

MODELLING OF THE EARTHQUAKE GROUND MOTIONS GENERATED BY THE NEWCASTLE EARTHQUAKE

R. KOO⁽¹⁾, M. CHENG⁽¹⁾, N. LAM⁽¹⁾, J. WILSON⁽¹⁾, G. HUTCHINSON⁽¹⁾ AND M. GRIFFITH⁽²⁾
THE UNIVERSITY OF MELBOURNE⁽¹⁾, THE UNIVERSITY OF ADELAIDE⁽²⁾

AUTHORS:

Raymond Koo is a Masters student at the University of Melbourne. He completed his undergraduate degree in the University of Auckland. He has been investigating the modelling of bedrock excitation.

Michael Cheng is a Masters student at the University of Melbourne, where he completed his undergraduate degrees of Civil Engineering and Science. He has been researching on soil dynamic modelling in earthquakes.

Nelson Lam is a Senior Lecturer and Senior Research Fellow at The University of Melbourne. He has 16 years of structural engineering experience. He was Chartered Engineer with Scott Wilson Kirkpatrick & Partners until 1989 when he began his academic career at The University of Melbourne specialising in the field of earthquake engineering. He has produced numerous publications in many different areas of earthquake engineering.

John Wilson is Chairman of the Board of Engineering, Victorian Division of the Institution of Engineers, Committee member of the Australian Earthquake Engineering Society, and Member of the Australian Standards Committee for Earthquake Loading. He was Senior Engineer with Ove Arup and Partners before becoming Senior Lecturer at The University of Melbourne in 1992. He is co-author of a book and numerous publications in many different areas of earthquake engineering and structural dynamics.

Graham Hutchinson is Professor and Head of the Department of Civil and Environmental Engineering at The University of Melbourne. He is President of the Australian Earthquake Engineering Society, and a past Chairman of the Victorian Division of the Institution of Engineers, Australia. He has written two books and over 100 papers on earthquake engineering and structural dynamics. He is also specialist consultant for earthquake engineering related projects all over the world.

Mike Griffith is Associate Professor at the Department of Civil and Environmental Engineering, The University of Adelaide.

ABSTRACT:

No strong motion accelerograms have been recorded from the mainshock of the Newcastle earthquake. Methodologies developed recently at the University of Melbourne have been employed to model earthquake ground motions generated by the earthquake to compare with macro-seismic data. The developed procedure consists of two components: (i) Prediction of bedrock motions based on a seismological source model and a regional crustal model (ii) Prediction of the effect of soil resonance on the response spectra. The acceleration, velocity and displacement parameters obtained from the procedure for a number of damage sites in Newcastle have been tabulated.

1. INTRODUCTION

A magnitude 5.5 earthquake which struck Newcastle, New South Wales, Australia in December 1989 caused widespread damages to infrastructures and resulted in 11 deaths. No strong motion accelerograms have been recorded from the mainshock of the earthquake and there were speculations over the attenuation and amplification of the earthquake ground motions. Significantly, the predominant geological feature that influenced the extent of seismically induced damages to infrastructures was the variation in the depth of the alluvial material overlying bedrock.

Methodologies developed recently at the University of Melbourne have been employed to model earthquake ground motions generated by the Newcastle earthquake. The developed procedure consists of two components: (i) Prediction of bedrock motions based on a seismological source model and a regional crustal model. (ii) Prediction of the effect of soil resonance on the response spectra. The acceleration, velocity and displacement parameters obtained from the above procedure for a number of damage sites in Newcastle have been tabulated.

2. SEISMOLOGICAL MODELLING OF BEDROCK MOTIONS

Recent seismological investigations indicate that the regional dependent frequency characteristics of earthquake ground motions are largely attributed to regional variations in the crustal properties. In comparison, the effect of regional variations is much more moderate in the average source properties of the generated seismic shear waves⁽¹⁾. The two generic crustal conditions, named as generic "hard rock" & "rock", have been defined in the context of a seismological model references 1 & 2.

The maximum response spectral displacement (RSD_{max}) predicted for the generic "hard rock" crustal conditions can be approximated by the following expressions, which have been derived from stochastic simulations of the seismological model⁽³⁾:

$$RSD_{max} = 14 \alpha_D(M) \beta(R) \gamma_D(M,R) \quad (RSD_{max} \text{ in mm}) \quad (1)$$

$$\text{where } \alpha_D(M) = 0.20 + 0.80 (M-5)^{2.3} \quad (2a)$$

$$\beta(R) = 30 / R \quad (R \text{ in km}) \quad (2b)$$

The crustal factor $\gamma_D(M,R)$ is an amplification ratio which accounts for the different crustal conditions⁽³⁾ (It is recommended that in the absence of reliable information on the crustal parameters that "rock" crustal conditions be conservatively assumed.):

$$\gamma_D(M,R) = 1.6 + (30-R)/200 + (6-M)/10 \quad (\text{for generic "rock"}) \quad (3a)$$

$$\gamma_D(M,R) = 1 \quad (\text{for generic "hard rock"}) \quad (3b)$$

Parameters defining velocity and acceleration properties can also be predicted by similar expressions⁽³⁾. The response spectrum modeling approach is the direct determination of the acceleration, velocity and displacement response spectra (RSA, RSV and RSD respectively) based on the ground motion parameters described above⁽³⁾.

