DEVELOPMENT OF DESIGN RESPONSE SPECTRA FOR NORTHERN PENINSULAR MALAYSIA BASED ON UBC 97 CODE

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ABSTRACT

The main objective of this paper is to develop design spectrum based on UBC 97 for Northern Peninsular Malaysia, which covers Penang Island, Alor Star and Ipoh. Existing reinforced concrete (RC) structures in Malaysia have been designed according to BS 8110 without any provision for seismic loading. Although situated on the stable shelf, several places especially in Northern Peninsular Malaysia, which is Penang Islands, Alor Star and Ipoh have experienced ground shaking effect due to the long distant earthquake occurred in Acheh and Nias recently. Northern Penang are situated close to the earthquake tremors may demand a quick review on the existing design code for designing structures. This paper presents the design spectrum for Northern Peninsular Malaysia based on total 193 boreholes from site investigation reports derived using Seismic Design provision of 1997 Uniform Building Code. The results indicated that most soil in Northern Peninsular Malaysia can be categorised as class D, S_D (stiff soil). Most of the soils categorised in S_D, but the highest Response Spectrum Acceleration (RSA) are in other categorised, which is Penang Island for S_C (0.76 g), Ipoh and Alor Star is S_E are 0.31 g and 0.47 g respectively.

Keywords: *Alor Star, Design Response Spectrum, Ipoh, Penang Island, UBC 97*

1.0 INTRODUCTION

Peninsular Malaysia is located in a low–seismicity region [1, 2] and situated on ‘stable Sunda Shelf’. It is also assumed to be an earthquake free zone [3]. Despite that, ground shaking still can be felt. Table 1 shows the earthquakes felt in Malaysia from year 1909 to 2005 for Peninsular Malaysia and from 1923 to 2005 for East Malaysia. According to Malaysian Meteorological Services (MMS), most of the earthquake events recorded in Malaysia is ranging from 4 to 6 magnitude.

Since Malaysia is classified between low to moderate seismicity area depending on distance to fault line, it was observed that past earthquake did not cause any problems to building in Malaysia. However, the Great Sumatran - Andaman earthquake that occurred on 26 December 2004 generated big tsumani and affected a few part of Peninsular Malaysia. It shows that long-distant earthquakes in several hundred kilometers away, can cause substantial damage to buildings. Due to the significant hazards that occur due to long-distant earthquakes, the structural performances and life safety of the buildings in Malaysia were started to be given more concern and attention.

Therefore, this paper is aim to develop the design response spectrum for Northern Peninsular Malaysia. The analysis has been conducted using NERA (Nonlinear Earthquake site Response Analysis) program. This analysis was performed to obtain ground motion parameters such as acceleration and surface response spectra at the specific site. Then, the smooth response spectra or design spectra acceleration was developed for each site soil condition. These particular design response spectra are very important and useful for structural design purposes.

Table 1: Earthquakes felt in Malaysia

State	Frequencies	Maximum Intensity Observed (Modified Mercalli Scale)
Peninsular Malaysia (1909-2005)		
Perlis	2	IV
Kedah	9	V
Penang	31	IV
Perak	18	IV
Selangor/ KL	37	IV
Negeri Sembilan	4	V
Melaka	9	V
Johor	21	IV
Pahang	4	III
Terengganu	1	IV
Kelantan	3	IV
Sabah and Sarawak (1923-2005)		
Sabah	24	VII
Sarawak	5	V

