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Testing the Extensibility of an Earthquake Vulnerability Microzonation Methodology by Application at Bargara, Queensland

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ABSTRACT: The author has developed an extensible methodology for conducting microzonation surveys for vulnerability to earthquake shaking. This methodology was used to survey the City of Bundaberg, Queensland. The methodology has now been used to conduct a similar survey of the adjoining town of Bargara. The geology of the two survey areas is quite different. This has allowed the methodology's extensibility to be tested. The results of that test are provided in this paper.

1 INTRODUCTION

The author has previously presented an earthquake shaking vulnerability microzonation methodology. (Turnbull, 2000 & 2001a). This methodology is based on an analysis of Nakamura Spectral Ratios (NSR) (Nakamura, 1989), obtained from velocity seismograms of ambient ground motion recorded at test sites throughout the area of interest. The NSR for each site is partitioned into three frequency ranges, nominally corresponding to three different structure categories: high-rise (0.5Hz to 1.1Hz); medium-rise (1.1Hz to 2.9Hz); and, low-rise (2.9Hz to 10Hz). This partitioning arrangement is depicted in Figure 1.

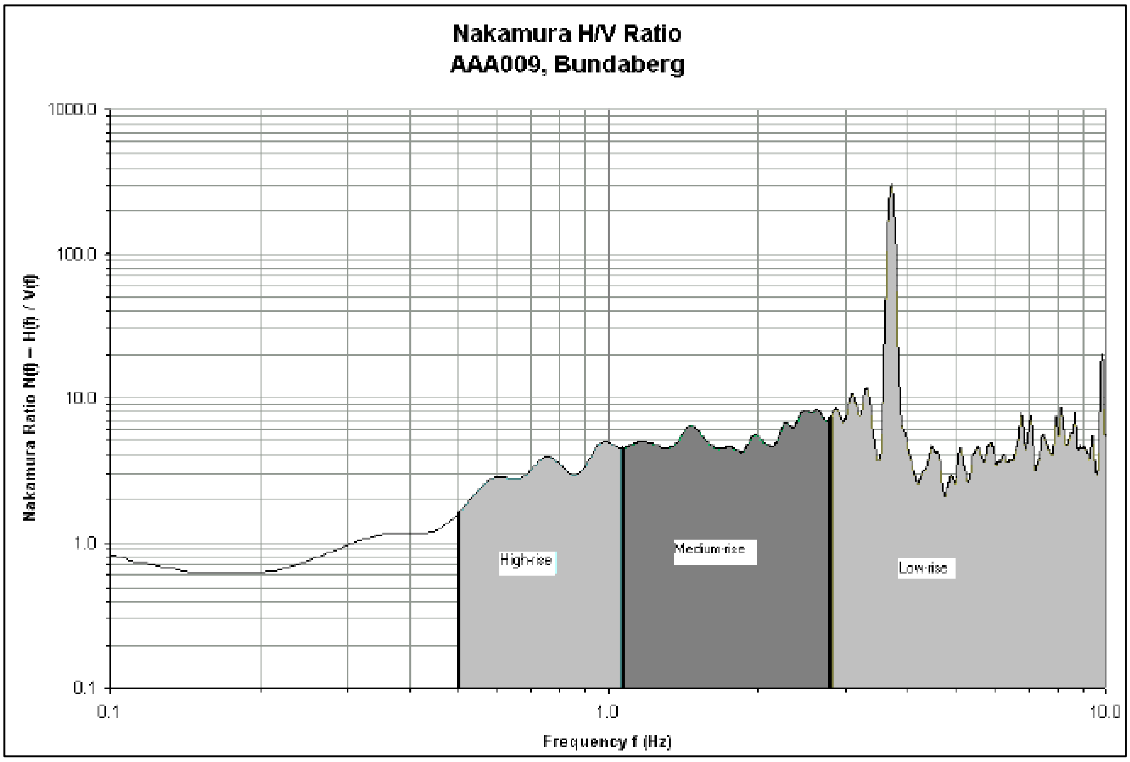

Figure 1. Partitioning of the NSR for low, medium and high rise building categories.

Within each category, and for each test site, the average Nakamura Ratio (N) is calculated, and the maximum average NR (N_{max}) is noted. The average value (N) for each site is then used to allocate a vulnerability rating (S_M) to that site by comparing it to N_{max}, according to the interpolation system depicted in Table 1.

