# RESPONSE SPECTRA RECOMMENDED FOR AUSTRALIA

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## SUMMARY

Response spectra suitable for intraplate regions such as Australia differ in shape from the familiar response spectral shapes derived from early accelerograph data from interplate regions. In applications such as building code provisions where the design-basis event is prescribed in probabilistic terms, rather than on maximum earthquake potential, the magnitude of the event will be smaller in intraplate regions, and the low-frequency response will be proportionately less. There is also the possibility of systematic divergence of earthquake source spectra between interplate and intraplate events. In this study we develop intraplate spectra empirically from statistical analysis of strong-motion data for magnitude ~6 intraplate earthquakes.

## 1 INTRODUCTION

The response spectra in the current loading code (AS 1170.4-1993) are based on the earliest and most familiar accelerograph recordings of earthquakes, but these recordings are atypical of the strong motion that is most likely to cause damage to structures in intraplate regions such as Australia. The earliest codifications of response spectral shape, such as those developed by the Applied Technology Council, did not consider earthquake magnitude as a parameter determining the shape of the response spectrum. Also, early codifications of response spectral shape were naturally directed toward critical facilities, where the worst-case scenario (*maximum credible earthquake*) was under consideration. This has led to an inherited tendency of codified response spectra to be representative of high-magnitude earthquakes. Because response spectra are usually *anchored* to a prescribed peak ground acceleration or acceleration coefficient, and because velocity and displacement increase more rapidly with magnitude than does acceleration, the early response spectrum codifications exaggerate the velocity and displacement response if the earthquake under consideration is not of high magnitude.

Subsequent to the early codifications of response spectral shape, the importance of earthquake magnitude (rather than just surficial site geology) has been recognised as a determining parameter. Also, ground-motion codes have been developed for ordinary facilities (as distinct from critical facilities), with probabilistic rather than worst-case criteria, representing earthquakes with magnitudes less than *maximum credible*. The response spectral shape should be appropriate for the magnitude of the most severe ground-motion event that is likely to occur in the length of time under consideration. For building codes, the usual span is 475 years (10% chance of exceedance in 50 years).

Because the magnitude of the probable event will be greater for *tectonically active* regions than for *stable* regions, the response spectral shapes will differ. In this sense, codified response spectral shapes will be different for *interplate* and *intraplate* regions. Aside from stronger overall response, the interplate spectrum will exhibit a *red shift* relative to the intraplate spectrum, all else being equal, because of the higher magnitude.

However, all else may not be equal, as it has been suggested[1] that interplate and intraplate earthquake sources are systematically different, the latter having higher *stress drop* and radiating more high-frequency energy (acceleration band) for a given earthquake magnitude (measured in the velocity band) or seismic moment (measured in the displacement band). An intraplate *blue shift*, affecting the acceleration band of the spectrum, would have obvious engineering ramifications. Empirical evaluations of this question, and the related issue of earthquake mechanism-dependence of strong motion, have tended to be inconclusive[2]. Conflicting results in the literature as to interplate/intraplate differences stem in part from variant definitions of the two categories. Here we take an earthquake to be typically *intraplate* if its mechanism is reverse or thrust, and if its *repeat time* is relatively long[1].

## 2 DATA

Our approach in this investigation was to delineate *intraplate* spectra empirically, by statistical analysis of intraplate strong-motion data, rather than in relation to *interplate* spectra. The main issues then had to do with the appropriate magnitude and whether there was sufficient intraplate data to obtain statistically meaningful results. We restricted our data selection to accelerograms recorded at *rock* sites, so as to bypass the site-response issue. The data set comprises 13 accelerograms (26 horizontal components) of strong motion recorded on rock at close range to earthquakes with magnitudes from 5.4 to 6.6: a narrower magnitude range would have yielded too few data. We accepted the magnitude range 6 ± 0.6 as reasonably representative of the magnitudes of historically damaging earthquakes in Australia and other intraplate regions. Data sources are the U.S. National Geophysical Data Center's worldwide archive, and the California Strong Motion Instrumentation Program. We accepted data for two earthquakes, Whittier and Northridge, on thrust faults close to the San Andreas plate margin in southern California.

## 3 ANALYSIS

**3.1 Normalisation scheme**. Peak ground velocity (PGV) is the parameter that was chosen for normalising all of the horizontal components of motion. Normalisation by PGV was chosen as the best way of handling the problem of having a finite range of magnitudes (it is not strictly appropriate to compare spectra for earthquakes of differing magnitude, because of the systematic *red shift* of spectra with increasing magnitude). All records were scaled to a common peak ground velocity of 5 cm/sec.

