## 1. INTRODUCTION

The Malay Peninsula is on a stable part of the Eurasian plate and is in a region of low seismicity. However the peninsula has a long history of experiencing tremors generated from the long distance earthquakes in the Sumatra fault and the sub-duction fault offshore of Sumatra (Balendra *et al*, 2001). The closest distance of these two major active faults from the Peninsula is 300 km and 500 km respectively. The sub-duction fault generated the magnitude 9.3 "Aceh" earthquake on the 26$^{th}$ of December 2004 and magnitude 8.7 "Nias" earthquake on the 28$^{th}$ of March, 2005. Although no damage to infrastructure was reported in Malaysia, these major events caused great concerns of the need to address seismic risks in view of the lack of preparedness within the community and the lack of considerations for seismic performance in the design of the infrastructure. The objective of this paper is to develop a practical model for predicting seismic actions on vulnerable structures in Malaysia based on projected earthquake scenarios generated by these distant seismic sources.

The first design earthquake scenario is a magnitude 9.5 earthquake generated from the sub-duction fault at the closest epicentral distance of 500 km from Kuala Lumpur (and the neighboring centers of population) as shown in Figure 1. Whilst this projected magnitude is close to that of the Aceh earthquake, the possibility of having earthquakes of this size was suggested prior to this event (eg. Zachariasen, *et al*. (1999)). The highest earthquake magnitude ever recorded in history is the magnitude 9.5 Chilean earthquake.

The second design earthquake scenario is a magnitude 7.8 earthquake generated from the Sumatran fault at the closer epicentral distance of 300 km. The design earthquake scenarios for Kuala Lumpur and the surrounding cities have been summarized in Table 1.

Table 1 Design Earthquake Scenarios

| Fault Source | Magnitude | Distance(km) |
|---|---|---|
| Sub-duction | 9.5 | 500 |
| Sumatran Fault | 7.8* | 300 |

*note: the stated earthquake scenario is consistent with the study reported in Balendra, *et al*., (2001), that has analysed the influence of long-distant earthquakes affecting the Singapore region.

The stated earthquake scenario enables the level of ground shaking to be predicted using a representative attenuation relationship, which can be obtained by:

(i) Empirical correlation of strong motion data,
(ii) Correlation of intensity data obtained from historical earthquake archives,
(iii) Acceleration simulations using Green's functional methodology, and
(iv) Accelerogram simulations by the stochastic methodology.

The relative merits and limitations of these methodologies were discussed in Lam *et al* (2005). It was concluded that the stochastic methodology is amongst the most viable means of obtaining representative attenuation relationship in low seismicity countries such as

Malaysia and Singapore. This contention has been based on the favorable comparisons of the stochastic simulation model GENQKE [Lam, *et.al*, 2000] with the recorded spectra of the Aceh & Nias earthquakes as shown in Figures 2a & 2b. The seismological parameters used in the GENQKE simulations were as follows : Seismic wave Quality Factor $Q_0$ = 150; Upper Crustal attenuation factor (Kappa) $\kappa$ = 0.02; Shear Wave Velocity (SWV) model of the rock has been developed using the global crustal data obtained from CRUST 2.0 (2001) and a methodology of constructing rock SWV profiles combining global and local data as described in Chandler *et al* (2005).

The rock response spectrum simulations for the design earthquake scenarios in Table 1 developed using GENQKE (as presented in Section 2) and the effects of soil amplifications on the rock motions are considered in Section 3. The seismic assessment of building structures using the developed response spectrum model is discussed in Section 4.