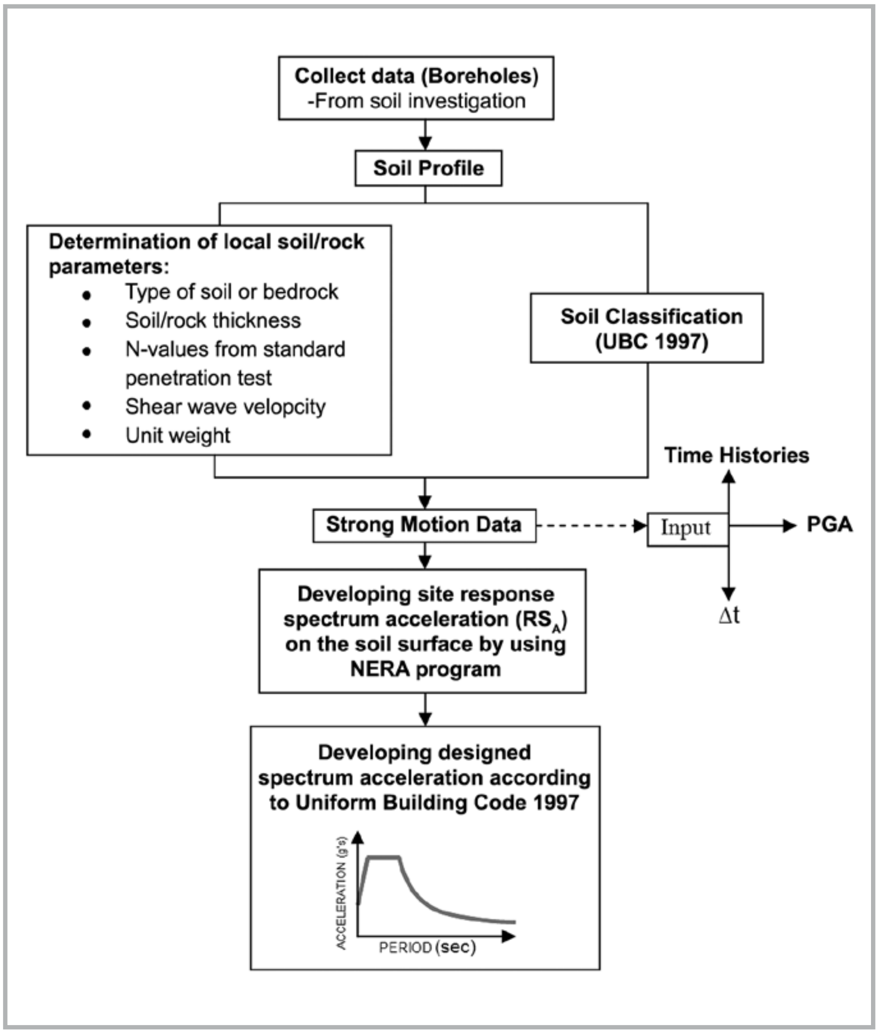

Figure 1: Representation of ship hull by transverse strip along the length of ship

Table 2: Locations of borelogs for Penang Island, Ipoh and Alor Setar

Locations		
Penang	**Ipoh**	**Alor Setar**
Universiti Sains Malaysia	Sek. Keb. Catur Avenue	Mukim Alor Merah
Daerah Timur Laut	Batu Gajah	Jabatan Kimia
Jelutong	Tasek Dermawan	SM.(Agama) Mergong
Georgetown	Bercham	SMK.Tunku Abdul Malek
Daerah Barat Daya	Ampang	Kolej Sultan Abdul Hamid
Bayan Lepas	Jelapang Jaya	Kompleks Mahkamah
Bayan Baru	Tronoh	SM.Sultanah Asma
Tanjung Tokong	Sri Kampar	Ibu Pejabat Polis Kontigen (Pusat Bandar)
Batu Feringghi	Pusing	Ibu Pejabat Polis Kontigen (Jalan Stadium)
Bukit Gambier	Tanjung Tualang	
Sungai Ara	Jln Ipoh	
Bukit Jambul	Jabatan Perhutanan Negeri	
	Jalan Tasek	
	Kampung Tasek	
	Buntong	
	Sungai Senam	
	Jelapang/Taman Meru	
	Jabatan Pengairan dan Saliran	
	Sek. Keb. Seri Tembok	