Table 1. Site vulnerability rating allocation.

Relationship of the average NR (N) at a particular site, to the maximum average NR (N_{max}) of all sites.	Site Vulnerability Rating Factor(S_M)
$N < 1.0$	0.67
$1.0 \leq N < 0.25N_{max}$	1.00
$0.25N_{max} \leq N < 0.5N_{max}$	1.25
$0.5N_{max} \leq N < 0.75N_{max}$	1.50
$0.75N_{max} \leq N < N_{max}$	2.00

The Site Vulnerability Rating Factors shown in Table 1 were chosen to reflect the soil profile Site Factors used in the Australian Building Code (Standards Association of Australia, 1993), shown in Table 2 for reference purposes. However, any other arbitrary rating system can be used.

Table 2. Summary of AS1170.4 – 1993 Site Factor allocations.

Soil Profile	Site Factor (S)
Rock with low or better strength	0.67
Rock with low or extremely low strength or not more than 30m of stiff or hard unconsolidated materials.	1.00
More than 30m of stiff or hard unconsolidated materials.	1.25
20m or more of stiff or hard unconsolidated materials containing 6 to 12m of soft or loose materials.	1.50
More than 12m of soft or loose materials.	2.00

Once each site has been allocated a Vulnerability Rating Factor (S_M) it is mapped. The vulnerability maps of the Bundaberg City area, derived from data obtained from 89 test sites with approximately 1km spacing, are shown in Figure 2. From left to right are shown the low-rise, medium-rise and high-rise microzonation maps. The maps in Figure 2 were produced using ArcGIS Spatial Analyst to convert the relative vulnerability values allocated to the 89 test sites into Inverse Distance Weighted (IDW) raster layers.

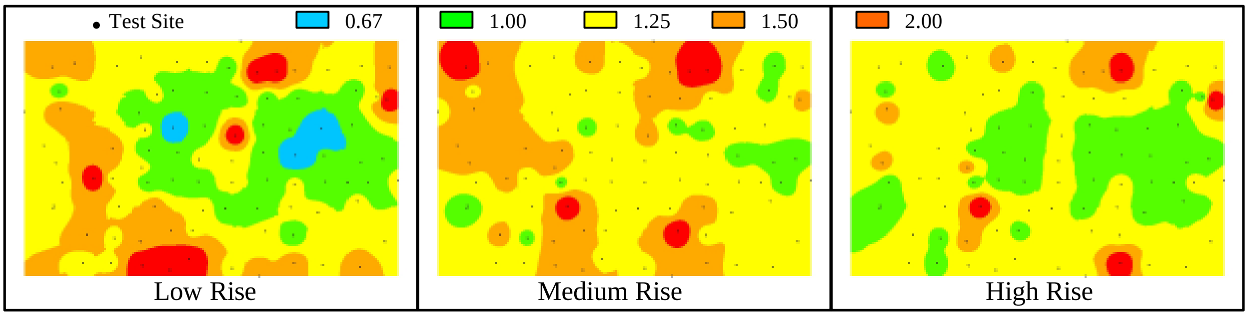

Figure 2. Earthquake shaking vulnerability maps of Bundaberg City determined from 89 test sites.

The methodology is based on the assumption that the relative amplitude of the NSRs at the test sites is related to the strong horizontal ground motion gain at that site in some unknown but consistent manner. No attempts are made to adjust for effects such as non-linearity of the relationship, or frequency shift of the NSR as compared to gain spectra obtained using reference site measurements.

Lachet and Bard (1994) have demonstrated that the NSR cannot be used as an indicator of the absolute horizontal ground motion gain. They suggest that the fundamental peak can be explained in terms of the fundamental-mode Rayleigh wave. Nakamura (1989 & 2000) maintains that the peak is a result of the resonance effects of vertically incident SH waves. Fah et al (2001), however, demonstrate that no SH-wave resonance effect is needed to explain the observed H/V ratios. Indeed, Far et al assert that higher mode Rayleigh waves are contributing, and that source distances and impedance contrasts between sediments and bedrock have a large effect on the amplitude and frequency of the maximum H/V ratio. Although it is recognised that such effects do exist, they have not yet been quantified to the extent that correction factors can be suitably defined.

Asten et al (2002) suggest that microtremor surveys using the peak amplitude of the NSR are, at best, only a first-order tool in microzonation of earthquake risk. They demonstrate that a circular array of instruments at the test site can be used to obtain the phase velocity of the microtremor energy; from which can be deduced estimates of shear-velocity profiles and hence the thickness of unconsolidated sediments.

