1. INTRODUCTION

Records from intra-plate earthquakes demonstrate that they have particular characteristics, such as frequency content, peak ground acceleration and duration (Sinadinovski *et al.*, 2000; Hao and Gaull 2004), which may vary throughout the continent. The lack of quality strong motion records of large Queensland earthquakes at short distances necessitates the use of synthetic seismograms for testing of structural behaviour.

In this study the structural effects of a moderate magnitude earthquake were simulated from a magnitude 4.4 sub-event recorded in 2004 at distance of around 50km, using Green's Function method. In this method of superposition it is assumed that the source parameters, path and site effects for the main event and its aftershocks are equivalent. Previous validation studies for similar events in Australia have shown that synthetics produced by this method are comparable with the Building Code AS 1170.4, and can be used to realistically represent ground motion during typical earthquakes (Jankulovski *et al.*, 1996; Sinadinovski *et al.*, 1996).

A set of spectral curves derived from the synthetics was normalised to approximate a magnitude 6 event being recorded at distance of 20 km, in order to be compared with the Design Spectrum recommended in the Australian Loading Code. Two similar size earthquakes have already occurred in Queensland in the last century (Turnbull, 2001). A dynamic analysis of a modelled high-rise building was then undertaken, to simulate vibration caused by the passage of seismic waves from one such typical earthquake.

2. SEISMIC DATA

The seismogram of the 16th of January 2004 event (Figure 1) is of an ML4.4 earthquake recorded by station Four Seasons (FS03) located at longitude 151.8667^{o}E and latitude 25.1068^{o}S, some 24km SW from Gin Gin in Queensland. FS03 is operated by the Central Queensland Seismic Research Group (CQSRG) as a node in its North Burnett Seismic Network. CQSRG is a research group of the Faculty of Informatics and Communication, of Central Queensland University. One of the authors (Mike Turnbull) is leader of that group.

Using data from six stations the earthquake was located to longitude 151.371^{o}E and latitude 24.988^{o}S, 30km southeast of Monto in Central Queensland. This places it approximately 52km northwest of station FS03. As can be seen in Figure 1, the seismogram indicates an S-P delta time of 5.82 s. If one applies a general factor of 8 km per delta second nominally, that would place the earthquake at a distance of about 47 km from station FS03.

The effects of the earthquake were felt over an approximate radius of 65 km. In the immediate vicinity of station FS03 several people reported that they thought the roofs of their houses were going to collapse. Using the peak amplitude of the vertical FS03 record the local magnitude of the earthquake was calculated to be ML4.4.

