al., in prep.) compares favourably against new ENA GMPEs (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).

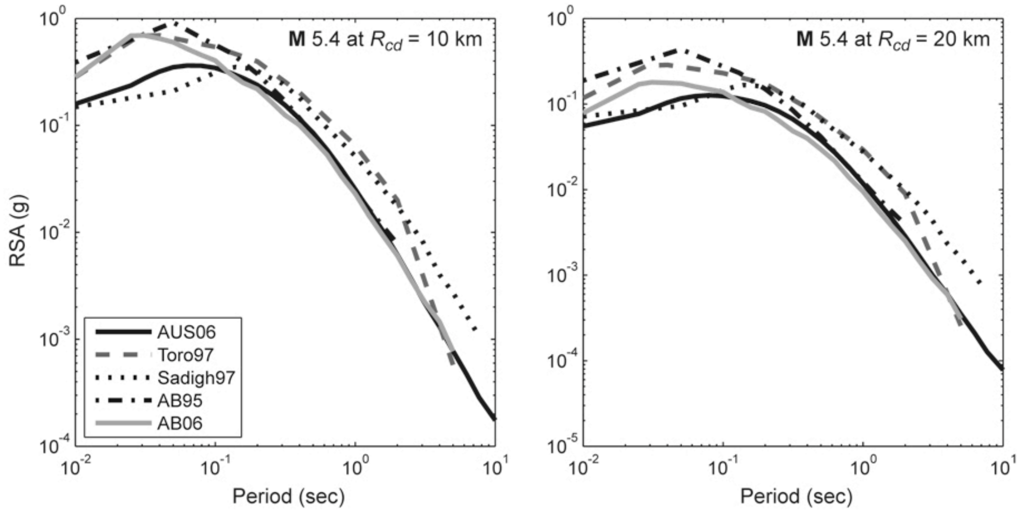

Figure 2. Comparison of the new SEA (AUS06) GMPE against several North American ground-motion attenuation models. The new SEA model demonstrates lower ground-motions over most periods relative to pre-2006 models. The new GMPE compares favourably with the Atkinson & Boore (in review; AB06) model at longer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

Then and now: the current Australian earthquake hazard model

Figure 3 compares modelled earthquake ground-shaking potential employing the ENA ground-motion attenuation model of Toro et al. (1997) (Fig. 3a) against the latest Australian model (Allen et al., in prep) (Fig. 3b) for a scenario earthquake in the

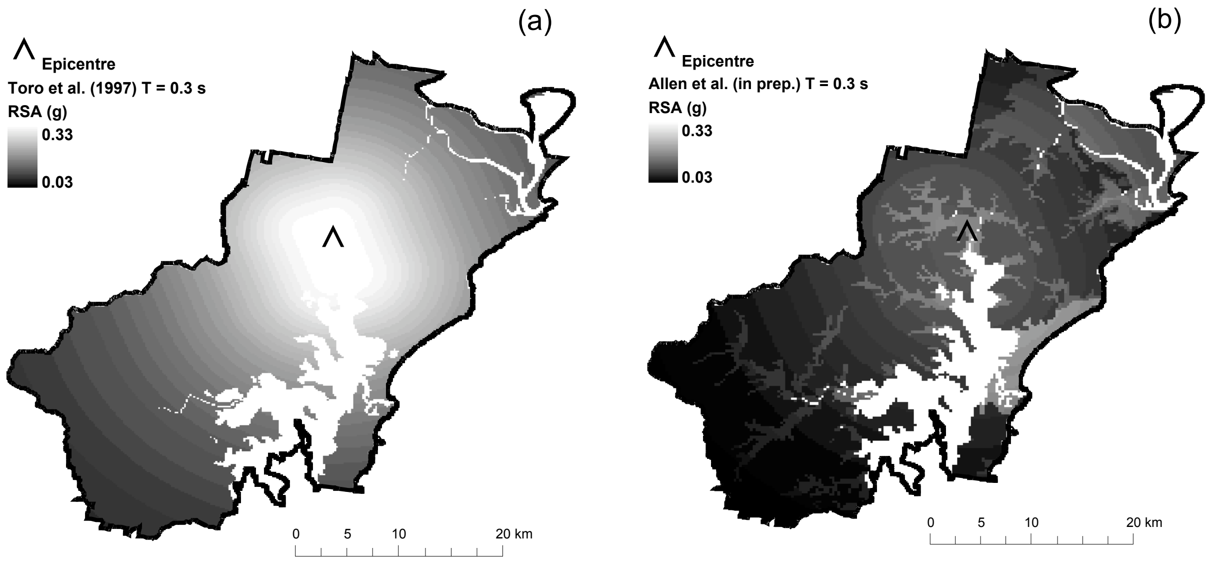

Figure 3. Comparison of earthquake hazard model output for the Newcastle region showing (a) previous capability employing an ENA attenuation model; and (b) present capability for SEA, employing the new southeast Australian ground-motion model in combination with the new national site response model.

Newcastle region. The SEA GMPE 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.

Summary

A comparison of SEA and ENA GMPEs 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 GMPEs (e.g. Toro et al. 1997). Recent revisions of source and site parameters (i.e. stress drop and kappa) may act to increase ground motions between periods of 0.1-0.3 seconds. However, it is expected that levels of PGA will still be lower than predicted by ENA models. The effect of this on hazard is yet to be fully tested. At present the underpinning GMPE is strongly biased towards eastern Australia, and, as such, application of this method to the western and central regions of the continent would be inadvisable 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 nationally. In some circumstances invoking models from 'analogous areas', such as 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 current methodology for earthquake hazard assessment in Australia. The products developed 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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