2.0 METHODOLOGY

The work described in this paper has been undertaken for earthquakes measured based on site classification. There were 193 boreholes data have been collected in various sites which represent the soil profile for Northern Peninsular Malaysia such as Penang Islands, Alor Star and Ipoh. The input parameters such as peak ground acceleration (PGA), dynamic soil properties, soil profile data and ground motion time histories are required for the analysis to perform response spectrum for various types of those three locations. Figure 1 shows the flow chart of the research methodology in developing design response spectra for Northern part of peninsular Malaysia. The details procedures are explained in the following sub-topics.

2.1 DATA COLLECTION

A total numbers of 50 soil investigation reports (S.I. reports) which covered 193 boreholes where 95 boreholes from Penang, 72 from Ipoh and 26 from Alor Setar. Most of the data for Penang Island were collected from Batu Feringghi, Tanjung Tokong, Georgetown, Daerah Timur Laut, Universiti Sains Malaysia and Bayan Lepas. Penang Island is irregularly shaped, with a granitic, hilly and mostly forested interior, the highest point being Western Hill (part of Penang Hill) at 830 metres above sea level. Sedimentary rocks are only found in Pulau Kendi, which is a small island to the south of Penang Islands [4].

Ipoh is situated in west coast of Peninsular Malaysia with more than 350 km away from Sumatran Fault Zone. This area is bounded on the north and south by the line of latitude 4º 45' N and 4º 15' N respectively, on the east by line of longitude 101º 15' E and on the west by 101º 00' E. The bedrock floor in Ipoh or Kinta Valley is covered with alluvium to depth varying from a few feet to more than hundred feet and the bedrock beneath the alluvium is mainly limestone [5].

Alor Setar with area of 666 sq km is the state's capital of Kedah. It is located 93 kilometers north of Butterworth, Penang and 45 km south of the Thai Malaysia border, with the latitude of 6º 7' N and longitude of 100º 22' E and resting on coastal alluvium. The specific locations of borelogs for Penang Island, Ipoh and Alor Setar are shown in the Table 2.

2.2 PEAK GROUND ACCELERATION (PGA)

Attenuation relations are mostly developed for estimating the expected peak ground acceleration (PGA) or peak horizontal acceleration at the site. These relationships based on a simple mathematical model that relates a ground motion parameters and earthquake source parameters such as magnitude, source to site distance and mechanism and also local site condition. Ideally, the peak ground acceleration can be divided into two categories; subduction and fault zones. Many attenuation formulas have been developed by previous researchers, but it is very important to consider the effects of far field earthquakes from Sumatra and other mechanisms for both zones. The attenuation relationships proposed by previous researchers and used in this study are listed as follows:

a) Attenuation relations for fault zone.

i) Campbell [6]

$$\ln Y = c_1 + c_2 M_w + c_3(8.5 - M_w)^2 + c_4 \ln\left(f_1(M_w, r_{rup})\right) + f_2(r_{rup}) + (c_9 + c_{10} M_w)\, r_{rup} \qquad (1)$$

where,

$$f_1(M_w, r_{rup}) = \sqrt{r_{rup}^{\,2} + [c_5 \exp(c_6 M_w)]^2} \qquad (2)$$

$$f_1 \begin{cases} 0 & r_{rup} \le r_1 \\ c_7(\ln r_{rup} - \ln r_1) & r_1 < r_{rup} < r_2 \\ c_7(\ln r_{rup} - \ln r_1) + (\ln r_{rup} - \ln r_2) & r_{rup} \ge r_2 \end{cases} \qquad (3)$$

ii) Component attenuation model [7]