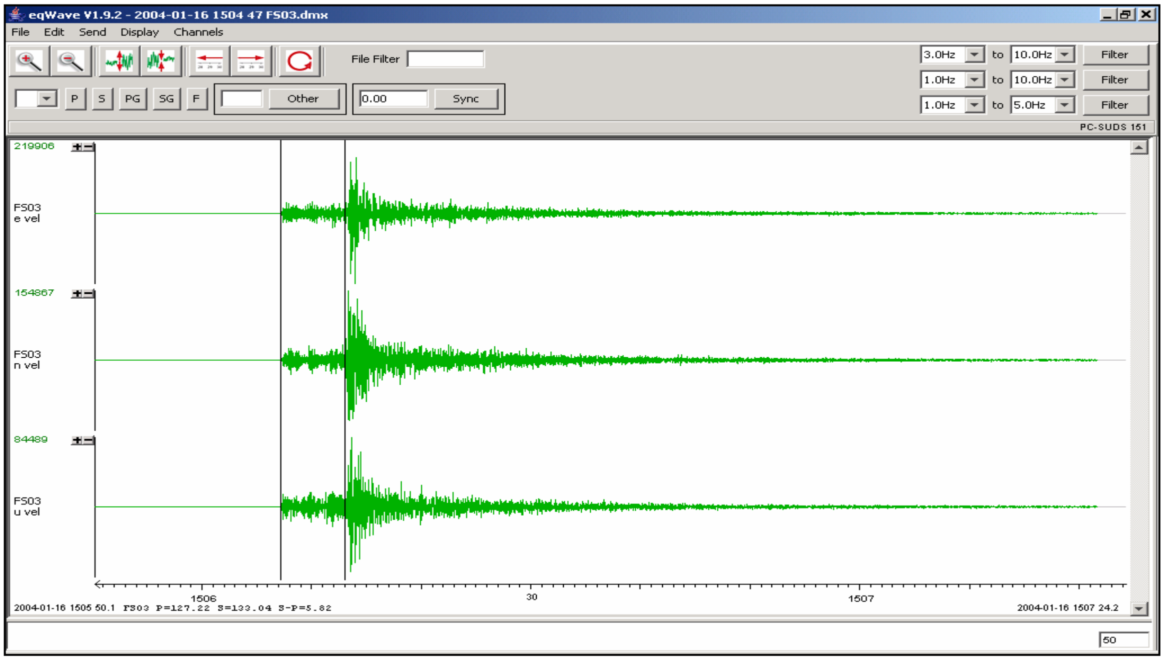

Figure 1 : Seismic record 2004-01-16 1504 47 FS03.dmx

In extrapolating to the stronger earthquake, the source parameters were set to a rupture length of 2 km, keeping the terms in the spectral formula to satisfy both the low-frequency and high-frequency constraints. In the production of these synthetics (Figure 2) a rupture velocity of 2.25 kms^{-1} was used and the surface rupture was oriented perpendicular to the source-receiver line. The procedure was applied in two steps summing over 100 sub-events which gradually increased the magnitude to 6.