The author's methodology does not rely on resonance peaks in the NSR to allocate vulnerability ratings. Neither is it a claim of the methodology to accurately deduce sedimentary thickness. The approach taken is to interpolate the averaged aggregate of the NSR amplitudes over a range of frequencies, between the maximum value observed in the dataset and an arbitrarily chosen open lower bound (in this case, unity). The intent is to pragmatically characterise the *relative* propensity for amplification of horizontal ground shaking at the test site, in a consistent and reproducible manner, with no respect for the cause or causes. This approach is unique in the various methodologies that have been previously employed in Australia (Turnbull, 2001b).

One of the features of the methodology that was envisaged in its development is its potential for areal extensibility. As the area of interest is increased the extra data can be incorporated into the dataset. The intention is to permit extension of the area of the microzonation, so that the relative shaking vulnerability of any zone within the area of interest can be established in comparison with any other zone within the test area. The ability of the methodology to accommodate this feature is tested by comparing the results obtained from:

- The original 89 site Bundaberg microzonation,
- An extended 127 site microzonation that includes the previous 89 sites, and
- An extended 229 site microzonation that includes the previous 127 sites.

In each case the additional test sites are in an area that is physically contiguous with the previous test site area.

The comparison will be done in two ways. Firstly, the changes in occurrence frequency of the relative vulnerability ratings will be examined for statistical consistency. However that, in itself will not demonstrate whether the locational redistribution of the ratings is consistent from dataset to dataset. Secondly, the microzonation maps will be presented in a matrix that enables visual comparison. As the test areas are physically contiguous, it will allow the locational distribution of the ratings to be compared for consistency.

2 FREQUENCY COMPARISON OF ORIGINAL AND EXTENDED MICROZONATIONS

The extended microzonation was conducted by adding 38 sites to the original test ensemble of 89. The additional sites were chosen to ensure that all of the Bundaberg City area was represented in the data set by extending the test ensemble radially beyond the metropolitan boundaries. Table 3 shows the occurrence frequency of the relative vulnerability ratings determined using both the original 89 sites and the extended 127 sites. These frequency profiles are further depicted in Figures 3 (a) and (b).

Table 3. Changed Relative Vulnerability Rating Frequency profiles from Original to Extended sites.

	Original 89 Sites			Extended 127 Sites		
Rating	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
0.67	3.37%	0.00%	0.00%	2.36%	0.00%	0.00%
1.00	32.58%	14.61%	38.20%	56.69%	22.05%	44.09%
1.25	40.45%	53.93%	49.44%	33.07%	48.03%	44.09%
1.50	14.61%	25.84%	7.87%	6.30%	25.20%	8.66%
2.00	8.99%	5.62%	4.49%	1.57%	4.72%	3.15%

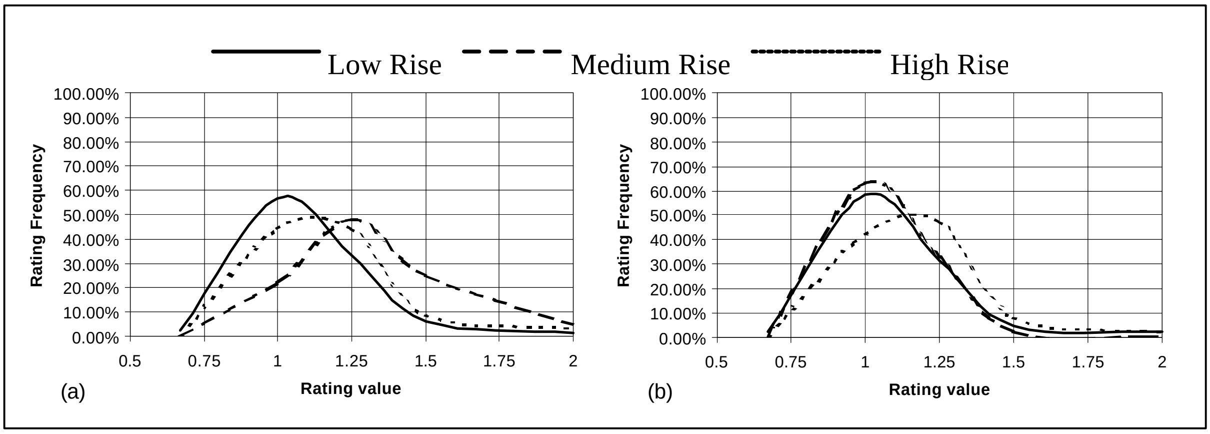

Figure 3. Relative Vulnerability Rating Frequency profiles of: (a) Original 89 site Bundaberg Microzonation (b) Extended 127 site Bundaberg Microzonation

In extending the number of test sites, the following changes in the frequency profiles of the relative vulnerability ratings are noted.