$$S_{\text{vmax}} = 1.625\Delta^{*}\alpha(M).G(R,D).\beta(R,Q) \qquad (4)$$

$$S_{\text{Amax}}\ (cm/s^2) = 2\pi S_{\text{Vmax}}/T_1 \qquad (5)$$

$$PGA = S_{\text{Vmax}}/3 \qquad (6)$$

where,

$$\alpha(M) = \Delta^{*}[a1 + a2(M - 5)^{a3}] \qquad (7)$$

$$G(R,D) = (30/1.5D)(2.5D/R)^{0.5} \qquad (8)$$

$$\beta(R,D) = (30/R)^{C1C2R^{\eta}C} \qquad (9)$$

The coefficients C_1, C_2 and the exponent η_c are defined as follows:

$$C_1 = 0.005 \qquad (10)$$

$$C_2 = 0.043\left(\frac{Q}{100}\right)^2 - 0.53\left(\frac{Q}{100}\right) + 1.8 \qquad (11)$$

$$\eta_c = 0.022\left(\frac{Q}{100}\right) + 0.8 \qquad (12)$$

b) Attenuation relations for subduction zone.

i) Azlan *et al.* [8]

$$\ln Y = 21.6187 + 3.3993^{*}M_W^{\,1.1034} - 7.7091^{*}\ln [R_{\text{hypo}} + 6.6233^{*}\exp(0.5554^{*}M_W)] + 0.0061^{*}H \qquad (13)$$

ii) Component attenuation model as in [7]

2.3 RESPONSE SPECTRUM ACCELERATIONS (RSA)

Recently, response spectrums of accelerations (RSA) are demanding by the users such as engineers, designers [9]. It is representing the earthquake actions, types of soil, geographical location and the site classification. RSA is can be modified accordingly where the ordinates are reduced to allow the dissipation of energy through inelastic deformation [10]. This spectrum is commonly called as design response spectrum.

In order to get the RSA, Nonlinear Earthquake site Response Analysis (NERA) software was used to analyse the collected data, based on some input parameters such as the peak ground accelerations (PGA), the strong motion data and soil data of each of borehole.

The parameters that are used to generate the RSA for each soil by using NERA software are as listed below:-

a) The peak ground acceleration (PGA).
b) The strong motion data from the Pacific Earthquake Engineering Research Center or from Consortium of Organisations for Strong-Motion Observation Systems (COSMOS) [11]
c) Soil data unit weight and shear wave velocity for each layer of every borehole.

2.4 SITE CLASSIFICATION, *S*

In order to develop the design response spectrum, the RSA obtained after the analysis should be combined according to their classes. The site classification $\bar{v}_s$ is based on Equation 14 [12], which is the average shear wave of the first 30 m below ground surface

$$\bar{v}_s = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{v_{si}}} \qquad (14)$$

where v_{si} is the shear wave velocity in m/s; d_i is the thickness of any layer between 0 and 30m from surface.

$\bar{v}_s$ is defined as the ratio of 30m to the time for vertically propagating shear waves travel from 30m depth to the surface. The site classification schemes in the NEHRP (2000) provisions are presented in Table 3.

Table 3: Soil classification based on shear wave velocity, NEHRP 2000 [12]

Soil Class or Soil Profile	Descriptions	Shear wave velocity, $\bar{v}_s$ Top 30m (m/s)
A	Hard Rock	>1500
B	Rock	760 - 1500
C	Very Dense Soil/ Soft Rock	360 - 760
D	Stiff soil	180 - 360
E	Soft Soil	<180

2.5 DESIGN RESPONSE SPECTRUM

The most difficult part of designing response spectrum is to identify the short, medium, long period of the spectrum and classification of type of soil.

Figure 2 shows a typical example of design response spectrum which represent the constant velocity and acceleration of ground shaking. The graph shows the average curve is smoothed to remove random irregularities which could cause large variations in response for a slight change in period. Since soil conditions affect a spectral shape, separate response curve are required for each representative soil type.

