



## Probabilistic Earthquake Risk Assessment of Newcastle and Lake Macquarie – Part 1 Seismic Hazard.

T. Dhu, D. Robinson, C. Sinadinovski, T. Jones, A. Jones & J. Schneider

*Geoscience Australia, Canberra, Australia.*

A. Mendez

*Aon/Impact Forecasting, Chicago, USA.*

### ABSTRACT:

Geoscience Australia is examining the risk to Australian communities from a range of geohazards which include earthquakes. As part of this project, a detailed study of the risk posed by earthquakes to Newcastle and Lake Macquarie has been recently completed. This paper is the first of two companion papers that detail the earthquake risk for the Newcastle and Lake Macquarie region.

Detailed analysis of local seismicity and geology was used to define a seismic source model consisting of three distinct source zones. This source model, amplification factors developed from local geotechnical data and an attenuation model developed for central and eastern North America were used in a probabilistic earthquake hazard assessment of Newcastle and Lake Macquarie region. The results of this hazard assessment suggest that the region has a higher level of earthquake hazard than suggested by the current Australian Standard for earthquake loading.

## 1 INTRODUCTION

At 10.27 am on the 28th December 1989 an earthquake measuring 5.6 on the Richter scale shook Newcastle, Australia's sixth most populous city. This moderate-magnitude earthquake claimed 13 lives and caused extensive damage to buildings and other structures. This event clearly demonstrated that moderate-magnitude earthquakes, which frequently occur in Australia, have the potential to dramatically impact Australian communities.

In addition to this tragic event, the Newcastle and Lake Macquarie region has a history of high seismicity when compared with many other parts of Australia. For example the region has experienced at least five earthquakes of local magnitude 5 or greater in the last 200 years (Sinadinovski et al., 2002). Whilst the region has not experienced any earthquakes larger than local magnitude 5.6, the relatively high occurrence of moderate sized earthquakes does suggest that this region has higher hazard than many other parts of Australia.

This paper is the first in a series of two companion papers detailing the results of Geoscience Australia's recently completed study into the earthquake risk in Newcastle and Lake Macquarie region (Dhu and Jones, 2002). This paper describes the earthquake hazard within the region, and provides an overview of the methodology used as well as the key components of our earthquake hazard model. The companion paper describes the vulnerability of the building stock in Newcastle and Lake Macquarie, and details the risk that earthquakes pose to the region (Jones et al., 2003).

## 2 EARTHQUAKE HAZARD METHODOLOGY

Earthquake hazard was calculated by simulating approximately 12,000 earthquakes in a stratified Monte Carlo simulation. Each simulated earthquake was assigned an appropriate probability of occurrence, and then the ground shaking associated with that event was calculated across the study region. In order to carry out this simulation, three models were required:

- A regional seismicity model, describing the probability of earthquakes occurring in the region.
- An attenuation model, describing generally how earthquake ground shaking decreases with distance away from the earthquake source.
- A site response model describing how local regolith (soils, geological sediments and weathered rock) affects the ground shaking experienced during an earthquake.

These three models are described in detail below

### 2.1 Regional Seismicity Model

The regional seismicity model used in this study was developed with the aid of a panel of geologists and seismologists from around Australia. The model was constructed using three seismic source zones which were felt to describe the seismicity of the region. The first of these zones is the Tasman Sea Margin Zone (TSMZ) which is a large region that can essentially be thought of as the background seismicity for south-eastern Australia. The TSMZ is thought to be associated with the opening of the Tasman Sea and the separation of the New Zealand and Australian land masses. In this study, the TSMZ was used to produce events with moment magnitudes up to and including 6.5 (Dhu and Jones, 2002).