**Figure 1. Seismic sources affecting Malaysian region**

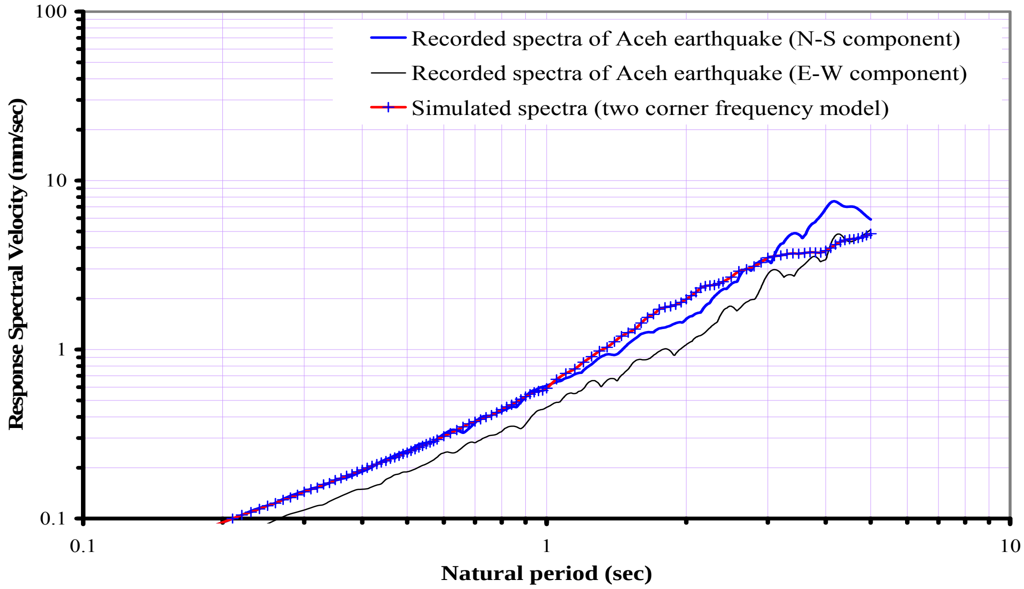
## 2. SIMULATIONS OF ROCK RESPONSE SPECTRA

The design earthquake scenarios noted in Table 1 have been simulated using the same seismological parameters used for the predictions shown in Figures 2a & 2b. The simulated response spectra together with the idealized bi-linear model as defined by equation (1) are shown in Figure 3.

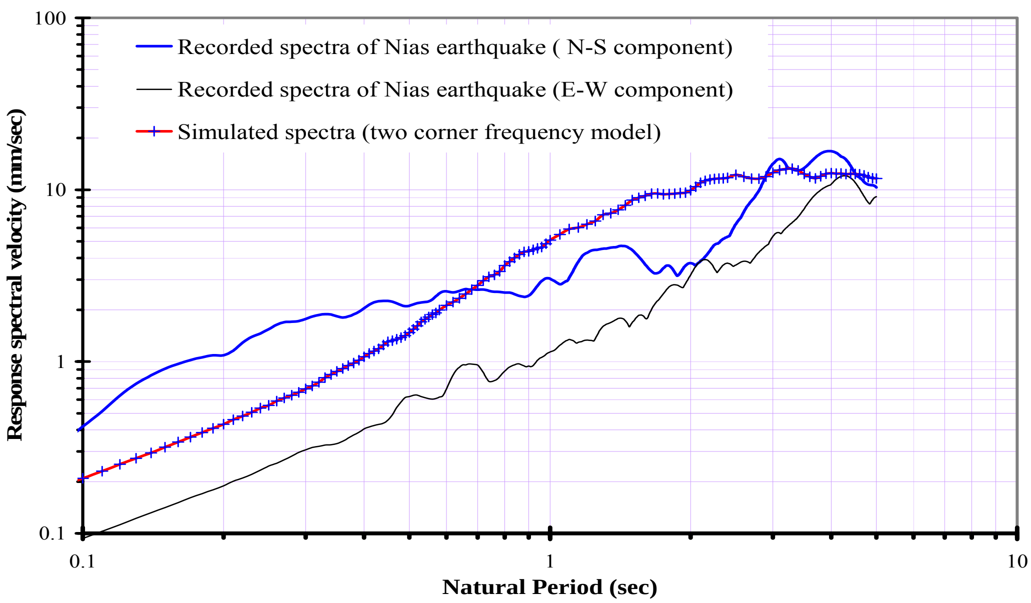
$RSV_{rock}$ (mm/sec) = 54 * T for T ≤ 2 sec

$RSV_{rock}$ (mm/sec) = 108 for T > 2 sec (1)

where T is the natural period (sec) and RSV is Response Spectral Velocity (mm/sec).




