Seismic site response analysis in Perth Metropolitan area

Jonathan Z. Liang[1], Hong Hao[2]

[1]PhD student, School of Civil and Resource Engineering, The University of Western Australia, Australia, email: lzy@civil.uwa.edu.au

[2]Professor of Structural Dynamics, School of Civil and Resource Engineering, The University of Western Australia, Australia, email: hao@civil.uwa.edu.au

Jonathan Liang is a PhD student of structural dynamics. The topic of his PhD research is the seismic risk analysis of Perth metropolitan area.

Hong Hao is professor of structural dynamics. He received a PhD degree from the University of California at Berkeley. Prior to joining UWA he worked in Seismographic Station in UC Berkeley and Nanyang Technological University in Singapore. His research interests include earthquake and blast engineering, and structural condition monitoring.

Abstract

Responses of the four site classes defined by the previous Perth Basin geology study are calculated in this study. The input bed rock motions were simulated using Green's function method corresponding to the design and extreme earthquake events in Perth Metropolitan Area (PMA). The response spectra of the simulated ground motions on rock and soil sites are estimated and compared with the respective design spectrum defined in both the Current and Draft Australian Earthquake Loading Code. It is found that both the draft and current design spectrum given in the code in general overestimate the spectral accelerations from both the upper and lower design events in large period ranges. However, they might underestimate the spectral accelerations at very high frequencies.

Keywords: site response, Perth, seismic

1. Introduction

Perth Metropolitan Area (PMA) is located on the Perth Basin which filled with sand, mud and sedimentary rocks. It is very important to reliably estimate seismic ground motions in PMA in order to perform a meaningful structure responses analysis to seismic ground excitations. Gaull and Michael-Leiba (1987) studied the seismic risk of Southwest Western Australia (SWWA) and predicted that the maximum credible earthquake (MCE) for the seismic zone 1 (the minimum distance from the edge of zone 1 to Perth is 50km) is ML7.5. The peak ground velocity (PGV) and acceleration (PGA) for the 475-year return period are 48 mm/s and 0.44 m/s^2, respectively. Gaull *et al.* (1995) presented an initial analysis of the site amplification effects of the Perth Basin using microtremor spectral ratios and found that the Perth Basin might amplify the bedrock motion by 2 to 10 times. Since then, many efforts have been spent in investigating site response of Perth Basin. Hao and Gaull (2004) performed site response analysis for two soft soil sites at PMA based on three design events corresponding to upper range, lower range and worst scenario event and indicated that the design spectra in the current Australian code might overestimate spectra accelerations on soft sites. However, Hao and Gaull (2004) do not provide the whole picture for site response in PMA since lack of exact geology information. McPherson and Jones (2006) investigated regolith thickness, and natural period for PMA by using borehole data, seismic cone penetrometer test (SCPT) data and microtremor data. They divided PMA into 4 soil classes based on the soil properties. The natural period of sites in Gaull *et al.* (1995) and McPherson and Jones (2006) are mainly based on microtremor data and linear soil properties. Many studies, Jarpe et al. (1989) and Schnabel (1973), have indicated that soil responses will be nonlinear under strong shaking. These studies also showed that the amplification factor derived from microtremor may not give a reliable prediction of strong ground motion response at some sites. Moreover, soil amplification analysis has not carried out in McPherson and Jones (2006)'s study.

Therefore, more detailed studies of PMA site responses to strong ground motion are necessary. In this study, detailed site response analyses with consideration of soil nonlinear behaviour are carried out using SHAKE2000. Three simulated base rock motions for PMA corresponding to upper range and lower range design events, and worst scenario event are used as input. More detailed discussion on the simulated ground motion for SWWA can be found in Liang et al. (2007). Two magnitudes of upper and lower range events are chosen within the range which b-value is from 0.75 to 1.0. The distances to produce design PGA value of 0.09g on rock site using attenuation from Liang et al. (2007) are approximately 92 and 10km, respectively. Ground motion time histories on ground surface and the corresponding response spectra are calculated. The response spectra of the calculated ground motions are compared with the respective design spectrum defined in both the Current (Standards Australia, 1993) and Draft Australian Earthquake Loading Code (AS/NZS 1170.4 Doc. D5212, 2004). Three input bed rock motions are listed in Table 1.

