

SITE RESPONSE ANALYSIS – A COMPARISON OF METHODS AND SCALES

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ABSTRACT:

The presence of sedimentary soil layers (regolith) can cause dramatic variations in localised earthquake hazard. Consequently, the response of regolith to earthquake ground shaking is an important research issue in both earthquake hazard as well as structural engineering. Earthquake hazard assessments are often carried out on a regional scale, as opposed to structural engineering problems that tend to deal with smaller scale or site-specific problems. The difference in scale between these two applications causes subtle but very important differences in the approach to site response analysis.

In order to emphasise the differences between these two scales of site response analysis, seismic cone penetrometer (SCPT) data from Newcastle has been modelled by two different techniques. At a broad scale, the SCPT data was combined to form a single site class that was then modelled using equivalent-linear techniques. This approach provides amplification factors that are generally applicable to the entire region, but lack in specific details. Contrastingly, individual SCPT holes were modelled using a technique based on total regolith thickness and shear wave velocity. This approach provides more detailed estimates of site response at a specific location, but lacks the ability to be applied across a broad region.

The objective of this paper is to examine the subtle and important differences between the two modelling approaches and to discuss their engineering implications.

1. INTRODUCTION

Developing realistic site amplification provisions for seismic design and assessment applications requires a reasonable and workable balance between over-simplicity and unwarranted complexity (Martin, 1994). A typical approach adopted by current earthquake codes of practice, is to categorize sites into some four to five generic site classes. For example, IBC2000 and UBC1997 of the United States specify site classes ranging between "hard rock" and "soft soil" based mainly on the average soil shear wave velocity. Whilst the model was developed for simplicity in application, important factors such as site period, soil-rock impedance contrasts and the dependence on earthquake source properties have not been explicitly parameterised.

As the world community becomes increasingly conscious of intraplate seismicity, seismic code provisions are required for a diversity of seismo-tectonic and geological environments. US soil classification schemes have been adopted in the codes of practice of countries, such as Australia, that do not have locally derived amplification provisions. When adopting amplification provisions from other regions of the world, it is imperative that the underlying implicit assumptions be reviewed. The use of these generic site classifications across the US has often led to concerns about ambiguities (Whitman, 1991). It is expected that the use of these classifications is far more problematic in applications outside the US.

In addressing the limitations of generic site classes, Geoscience Australia (GA) has developed regolith amplification factors for Newcastle and Lake Macquarie based on local conditions. Seismic cone penetrometer tests (SCPTs) obtained locally were used to develop a representative "average" soil profile, which was then used as input to a stochastic procedure to generate a median site amplification function. Detail of GA procedure can be referred to Dhu (2002a) published in this volume. A summary is outlined in Section 2.

The amplification factors of GA, which are based on the "average" soil profile, are generally applicable to the entire area in estimating the total cost of damage for any given earthquake scenario and is ideal for situations where detailed information on individual sites is not required. To compliment the area-specific modelling procedure of GA, this paper presents a site-specific modelling methodology, which was developed at University of Melbourne (MU) to include site period and soil depth as modelling parameters. The importance of addressing site resonance in intraplate countries characterised by non-ductile construction offers significant advantages in explicitly parameterising site period. This can be demonstrated effectively using soil displacement response spectra. Salient details of the MU methodology are presented in Section 3.

The objective of this paper is to present the area-specific and site-specific methodologies as complimentary tools.

2. AREA-SPECIFIC PROVISIONS

2.1. Geotechnical Datasets

As part of its earthquake risk assessment of Newcastle and Lake Macquarie, GA, in collaboration with the University of Newcastle, acquired approximately 100 SCPTs across the Newcastle and Lake Macquarie region (Dhu and Jones, 2002a). These SCPTs were used as the basis of GA's classification of the regolith in the region as described in Dhu et al. (2002b). Regolith site class E, which consists of sands, silts and clays overlying weathered rock, has been used as a test case in this study. This site class has been defined on the basis of ten SCPTs distributed over the study region. The velocity data from these SCPTs is presented in Figure 1.

