

# COMPARING THE PREDICTIONS OF THE COMPONENT ATTENUATION MODEL WITH REAL AUSTRALIAN EARTHQUAKES RECORDS

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## ABSTRACT:

The lack of instrumented earthquake data in Australia means that a representative response spectrum attenuation model cannot be developed from strong motion accelerogram data by conventional regression analysis. There are also inadequate seismogram records in Australia to develop a seismological model, or stochastic model. Consequently, attenuation models developed from overseas have been used in Australia. When choosing a "representative" model, regional conditions must be taken into account. However, this could have been handled in a more systematic and transparent manner. The Component Attenuation Model (CAM) provides a systematic way of combining generic information from overseas models with local information. CAM expresses the response spectrum in terms of the product of a source function and numerous path functions. The source function is generic but could be modified in accordance with observations from local earthquakes. Path functions should account fully for local conditions. For example, the Quality factor (Q) has been incorporated into the 2002 version of CAM as an input parameter for the path attenuation factor. In this paper, the response spectra predicted using CAM are compared with both instrumented and/or macro-seismic field measurements from the Ellalong earthquake, Newcastle earthquake and the Tennant Creek aftershock. All these events were in the magnitude range of 5 to 5.5. Further comparisons are also made with the well known attenuation model of Toro and Sadigh. Significantly, the scaling relationships built into CAM allows realistic predictions for events of much larger magnitude.

## 1. INTRODUCTION

In intraplate regions such as Australia, developing response spectrum models by the regression of representative strong motion data recorded locally is not infeasible due to the paucity of data. Consequently, response spectrum models for these regions are typically based on overseas codified models (refer commentary in AS1170.4: 1993) or attenuation models such as those developed by Toro (1997) and Sadigh (1997). The choice of a "suitable" model requires experienced seismologists to exercise judgement based partly on the comparison with data recorded locally (typically from small earthquake events and tremors). However, there are difficulties in extrapolating ground motion properties for a large earthquake event from observations of small events (Gibson, 1995). Intensity information from iso-seismal maps of major local historical events has been used extensively in developing local attenuation models (eg. Gaul, 1990), although it is recognised that there are considerable scatters associated with intensity information due to uncertainties in site effects and building vulnerability.

This suggests that intraplate response spectrum models have been developed in a somewhat *ad-hoc* and often non-transparent manner with a significant amount of professional judgement. Recommendations developed from a non-transparent process can lead to problems in code development and implementation (Wilson, 2001). Addressing this, code recommendations for Australia have been presented recently in a more transparent format (Lam, 2001a). The global trend in earthquake engineering towards a performance-based approach is associated with the need for a better understanding of both seismic hazard and system behaviour.

The seismological model which was pioneered by eminent seismologists in the US in the early 80's defines earthquake ground motion properties in terms of the Fourier spectrum (eg. Boore, 1983). The model which was originally based on a simple theoretical framework has been further developed based on the analysis of a large volume of representative seismological data (eg. Atkinson, 1993,2000). This semi-empirical approach relies mainly on low intensity far-field measurement and waives the need to regress strong motion accelerogram data. Thus, it has had special appeals for applications in the low seismicity region of Central and Eastern North America (CENA). Importantly, the model provides a platform from which seemingly complex earthquake processes can be modelled and interpreted in relatively simple terms.

Lam and Wilson have recognised the potential of the seismological model for a worldwide application and transformed the Atkinson version of the model developed for the CENA region from the original Fourier spectrum format into the engineering response spectrum format (Lam, 2000a-c). Whilst Australia could develop a seismological model of its own from local seismological data, a more viable approach is to adapt and verify the already developed models.

This seismological-engineering model, known as the Component Attenuation Model (CAM, as outlined in Section 2) represents various source and path effects by separate component factors so that variations in regional conditions can be readily accommodated. Predictions from CAM are compared with both Australian field observations in Section 3 & 4 and with the well known attenuation models of Toro (1997) and Sadigh (1997) in Section 5.

## 2. OVERVIEW OF CAM

The Component Attenuation Model (CAM) provides attenuation relationships for three response parameters which can be used to construct response spectrum in either the response spectral acceleration (RSA), response spectral velocity (RSV) or response spectral displacement (RSD) formats (Lam, 2000b). Due to length limitations, this paper considers only the  $RSV_{max}$  parameter which defines the highest point on the velocity response spectrum.  $RSV_{max}$  controls the response spectrum behaviour in the period range of greatest engineering interests and relates directly to the

peak ground velocity (*PGV*). The scaling of the design response spectra in AS1170.4 (1993) is effectively based on these two parameters.

