An Approach for Seismic Design in Malaysia following the Principles of Eurocode 8



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1. INTRODUCTION

Eurocode 8 is a useful document providing systematic guidance for the seismic design of buildings and other structures. It is difficult to apply to countries outside of Europe however as it appears to have a very limited definition of the seismic hazard that is basically expressed in terms of the peak ground acceleration having a 10% probability of being exceeded in the next 50 years (equivalent to a return period of 475 years). It does incorporate spectral shapes that are anchored to this peak ground acceleration, however, and this enables earthquake ground motion response spectra thresholds, that define when seismic ground motion needs to be considered and whether ductile detailing of superstructures is necessary, to be estimated. Response spectra are very helpful as they give a direct indication of the distortion that a structure is ilkely to experience during the design seismic ground motion provided that the fundamental period of the structure is known.

The study reported in this paper includes a preliminary probabilistic seismic hazard assessment for Malaysia including Peninsular Malaysia, Sarawak and Sabah. This assessment is based on the USGS database for earthquakes in the past 40 years, combined with recently developed attenuation relationships by the Nanyang Technological University (NTU). Design response spectra having a 10% probability of being exceeded in the next 50 years applicable to bedrock sites were developed for several locations in Malaysia. It is shown that these vary considerably both in terms of magnitude and in terms of spectral shape. These spectra are compared with the Eurocode 8 design thresholds and recommendations for seismic design in Malaysia are made.

2. EUROCODE 8 DESIGN CRITERIA

Eurocode 8 states that earthquakes can be ignored if the bedrock peak ground acceleration having a 10% probability of being exceeded in the next 50 years is less than 4%g ($0.39 m/s^2$). For higher seismic ground motions, it also states that simplified design rules that avoid the use of ductile detailing can be used if the bedrock peak ground acceleration having a 10% probability of being exceeded in the next 50 years is less than 8%g ($0.78 m/s^2$). For larger seismic ground motions, the full provisions of Eurocode 8 including ductile detailing requirements are recommended.

Unfortunately, peak ground acceleration is not sufficient to define seismic ground motion as it does not take into account the frequency content of the motion. It is well established that the building's response is dependent on the frequency content and it is conventional practice to define seismic ground motion in terms of response spectra which define the peak elastic response of structures as a function of their modal periods (Housner, 1959). For buildings up to about 10 storeys, their fundamental period, which is equal to about the number of storeys divided by 10, is sufficient to define their seismic response. For higher buildings, full elastic dynamic analyses are required as their higher mode responses often become significant.

Eurocode 8 does include standard response spectral shapes and these can be used together with the threshold peak ground accelerations as discussed previously to define threshold seismic design criteria in terms of bedrock response spectra. Figure 1 shows these criteria when seismic design needs to be considered and ductile detailing is recommended. It should be noted that very similar bedrock outcrop response spectral criteria can be determined from the United States Building Code (ASCE 7, 2010) for deep soil sites having SPT N values between about 15 and 50 blows per 300mm.

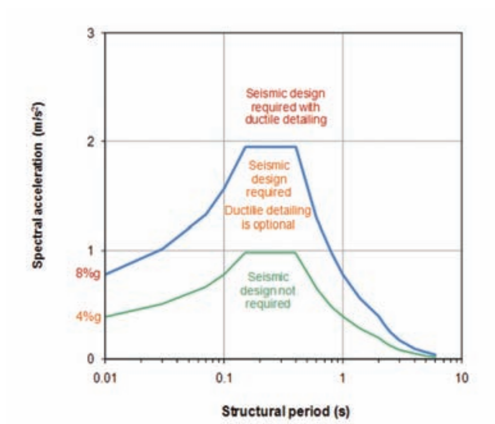


Figure 1: Eurocode 8 seismic design criteria expressed as bedrock spectra

3. SEISMIC HAZARD ASSESSMENT

3.1 Seismic hazard assessment methodology

The probabilistic seismic hazard assessment methodology, e.g. Cornell (1968), McGuire (1993), has been applied using Oasys SISMIC, an in-house program of Arup. The probabilistic seismic hazard assessment methodology comprises the following steps:

i) Potential seismic sources are defined on the basis of regional geotectonics and seismicity.

ii) Seismicity parameters defining the rate of earthquake activity are derived for each of the potential seismic sources.
iii) Ground motion attenuation relationships, considered to be appropriate for the region, are identified.
iv) The annual frequencies of various levels of specified ground motion levels being exceeded are derived by first determining the likelihood that each ground motion will be exceeded if an earthquake of a certain magnitude at a certain distance occurs. By multiplying this likelihood with the annual frequency of such an event occurring in any of the source zones, the annual frequency of the ground motion occurring is derived. By summing the results from all relevant earthquake distances and magnitudes, the overall annual frequency is established.