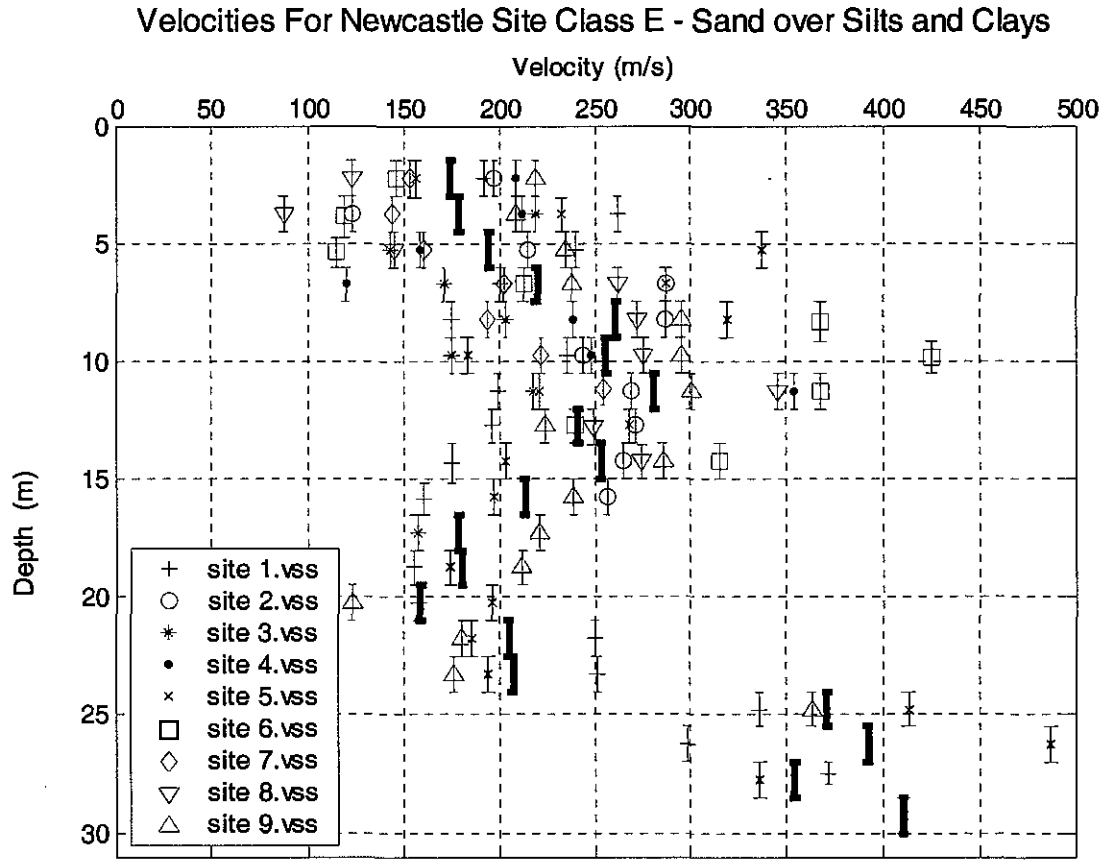


Figure 1: Velocity data from SCPTs in regolith class E (Dhu et al., 2002b). Note the thick, dark lines are the mean velocity at each depth.

2.2. Regional Risk Assessment Approach

For the purposes of the regional earthquake risk assessments carried out by GA, it is necessary to define amplification factors for every building or point of interest in the study region. It is not practical to define individual amplification factors for each building or point of interest. Consequently, it is necessary to classify the study region into areas where the regolith is thought to behave consistently during an earthquake.

After dividing the study region into these regolith site classes, it is necessary to create amplification factors that can be used when calculating the earthquake risk or hazard at each point. Natural processes are inherently variable, and consequently it is not realistic to assume that a single geotechnical model will accurately represent the entire region classified by a single site class. Hence, calculating the site response of a single representative velocity profile will not adequately capture the response of an entire site class. Consequently, a series of 50 velocity profiles were statistically generated for this site class. The mean velocity profile presented in Figure 1 was used as a typical profile for each class. Fifty velocity profiles were then generated from lognormal distributions based on variability observed in North America. Examples of the randomised velocity profiles are displayed in Figure 2. The total regolith thickness and strain dependent material properties were also randomised for each of the velocity profiles.

