A DISPLACEMENT BASED PREDICTION OF THE SEISMIC HAZARD FOR AUSTRALIA

N. LAM, J. WILSON, M. EDWARDS AND G. HUTCHINSON
THE UNIVERSITY OF MELBOURNE

AUTHORS:

Nelson Lam is a 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, Treasurer 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.

Mark Edwards is a member of both the Australian Earthquake Engineering Society and the New Zealand National Society for Earthquake Engineering. He has had four years geotechnical and ten years structural engineering experience with an on-going interest in earthquake engineering and its applications. He is currently carrying out research on the displacement based method at the University of Melbourne. He has authored and co-authored a number of publications in the earthquake engineering area.

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.

ABSTRACT:

The displacement based design procedure has been developed recently for the seismic design and the evaluation of different types of structures. The substitute structure model used in the procedure enables the inelastic displacement to be predicted from the elastic displacement spectra. This paper introduces a new displacement spectrum model for both rock and soil sites. The displacement spectrum model for rock sites takes into account the properties of the earthquake source and the transmission path in accordancewith a seismological model. The displacement spectrum model for the soil sites takes into account the natural period of the site and the frequency properties of the bedrock excitations.

1. INTRODUCTION

The displacement based design procedure has been developed recently for the seismic design and the evaluation of different types of structures [1-3]. The substitute structure model used in the procedure enables the inelastic displacement to be predicted from the elastic displacement spectra. This paper introduces a new displacement spectrum model proposed for both rock and soil sites. The displacement spectrum model for rock sites takes into account the properties of the earthquake source and the transmission path in accordance with a seismological model [4,5]. The displacement spectrum model for the soil sites takes into account the natural period of the site and the frequency properties of the bedrock excitations [6].

The frequency content of the seismic shear waves generated at the earthquake source depends on the moment magnitude, M_w, and the shape of the Fourier spectrum of the source. The spectrum shape has been generalised by Atkinson into a generic Eastern North American (ENA) "intraplate" model and a generic Western North American (WNA) "interplate" model based on the analyses of a large number of accelerograms recorded in North America [7,8]. These generic source models reflect the significant differences in the average frequency content of earthquakes generated in the two regions. The effects of the transmission path, which include geometrical and anelastic attenuation and amplification, have also been generalised into the ENA and the WNA crust model which assumes a shear wave velocity gradient as shown in Figure 1 [9] and the set of geological parameters listed in the following table :

Table 1 Geological Parameters of the Generic ENA and WNA Crust Models [7-10]

Crust	Whole Path Attenuation Quality Factor $Q(f) = Qo\, f^n$		Upper Crust Attenuation Factor	Shear Wave Velocity at Mid-Crust	Shear Wave Velocity at Upper-Crust
	Qo	n	κ	β_m	$\beta_{(z)}$
ENA	680	0.36	0	3.5km/sec	refer Fig. 1
WNA	204	0.56	0.035-0.050	3.8km/sec	refer Fig. 1

The response spectra derived from these generic source and crust models demonstrate that the displacement demand varies with the moment magnitude and the crustal properties. In contrast, the displacement demand appears to be insensitive to the source properties for high natural periods typical of flexible and ductile structures (refer Figure 2 & 3).

The procedure to predict the displacement demand at a site consists of the following steps :
(a) Seismicity modelling (section 2).
(b) Displacement spectrum modelling for rock sites (section 3).
(c) Displacement spectrum modelling for soil sites (section 4).
These steps are described below.

2. SEISMICITY MODELLING

The level of seismic activity (seismicity) in a region can be expressed in the form:

$$\log_{10} N = a_5 - b\,(M - 5) \qquad (1)$$

where N is the expected number of earthquakes of magnitude greater than M which occur within an area of 100,000 km^2 over the next 100 years; and a_5 and b are the seismicity constants.