3.2 Earthquake catalogue

Instruments for recording earthquake motion have been deployed round the world since the turn of the 20th Century. Seismic networks became more widespread, and by the mid 1960's, the increased number of instruments enabled the reliable detection of smaller magnitude events. The seismological data used in this study has been obtained from the USGS catalogue (http://earthquake.usgs.gov/earthquakes/eqarchives/epic) which provides data on events greater than magnitude 4.5 since 1972. The data covers an area between latitude 14 °S to 22 °N and longitude 90 °E to 132 °E.

All catalogues contain some aftershock sequences. Aftershocks are earthquake events that are usually connected with a parent event, which is often large, whilst foreshocks precede such events. Immediately after a large earthquake, numerous aftershocks occur on a short time scale, however, later in aftershock sequences the time interval between earthquakes becomes longer. The removal of fore and aftershocks can be a subjective procedure which relies on the skills of the seismologist to identify such events. Gardner and Knopoff (1974) have proposed a windowing procedure to remove aftershocks which is based on the Southern California earthquakes. The procedure relates the maximum possible distance and time of an aftershock to the main shock magnitude. This method has been adopted for this project. Figure 2 shows all the events within the study area after the fore and aftershocks have been removed.

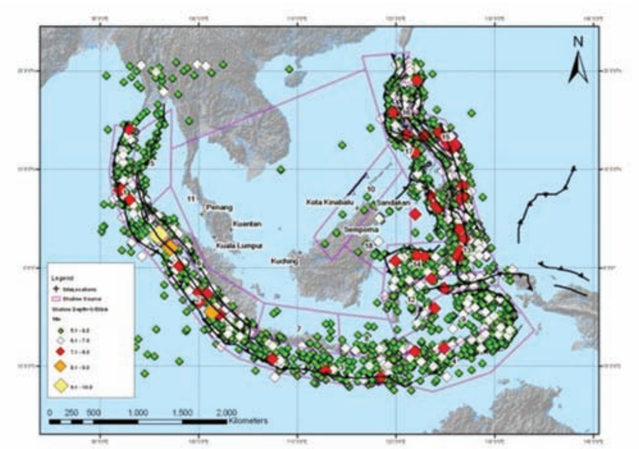


Figure 2a: Earthquake catalogue since 1972 to a depth of 50km with after-shocks removed

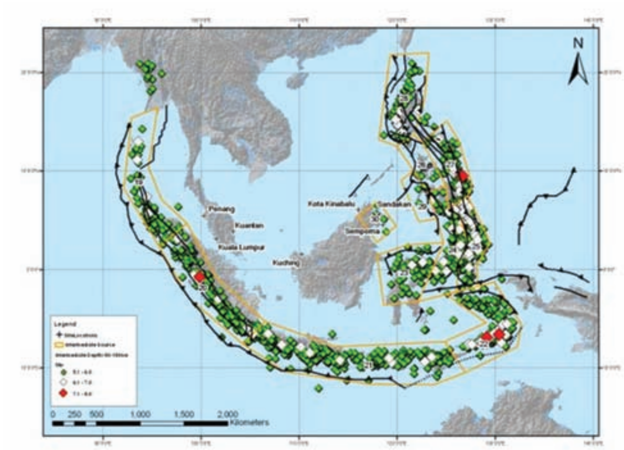


Figure 2b: Earthquake catalogue since 1972 at depths of 50 to 150km with aftershocks removed

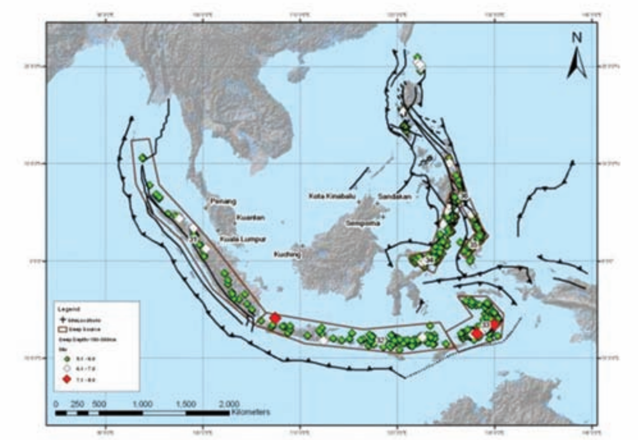


Figure 2c: Earthquake catalogue since 1972 at depths of 150 to 300km with aftershocks removed

