International Journal of Civil Engineering and Geo-Environment

Journal homepage:http://ijceg.ump.edu.my
ISSN:21802742

SITE SPECIFIC SEISMIC HAZARD ASSESSMENT FOR KUALA LUMPUR AND VICINITY FROM LONG DISTANCE EARTHQUAKES

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A R T I C L E I N F O

Keywords:

Seismic hazard assessment
Long distance earthquake
Site amplification
Flexible soil
Kuala Lumpur

A B S T R A C T

Earthquake motion on a building is dependent upon its underlying soil. A proper site specific hazard assessment is necessary for safe design of structures especially on flexible soil. Kuala Lumpur and Selangor is considered to be safe against earthquake threat. However, more tremors are being felt by occupants due to long distance earthquakes from Sumatra, raises concern on the safety of the buildings in this region. Previous studies on flexible soil in Singapore discovered that the amplification due to soil resonance could be up to 12 times higher than the motion on rock. To validate this, site specific hazard assessment has been conducted on six sites in Kuala Lumpur and Selangor areas. The analysis is based on modified time history and using one-dimensional ground response analysis. The soil amplifications are found to be much higher than the values recommended by Eurocode 8. The adoption of Eurocode 8 for seismic design in this region should be carefully done by taking into account the effect of long distance earthquake to the wave propagation in flexible soil.

1. Introduction

Ground motion levels used for structural design is highly dependent on local site condition. Sites with weak, flexible soil yield higher spectral acceleration at periods larger than 0.4s, compared to stiff soils (Seed et al., 1976). In general, flexible soil sites tend to amplify the long-period motions while stiffer soils will amplify the shorter-period motions.

Peninsular Malaysia was considered to be safe from earthquake threat due to its far location from nearby faults. However, the tremors felt from earthquakes in Sumatra increase awareness of engineers on the importance of earthquake loads to the design of structures. Previous study shows that the magnitude of peak ground acceleration (PGA) from far-field earthquake is relatively low at approximately 20gals (Nabilah and Balendra, 2012). However, local soil properties could amplify the motion further, possibly damaging the structure resting on it. Balendra and Li (2008) conducted seismic hazard assessment on three sites in Singapore, namely Marine Parade, Katong Park and Katong sites, all with clay layers. The soil amplification factors vary from 10 to 12, which resulted to spectral acceleration of 60 to 100gal. The fundamental period of the soils vary from 1 to 2s, which will affect primarily the high-rise buildings resting on it. Marto et al. (2011) developed 4 synthetic time-histories to evaluate the effects of soil amplification to the ground motion in Putrajaya and Kuala Lumpur, Malaysia. From their study, the average amplification factor in Putrajaya is 1.94 for soil class D and 2.17 for soil class E. Husen et al. (2008) reported several weak soils in Bandar Puteri Puchong, Mutiara Damansara and Bandar Petaling Jaya in Kuala Lumpur, and these soils should be analysed further.

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Due to the low seismic load in Kuala Lumpur area, proper analysis should be conducted as the amplification could be large for soft soils due to long distance earthquake. In this research, one-dimensional ground response analysis is conducted on modified time-history records using soil profile of 6 sites in Kuala Lumpur and Selangor areas

2. Soil data

Major areas in Kuala Lumpur are underlain by limestone formation, known as Kuala Lumpur limestone. It is commonly found at the depth of 50m, to the extreme depths of 100m. The overlaying soils in Kuala Lumpur consist of alluvial deposits, mine tailings, man-made fills, organic mud and peat, and residual soils of various rock formations. Some geological problems encountered during construction in Kuala Lumpur are, among others, collapsed weak soil above limestone bedrock and very flexible soils due to mine tailings (Tan, 2006). Another area of interest are Klang and Banting in Selangor, where constructions were done over soft silty clay called Klang clay. In a soil study conducted by Tan et al. (2003) for a development project, the site is overlain by alluvial deposit consisting of very soft to firm silty clay up to 30m deep.

Wave propagation along the soil strata is highly dependent upon the shear wave velocity of the upper 30m of the soil. The shear waves in far field earthquakes are of long periods, as the shorter periods are damped out as they travel over long distances. Propagation of the waves through soil layers could be amplified by resonance when the fundamental period of soil is similar to the dominant period of the waves. As flexible soils possesses high natural periods (similar to the incoming waves), they are more affected by the far-field earthquakes compared to stiffer soils. In this research, profiles of flexible soil with high natural periods are selected for the analysis.