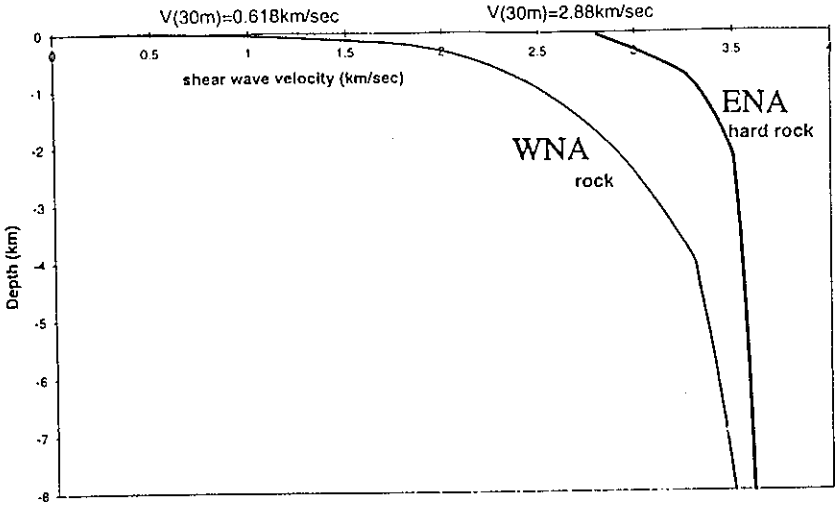

Figure 1 Shear Wave Velocity Gradients of the Generic Crust Models

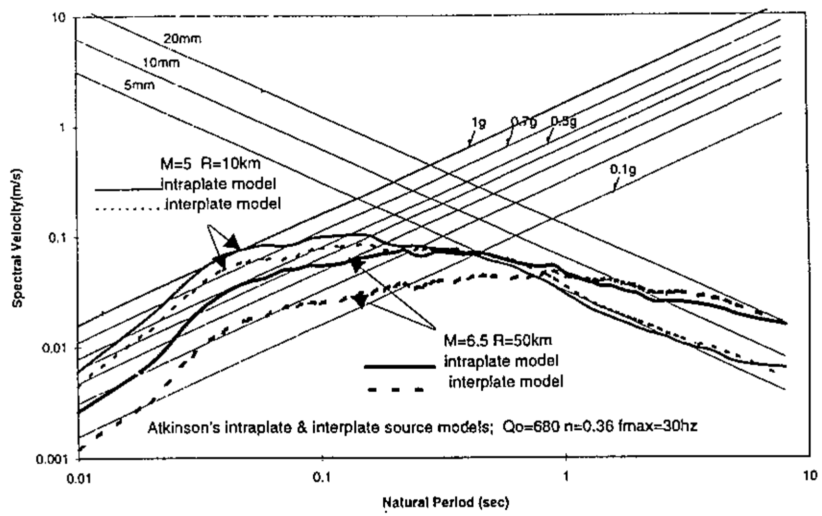

Figure 2 Reponse Spectra associated with ENA &WNA Source Models

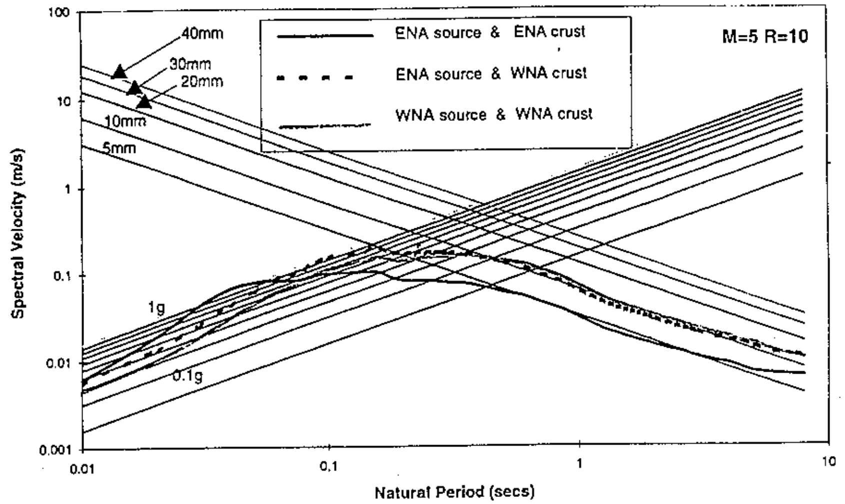

Figure 3 Reponse Spectra associated with ENA &WNA Crust Models

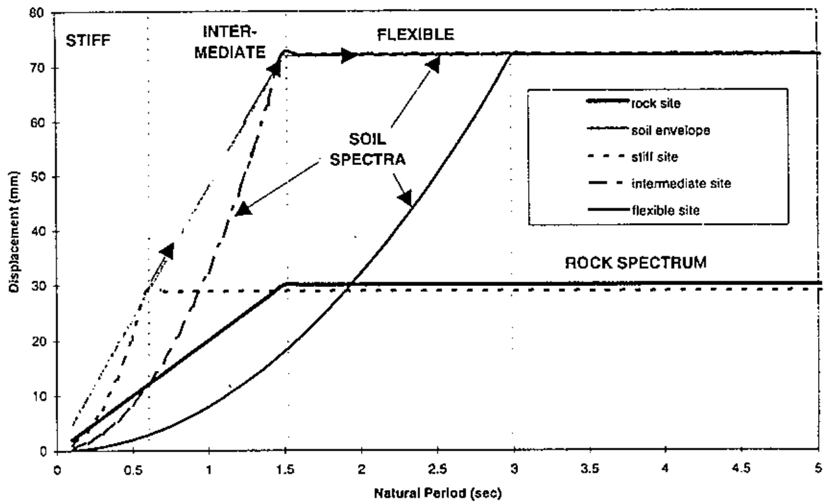

Figure 4 Displacement Spectra of Rock and Soil Sites

If no major active faults have been identified in the vicinity of a site in an intraplate region, a uniform distribution of seismicity surrounding the site may be assumed. The number of earthquakes, N^*, generated within R kilometers from the site is proportional to the source area, πR^2, and the return period, T_{RP}, as shown by the following expression:

$N^* = N (\pi R^2 T_{RP})/(100 \text{ years} \times 100{,}000 \text{ km}^2)$ (2)

The design earthquake magnitude, M, for a given value of R, a_s and b can be determined by substituting equation 1 into equation 2, taking $N^* = 1$ (one event), and rearranging the terms as follows:

$M = 5 + \{\log_{10}(\pi R^2 T_{RP}) - 7 + a_s\}/b$ (3)

It can be shown that if $a_s = 1.9$, $b = 0.9$ and T_{RP}=500 years the resulting M-R combinations (refer Table 2) are associated with a peak ground velocity of approximately 60mm/sec (assuming ENA crust) which corresponds to an acceleration coefficient of 0.08g which is representative of the average seismicity of the Australian capital cities.

It is recognised that moment magnitude (M_w) should be used in defining M for applying the procedure to be described in section 3. However, $M_w = M_L$ (local magnitude) may be assumed for $M_L < 6$, and $M_w = M_s$ (surface wave magnitude) for $6 < M_s < 7$ for practical purposes although slight adjustments may be required in some regions.

3. DISPLACEMENT SPECTRUM MODELLING FOR ROCK SITES

The displacement spectrum is assumed to be bi-linear (refer Figure 4) and is defined as follows :