3. THE BEDROCK MODELLING OF THE NEWCASTLE EARTHQUAKE

There were no strong motion accelerograms in the Newcastle area at the time of the earthquake. Thus, the seismological model has been employed to model the Newcastle Earthquake. The model has been checked by comparing with peak acceleration and velocity recorded from the nearby Ellalong Earthquake⁽⁴⁾. [Figures 1 & 2]

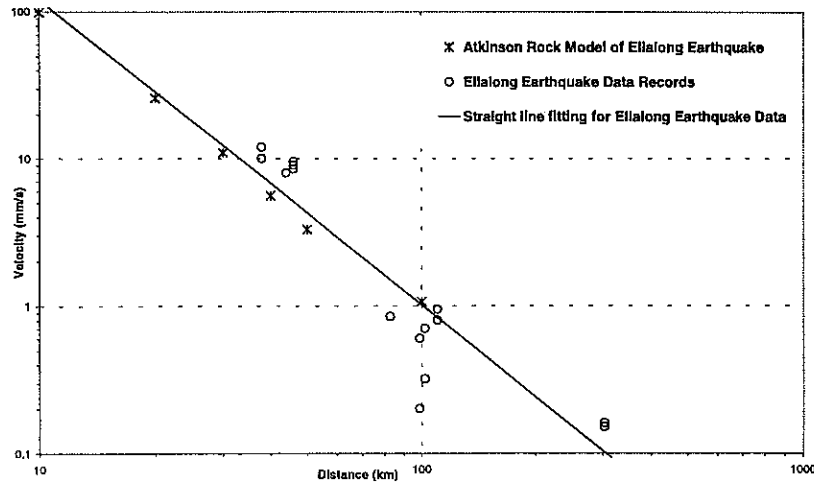


Figure 1. Peak Velocity of Rock Sites of Ellalong Earthquake.

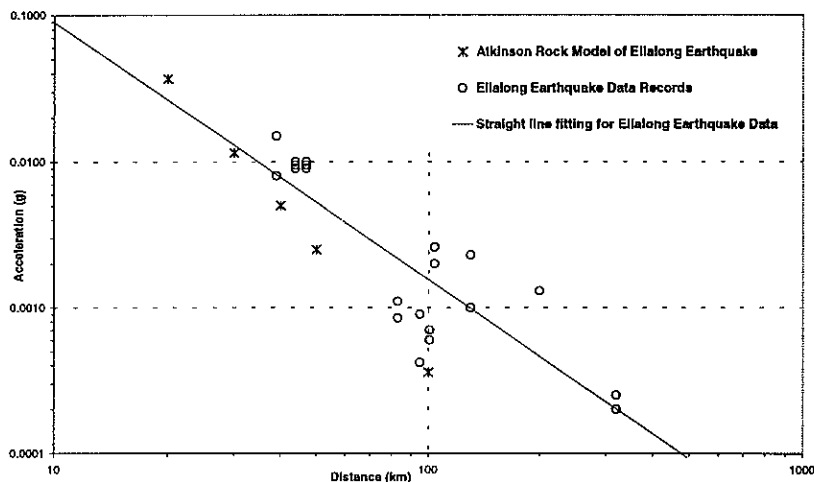


Figure 2. Peak Acceleration of Rock Sites of Ellalong Earthquake.

The Ellalong Earthquake of magnitude 5.3, occurred 3-4km west of Ellalong at the town of Cessnock, 50km west of Newcastle on 6th August 1994⁽⁵⁾. Since the earthquake was very shallow (depth ~ 1 to 2 km), it has been assumed that the entire wave travel path was within the upper crust region which possessed very low attenuation properties as inferred by the seismological model^(2&6).

By utilising the existing Atkinson rock model with modification to the parameters to simulate the Ellalong Earthquake, the recorded peak velocity and acceleration have been compared with the simulated data. [Figures 1&2] The good agreement of the seismological model with field measurements confirms the accuracy of equations (1-3) in predicting ground motion parameters for rock sites and bedrock.

4. FRAME ANALOGY SOIL AMPLIFICATION MODEL FOR SOIL SITES

The procedure developed recently by the authors to model the effect of soil resonance is known as the "Frame Analogy Soil Amplification" (FASA), as it is based on drawing an analogy between the dynamic response of a soil column and a moment resisting frame developing "beam-sway" mechanism^(3&7), to predict the peak ground acceleration (PGA) and the maximum response spectral acceleration (RSA_{max}) on soil sites. According to the FASA model, RSA_{max} is proportional to the RSA of the bedrock response spectrum (Sa_i) at the natural period of the site (T_i , which is also the corner period of the soil response spectrum). Further details of the FASA procedure for modelling acceleration response spectra is described in reference 7. The level of PGA and RSA_{max} on a soil site depends largely on both T_i and the shape of the characteristic response spectrum of the underlying bedrock. The key equations in the FASA model are summarized in Figure 3.