4 borehole data have been collected in Kuala Lumpur and Selangor namely Sungai Besi (Site KL-1) and Subang (Site KL-2) for normal soil condition and Klang (Site KL-3) and Banting (Site KL-4) for clay soil deposits. In addition to the collected borehole data, additional soil profiles are obtained from study by Marto et al. (2011) in Kuala Lumpur city center, named sites KL-5 and KL-6. The locations of the sites are shown in Figure 1.

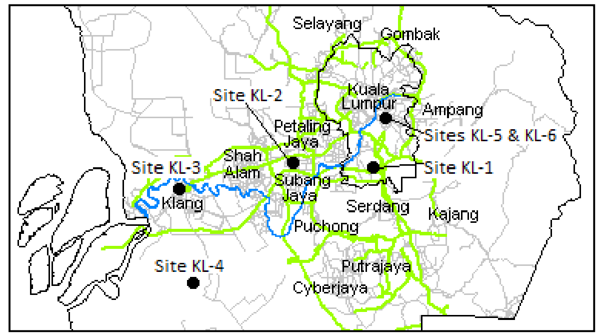
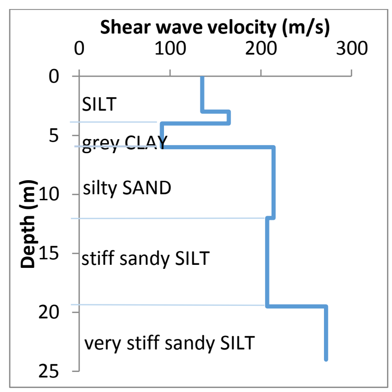
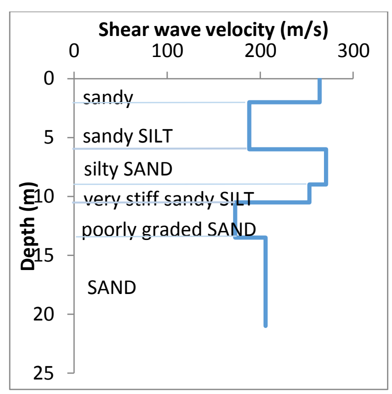


Figure 1: Locations of sites KL-1 to KL-6

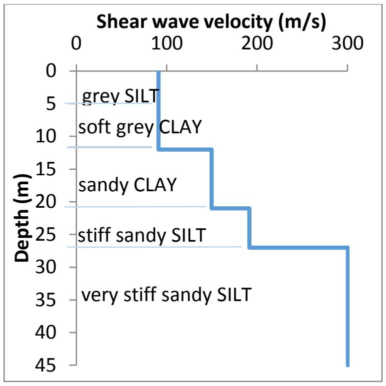
The data collected are standard penetration test (SPT) values and soil profiles. Since it is uncommon to conduct in-situ tests for shear wave velocity (V_s), the values of V_s are computed based on the SPT values using the empirical formulas by Ohta and Goto (1978) and Imai and Tonouchi (1982) as recommended by Adnan et al. (2007). The soil profile and shear wave velocity of the sites in and around Kuala Lumpur are presented in Figure 2.



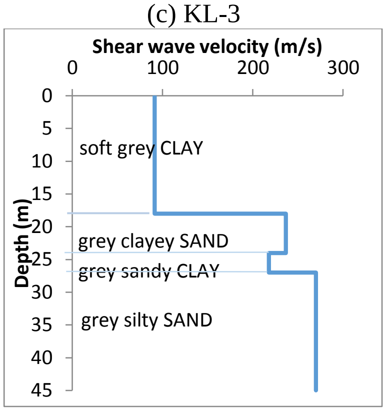
(a) KL-1



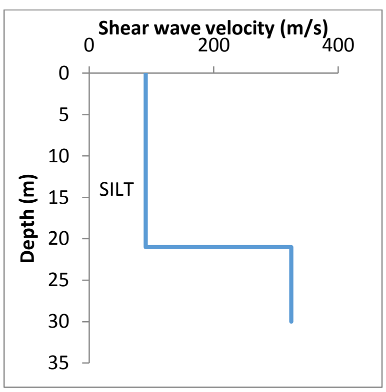
(b) KL-2



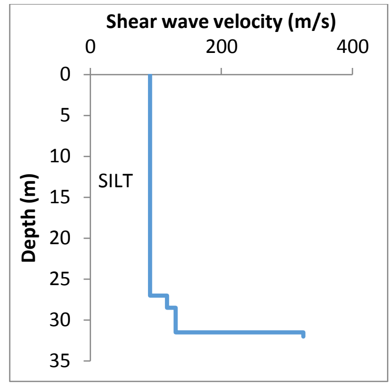
(c) KL-3



(d) KL-4



(e) KL-5



(f) KL-6

Figure 2: Soil profile and shear wave velocity of sites in Kuala Lumpur and Selangor