Table 1. Simulated base rock ground motion

Design event		Local Magnitude	Epicentral distance
475 year return period	Lower range design event	5.4	10km
475 year return period	Upper range design event	7.2	92km
10,000 year return period	Worst case scenario	7.5	50km

2. Geology of PMA

PMA is divided into four separate site classes based on the soil material type and thickness (McPherson and Jones 2006). The regolith thickness, shear wave velocities and natural period of each site class are listed in Table 2. Typical soil stratigraphies for four site classes, shallow sand (SS), deep sand (DS), mud-dominated (MS) and limestone-dominated (LS), are derived based on the mean values of thickness and shear wave velocity (SWV) for each site class and used in the analysis. The ground water level is assumed to be 1.9 m below the ground surface.

Owing to the lack of nonlinear soil properties in PMA, those derived by Seed and Idriss (1970), Sun *et al.* (1988) and Schnabel (1973) are used in this study to model the nonlinear soil modulus value and damping ratio for sand, clay and rock, respectively.

Table 2. Regolith thickness, shear wave velocities and natural period for site classes (from McPherson and Jones, 2006)

Site Class	Mean thickness (m)	STD thickness (m)	Mean SWV (m/s)	STD SWV (m/s)	Mean Period (sec)	STD Period (sec)
Shallow sand (SS)	20	13	294	43	0.65	0.46
Deep sand (DS)	42	14	300	82	0.5	0.5
Mud-dominated (MS)	18	13	330	179	0.5	0.35
Limestone-dominated (LS)	40	18	900	-	0.22	0.38

STD: standard deviation.

3. Site Response at PMA

Using the mean value of regolith thickness and shear wave velocities given in Table 2, and the simulated base rock motions as input, the dynamic site response analyses are carried out.

3.1 SS site

The amplification spectra for the SS site are shown in Figure 1 and the comparisons of the calculated spectral accelerations and the code spectral accelerations are given in Figure 2. As shown in Figure 1, the amplification spectra corresponding to the three base rock motions differ, indicating nonlinear site responses. In general, when the base rock motion is larger, the site amplification spectrum has peaks occurring at lower frequencies. The increased nonlinearity of soft soil responses also reduces the amplification ratios because of the increase in hysteretic damping. The amplification ratio of this site is 3.3-3.8 and this amplification occurs at the natural period of the site which is calculated to be 0.26-0.3sec.

The spectral accelerations corresponding to the lower range design event in general lie well below the draft code spectrum. However, the current design spectrum might underestimate that from the upper range design event, especially in the lower period range (0.05sec to 0.35sec). Spectral accelerations from the worst case scenario event exceed draft code specification only in the low period range, but goes over the current code spectrum in the range of 0.01sec to 0.4sec. Compared to a previous study (Hao and Gaull 2004), which predicted ground motions by stochastic simulations and concluded that the current code design spectrum overestimates design earthquake forces, this study predicts larger ground motions. Comparing with the study by Gaull (2003), the natural period of SS site is close to that of zone 1, in which the ground conditions are characterised by sand at shallow depth with mean thickness of 10m. However, the estimated natural period for SS site is smaller than that predicted by McPherson and Jones (2006), but it falls within the range of the mean and mean minus one standard deviation.