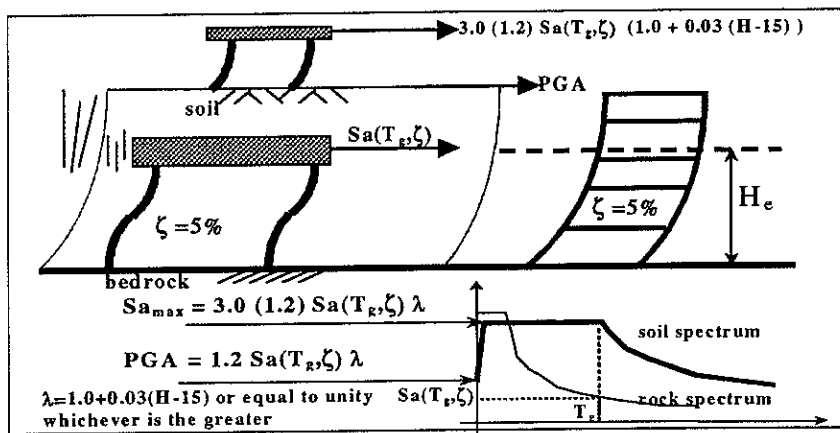


Figure 3.
The Frame Analogy
Soil Amplification
(FASA) Model.

Table 1. Site prediction using FASA model for different sites in Newcastle Earthquake

Site	T_i (sec)	T_g (sec)	RSA_{max} (g)	RSV_{max} (PGV) (mm/sec)	RSD_{max} (mm)
Newcastle Workers Club	0.55	0.82	0.337	431 (215)*	56.3
Hamilton - James & Murray Sts.	0.51	0.78	0.386	467 (234)*	57.6
Hamilton - Francis Xavier	0.50	0.76	0.541	642 (321)*	77.7
Newcastle RSL	0.22	0.43	0.940	636 (318)*	43.9
Franklins (old store bldg)	0.25	0.47	0.860	630 (315)*	47.0
Newcastle Technical College	0.55	0.68	0.486	517 (259)*	56.2
Taxation Office	0.16	0.34	1.057	560 (280)*	30.2
Tudor Inn Motel	0.18	0.37	1.011	582 (291)*	34.2
Ambassador Hotel	0.77	0.89	0.420	586 (293)*	83.2

* Values in brackets are the implied peak ground velocity (PGV), for $PGV \sim RSV/2$.

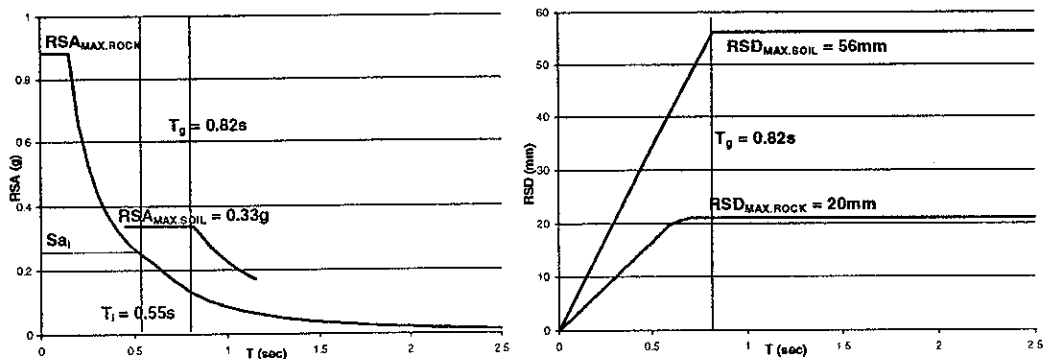


Figure 4 & 5. RSA & RSD for bedrock and soil site at Newcastle Workers Club.

Figure 4 & 5. RSA & RSD for bedrock and soil site at Newcastle Workers Club. Using the FASA model, the RSD_{max} and RSA_{max} of soil sites in Newcastle have been estimated to range between 30 and 83mm and 0.3g and 1g respectively. [Table 1] The rock RSD_{max} and Sa_{max} are about 20mm and 0.8g respectively. [Figures 4 & 5]

According to the Australian Standard AS 1170.4⁽⁸⁾ the acceleration coefficient (a) has been specified as 0.11g for the Newcastle region (which corresponds to a PGV of 82mm/s). Clearly, this is much lower than the 220~320mm/s predicted by the seismological model and the FASA model. [Table 1] Significantly, the very high predicted PGV level is consistent with speculations by McCue *et al* [1995] based on extrapolations from the Modified Mercalli Intensity data.

5. CONCLUSIONS

1. Predictions of the ground motion parameters by the seismological model are in good agreement with field measurements from the Ellalong Earthquake.
2. The maximum response spectral acceleration, velocity and displacement have been estimated for the 9 Newcastle soil sites by the seismological model and the FASA model [Table 1].
3. The predicted PGV in this study significantly exceed current code specifications. However, they were in good agreement with speculation based on extrapolation from the Modified Mercalli Intensity data.

6. REFERENCES

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