The study region has experienced high rates of occurrence for moderate magnitude earthquakes. The Newcastle Triangle Zone (NTZ) was defined by geological structures of the Lower Hunter region that bound this high seismicity for events with moment magnitudes up to and including 5.4 (Dhu et al., 2002). The Newcastle Fault Zone (NFZ) was defined to capture the presence of faults in the region which were though capable of generating larger earthquakes with moment magnitudes up to and including 6.5 (Dhu et al., 2002). The relative levels of seismicity for these three zones is presented in Figure 1. Note that the NTZ and NFZ both have higher levels of seismicity than the TSMZ

Two different configurations of the three earthquake source zones were used to simulate earthquakes in this study (Figure 2). The first configuration consisted of the NTZ embedded in the TSMZ, and was used to generate earthquakes with moment magnitudes between 3.3 and 5.4. The second configuration was used to generate earthquakes with moment magnitudes greater than 5.4 up to and including magnitude 6.5. This configuration consisted of the NFZ embedded within the TSMZ. The separation of the region into the two configurations accounts for different geological structures generating different magnitude earthquakes (Dhu et al., 2002).

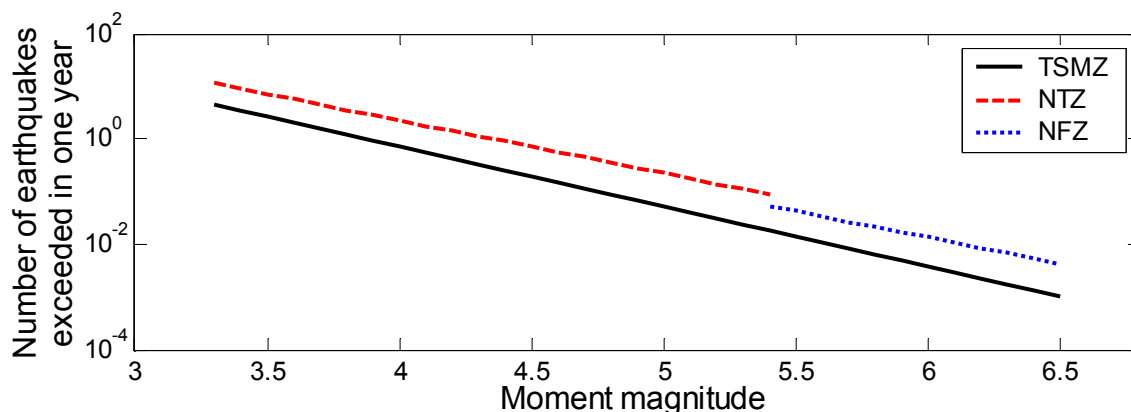


Figure 1: Cumulative Gutenberg-Richter recurrence relationship for seismic source zones. The seismicity rates have all been normalised to an area of 100 000 km<sup>2</sup>