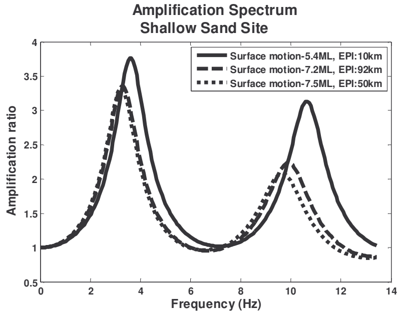

Figure 1 SS site amplification spectrum

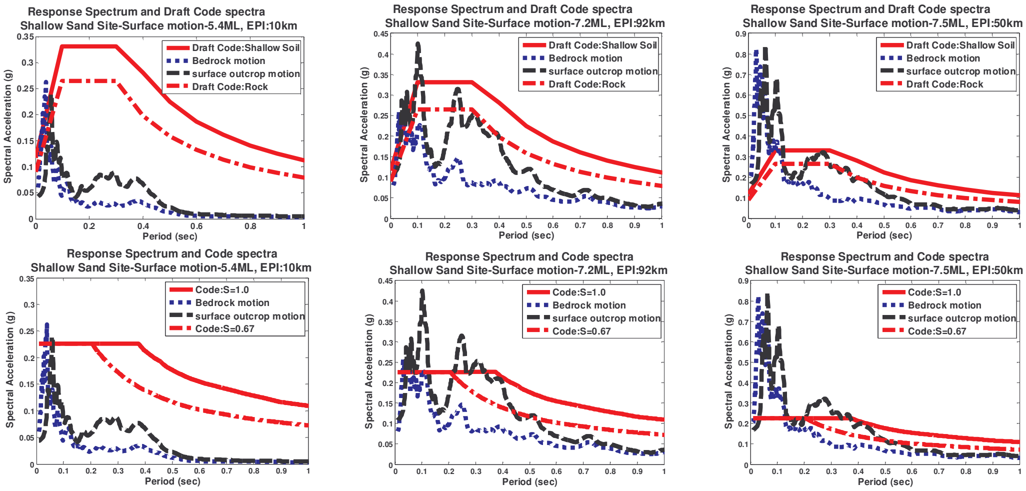

Figure 2. Comparison of SS site response spectrum and code spectra

Table 3. Summary of PGA, amplification factors and natural period of SS site

SS	ML5.4, Distance: 10km	ML7.2, Distance: 92km	ML7.5, Distance: 50km
Amplification	3.8	3.4	3.3
Period (sec)	0.28	0.30	0.31

3.2 DS site

For this site, significant deamplification of ground motion relative to the base rock motion at frequencies above 10Hz is observed. Amplification is noted as significant between the frequency range of 1 to 3Hz. The natural period of the site is evaluated as 0.57sec to 0.67sec (1.5Hz to 1.75Hz) as shown in Figure 3. The comparison of DS site response spectrum and code spectra is shown in Figure 4. Code spectra prove to be conservative at this site for period above 0.025sec. The worst case scenario event does slightly exceed the draft code specification for a small range of period below 0.15sec and goes over the current code spectrum for period below 0.25sec. The nonlinearity of soft soil response significantly reduces the site amplification ratios.

The natural period of DS site falls within the range of 0.3 sec to 0.7 sec, the period predicted for zone 2 of deep sand site with mean thickness of 20m to 40m (Gaull 2003). Ignoring the effect of nonlinear soil responses, the natural period for DS site is also similar to the mean value predicted by McPherson and Jones (2006).