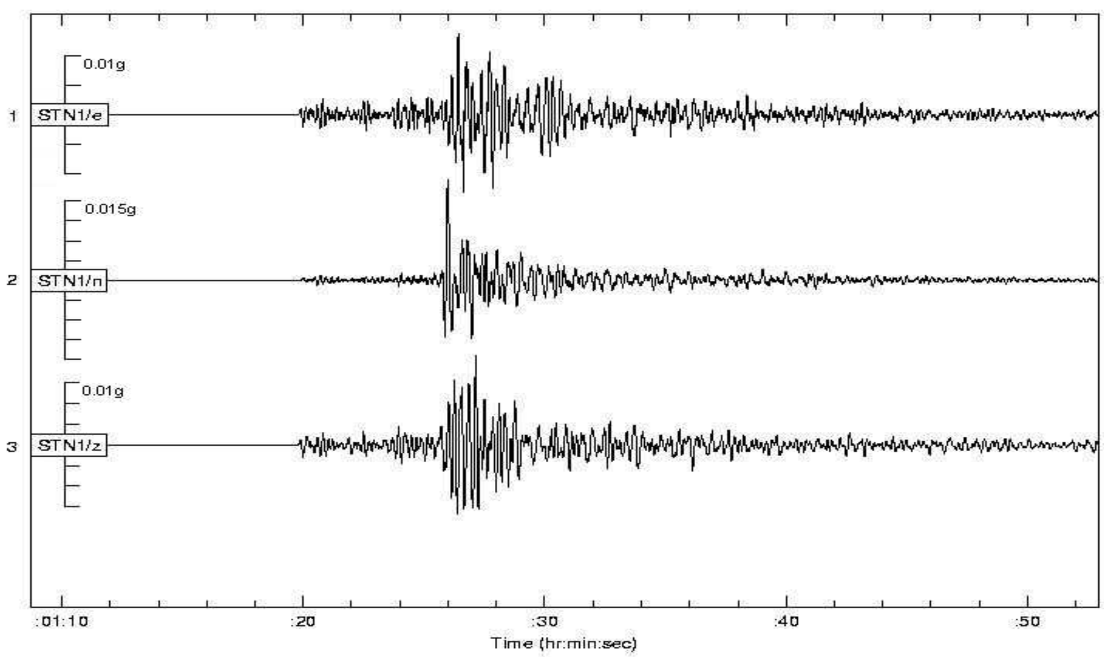

Figure 2: Synthetic output for the Four Seasons record

3. RESPONSE SPECTRUM

The standard Response Spectrum program was used as described by the U.S. Geological Survey procedure (Converse, 1992). In the processing step, the response of a simple harmonic oscillator with a single degree of freedom was calculated for the synthetic input. The maximum response was calculated for oscillators with different natural periods, having damping ratios of 0%, 2%, 5%, 10% and 20% of the critical damping. Figure 3 represents the acceleration response spectra for the Four Seasons record for all three components, for an oscillator with natural periods between 0.01 and 10 seconds, and for five defined damping ratios.