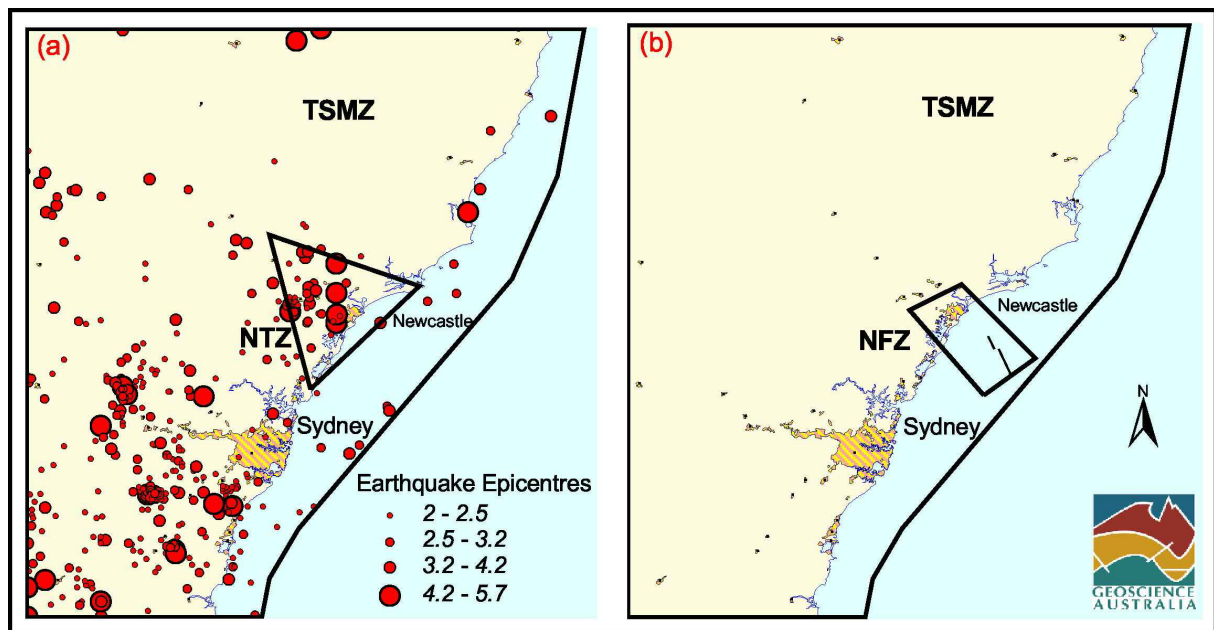


Figure 2: Seismic source model including epicentres of previous earthquakes from 1841 - 2000. Part (a) is the model used for generating earthquakes with moment magnitudes ranging from 3.3 to 5.4 inclusive. Part (b) was used to generate earthquakes with moment magnitude larger than 5.4 up to and including moment magnitude 6.5

## 2.2 Attenuation Model

The limited amount of regional strong motion data recorded for Australian earthquakes has made it particularly difficult to develop an attenuation model for Australian conditions. The current map of earthquake hazard used in Australia's earthquake loading standard (AS1170.4, 1993) was developed using an attenuation model derived from Australian intensity data (Gauil et al., 1990). Whilst this attenuation model was developed using Australian data, it incorporates factors to convert intensity to peak ground acceleration (PGA) that were developed for other regions of the world.

This study has adopted an attenuation model developed for central and eastern North America (Toro et al., 1997). The Toro et al. (1997) model was selected because:

- the 'intraplate' tectonic environment in central and eastern North America is thought to be similar to the environment in south-east Australia;
- it describes the attenuation of response spectral acceleration (RSA) as well as PGA, and;
- it includes both a median attenuation model and a measure of the model variability due to the randomness inherent in natural processes.

However, it should be emphasised that this study has *not conducted any detailed analysis of the applicability of the Toro et al. (1997) model to Australia.*

A comparison of the Toro et al. (1997) and the Gauil et al. (1990) attenuation models for PGA is presented in Figure 3. For distances less than 10-50 km the Toro et al. (1997) model attenuates less, and consequently has higher PGAs than the Gauil et al. (1990) model. The opposite is true for larger distances, with the Gauil model generating higher PGAs at these larger distances. Overall the differences between these models are relatively small.