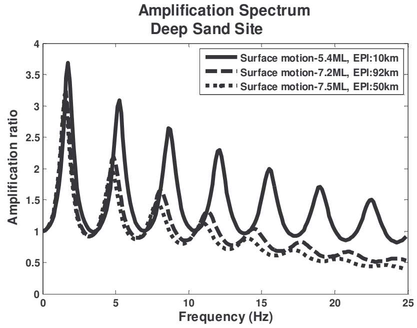

Figure 3. DS site amplification spectrum

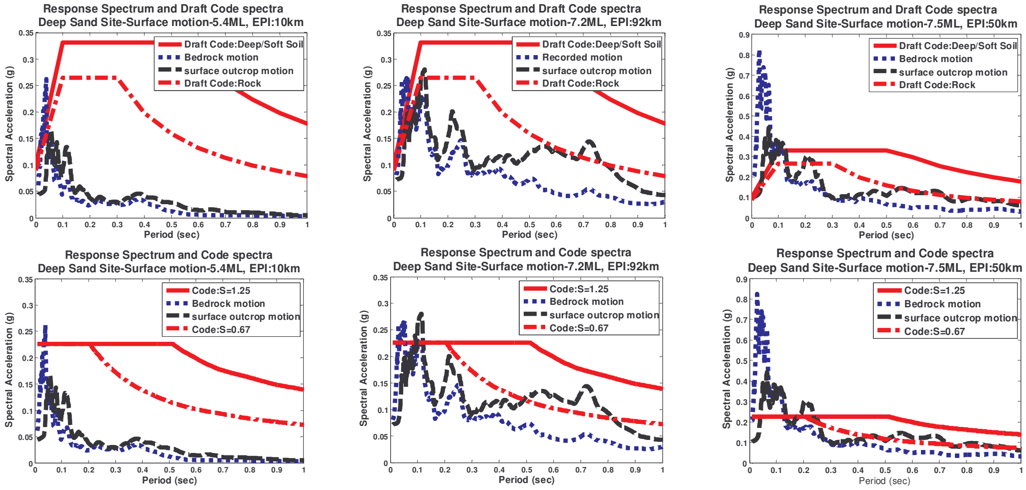

Figure 4. Comparison of DS site response spectrum and code spectra

Table 4. Summary of PGA, amplification factors and site period of DS site

DS	ML5.4, Distance: 10km	ML7.2, Distance: 92km	ML7.5, Distance: 50km
Amplification	3.7	3.2	3.2
Period (sec)	0.57	0.62	0.67

3.3 MS site

As can be seen in Figure 5 and Table 5, the largest amplification ratio is about 3.3 to 3.5, occurring at the natural period of the site of 0.22sec. The soil nonlinear response at this site is insignificant as compared to the SS and DS sites. For the worst case scenario event, spectral acceleration significantly exceeds the draft code spectrum at periods lower than 0.25sec and the current code spectrum for period lower then 0.3sec. The lower range event again lies below both the draft code and the current code specifications. The upper range event does exceed the draft code spectrum in the range of 0.2sec to 0.3sec and 0.05sec to 0.1sec. The current code underestimates the spectrum from upper range design event at periods lower than 0.3sec.

The natural period of MS site is similar to that in zone 4 around the south of Swan River and the east of Canning River where Gaull (2003) indicated that sediments resonating at between 0.1sec and 0.3sec. McPherson and Jones (2006) predicted a longer natural period for this site.