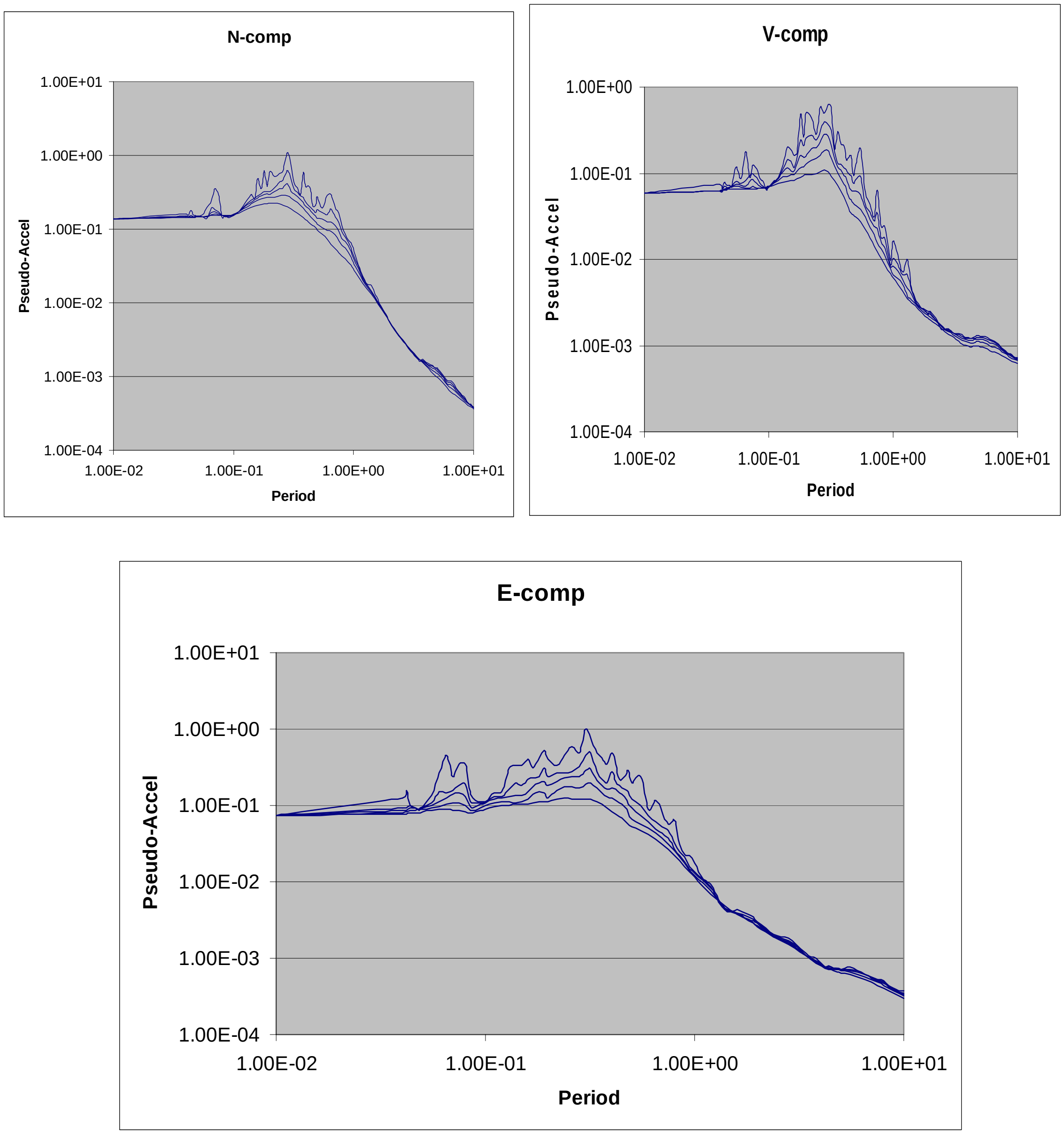

Figure 3: Response spectra for the synthetics based on the Four Seasons record for different levels of damping

4. DYNAMIC ANALYSIS

In order to examine the practical implications concerned with the usage of location-specific design spectra the lateral load on a sample high-rise building will be evaluated. The sample structure is a reinforced concrete 15-storey building with a typical floor of 21x21 m. (Figure 4). The typical floor consists of a 200 mm flat slab, a number of columns and several shear walls, which are grouped around the lift core and the stair case. The shear walls are eccentrically located on the floor, which will generate some global torsion.

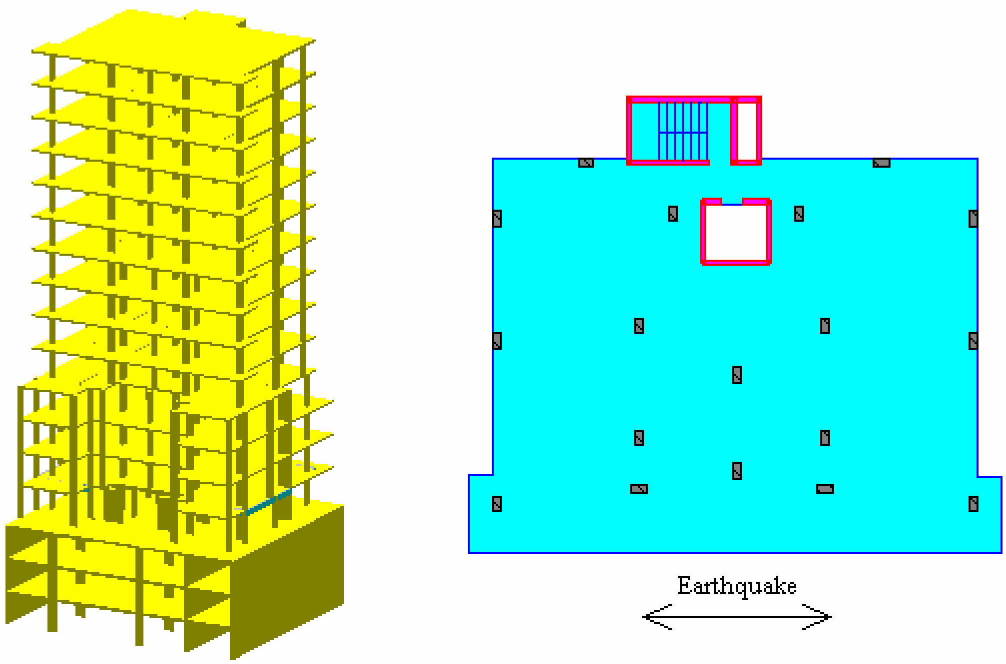

Figure 4: Example High-Rise Building: 3D View and Typical floor

The natural periods of the structure in the X-X direction (horizontal on the paper) are:
T1 = 1.55 s, T2 = 0.60 s, T3 = 0.39 s. We will examine only the X-X direction, since it will attract larger earthquake force due to larger stiffness in comparison to the perpendicular direction.