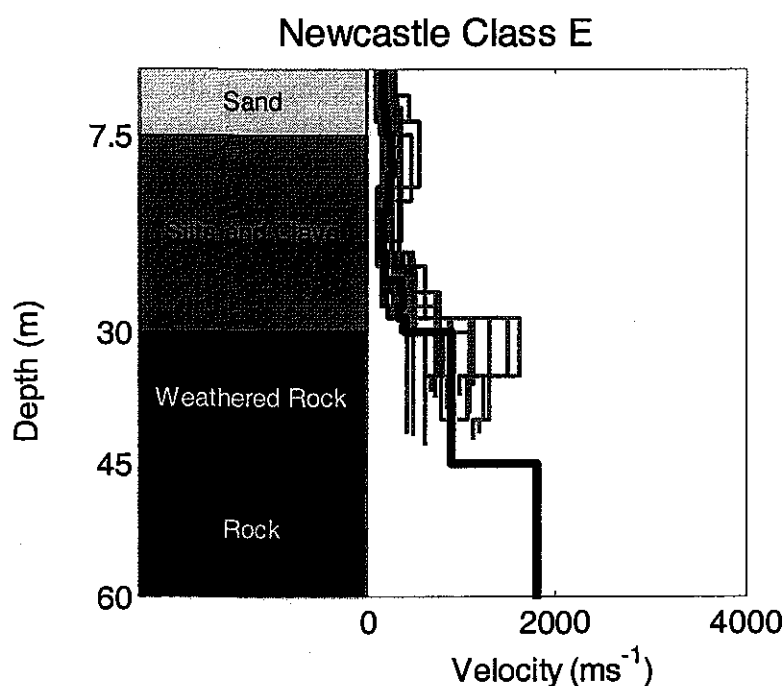


Figure 2: Examples of the randomised velocity profiles (light) calculated from site class E's median profile (dark)

Amplification factors were calculated for all 50 of the randomised profiles, using an equivalent-linear methodology (Electric Power Research Institute, 1993; Dhu et al., 2002b). These amplification factors are log-normally distributed, and hence an appropriate median and standard deviation are calculated from the data. This "distribution" of amplification factors is then used to randomly select amplification factors when calculating earthquake risk or hazard for any point within this site class (Dhu et al., 2002c).

3. SITE-SPECIFIC PROVISIONS

The stochastic procedure presented in Section 2 is designed to provide amplification factors for a statistical or probabilistic hazard assessment of a region. These amplification factors are not designed to precisely describe the dynamic properties of individual soil columns. Significantly, site specific details such as the total thickness of the soil layers which controls the period of the trapped shear waves (ie the site natural period) has not been accurately represented by the stochastic model. To assess the implications, results obtained from the stochastic procedure based on site category Class E are compared with those obtained directly from equivalent-linear shear wave analysis [using program SHAKE (Schnabel et al., 1972)] of the original SCPT records from Newcastle pertaining to the same site class. The analyses employed synthetic bedrock motion records that were generated by the computer program GENQKE (Lam et al., 2000).

The response spectral amplification factors obtained from the SHAKE analysis of individual soil columns are shown in Figure 3 along with the amplification functions predicted by the stochastic procedure. The variability of the locations of the individual amplification peaks is important to note. Whilst the amplification factors at resonance were consistently in the order of 3-5, the period at resonance (or site period) varied between 0.5 and 1sec. This has significant implications since the peak response spectral displacement demand (Δ) at resonance is proportional to the site period when the response spectral velocity is held constant. For example, in Figure 3 Site-2 & Site-8 have almost the same response spectral velocity but very different response spectral displacement, as demonstrated in Figure 4. The storey drift behaviour on the two sites are consequently very different.

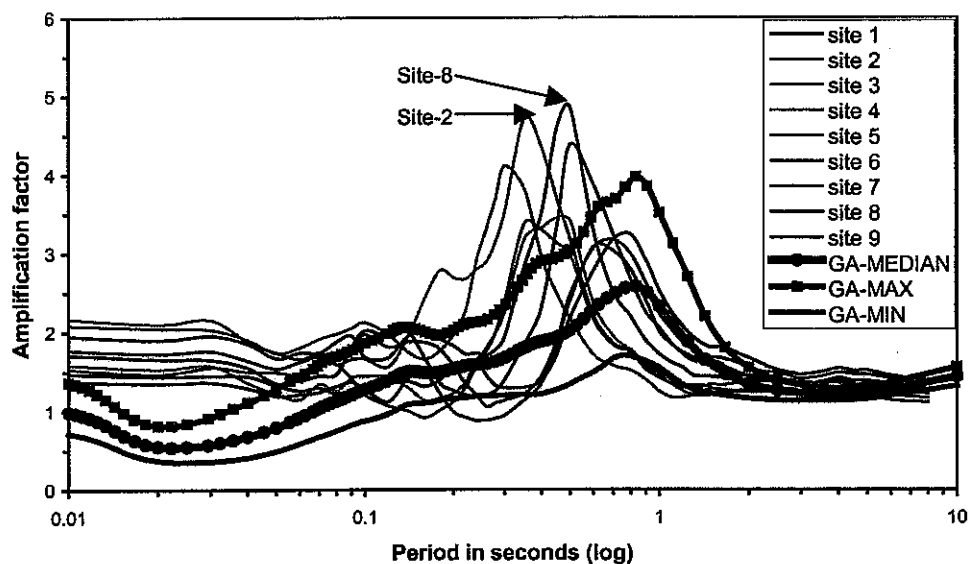


Figure 3. Comparison of amplification factors between GA & MU approach (log normal distribution)