$RSV_{max}$  (mm/sec) is defined in CAM by Eq.1 as the product of numerous component factors:

$$RSV_{max} = \alpha(M) \cdot G(R, D) \cdot \beta(R, Q, M) \cdot \gamma_{mc} \cdot \gamma_{uc} \quad (\text{soil factors not shown}) \quad (1)$$

where  $\alpha(M)$  represents the effect of earthquake magnitude as shown in equation (2).

$$\alpha(M) = 70(0.35 + 0.65(M - 5)^{1.8}) \quad (2)$$

Although Eq.2 models the effect of magnitude only, the  $\alpha$  factor could be extended to account for variations in the type of faulting and regional stress-drop characteristics. The equation was developed for the magnitude range M5-M7.5 for distances exceeding 10km although good correlation has been obtained for larger earthquake magnitudes (Bala,2002; Lam,2002b).  $M$  is defined as the moment magnitude as opposed to the usual local magnitude which has historically been used to characterise Australian earthquakes. Disparities between the two magnitude scales arising from saturation are only significant for magnitudes well in excess of 6.

$G(R, D)$  represents the effect of geometrical attenuation where  $R$  is the nearest distance between the site and the surface of fault rupture and  $D$  is the depth of the Moho discontinuity. The model is not intended for handling near-fault conditions associated with directivity effects (which are manifested in the form of elliptical isoseismal contours) and hence  $R$  should preferably be at least 10km for  $M > 5$  and 20km for  $M > 6$ .  $G$  can be simplified as follows for  $10\text{km} < R < 50\text{km}$ :

$$G(R) = 30/R \quad (3)$$

The anelastic attenuation factor  $\beta$  which represents energy dissipation effects incorporates the Quality factor ( $Q$ ) as an input parameter to account for regional variations in the wave transmission properties of the earth crust. Long distance attenuation of up to 500km can be modelled by the full expression for the  $\beta$  factor as presented in Lam (2002a) and reproduced diagrammatically in Figure 1. The effect of  $Q$  is shown to be critical only when  $R > 100\text{km}$ .  $\beta$  can be approximated to unity for distances up to 50km. For greater distances, information on  $Q$  as obtained by studies such as that undertaken by Wilkie (1995) can be critical to modelling accuracy.

The mid-crustal factor  $\gamma_{mc}$  is given by Eq.4 which has been simplified from wave theory.

$$\gamma_{mc} = 3.8 / \sqrt[3]{V_{source}} \quad (4)$$

where  $V_{source}$  is the estimated shear wave velocity at the depth of rupture which is typically less than 10km in Australia. The values of  $\gamma_{mc}$  for the "hard rock" conditions of CENA and the "rock" condition of WNA are 1.0 and 1.3 respectively based on average crustal properties (Boore,1997).

The upper-crustal factor  $\gamma_{uc}$  which can be calibrated in accordance with the regional crustal shear wave velocity gradient is estimated at 1.0 and 1.25 for the generic shear wave velocity profiles identified for CENA and WNA respectively. A full expression to allow for intermediate regional conditions has yet to be developed. Special crustal effects such as basin edge effects have not been considered. Additional site factors representing the effects of soil resonance have been developed (Lam, 2001b) but is not shown herein. Further details on the modelling of site effects could also be found in the companion paper (Srikanth, 2002). Full details for each of the equations listed in this section and their derivations can be found in Lam (2000b&c, 2002a).

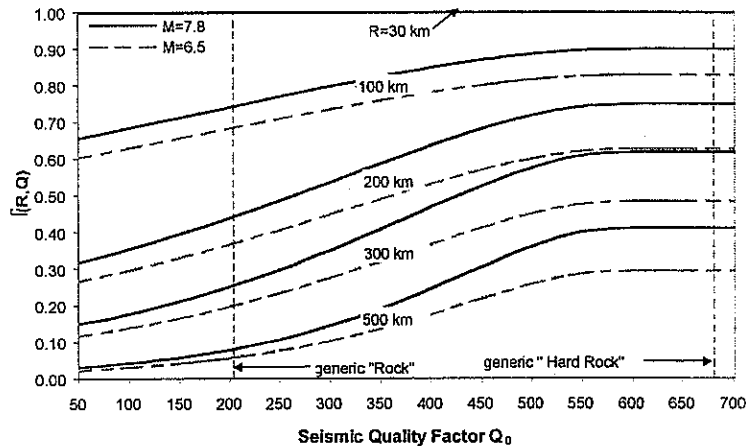


Figure 1  $\beta$  factor representing effects of energy dissipation (Chandler, *submitted*)