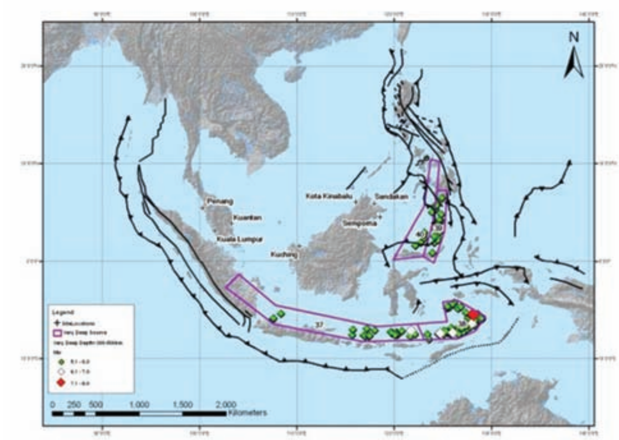


Figure 2d: Earthquake catalogue since 1972 at depths of 300 to 500 km with aftershocks removed

Figure 2: Earthquake catalogue since 1972 at depths with aftershocks removed

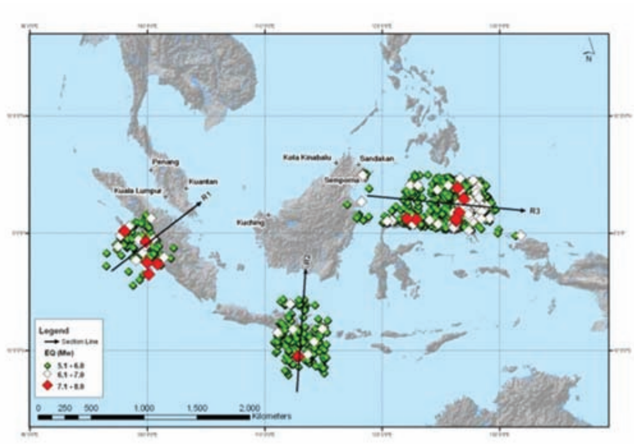


Figure 3a: Plan showing the location of the three sections through the crust

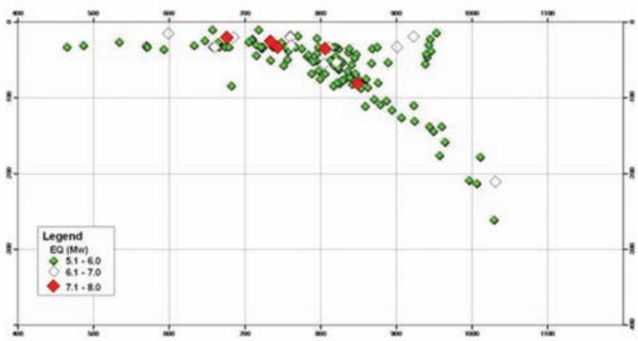


Figure 3b: Section R1 through Sumatra

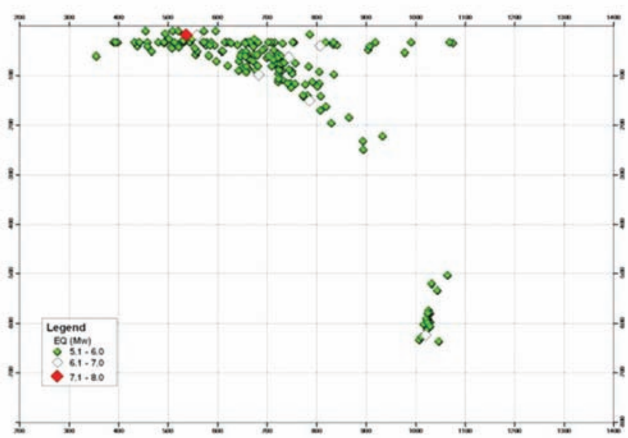


Figure 3c: Section R2 through Java

It is clear that Malaysia is surrounded to the west, south and east by areas of very high seismicity that are associated with major tectonic structures formed at the boundaries between the Asia tectonic plate and the India-Australia tectonic plate to the southwest and the Pacific tectonic plate to the east. These boundaries generally represent subduction zones which dip under the Asian tectonic plate. In addition, there are surface fault zones close to the surface above the deeper subduction zones. Figure 3 shows a plan and three sections through the crust to illustrate this effect.

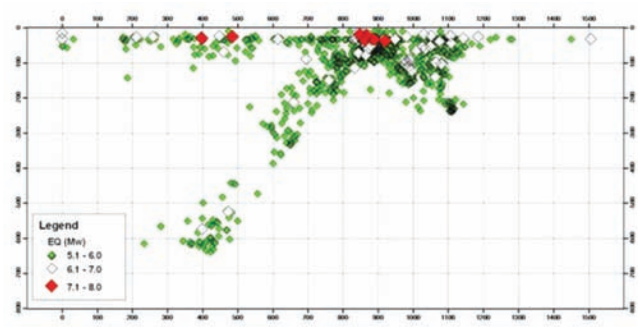


Figure 3d: Section R3 through the Celebes Sea

3.3 Catalogue completeness and earthquake magnitude recurrence

The statistical completeness of the catalogue has been assessed. Figure 4 shows the magnitude recurrence relationship for earthquakes in the whole study area in the conventional form proposed by Gutenberg and Richter (1956) as follows:

$$\mathrm{Log}_{10} N = a - bM$$

where N is the annual number of earthquakes greater than magnitude M and a and b are constants.