**3.2 Statistics of response spectra**. Normalised response spectra for all 26 horizontal components of motion are illustrated in Figure 1. These spectra are for 5% of critical damping, the conventional reference damping value. A few of the spectra have long-period band limits less than 10 sec. Pseudo-relative velocity, plotted logarithmically in Figure 1, is more nearly lognormally-distributed than normally-distributed for a given oscillator period.

The statistics of the normalised response spectra are illustrated in Figure 2, which shows the median and the 16th and 84th percentiles of the data. A noticeable aspect of the statistics is that the standard deviation of the data is nearly uniform over the whole band. The response, at any oscillator period, for this sample of velocity-normalised strong-motion records can be predicted within about 60% (geometric s.d. of approximately 1.6).

**3.3 Peak ground acceleration and displacement**. The median peak ground acceleration of the velocity-normalised records is 0.099 gravity, with a (geometric) standard deviation of 1.54. For peak ground displacement, the result is 0.55 cm, with a standard deviation of 1.52. These results must be taken as being specific to an earthquake magnitude of 6.

## 4 RECOMMENDED SPECTRA FOR ROCK SITES

The shape of the median response spectrum lends itself to representation by the trapezoidal-tent scheme[3]. This is illustrated in Figure 3, showing a straight-line representation of the median spectrum in the manner of Newmark and Hall. The straight lines have slopes of +1, 0 and -1 respectively in the acceleration, velocity, and displacement bands of the response spectrum. These lines are parallel to the lines representing peak ground acceleration, velocity, and displacement (dashed lines).

## 5 SITE RESPONSE AND 'S' FACTORS

The seismic response of surficial low-rigidity geologic strata is intrinsically frequency-dependent, and so codification of the effect in terms of site amplification factors, *S* factors, needs to be frequency-specific. With the Newmark-Hall trapezoidal-tent spectral shape, it is convenient to divide the spectrum into three frequency bands (acceleration, velocity, and displacement) and to determine S factors for the three bands. The S factors in the current code (AS 1170.4-1993) are appropriate for the velocity band of the spectrum, for frequencies between about 1 and 10 Hz (periods between 0.1 and 1 sec). We propose S factors that are smaller at higher frequencies and larger at lower frequencies.

A significant new empirical investigation of site response factors has been reported[4] in the context of revision of the U.S. Uniform Building Code. Their site categories A, B, C, and D have approximate correspondence with site factors of 1, 1.25, 1.5, and 2 in AS 1170.4-1993. These categories, in briefest terms, are *rock*, *firm*, *soft*, and *very soft*. Crouse and McGuire obtained empirical site factors at oscillator periods of 0.3 and 1 sec, and the proposed spectra are based on these results.

For the central (velocity) band, the S factors are 1, 1.3, 1.5, and 2 for site categories A, B, C, and D, essentially the same as in the current code. For periods beyond 0.7 sec, the amplification factors are 50% greater (S factors of 1, 1.95, 2.25, and 3 respectively), while at high frequencies, beyond 10 Hz, the amplification is only half as much (S factors of 1, 1.15, 1.25, and 1.5). The current code spectra are overly conservative at high and low frequencies (acceleration and displacement bands of the spectrum). Proposed dynamic amplification factors giving the ratio of spectral acceleration to peak acceleration on rock are listed below for the four site categories.

VELOCITY-BAND SITE FACTOR

| Period (sec) | S=1 (A) | S=1.3 (B) | S=1.5 (C) | S=2 (D) |
|---|---|---|---|---|
| 0.04 | 1 | 1.15 | 1.25 | 1.5 |
| 0.1 | 1.92 | 2.50 | 2.88 | 3.84 |
| 0.3 | 1.92 | 2.50 | 2.88 | 3.84 |
| 0.7 | 0.82 | | | |
| 1.05 | | 0.71 | 0.82 | 1.10 |
| 3.0 | 0.045 | 0.087 | 0.100 | 0.134 |

## 6 DISCUSSION

The main assumption determining the shape of the proposed response spectra has to do with earthquake magnitude. Specifically, the spectra are based on data for the magnitude range 6 ± 0.6. Allowance for stronger long-period response should be made if higher magnitudes are under consideration. The results herein are for elastic response spectra and for 5% critical damping. Inelastic spectra, and results for other damping values, can be readily derived[3]. The proposed response spectra can be *anchored* to any given peak ground motion parameter, whether it be peak ground displacement, velocity, or acceleration.

## 7 REFERENCES


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