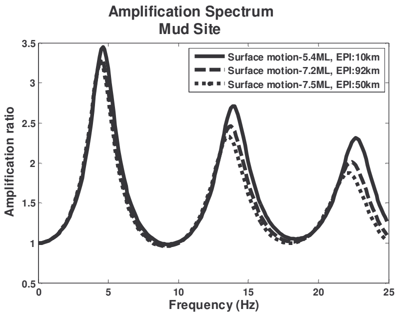

Figure 5. MS site amplification spectrum

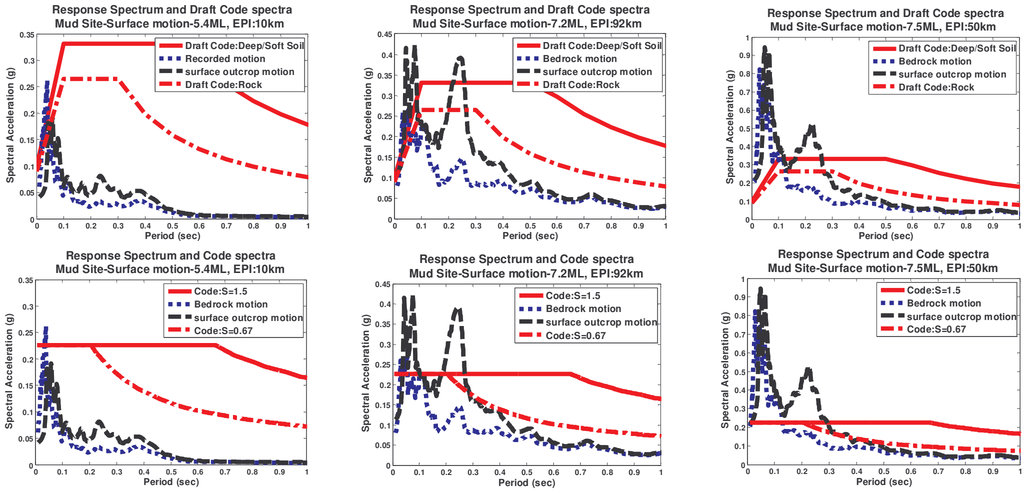

Figure 6. Comparison of MS site response spectrum and code spectra

Table 5. Summary of PGA, amplification factors and site period of MS site

MS	ML5.4, Distance: 10km	ML7.2, Distance: 92km	ML7.5, Distance: 50km
Amplification	3.5	3.3	3.3
Period (sec)	0.22	0.22	0.22

3.4 LS site

In general, the surface motions at this site closely resemble the base rock motion. This is expected as the region predominantly comprised of rock itself. The site has a high natural frequency (about 6.0 Hz) as shown in Figure 7. Some amplification of base rock motion above 10Hz is due to the thin sand layer on the surface. Examining the spectral accelerations presented in Figure 8 reveals that both the draft and current code provide conservative estimations of acceleration for period higher than about 0.15sec. However, both codes underestimate the upper range design event for period lower than about 0.1Hz. The worst case scenario event exceeds the boundaries set out by codes for most frequencies greater than about 8Hz. Gaull (2003) do not include this site in his study and McPherson and Jones (2006) predicted similar natural period for this site.