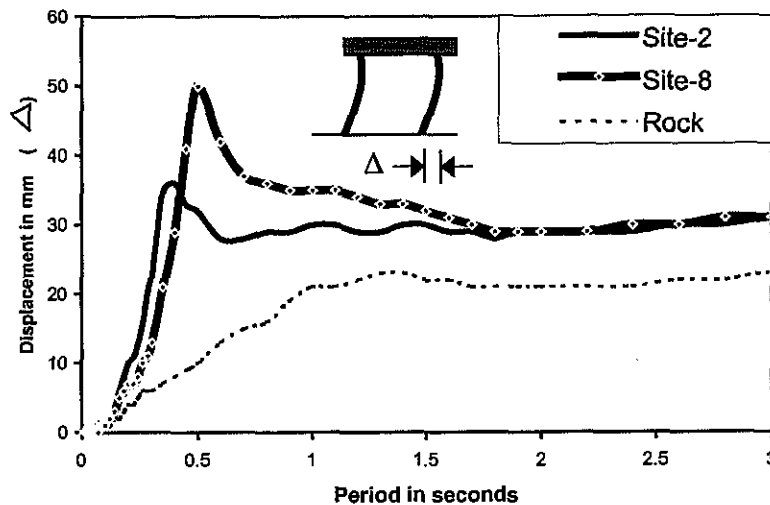


Figure 4. Soil and Rock Response Spectral Displacement

A simple manual procedure known as the Frame Analogy Soil Amplification (FASA) model developed in recent years at the University of Melbourne (MU) facilitates the incorporation of the site period in the construction of the site specific displacement response spectrum as shown in Figure 4 (Lam et al., 2001). Application of the MU procedure in the recent study by Chandler et al. (2002) shows excellent linear correlation between Δ and the site period. Consequently, Δ is well correlated with the total thickness of the soil layers.

4. CLOSING REMARKS

The comparative analysis presented in this paper shows that the soil amplification factors developed from the GA stochastic procedure are generally consistent with results obtained from the SHAKE analysis of individual SCPT records. However, more representative predictions of the displacement demand could be obtained by the analysis of individual SCPT or borehole records when input data, which accurately represents site-specific and scenario-specific information, are available.

5. REFERENCES

- Chandler, A.M., Lam, N.T.K., and Sheikh, M.N., (2002) Response spectrum predictions for potential near field and far field earthquakes affecting Hong Kong: Soil sites, *J Soil Dynamics & Earthquake Engineering*, [In press]
- Dhu, T., and Jones, T., (.eds) (2002a) *Earthquake risk in Newcastle and Lake Macquarie*. Geoscience Australia, ACT, Australia.
- Dhu, T., Jones, A., Fityus S., Jones, T., Robinson, D., Schneider, J., and Silva, W., (2002b) *Site response analysis in Newcastle and Lake Macquarie*. This Volume.

Dhu, T., Robinson, D., Sinadinovski, C., Jones, T., Corby, N., Jones, A., and Schneider, J., (2002c) Earthquake Hazard. In: Dhu, T. and Jones, T. (eds). Earthquake risk in Newcastle and Lake Macquarie. Geoscience Australia, ACT, Australia.

Electric Power Research Institute (1993) Vol 2: Appendices for ground motion estimation. In: Guidelines for determining design basis ground motions – EPRI TR-102293, Palo Alto, California, U.S.A.

Lam, N.T.K., Wilson, J.L., and Chandler, A.M., (2001) Seismic displacement response spectrum estimated from the frame analogy soil amplification model, J Engineering Structures, Vol 23, pp 1437-1452.

Lam, N.T.K., Wilson, J.L., and Hutchinson G.L., (2000) Generation of synthetic earthquake accelerograms using seismological modeling: a review, J Earthquake Engineering, Vol 4, No 3, pp 321-354.

Martin, G.R., and Dobry, R., (1994) Earthquake site response and seismic code provisions, NCEER Bulletin, Vol 8, No 4, pp 1-6.

Schnabel, P.B., Lysmer, J., and Seed, H.B., (1972) A computer program for earthquake response analysis of horizontally layered sites. In: Earthquake Engineering Research Centre EERC report 72-12. Berkeley (CA): University of California at Berkeley.

Whitman, R.V., (1992) Proceedings from the Site effects workshop, October 24-25, 1991, Technical report NCEER-92-0006.