In the Low Rise category there is a strong reduction in the percentage of 1.50 and 2.00 ratings, with a corresponding increase in the proportion of 1.00 and 1.25 ratings.

In the Medium Rise category there is a moderate reduction in the percentage of 1.25 ratings, with a corresponding increase in proportion of 1.00 ratings.

In the High Rise category there is a very slight shift towards lower vulnerability ratings.

The general trend towards a lower vulnerability regime for most of the test sites has been brought about by the presence, in the additional sites, of sites that present a far greater relative vulnerability for Low Rise structures than any of the sites used in the original ensemble. This is particularly so in the Low Rise category, with the Medium and High Rise categories only being affected in a minor way.

The implication to be drawn from this change in relative vulnerability regime is that the results from a particular data set ensemble are only *internally* consistent. Whilst the size of the data set can, within reason, be reduced to elicit local detail, extending the data set has the potential to dilute local detail as zones of higher relative vulnerability are introduced. The information obtained from one data set cannot, in general, be directly compared to information obtained from a second, different dataset, even if one dataset is a subset of the other. However, different data sets can be combined to produce extended, independently consistent, relative vulnerability microzonations.

3 FREQUENCY COMPARISON OF EXTENDED AND EXPANDED MICROZONATIONS.

To further test the extensibility of the methodology, an extra 102 test sites were added to the data set. These sites were located in the Burnett Shire, to the east of Bundaberg City. Table 4 shows the occurrence frequency of the relative vulnerability ratings determined using the expanded 229 sites. For ease of comparison the same information for the prior extended 127-site data set is repeated. These frequency profiles are further depicted in Figures 4 (a) and (b).

Table 4.Changed Relative Vulnerability Rating Frequency profiles from Extended to Expanded sites.

	Extended 127 Sites			Expanded 229 Sites		
Rating	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
0.67	2.36%	0.00%	0.00%	2.62%	0.87%	0.44%
1.00	56.69%	22.05%	44.09%	58.52%	63.32%	41.92%
1.25	33.07%	48.03%	44.09%	31.44%	32.75%	47.16%
1.50	6.30%	25.20%	8.66%	4.80%	2.62%	8.30%
2.00	1.57%	4.72%	3.15%	2.62%	0.44%	2.18%

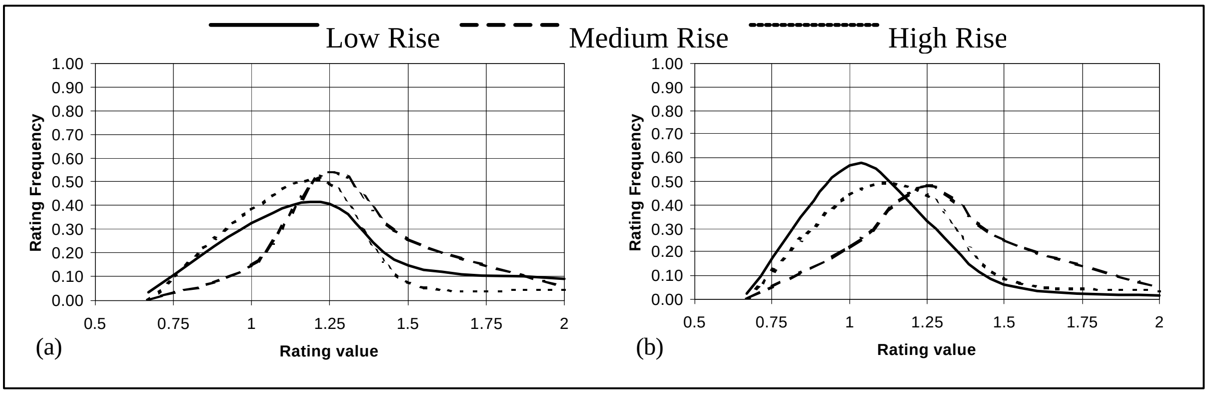

Figure 4. Relative Vulnerability Rating Frequency profiles of: (a) Extended 127 site Bundaberg Microzonation (b) Expanded 229 site Microzonation

In expanding the number of test sites the only relative rating profile that has been substantially changed is that of the Medium Rise building category. For that category there has been a significant shift from a moderately high relative vulnerability regime, to a lower relative vulnerability system. As was the case with the Low Rise category in the previous test this has been brought about by the presence, in the additional sites, of sites that present a far greater relative vulnerability for medium rise structures than any of the sites used in the original collection.