The base shear evaluated according to AS 1170.4 is 2.3%, using 1/500 annual probability of exceedence of 0.06 g acceleration coefficient, and site factor of S = 1.0.

For comparison purposes a location-specific synthetic response spectral curve with 5% damping, is also used to evaluate the lateral force. (Figure 5)

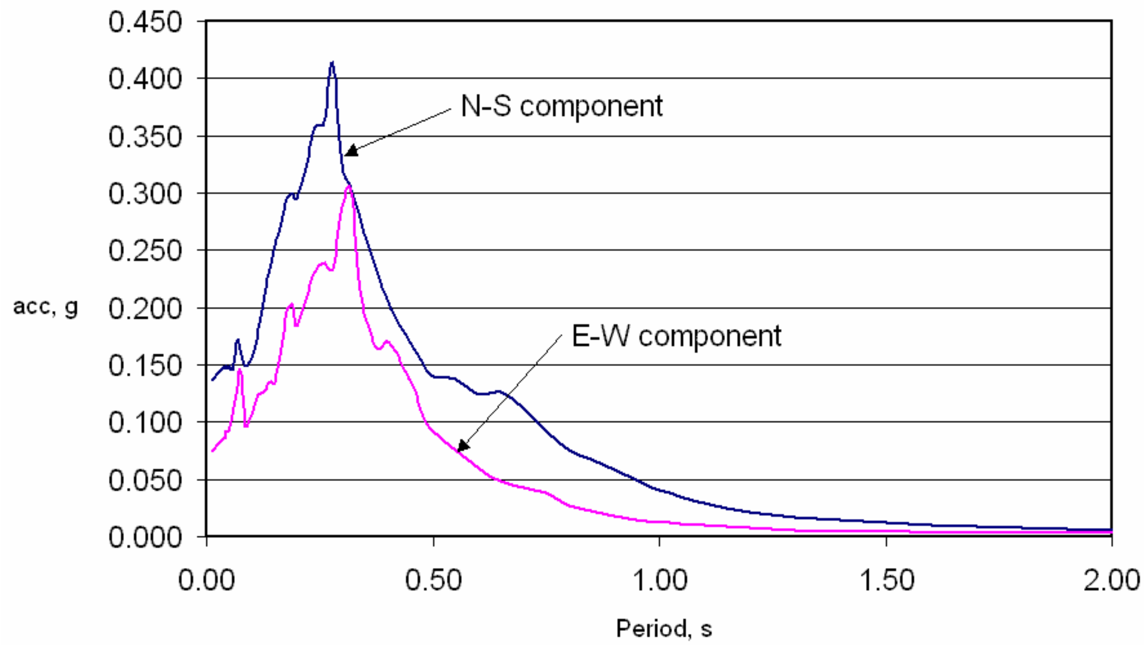

Figure 5: Location-Specific Synthetic Response Spectrum Curve (SE QLD)

If the synthetic response spectrum for Redcliffe, QLD, is used to implement dynamic analysis to evaluate the later earthquake forces, base shear of 1.1% for N-S, and 0.5% for E-W direction can be obtained. It is observed that, by assuming the worst orientation of the structure, the lateral load obtained by the location-specific curve is about 50% lower than the force obtained by AS 1170.4. This illustrative example confirms the hypothesis that the synthetic location-specific spectral curves, in combination with dynamic analysis will provide generally lower earthquake design load. This is especially significant when the orientation of the structure is considered. The conservative implication is that by implementing location-specific spectral curves the lateral earthquake design force can be reduced by 20% to 30%.

It is also important to observe that dynamic analysis can potentially provide more accurate distribution of the lateral load. In this example the 2^{nd} mode shape dominates the dynamic response. If the lateral load distribution is examined significant difference between the triangular distribution obtained by equivalent static approach AS 1170.4, and the load distribution obtained by dynamic analysis such as the spectral method, can be observed (Figure 6).