$RSV_{max}$  obtained from Eq.1 can be related directly to the peak ground velocity ( $PGV$ ) by Eq.5. The inferred  $PGV$  values can then be compared directly with seismogram measurements and with recorded Intensity information using the "Newmark-Rosenblueth" approximate expression of Eq.6.

$$PGV \approx 0.5 RSV_{max} \quad (5)$$

$$2^{MMI} \approx 7/5 PGV \quad (6)$$

### 3. COMPARISON WITH PRE 1984 ISOSEISMAL RECORDS

Information from iso-seismal maps collected from a number of Australian earthquakes including the M6.9 Meckering earthquake of 1969 and the M6.2 Cadoux earthquake of 1979 have been used to study earthquake attenuation behaviour (Gaul, 1990). In view of variations in crustal properties across the continent, separate attenuation relationships were developed for (i) Western Australia (WAus) which is characterised by hard rock conditions typical of mid-continental regions like CENA and (ii) Southeastern Australia (SEAus) which is characterised by softer rock conditions similar to WNA. The developed relationships are shown by Eqs. 7a & 7b respectively.

$$MMI = 1.5 M_L - 3.2 \log R + 2.2 \quad (\text{WAus}) \quad (7a)$$

$$MMI = 1.5 M_L - 3.9 \log R + 3.9 \quad (\text{SEAus}) \quad (7b)$$

In Table 1, the  $PGV$ 's predicted from Eqs.6,7a&7b (Gaul) and Eqs.1-4 (CAM) are compared.

Table 1 Predicted  $PGV$ 's (in mm/sec) from the relationship of Gaul and CAM

M-R(km)	Average Australian sites (Gaul,1990)			USA hard rock and rock sites (CAM)		
	WAUS	SEAus	crustal factor	CENA	WNA	crustal factor
M5 R30	22	36	1.64	12	20	1.67
M5.5 R30	38	60	1.58	20	30	1.50
M6 R30	64	100	1.56	35	56	1.60

$PGV$  values for hard rock ("WAus" and "CENA" columns) and rock ("SEAus" and "WNA" columns) by the two independent sets of relationships each differ by a factor of 1.8-2.0. This difference is considered to reflect the site amplification effects inherently associated with the models presented by Gaul. Interestingly, the implied site factor is very consistent across different crustal conditions and earthquake scenarios. The crustal factor which has been normalised to unity for hard rock conditions represent the amplification of motion intensity in softer crustal conditions. The factors as inferred from the Gaul's relationship for Australian earthquakes (ratio

of *PGV*'s for Rock : Hard Rock) were also highly consistent with similar factors inferred from CAM based originally on North American earthquakes. Furthermore, the rate of increase in *PGV* with increasing magnitude was highly consistent between the two sets of relationships. For example, the *PGV* predicted for a M5.5 event was consistently 1.5-1.7 times that of the same predicted for a M5 event. The *PGV* ratio for a M6:M5 event was also consistently 2.8-2.9. In summary, the source factor (Eq.2) and the crustal factors ( $\gamma_{mc}$  and  $\gamma_{uc}$ ) of CAM appear to be very consistent with the intensity observed from historical earthquakes in Australia.

#### 4. COMPARISONS WITH RECORDS FROM MORE RECENT EARTHQUAKES

Intensity information recorded from the M5.6 Newcastle earthquake event was more precise due to proximity to built-up areas and the destructive nature of the earthquake. Significantly, *MMI* observed on alluvial sites and rock sites could be distinguished for that event with rock sites typically showing a *MMI* value of VI-VII at an epicentral distance of 15km (Map no. 3 of Melchers, 1990). The *RSV<sub>max</sub>* value calculated using CAM for the earthquake at an epicentral distance of 15km for "rock" conditions (ie.  $\gamma_{mc}=1.3$  and  $\gamma_{uc}=1.25$ ) is 136mm/sec from Eqs.1-4. The inferred *PGV* and *MMI* is accordingly 68mm/sec (Eq.5) and VI-VII respectively (Eq.6) which is very consistent with the field observations. Further, the higher *MMI* value of VIII observed on alluvial sites was also very consistent with a site magnification factor of 2 inferred from the comparative study with Gaul as described in Section 3.

Even more precise ground motion information was obtained from the M5.3 Ellalong earthquake of 1994 where some five seismographs located on rock sites within 40-50km of the epicentre were activated with a *PGV* averaging around 10mm/sec recorded (McCue, 1995). The *PGV* calculated from CAM was 15mm/sec (assuming the same crustal condition as for the Newcastle earthquake). The slightly lower recorded *PGV* is believed to be due to the geology of the Sydney basin which is characterised by a thick layer of soft rock sediments with high energy absorption properties. The significant of this energy dissipation effect increases with increasing distance.