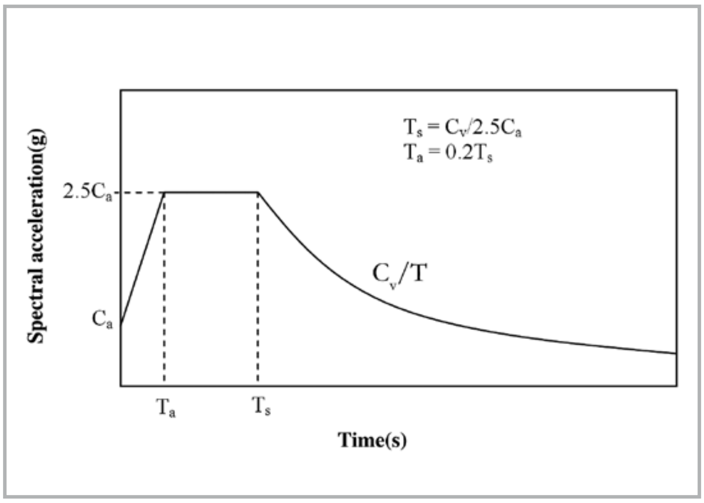

Figure 2: Design response spectrum based on UBC 97

For design purposes, the response curve must represent the characteristics of all seismic events according to their site classes. The ground coefficients C_a and C_v are dependent on soil classes [13]. The coefficient C_a defines the short period portion of the spectrum for structures with fundamental periods, T_s of less than $C_v/2.5C_a$. C_v is defines as the longer period, constant velocity, portion of the spectrum.

Design spectrum acceleration is a set of smoothed curves and a series lines that useful for designing of new structures or for the seismic safety evaluation of existing structures to resist future earthquakes [14].

3.0 RESULTS AND DISCUSSIONS

The result of site classification for 193 boreholes at Penang Island, Ipoh and Alor Star is tabulated in Table 4. Most of the soils are classified as very dense soil/soft rock (C), stiff soil (D) and soft soil (E). It can be concluded that most of the soil at Northern part of Peninsular Malaysia as stiff soil (D).

The soil classification can be determined using Equation (1) and Table 3 which related with shear wave velocity.

Table 5 summarises that most of the soils at the western part of Penang are categorised as S_D (stiff soil) which represent 50 samples out of 95 and followed by site S_C (soft rock) with 38 samples and S_E (soft soil) 7 samples. While the soil classifications for Ipoh can be generally deduced that consist of three types of soil conditions; class S_c (21), S_D (46) and S_E (5). Soil classifications at Alor Star are categorised into two types which is S_D (13) and class S_E (13) with total of 26 boreholes.

After classifying the soil data (each borehole) according to their classes, the RSA were generated using NERA software. Figure 3 shows the response spectrum acceleration for Penang Island. For site class C, S_C gave a maximum value of RSA = 0.76 g, recorded at 0.06 s as shown in Figure 3. Followed by S_D with the peak of RSA 0.58 g recorded at 0.14 s and S_E with a highest RSA 0.50 g at 0.13 s. The different spectral acceleration (g) between S_C and S_D is about 24 % and the percent different between S_D and S_E only 14 %.

Figure 4 shows the response spectrum acceleration for Ipoh with 3 different classes of soil namely C, D and E. It shows that class E, S_E gave a maximum value of RSA = 0.31 g (0.66 s). Followed by S_D with produced the peak of RSA 0.28 g (0.40 s) and S_C with a highest RSA 0.25 g (0.09 s). The different spectral acceleration between S_C and S_D is 11 % and the percent different between S_D and S_E is only 10 %.