(a) ACEH earthquake M = 9.3 R = 1200 km




(b) NIAS earthquake M = 8.7 R = 750 km

**Figure 2. Comparison of recorded and simulated response spectra**

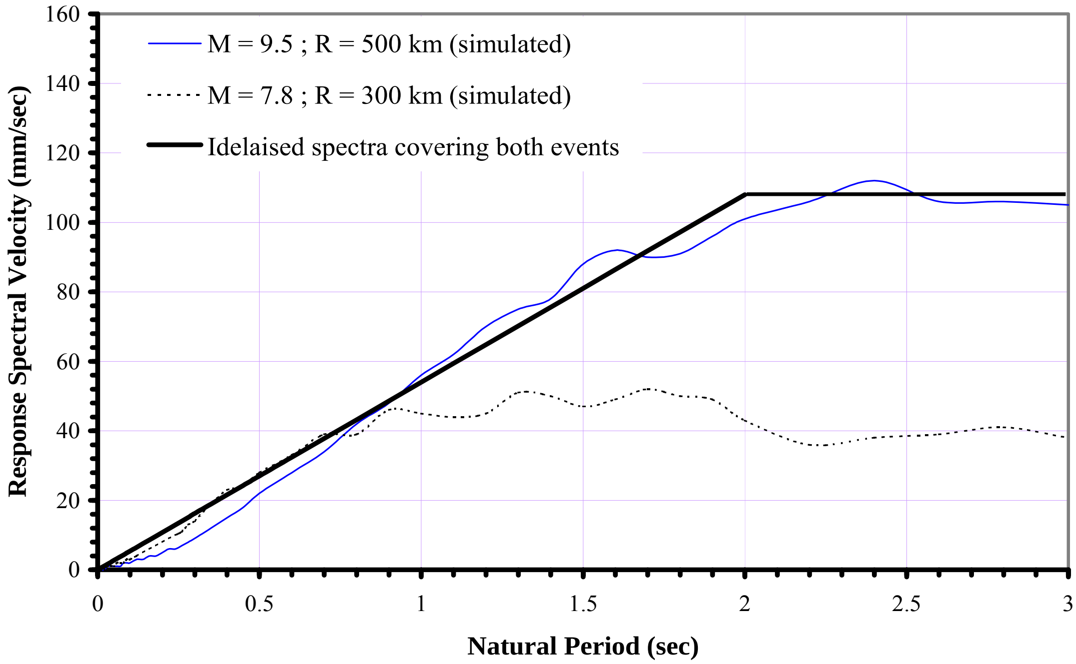



**Figure 3. Simulated and idealised design response spectra on rock**

## 3. EFFECTS OF SOIL AMPLIFICATION ON ROCK MOTIONS

The effects of soil amplification on the rock motions presented in Section 2, were analyzed using a one-dimensional shear wave analysis [program SHAKE, Schnabel *et al*, 1972] based on the information provided by borehole records obtained from different parts of the Malaysian peninsula including Singapore. In analysing these profiles, the in-situ layering conditions have been adopted. The damping and modulus degradation models adopted in this study were consistent with that used in earlier studies (eg. Venkatesan et al, 2004). The natural periods of these soil profiles varied between 0.3 and 1.2 sec. Structures found on these soil sites are assumed to possess the notional 5% critical damping.

Figure 4 presents the velocity response spectrum of a deep (flexible) soil site with a site natural period of 1.2 sec. An idealized bi-linear model is also shown in the figure alongside the response spectrum for the bedrock surface and the soil surface. Similar response spectra were obtained for sites possessing different natural periods. It was observed from the simulated response spectra that the highest velocity demand on the soil site was about 5 times that of the bedrock at the site natural period. In other words, the highest velocity demand on the soil site increases with increasing site natural period as can be inferred from the trend shown in Figure 5. Thus the response spectrum for a soil site can be calculated and constructed for any given site natural period as shown in Figure 6.