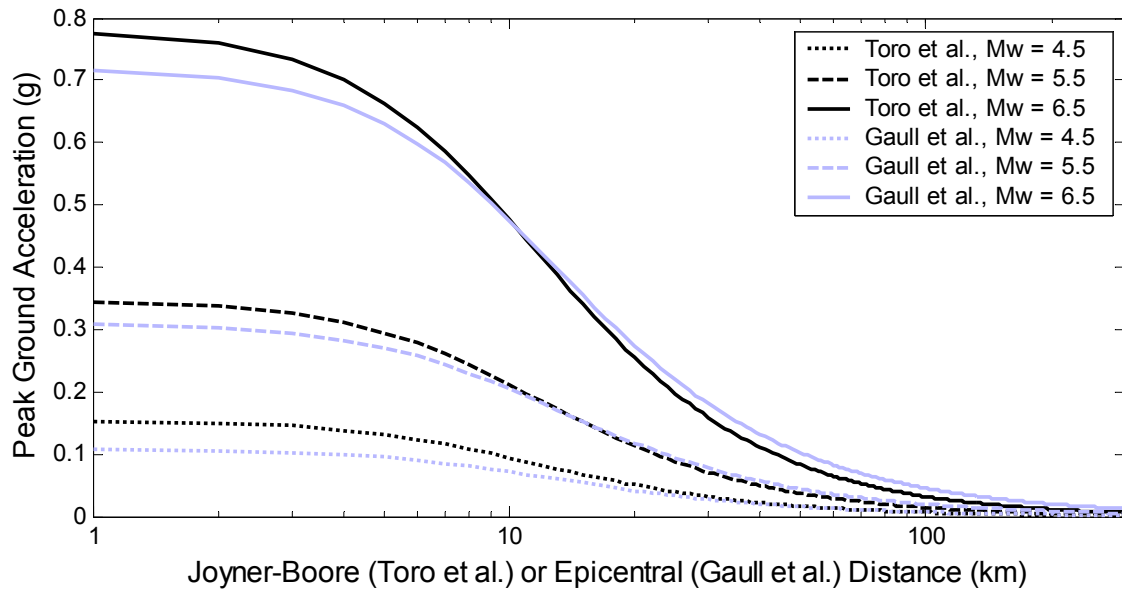


Figure 3: Comparison of attenuation models

### 2.3 Site Response Model

Variations in the amount and type of regolith present in a region can cause substantial variations in the localised earthquake hazard. In order to identify localised changes in earthquake hazard due to variations in the regolith, the Newcastle and Lake Macquarie region was divided into six regolith site classes (Figure 4). These classes represent regions that are considered to have a similar response to earthquake ground shaking, and are summarised below:

- Class C. Weathered rock (maximum thickness 15 m).
- Class D. Silt and clay (maximum thickness 16.5 m).
- Class E. Sand overlying silt and clay (maximum thickness 30 m).
- Class F. Sand with interbedded silt and clay (maximum thickness 39 m).
- Class G. Silt and clay with interbedded sand (maximum thickness 30 m).
- Class H. Barrier sand (maximum thickness 30 m).

The regolith in the classes containing sands, silts and/or clays includes up to 15 m of weathered rock.

The development of these site classes is described in detail in Dhu and Jones (2002). All of the site classes containing sands, silts and/or clays were developed from seismic cone penetrometer tests (SCPTs) undertaken primarily in the Newcastle municipality and the barrier sands to the east of Lake Macquarie (Figure 4). These site classes were extrapolated to the remainder of the study region based on limited SCPT data, microtremor data and inferences regarding the depositional processes in the region.

The site response for each regolith class was calculated using an equivalent-linear methodology described in more detail by Dhu et al. (2002). Given an input rock motion, this equivalent-linear methodology is used to calculate the ground motion experienced at the surface of the regolith. The response of a given regolith model is described by period dependant amplification factors defined by the ratio of the RSA of the rock motion to the RSA of the regolith motion. As with the attenuation model, the calculated amplification factors incorporated a measure of the variability in site response due to natural variabilities in the regolith.

A comparison of the amplification factors from the Australian earthquake loading standard and the appropriate factors from this study are presented in presented in Figure 5. The amplification factors from this study are typically greater than those from the standard for periods less than 1 s.

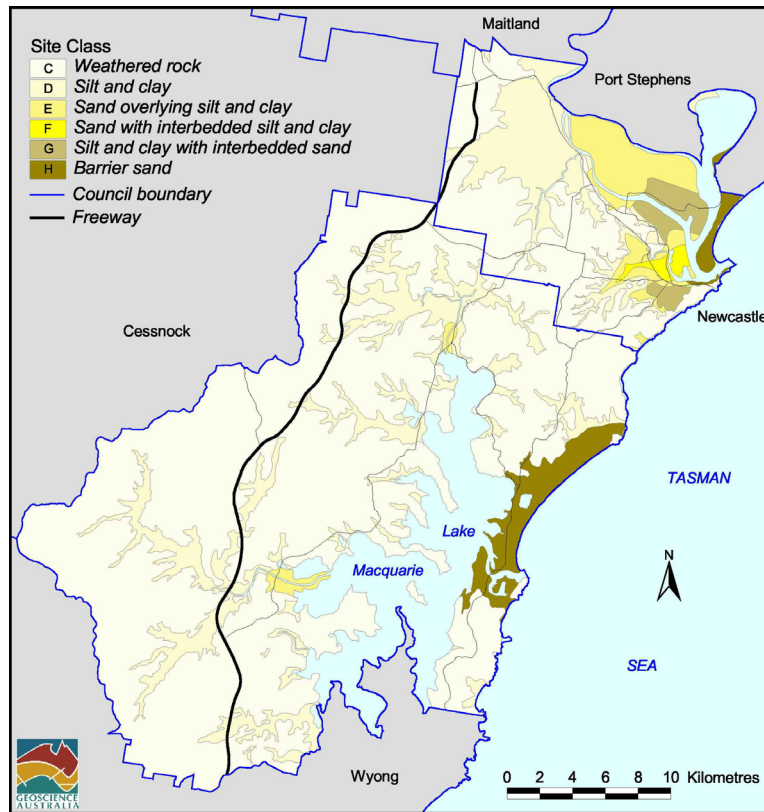


Figure 4: Regolith site classes in Newcastle and Lake Macquarie.