Table 4: Site classification for each borehole for Penang Island, Ipoh and Alor Setar

Penang Island		Ipoh		Alor Setar	
Locations	**Site Classifications**	**Locations**	**Site Classifications**	**Locations**	**Site Classifications**
USM	D	Sek. Keb. Catur Avenue	C,D	Mukim Alor Merah	D,E
Daerah Timur Laut	D	Batu Gajah	C,D	Jabatan Kimia	D
Jelutong	D,C	Tasek Dermawan	C,D	SM.(Agama) Mergong	D,E
Georgetown	D	Bercham	D	SMK.Tunku Abdul Malek	D,E
Daerah Barat Daya	D	Ampang	D,E	Kolej Sultan Abdul Hamid	E
Bayan Lepas	D	Jelapang Jaya	D	Kompleks Mahkamah	D
Bayan Baru	D,E	Tronoh	D	Ibu Pejabat Polis Kontigen (Pusat Bandar)	D
Tanjung Tokong	E	Sri Kampar	E		
Batu Feringghi	C,D,E	Pusing	C	Ibu Pejabat Polis Kontigen (Jalan Stadium)	D,E
Bukit Gambier	C,D,E	Tanjung Tualang	D		
Sungai Ara	C,D	Jln Ipoh	C,D	SM.Sultanah Asma Bukit Gam	D,E
Bukit Jambul	C,D	Jabatan Perhutanan Negeri	C		
		Jalan Tasek	D,E		
		Kampung Tasek	C		
		Buntong	D,E		
		Sungai Senam	C,D		
		Jelapang/Taman Meru	D		
		Jabatan Pengairan dan Saliran	D		
		Sek. Keb. Seri Tembok	D		

Table 5: Total of each site class

Area	S. I. Reports	Borehole	Site Classification, S				
			A	B	C	D	E
Penang Islands	21	95	0	0	38	50	7
Ipoh	20	72	0	0	21	46	5
Alor Star	9	26	0	0	0	13	13