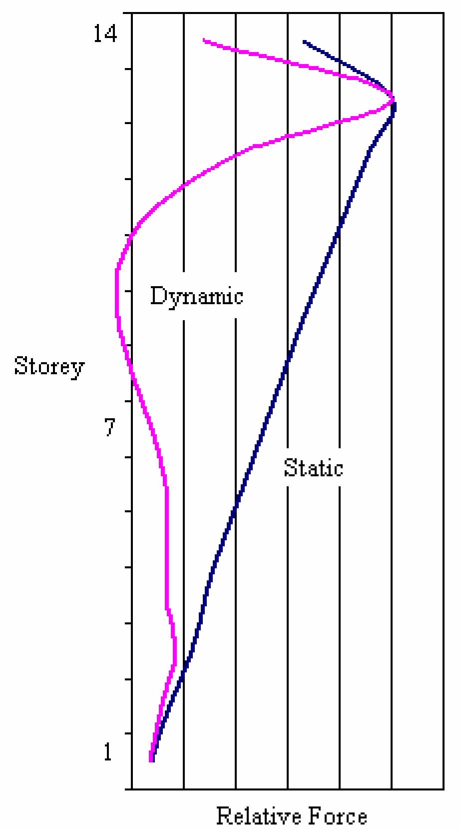

Figure 6: Lateral Force Distribution: AS1170.4 Equivalent Static v. Spectral Method

5. CONCLUSION

Intra-plate earthquakes have particular characteristics, such as frequency content, peak ground acceleration and duration, that may vary throughout the continent. The lack of quality strong motion records of large Queensland earthquakes at short distances necessitates the use of synthetic seismograms for testing of structural behaviour.

In this study the structural effects of a moderate magnitude earthquake was simulated from a magnitude 4.4 sub-event recorded in 2004 at the Four Seasons seismometer near Bundaberg, Queensland, using the empirical Green's Function method. Previous validation studies for similar events in Australia have shown that the spectra of synthetics produced by this method are comparable with the Building Code AS 1170.4, and can be used to realistically represent ground motion during typical earthquakes in the study area.

A set of spectral curves derived from the synthetics was first compared with the Design Spectrum recommended in the Australian Loading Code. A dynamic analysis of a modelled high-rise building was then undertaken, to simulate vibration caused by the passage of seismic waves from a typical moderate size earthquake at close distance. The results of modeling the structural response indicate that the design code may overestimate the design base shear, and the distribution of seismic forces over the building height, for tall buildings. This is especially evident for buildings over 15 storeys, with width less than 25 m, for which cases the earthquake (rather than wind) forces govern structural design.

The results of this case study emphasise the need for evaluation of location specific spectral curves and their usage in the structural design of high-rise buildings.

6. REFERENCES

Converse, A.M. (1992) Basic strong-motion accelerogram processing software, USGS Open-file Report 92-296A.

Hao, H. and Gaull, B. (2004) Response spectrum characteristics of recorded strong ground motions in SWWA, AEES Conference, Mt Gambier, South Australia.

Jankulovski, E., Sinadinovski, C., and McCue, K.F. (1996) Structural response and design spectra modeling: results from some intra-plate earthquakes in Australia, 11th World Conference on Earthquake Engineering, Acapulco, Mexico.

Sinadinovski, C., McCue, K.F., Somerville, M., Muirhead, K., and Muirhead, K. (1996) Simulation of intra-plate earthquakes in Australia using Green's function method: Sensitivity study for Newcastle event, AEES Conference, Adelaide, South Australia.

Sinadinovski, C., McCue, K.F., and Somerville, M. (2000) Characteristics of strong ground motion for typical Australian intra-plate earthquakes and their relationship with the recommended response spectra, Soil Dynamics and Earthquake Engineering, Vol 20, pp 101-110.

Turnbull, M.L. (2001) A seismic hazard Assessment and microzonation of Bundaberg, M.Sc. Thesis, Central Queensland University.