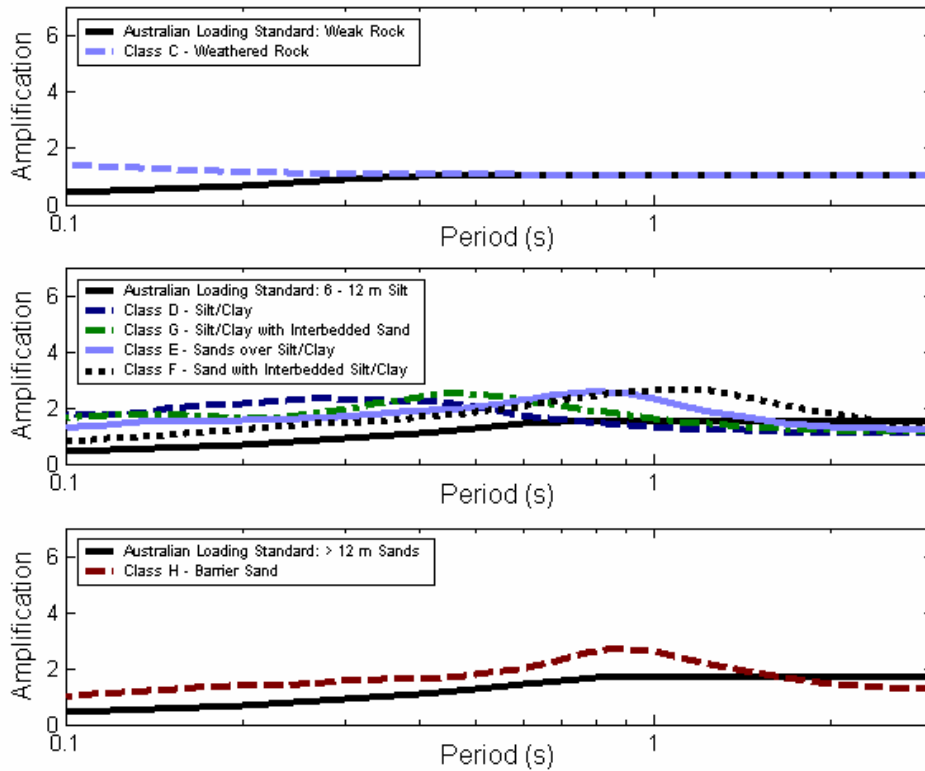


Figure 5: Amplification factors from this study compared with the appropriate factors from the Australian Earthquake Loading Standard (AS1170.4, 1993). Note that the amplification factors for Classes C – H have all been calculated as part of this study.

## 2.4 Calculation of Hazard

The previous three Sections described the source, attenuation and site response models that have been developed for the Newcastle and Lake Macquarie region. In order to calculate the earthquake hazard in the region, it is necessary to integrate these models. The approach taken in this study is outlined below:

1. A spacing of 250 m was used to create a grid of sample points at which the hazard was calculated.
2. Simulated earthquakes were assigned an appropriate probability of occurrence based on magnitude and source zone.
3. For each earthquake - sample point combination the following procedure was carried out:
  - An attenuation function was selected by choosing a random variation from the median attenuation model;
  - The attenuation function was used to determine the rock RSA at the sample point;
  - The appropriate median amplification factor was selected based on the sample point's site classification, the magnitude of the earthquake and the level of the rock RSA, and;
  - A random variation of the amplification factor was selected and used to amplify the rock RSA to produce a regolith RSA.
4. Each regolith RSA was assigned the same probability of occurrence as its causative earthquake.

Note that random variations for both the attenuation function and the amplification factors were selected by randomly choosing a scaling variable from a normal distribution. This scaling variable was multiplied against the appropriate variability parameter and then added to either the median attenuation or amplification factors.