2.1 Soil classification

The sites in Kuala Lumpur and Selangor are classified based on Eurocode 8 (2004) where very hard rock is classified as class A while very flexible soil with shear wave velocity (V_s) of less than 180m/s is of class D. Soil class S_1 is for profiles with at least 10m thick soft clay with high plasticity index. The period of the soil, T_1, with thickness H is approximated as T_1=4H/V_s. The summary of site properties is shown in Table 1.

Table 1: Properties of selected sites in Kuala Lumpur and Selangor

Site	Weighted average of V_s (m/s)	T_1 (s)	Soil class (Eurocode 8)
KL-1	200.6	0.48	C
KL-2	216.0	0.39	C
KL-3	200.0	0.90	S_1
KL-4	190.5	0.94	S_1
KL-5	115.0	1.00	D
KL-6	100.0	1.28	D

2.2 Other soil properties

Whenever data are unavailable, the unit weight is estimated using recommended values by Coduto (1999) based on soil type. Chen and Tan (2003) reported that the plasticity index (PI) of Klang clay varies from 20 to 80%. Thus, in this study, the PI of clay for sites KL-3 and KL-4 are taken as 50% for fat clay (high PI) and 30% for lean clay (medium PI). For other sites, the average PI of clay is taken as 15%, representing a much lower plasticity and swelling potential. The shear wave velocity of bedrock is taken as 1000m/s (Subramanian, 2008). This value will highly influence the result of soil analysis.

3. Ground response analysis

3.1 Development of modified time-history

The time-histories for wave propagation analysis are obtained by modifying the original time-histories to match a target spectrum. This procedure is done using SeismoMatch V1.0.3 (2011) which is based on methodology proposed by Lilhanand and Tseng (1988) using time domain method. First, the time-histories were selected based on the earthquake magnitude and distance from deaggregation analysis. Next, the time-histories were scaled to the required PGA, and modified to match the spectral acceleration at rock site. In this project, 5 earthquake time-history records were modified and used for the ground response analysis.

3.2 Performing ground response analysis

The wave propagation in soil strata is determined based on one-dimensional ground response analysis, where the ground motion responses are predominantly due to vertical wave from the bedrock. The ground response analysis is conducted using DEEPSOIL V5.0 (2011), based on equivalent linear analysis.

4. Result of Site Specific Analysis

Ground response analysis is conducted for the soils from six sites in Kuala Lumpur and Selangor using input from modified time-history records of five ground motions. For each soil site, five results are obtained, and the mean of the response spectra is calculated and shown in Figure 3. The maximum response acceleration is 0.12g for soil class C, 0.17g for soil class D and 0.22g for soil class S_1. As expected, soil class S_1 which is underlain by very soft clay produces the largest motion compared to other soil types. The motion peaks at the soil period, which is around 0.5s for soil class C and 1s for soil class S_1. However for soil class D, the motion peaks at approximately 1.5 to 2s, which is higher than the soil period of 1 to 1.3s. This is possibly due to the frequency content of the incoming earthquake.

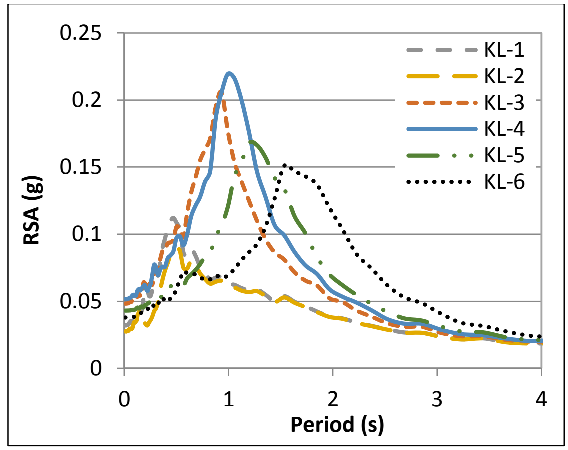


Figure 3: Mean response spectra at 5% damping

The amplification factor for different soil sites are shown in Figure 4. As expected, soil class S_1 produces the highest amplification of approximately 4.5. This is due to the overlaying soils (clay) with high *PI*, resulting to lower damping of the input motion. It is also possible that the period of the soil coincides with the period of the earthquakes, resulting to higher amplification factor compared to other soils.