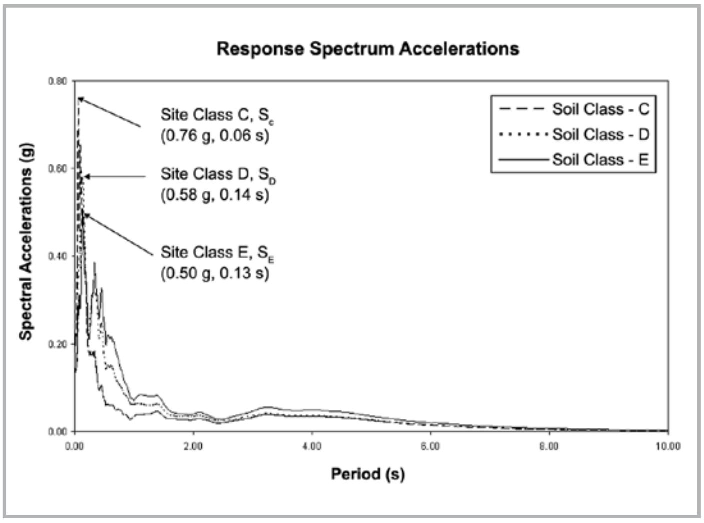

Figure 3: Response spectrum accelerations for Penang Island

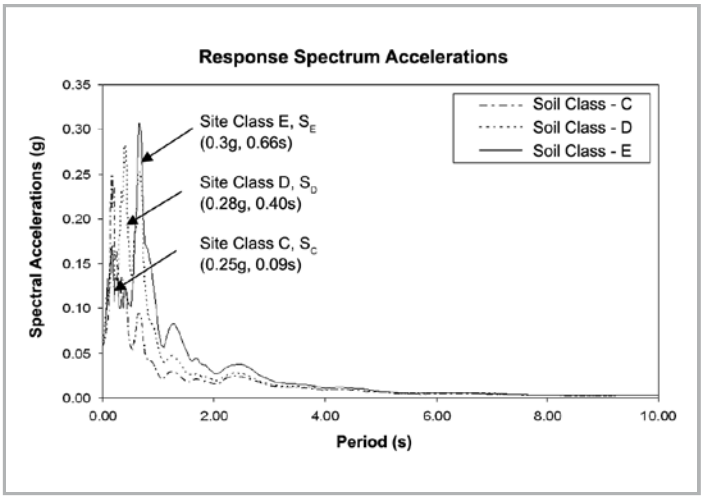

Figure 4: Response spectrum accelerations for Ipoh

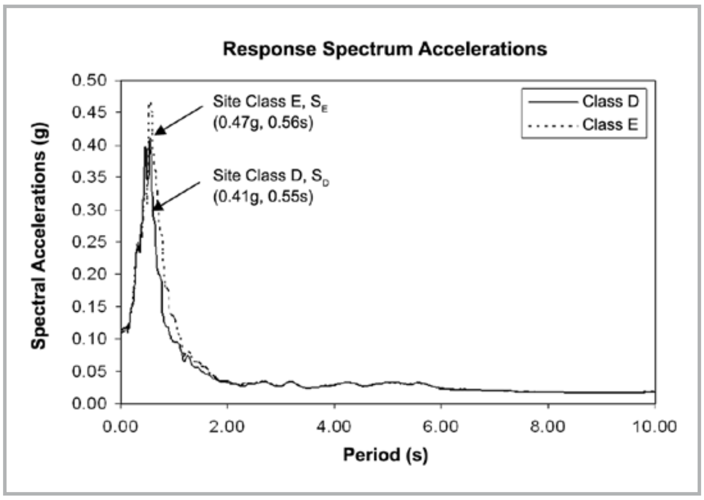

Figure 5: Response spectrum accelerations for Alor Setar

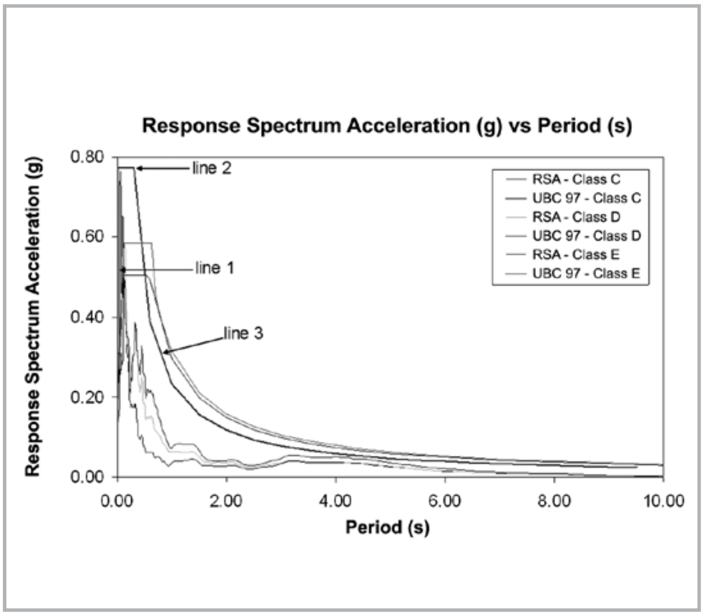

Figure 6: Recommended design response spectrum for Penang Island based on various soil types

Based on the above figures, the RSA are strongly depend on the soil characteristics, depth of soil layer, soil type and peak ground acceleration (g). These parameters are very important as data input to NERA programme which transform these data into Response Spectrum Accelerations (RSA) as different locations and soil classification, *S*.

Figure 5 shows the RSA for Alor Star sites which the S_E produced highest peak of RSA same as Ipoh sites, it slightly higher with 0.47 g and different for S_D only 0.06 g, with the peak RSA is 0.41g.

The design response spectrum can be plotted using the equation as stated in UBC 1997 codes and mapping according to RSA as plotted in Figures 3, 4 and 5.

The equations of the three parts of the curve are as follows by using UBC 97 code of practice.