## 3 EARTHQUAKE HAZARD

The Australian earthquake loading standard, AS1170.4-1993, presents earthquake hazard in terms of an 'acceleration coefficient' that has a 10% chance of being exceeded in 50 years. This acceleration coefficient is considered to be equivalent to PGA. The earthquake hazard from AS1170.4-1993 and the equivalent hazard calculated in this study are presented in Figures 6 and 7 respectively. A comparison of these figures demonstrates that they both have the same trend of increasing hazard towards the north-east of the study region. The hazard calculated within this study is typically greater than the hazard suggested by the Australian earthquake loading standard.

The hazard presented in Figure 7 was defined in terms of PGA calculated on unweathered rock. However, the entire study region is covered by varying thicknesses and types of regolith which can strongly affect the earthquake hazard. In addition to this, the buildings in the study region are typically more vulnerable to RSA at periods of around 0.3 s than they are to PGA. Figure 8 presents earthquake hazard in terms of the RSA at a period of 0.3 s, calculated on regolith, that has a 10% probability of exceedance in 50 years. This figure demonstrates that the regolith from rivers, streams, wetlands and barrier sands exhibit more hazard than the weathered rock material which covers the majority of the region.

## 4 CONCLUSIONS

Detailed modelling of earthquake source zones and local site response combined with the use of an attenuation model developed for central and eastern North America has led to an estimate of earthquake hazard that is greater than the estimate currently proposed by the Australian Standard for earthquake loading. This difference is due primarily to the increased level of detail that has been included in this study as opposed to the broad scale study that is required for any national standard. Whilst it should be emphasised that the results are entirely dependant upon the input models used, they also represent the most detailed assessment of earthquake hazard published for any Australian city to date.

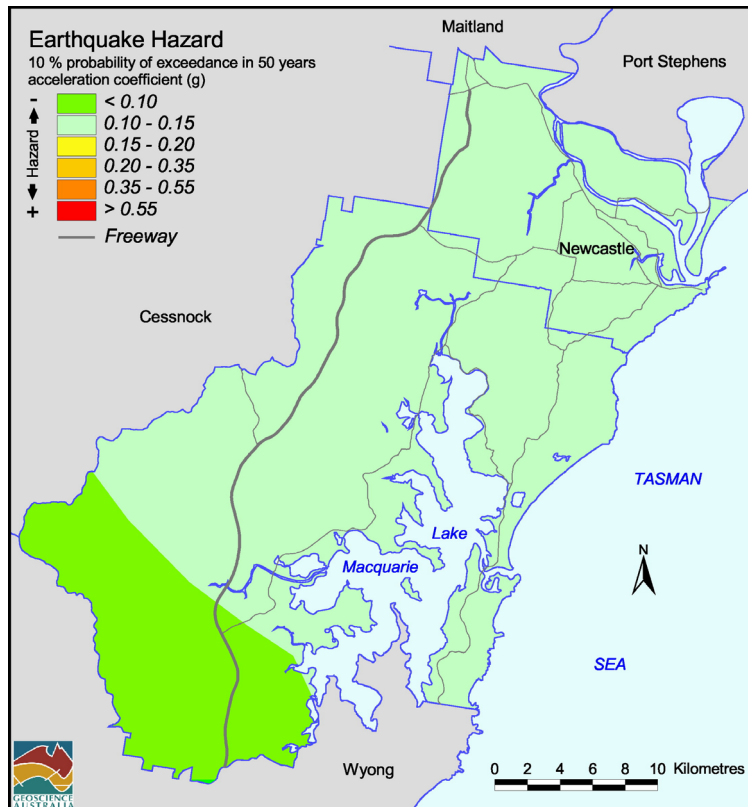


Figure 6: Earthquake hazard on rock in Newcastle and Lake Macquarie as suggested by from the Australian Standard for Earthquake Loading (AS1170.4, 1993). Earthquake hazard has been defined in terms of ‘acceleration coefficient’ (considered equivalent to PGA) on rock with a 10% chance of exceedance in 50 years.