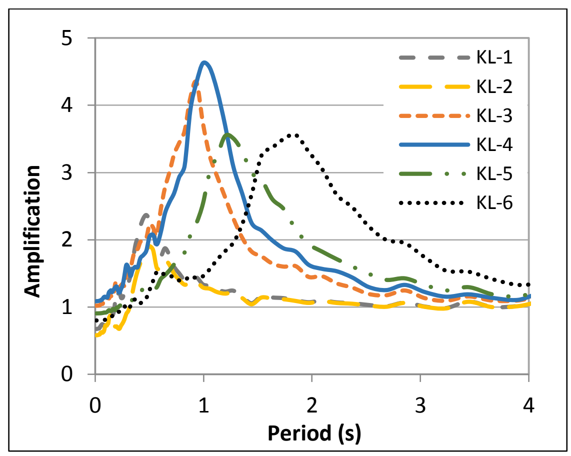


Figure 4: Average soil amplification at 5% damping

The amplifications obtained from this analysis are very high compared to values recommended by Eurocode 8 (2004), which are 1.35 to 1.4 for soil classes C and D respectively. The corner periods for the limit of maximum response spectral acceleration (RSA), T_C, specified by Eurocode 8 (2004) are also very different from the analysis especially for soil class D. The code specified T_C value of 0.8s, however it is shown that the maximum amplification for the said soil class corresponds to the period of 2s. This is due to the low frequency content of long distance earthquakes, resulting to higher corner period values.

4.1 Implications in adapting Eurocode 8 for seismic design

Malaysia will soon adopt Eurocode 8 (2004) for the design of structures against seismic load. Based on Eurocode 8 (2004), areas with very low seismicity (PGA is less than 0.04g on soil class A) does not need to be designed for earthquake load. However, it should be pointed out that the amplification for soil classes C and D in Kuala Lumpur and Selangor are much larger than the value specified in Eurocode 8 (2004).

To illustrate the importance of soil amplification in long distance earthquakes, the response spectral acceleration (RSA) analysed are compared to the minimum PGA in Eurocode 8 (2004) as shown in Figure 5. It is observed that the RSA for soil class C and D fall outside the limit in the code beyond the period of 0.4 and 0.6s respectively. In addition, the maximum RSA is very much larger for soil class D compared to the limit in Eurocode 8 (2004). For flexible soil with clay layers, the RSA is much larger than the limit in the code, as shown in Figure 5. The figure shows that seismic design is still required for higher period (flexible) soils. This generally affect structures of medium to high rises, where the fundamental period of the buildings are typically on the higher side. In addition, PGA alone cannot be used as a benchmark for seismic design requirement, as the soil factor also plays a very important role in amplifying the motion beyond the limit specified.

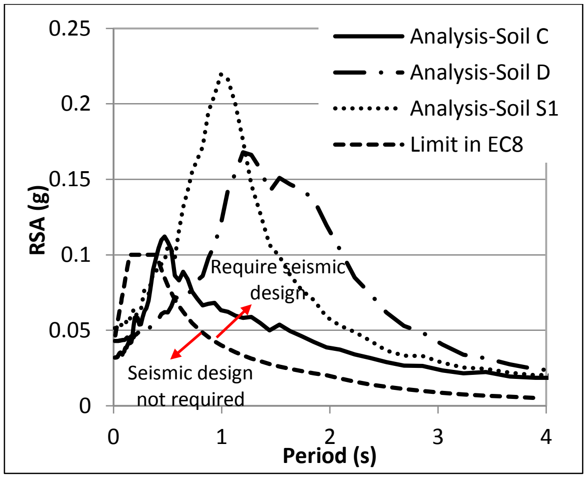


Figure 5: Comparison between response spectral acceleration (5% damping) from analysis with the limit by Eurocode 8 for seismic design for soil classes C, D and S_1

5. Conclusions

Site specific seismic response analysis has been conducted for six soil sites in Kuala Lumpur and Selangor. The soil periods are in the ranges of 0.4s to 1.3s, which fall in the category of soil classes C, D and S_1 according to Eurocode 8 (2004). The wave propagation is based on one-dimensional ground response analysis, using modified time-history data from 5 earthquake events with similar magnitude and distance with the region considered. It is found that the amplifications of motion are higher compared to the value recommended in Eurocode 8 (2004) especially for the weaker soil. The limiting periods for maximum acceleration are also found to be much higher compared to the code. It is found that the implementation of Eurocode 8 (2004) in this region should consider the effect of long distance earthquake for safe design of structures.

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