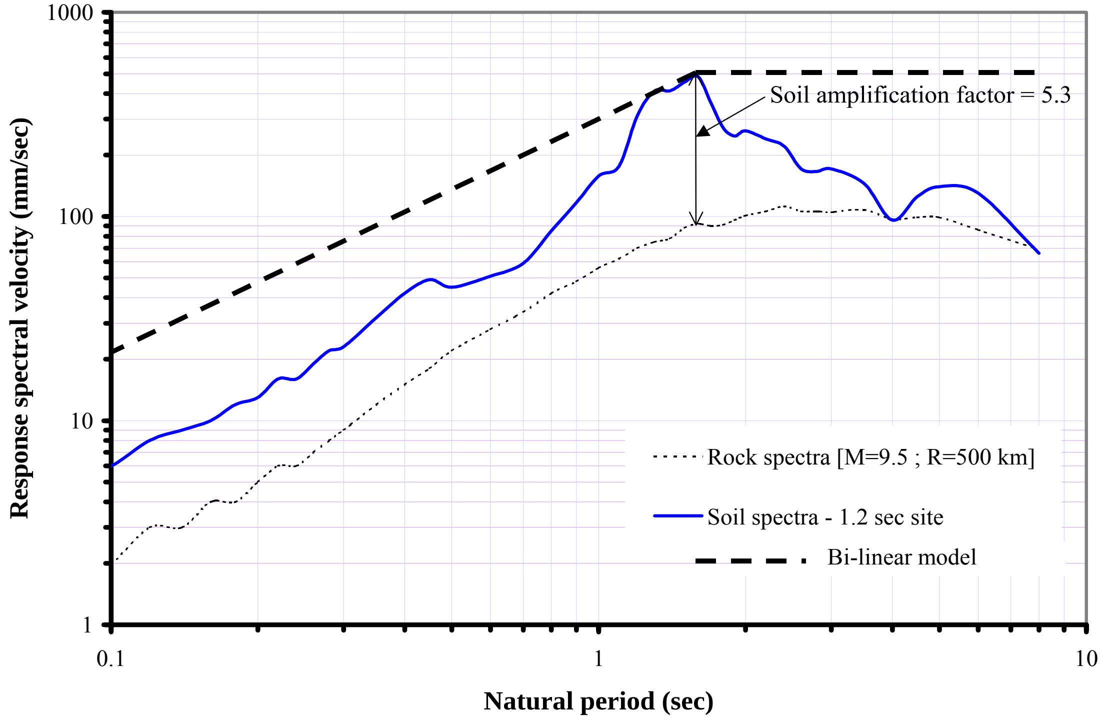



**Figure 4. Bi-linear idealisation of soil velocity response spectra**

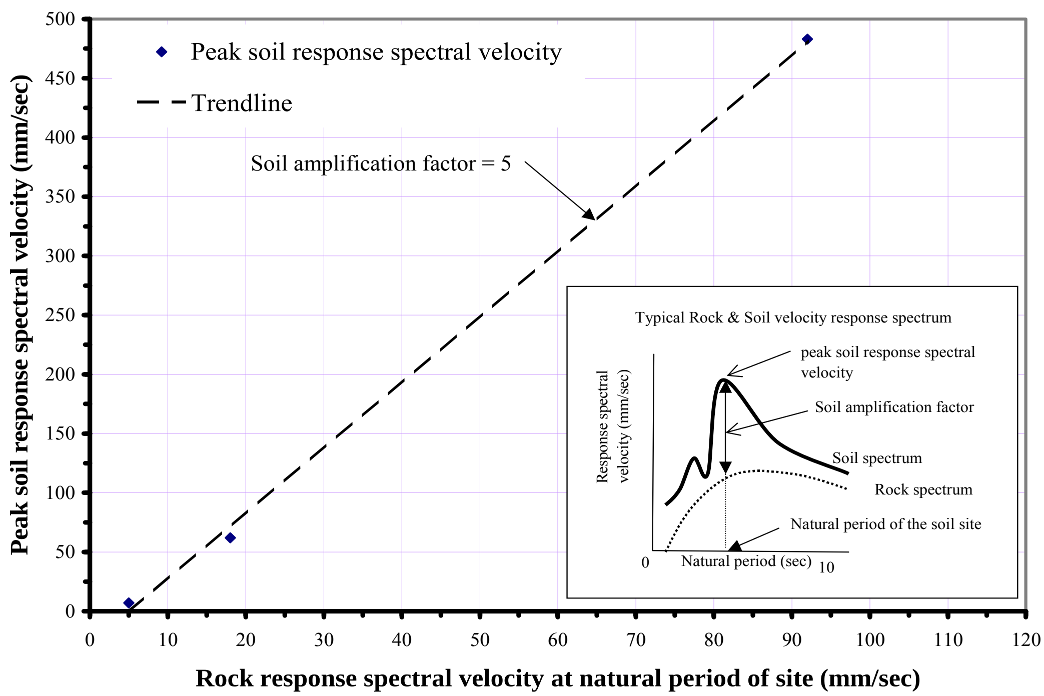



**Figure 5. Peak soil response spectral velocity and soil amplification factor**

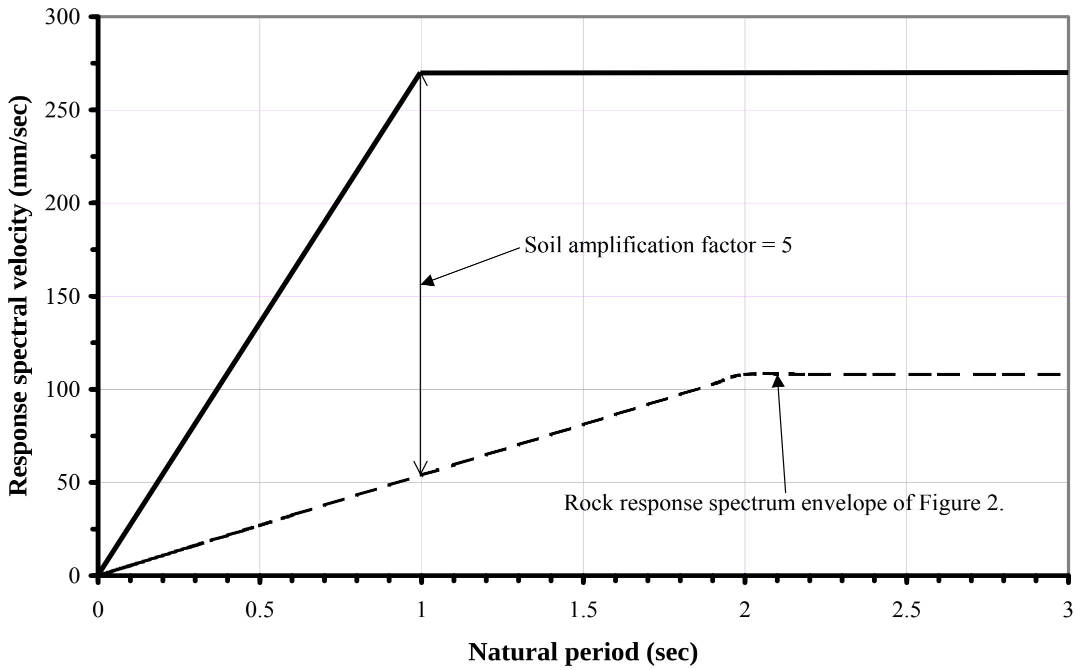



**Figure 6. Velocity response spectrum model for soil site with natural period = 1 sec**

## 4. APPLICATION OF THE DEVELOPED MODEL

In this section, the soil response spectrum model developed in Figure 6 is used to predict the drift demand of a precast concrete building with a soft-story at ground level (Figure 7). Assuming a natural period of 1 second for the soft-storey building, the predicted velocity demand on the structure is 270mm/sec according to Figure 6. The corresponding response spectral displacement (RSD) demand on the generalized single-degree-of-freedom system is calculated from Equation 2 to be in the order of 40mm - 50mm.

$$RSD\ (mm) = RSV_{(mm/sec)} * T/2\pi \qquad (2)$$

The calculated displacement demand is translated into a significant drift of 1.5%-2% on the building shown in Figure 7 based on a soft-storey height of 3-4m. This example demonstrates the vulnerability of soft-storey buildings on soft soil sites in an earthquake.