In contrast to the Newcastle earthquake and the Ellalong earthquake, the Tennant Creek earthquake of 1998 occurred in the intercontinental region of Central Australia which is characterised by hard rock conditions similar to CENA. The velocity response spectrum recorded from the M4.9 aftershock at an epicentral distance of 10km was also highly consistent with the predictions by CAM as shown in Figure 2 (and reported in Lam, 2000c). Note, the difference in the corner period ( $T_1$ ) between Figure 2 for hard rock and the illustrations in Koo (2000) and Lam (2001a) for rock.

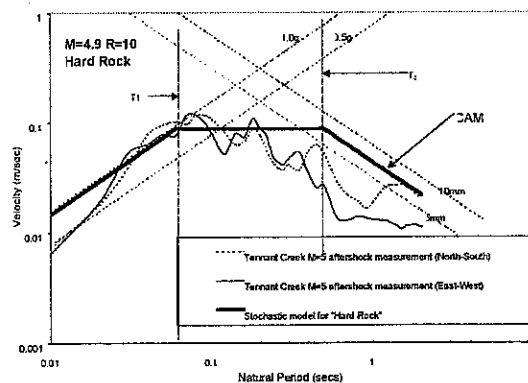


Figure 2 Response spectra from Tennant Creek aftershock and CAM predictions(Lam, 2000c)

## 5. COMPARISONS WITH PREDICTIVE MODELS BY TORO AND SADIGH

Further comparisons are made between CAM and the predictive models of : (i) Toro (1997, model developed for mid-continental earthquakes within CENA and representing hard rock conditions and (ii) Sadigh (1997, model developed for shallow Californian earthquakes and representing rock conditions. Predictions are listed in Table 2 under separate groupings for "hard rock" and "rock" conditions, assuming reverse faulting.

Table 2  $RSV_{max}$  (and  $PGV$ ) predictions in mm/sec

Earthquake Scenarios	Hard Rock		Rock	
	CAM (hard rock)	Toro	CAM (rock)	Sadigh
M5 R=30km	25(13)	25(13)	39(20)	26(13)
M5.5 R=30km	38(19)	41(20)	60(30)	46(23)
M6 R=30km	70(35)	77(38)	112(56)	82(41)

A reference distance of 30km has been adopted in the comparison to circumvent complications arising from near fault effects. Predictions for other distances could be made using Eq.3 and the full expression for  $\beta$  where necessary (refer Section 2). Excellent correlation was observed between the CAM (hard rock) model and the model of Toro for similar crustal conditions. However, predictions by Sadigh (97) for Californian earthquakes of  $M=5$  are some 35% lower than predictions by CAM for similar crustal conditions. The lower values associated with Californian earthquakes is postulated to have resulted from stress drop which is generally lower than what was implicit in the CENA database (which is the basis of the Atkinson model and CAM). Interestingly, this regional variation seems to diminish with increasing magnitude. For example, predictions by the two models differ only by 25% at  $M=6$ , and show little differences at  $M7.5$  (Lam, 2000c). Refer Figure 3 for a 3D diagrammatic illustration.

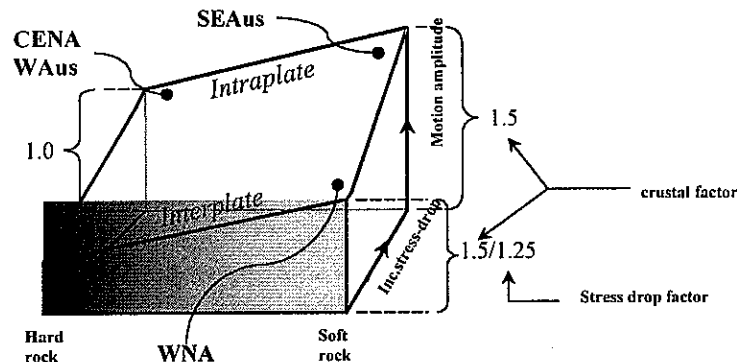


Figure 3 Crustal factor and stress drop factor ( $M=5.5$ )

## 6. CLOSING REMARKS

The comparative study presented in this paper confirms the robustness of the CAM relationships. Improved estimates for the path effects could be achieved through studying crustal conditions and combining regional seismological information with geological information. Source effects are less predictable but useful trends could be revealed by collating and analyzing near-field information collected worldwide. Difficulties associated with the collection of adequate earthquake data in intraplate regions could be alleviated through such research efforts. CAM is conceptually different to most existing attenuation models in that it is not based on a defined database of earthquake data. CAM instead provides a convenient platform on which relevant research contributions to ground motion modeling from different sources could be used and presented in a transparent format.

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