This further emphasises that the results obtained from any particular data set are *internally* consistent. It also demonstrates that dilution or enhancement of the information pertaining to individual building categories, elicited by expanding or contracting the size of the data set, is internally consistent to that category, and not to all categories as a whole.

4 SUMMARY OF FREQUENCY COMPARISONS

Extending the dataset by increasing the test area from which the data are obtained results in consistent changes in the frequency of occurrence of the relative vulnerability ratings. The consistent changes can be rationally explained in terms of higher vulnerability ratings in the additional dataset diluting the range of ratings appearing in the subset. The comparison demonstrates the internally consistent nature of each dataset by emphasising the relative nature of the ratings as the dataset is expanded.

5 VISUAL TEST OF EXTENSIBILITY

Although the comparison of occurrence frequency of the ratings demonstrates the internal consistent nature of the datasets, it does not demonstrate that the localities of the ratings are repositioned in a manner consistent with prior positioning as the test area is increased. Figure 5 displays a matrix of microzonation maps depicting the visual changes that occur for the three building categories, as the test area is progressively extended contiguously.

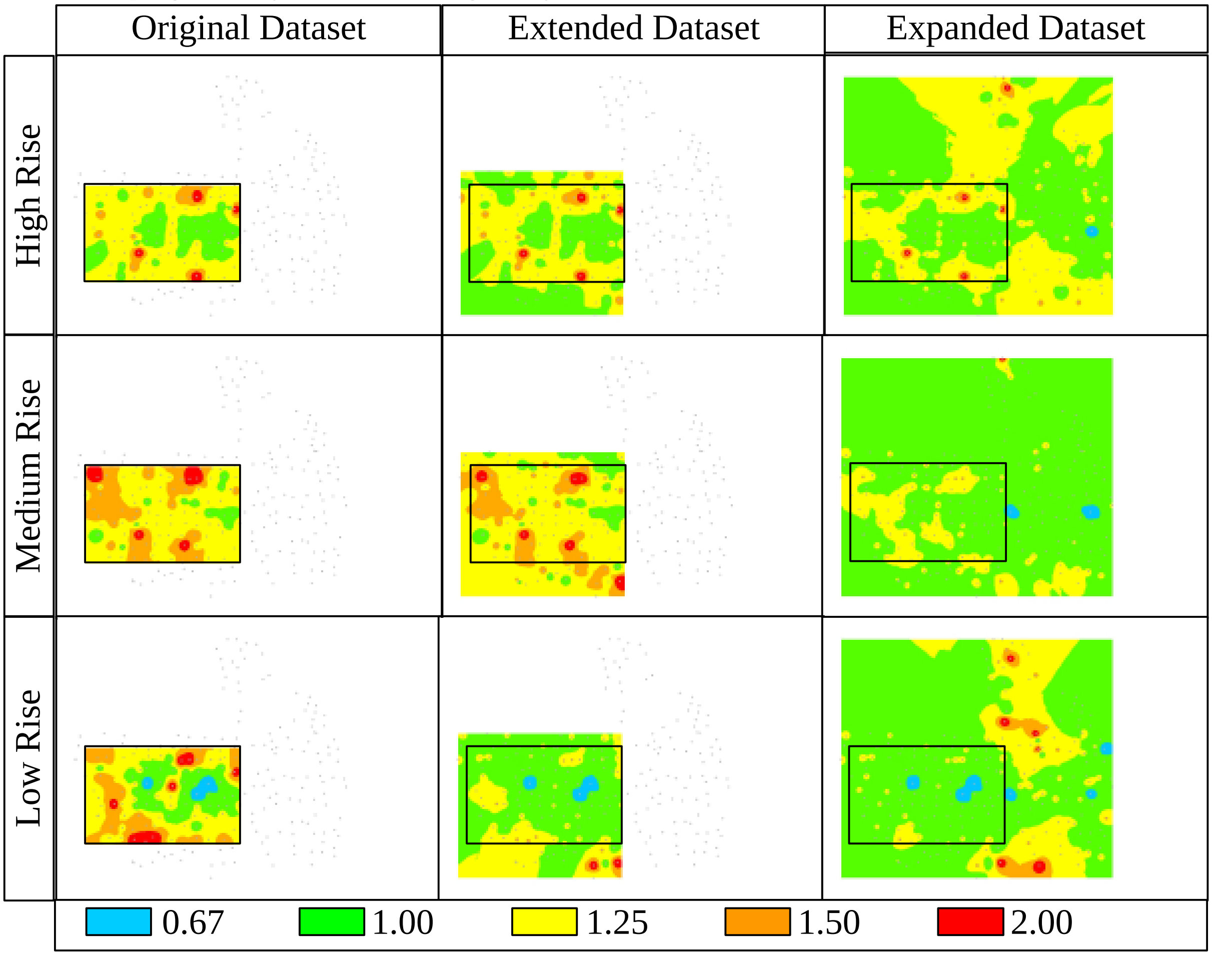

Figure 5. Changes in the original microzonation map as dataset collection area is increased.

The effect of the dilution of detail is particularly apparent in the low and medium rise categories. In all categories the visual transition from the original, through the extended to the expanded microzonation, (left to right) shows a pattern of change consistent with the predicted dilution of localised information. The transition for any particular test site is consistently to reduce the relative vulnerability rating, or to maintain the same value, as the test area increases.

6 SUMMARY AND CONCLUSION