$S_d(T) = S_V\, T/(2\pi)$ (4a)

$S_d(T) = S_D$ (4b)

whichever is the lesser.

The peak spectral velocity, S_V, and the peak spectral displacement, S_D, defining the displacement spectrum have been approximated by (units in mm and mm/second) :

$S_D = S_D^*\, \alpha_D(M)\, \beta(R)\, \gamma_D(M,R)$ (5a)

$S_V = S_V^*\, \alpha_V(M)\, \beta(R)\, \gamma_V(M,R)$ (5b)

where S_D^* = 14mm and S_V^* = 95mm/second are the benchmark values at M=6 and R=30km;

The magnitude factors, $\alpha_D(M)$ and $\alpha_V(M)$ are defined by :

$\alpha_D(M) = 0.20 + 0.80\,(R-5)^{2.3}$ (6a)

$\alpha_V(M) = 0.35 + 0.65\,(R-5)^{1.8}$ (6b)

The distance factor, β, is defined by :

$\beta = 6.5/\{6.5 + (R-30)/4.4\}$ (7)

The crust factors, $\gamma_D(M,R)$ and $\gamma_V(M,R)$, for WNA crust are defined by :

$\gamma_D(M,R) = 1.6 + (30-R)/200 + (6-M)/10$ (8a)

$\gamma_V(M,R) = 1.6 + (30-R)/100 - (6-M)/10$ (8b)

The crust factors for the ENA crust are equal to unity by definition.

Equations 5 - 8 have been derived by mapping (curve-fitting) results obtained from the time-history analyses of a large number of synthetic accelerograms generated in accordance with the seismological model described in Ref.5. The M-R combinations derived for $a_s = 1.9$, b=0.9 and

T_{RP}=500, using equation 3, and the associated S_D and S_V values are shown in Table 2 together with the values obtained directly from time-history analyses (shown as (*value*)) as follows:

Table 2 - Predicted values of S_D and S_V using equations 5 - 8 (units: mm and second)

M	5	5.5	6	6.5	7
R(km)	10	20	30	50	70
S_D(ENAcrust)	9(*6*)	8(*8*)	14(*13*)	18(*17*)	24(*22*)
S_V(ENAcrust)	110(*102*)	78(*82*)	95(*92*)	95(*79*)	104(*93*)
S_D(WNAcrust)	17(*11*)	13(*13*)	22(*21*)	27(*25*)	31(*30*)
S_V(WNAcrust)	188(*181*)	129(*145*)	152(*153*)	138(*124*)	135(*126*)

The comparisons between the tabulated and the bracketed results show that the errors introduced by the curve-fitting were insignificant.