## 5. CLOSING REMARKS

A response spectrum model for the projected major distant earthquake scenarios affecting Kuala Lumpur and the surrounding cities has been developed from a combination of seismological, geotechnical and structural response modeling. The response spectrum model can be applied to assess the drift demand of idealised soft-storey buildings and buildings of other structural forms provided that the appropriate participation factors have been incorporated into the calculations. Importantly, the seismological simulations have been evaluated by comparing the predicted response spectra with those recorded in Singapore from the recent major earthquake events of ACEH and NIAS.

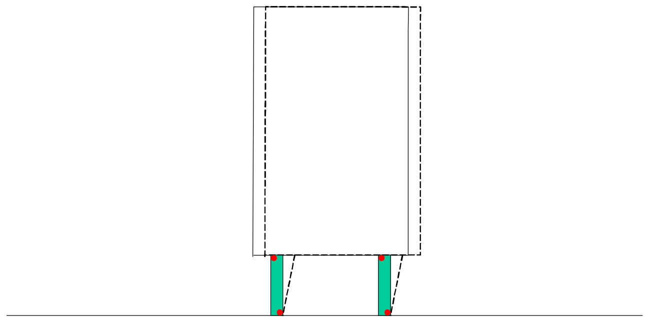


**Figure 7. Drift behavior of a soft-storey building**

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Website providing information on the 2005 NIAS earthquake: **http://neic.usgs.gov/neis/eq_depot/2005/eq_050328/neic_weax_ff.html** and http://www.worldatlas.com.

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