Line 1 (constant): $$C_d = \frac{F_a S_s}{B_a}$$

Line 2 (constant): $$C_d = \frac{F_v S_1}{T B_v}$$

Line 3 (curve): $$C_d = \frac{F_v S_1 T_d}{T^2 B_d}$$

where B_a, B_v and B_d are damping factors

The recommended design response spectra for Penang Island for soil class C, D and E is shown in Figure 6. Figures 7 and 8 shows the recommended design response spectrum for Ipoh with class C, D and E, and Alor Star with class D and E.

The value of response spectra acceleration can be applied to structures as a seismic load using design response spectrum analysis. Such applications to a reinforcement concrete building can be found in [15] and [16].

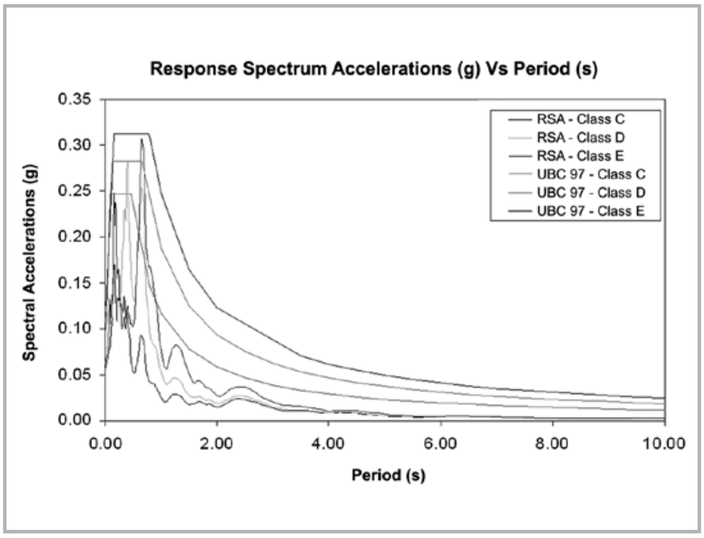

Figure 7: Recommended design response spectrum for Ipoh based on various soil types

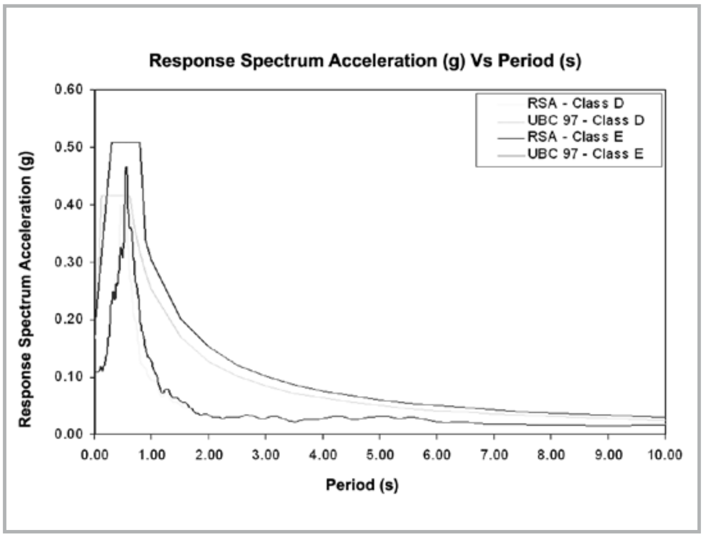

Figure 8: Recommended design response spectrum for Alor Setar based on various soil types

4.0 CONCLUSION

It can be concluded that most of Northern Peninsular Malaysia has soil classification S_D, which is stiff soil. Most of the soils are categorised in S_D, with the highest RSA at Penang Island with S_C of 0.76 g, Ipoh and Alor Star is SE are 0.31g and 0.47g respectively. It is strongly recommended that the maximum value of the design response spectra to be adopted in the design according to the soil classes.

Hence, it is important to have more soil data in order to generate response spectrum acceleration (RSA) for specific location. In addition, the soil data should cover the whole area in Northern Peninsular Malaysia, so that better results for RSA and also the design response spectrum could be obtained.

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