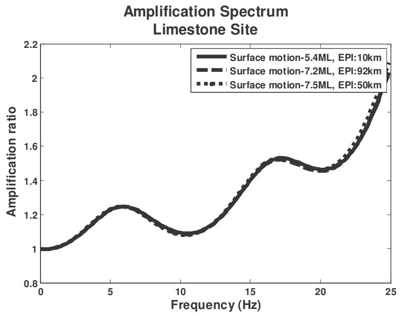

Figure 7. LS site amplification spectrum

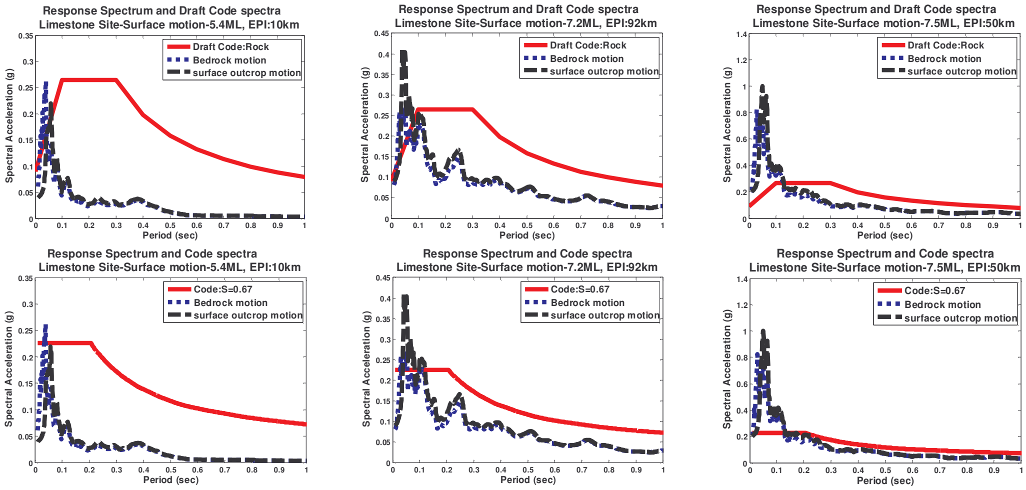

Figure 8. Comparison of LS site response spectrum and code spectra

Table 6. Summary of PGA, amplification factors and site period of LS site

LS	ML5.4, Distance: 10km	ML7.2, Distance: 92km	ML7.5, Distance: 50km
Period (sec)	0.17	0.17	0.17

4. Conclusion

An upper range and a lower range 475-year return period design event, as well as a worst-scenario event on rock site are simulated and used as input to estimate the responses of four typical sites in PMA. The site amplifications and site predominant vibration periods are calculated and the site response spectra are compared to the draft code and the current code design spectrum. The results have shown the following:

1. The site predominant vibration periods obtained in this study are close to that reported by Gaull (2003). McPherson and Jones (2006) predicted longer natural periods for most sites. However, the site predominant vibration periods calculated in this study fall within the range of the mean and mean minus one standard deviation presented by McPherson and Jones (2006).
2. Both the draft and current design spectrum given in the code in general overestimate the spectral accelerations from both the upper and lower design events in large period ranges. However, they might underestimate the spectral accelerations at very high frequencies.
3. The worst-scenario event produces larger spectral accelerations than the design spectrum in the high frequency range. The spectral accelerations might be still smaller than the code spectrum in low frequency range.

5. Reference

AS/NZS 1170.4 Draft no.D5212 (2004). *Structural Design Actions-Part 4 Earthquake Actions*, sub-committee BS-006, Standards Australia.

Gaull, B. (2003). "Seismic parameters for the upper sediments of the Perth Basin," *AGS Symposium*.

Gaull, B., Kagami, H. and Taniguchi, H. (1995). "The Microzonation of Perth, Western Australia, Using Microtremor Spectral Ratios," *Earthquake Spectra* 11, 173-191.

Gaull, B. and Michael-Leiba, M. (1987). "Probabilistic earthquake risk maps of southwest Western Australia," *BMR Journal of Australian Geology and Geophysics* 10, 145-151.

Hao, H. and Gaull, B. A. (2004). “Design earthquake ground motion prediction and simulation for PMA Based on a modified ENA seismic ground motion model for SWWA,” *Australian Earthquake Engineering Society Proceedings of the 2004 Conference, Mt Gambier, South Australia.*

Jarpe, S., Hutchings, L., Hauk, T. and Shakal, A. (1989). "Selected strong- and weak-motion data from the Loma Prieta earthquake sequence," *Seismological Research Letters* 60, 167-176.

Liang, Z., Hao, H., Gaull, B. A. and Sinadinovski, C. (2007). "Estimation of strong ground motions in Southwest Western Australia with a combined Green's function and stochastic approach," *Journal of Earthquake Engineering*, Accepted.

McPherson, A. and Jones, A. (2006). "Appendix D: PERTH BASIN GEOLOGY REVIEW and SITE CLASS ASSESSMENT." *Perth Basin geology*.

Schnabel, P. B. (1973). "Effects of Local Geology and Distance from Source on Earthquake Ground Motions," University of California, Berkeley, California.

Seed, H. B. and Idriss, I. M. (1970). "Soil Moduli and Damping Factors for Dynamic Response Analysis." Report No. EERC 75-29, Earthquake Engineering Research Center. Berkeley, California, University of California.

Standards Australia (1993). Minimum design loads on structures, Part 4: Earthquake loads-AS1170.4-1993

Sun, J. I., Golesorkhi, R. and Seed, H. B. (1988). "Dynamic Moduli and Damping Ratios for Cohesive Soils." Report No. EERC 88-15, University of California, Berkeley.