From Table 2, S_D = 31mm and S_V = 135mm/sec is predicted for M=7 and R=70km assuming WNA crust parameters. The corresponding displacement spectrum calculated using equation 4 is shown in Figure 4 (bold line).

4. DISPLACEMENT SPECTRUM MODELLING FOR SOIL SITES

The displacement spectrum, $S_d(T)_{(soil)}$ for a soil site of natural period T_g can be approximated by the bi-linear expression which is based on a procedure developed recently by the authors [6] :

$S_d(T)_{(soil)} = (T/T_g)^2 S_{D(soil)}$ (for $T< T_g$) (9a)

$S_d(T)_{(soil)} = S_{D(soil)}$ (for $T> T_g$) (9b)

where

$S_{D(soil)} = \delta S_d(T=T_g)_{(bedrock)}$ (9c)

$S_d(T=T_g)_{(bedrock)}$ is the spectral displacement defined by equations 4a & 4b for $T=T_g$

$\delta = 1.2\,(2.5)\,\{7/(\zeta_{soil}+2)\}^{1/n}$ (9d)

(n=2 for soil in resonance with the bedrock excitations and n=4 for other conditions.)

δ may be taken to be equal to 2 - 3 assuming ζ_{soil} (soil damping) = 5 - 15% for low seismicity conditions.

The displacement spectrum for soil sites classified as stiff, intermediate and very flexible corresponding to T_g=0.6sec, 1.5sec and 3.0 sec respectively (assuming δ = 2.5) are shown in Figure 4.

The development of the displacement spectrum models is part of the long term research programme undertaken by the authors to rationalise the seismic design procedure for Australia.

5. CONCLUSIONS

(i) Generic ENA and WNA source and crustal models have been defined. The peak displacement demand is significantly dependent on the moment magnitude and the crustal model but not on the source model.

(ii) A set of M-R combinations has been derived for a given return period and seismicity level.

(iii) Expressions have been derived to predict the displacement spectrum for a rock site using M, R and the crust classification as the input parameters.

(iv) Expressions have been derived to predict the displacement spectrum for a soil site using the site natural period, T_g , the soil damping ratio, ζ_{soil}, and the bedrock response spectrum as the input parameters.

6. ACKNOWLEDGEMENT

The development of the procedure described in this paper forms part of a project funded by the Australian Research Council (large grant), titled : "Earthquake Design Parameters and Design Methods for Australian Conditions".

7. REFERENCES

1. Priestley,M.J.N.(1995), Displacement-Based Seismic Assessment of Existing Reinforced Concrete Buildings, *Proceedings of the Fifth Pacific Conference of Earthquake Engineering,* Melbourne, pp225-244.
2. Edwards, M. , Wilson, J.L, Lam, N.T.K. and Hutchinson, G.L.,1998 : " The displacement based approach from an intraplate perspective", *Proceedings of the Australasian Structural Engineering Conference,* Auckland, 1998. (paper accepted for oral presentation at the conference)
3. Lam, N.T.K., Wilson, J.L and Hutchinson, G.L.,1998 : "Seismic evaluation of building structures in Australia", *Proceedings of the Australasian Structural Engineering Conference,* Auckland, 1998. (paper accepted for oral presentation at the conference)
4. Lam, N.T.K., Wilson, J.L. and Hutchinson, G.L., (1999): "Generation of synthetic accelerograms for intraplate conditions", *Journal of Earthquake Engineering* (in press)
5. Lam, N.T.K., Wilson, J.L. and Hutchinson, G.L., (1998): "Development for intraplate response spectra for bedrock in Australia", *Proceedings of the 1998 Technical Conference of the New Zealand National Society for Earthquake Engineering,* Wairakei, 27-29 March, 1998.
6. Lam, N.T.K., Wilson, J.L and Hutchinson, G.L.,(1997):"Introduction to a new procedure to construct site response spectrum",*Proceedings of the15th ACMSM,* Melbourne, pp345-350.
7. Atkinson,G. (1993), Earthquake Source Spectra in Eastern North America, *Bulletin of the Seismological Society of America,* Vol.83, pp1778-1798.
8. Atkinson,G. and Silva, W.(1997), An Empirical Study of Earthquake Source Spectra for Californian Earthquakes, *Bulletin of the Seismological Society of America,* Vol.87, pp97-113.
9. Boore,D.M. & Joyner,W.B.(1997), Site Amplifications for Generic Rock Sites, *Bulletin of the Seismological Society of America,* Vol.87(2),pp327-341.
10. Atkinson,G.M. & Mereu, R.F.,(1992), The shape of Ground Motion Attenuation Curves in Southeastern Canada, *Bulletin of the Seismological Society of America, Vol.82(5),* pp2014-2031.