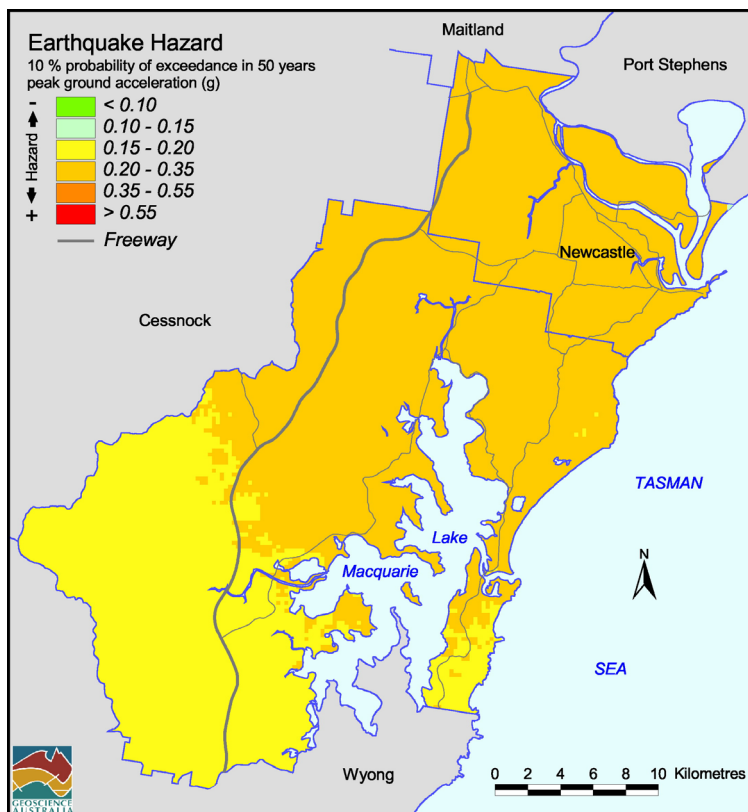


Figure 7: Earthquake hazard on rock in Newcastle and Lake Macquarie as suggested by this study. Earthquake hazard has been defined in terms of PGA on rock with a 10% chance of exceedance in 50 years.

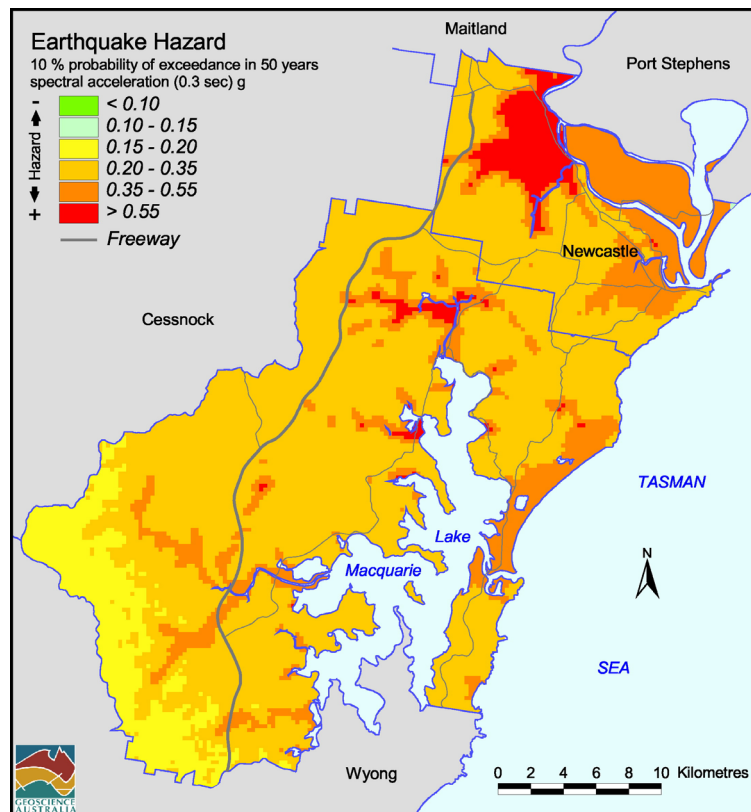


Figure 8: Earthquake hazard on regolith in Newcastle and Lake Macquarie as suggested by this study. Earthquake hazard has been defined in terms of RSA at 0.3 s on regolith with a 10% chance of exceedance in 50 years.

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