The methodology described herein is designed to provide a simple and pragmatic means of characterising the relative propensity of zones within a test area to amplify horizontal ground motion due to seismic excitation (relative vulnerability to seismic shaking). This is done by arbitrary interpolation of the aggregated amplitudes of Nakamura Spectral Ratios (NSR) averaged over the frequency range of interest. The methodology does not rely on resonance peaks in the NSRs to determine propensity to shaking. Comparing the results obtained from progressively larger and contiguous test areas has demonstrated that the methodology is extensible in that respect. As the test area is increased, sites of higher relative vulnerability may be introduced into the dataset, thereby diluting local detail that is evident in reduced datasets. As a corollary, detail can be elicited by considering data subsets restricted to the local area of interest.

REFERENCES:

Asten, M.W. Lam, N. Gibson, G. & Wilson J. 2002. Microtremor survey design optimised for application to site amplification and resonance modelling, *Proceedings of the Australian Earthquake Engineering Society Annual Conference*, Adelaide, Oct. 2002.

Far D. Kind, F. & Giardini, D. 2001. A theoretical investigation of average ***H/V*** ratios, *Geophys. J. Int.*,**145**, 535-549.

Lachet, C. & Bard, P.-Y. 1994. Numerical and Theoretical Investigations on the possibilities and limitations of Nakamura's technique, *J. Phys. Earth*, **42**, 377-397.

Nakamura, Y. 1989. A Method for Dynamic Characteristics Estimation of Subsurface using Microtremor on the Ground Surface, *Quarterly Report of Railway Technical Research Institute Vol. 30, No. 1*, pp. 25-33, February 1989.

Nakamura, Y. 2000. Clear Identification of Fundamental Idea of Nakamura's Technique and its Applications, *Twelfth World Conference on Earthquake Engineering*, Available on line 20020923 0300UTC http://www.sdr.co.jp/n_tech_and_application.pdf

Standards Association of Australia 1993. *AS 1170.4 – 1993, Minimum design loads on structures (known as the SAA Loading Code) Part4: Earthquake loads*, Standards Australia. ISBN 0-7262-8297-

Turnbull, M.L. 2000. Seismic Microzonation of Bundaberg, Queensland, *Proceedings of the Australian Earthquake Engineering Society Annual Conference*, Hobart, Nov. 2000.

Turnbull, M.L. 2001a. A seismic assessment and microzonation of Bundaberg, *Central Queensland University, Masters Degree Thesis.*

Turnbull, M.L. 2001b. Seismic Hazard Microzonation, a Comparison of Different Methodologies That Have Been Used in Australia, *Proceedings of the Australian Earthquake Engineering Society Annual Conference*, Canberra, Nov. 2001.