In this form, the annual number of earthquakes greater than magnitude M is plotted as a function of that magnitude. If a data set is complete, the annual number of earthquakes greater than each magnitude will be similar for a range of time periods (assuming there are no temporal trends in the level of seismicity). Figure 4 shows the annual number of earthquakes from various time periods since 1970 which are complete above magnitude 5. A complete set of data includes records for all the events that occurred above a certain magnitude over a considered time period.

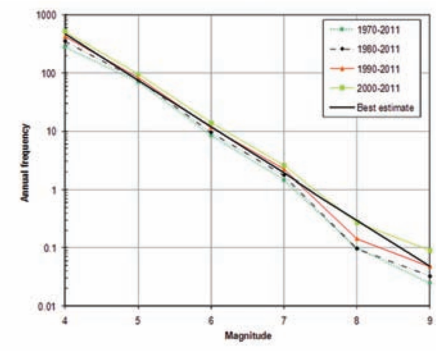
3.4 Seismic source zoning

Figure 2 shows the various area source zones that have been assumed for the probabilistic seismic hazard estimation. The seismic activity within each area has been represented by a Gutenberg Richter relationship that matches the observed seismicity within each area and the sum of these relationships for each of the four depth ranges are shown by the best estimate lines in Figure 4.

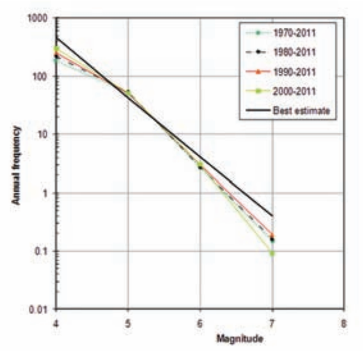
3.5 Minimum and maximum magnitude

A minimum earthquake magnitude of Mw equals to 5 is adopted for this study for the reason that, below this magnitude, an earthquake is unlikely to cause any significant structural damage.

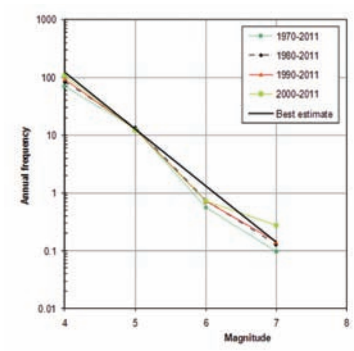
For earthquakes down to 50km, generally a maximum magnitude of 8.5 has been assigned except for Areas 1 to 3 which have been assigned a maximum magnitude of 9.5, Area 10 with a magnitude of 7.5, Area 11 with a magnitude of 7 and Area 18 with a maximum magnitude of 8. For earth-quakes between 50km and 150km, a maximum magnitude of 8 has generally been assigned except for Areas 26, 29 and



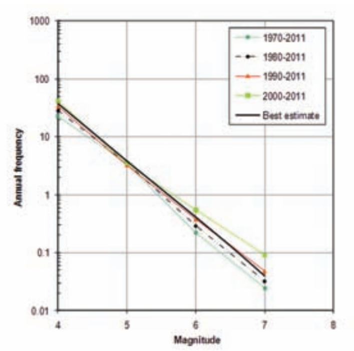
a) Earthquakes to 50km depth



b) Earthquakes from 50 to 150km depth



c) Earthquakes from 150 to 300km depth



d) Earthquakes from 300 to 500km depth

Figure 4: Magnitude recurrence plots for earthquakes at various depth ranges

Table 1: Focal depths and weightings

Zone Numbers	Seismogenic Depth	Focal Depth (weighting %)			
1 to 18	50km	10km (20%)	20km (25%)	30km (25%)	40km (30%)
19 to 30	150km	65km (30%)	90km (25%)	110km (25%)	135km (20%)
19 to 30	300km	170km (35%)	200km (23%)	250km (28%)	300km (14%)
19 to 30	500km	350km (32%)	400km (27%)	450km (23%)	500km (18%)

30 which have been assigned a maximum magnitude of 7.5. For earthquakes between 150 and 300km, a maximum magnitude of 8 has been assigned in the areas within Indonesia and a maximum magnitude of 7.5 has been assigned to the areas in the Philippines. For earthquakes between 300 and 500km, a maximum magnitude of 8 has been assigned in the areas within Indonesia and a maximum magnitude of 7 has been assigned to the areas in the Philippines.

3.6 Focal depth

The focal depths of the earthquakes reported in the USGS catalogue have been analysed. It should be noted that a depth of 33km is the default value for the data for unknown focal depth. Consequently, depth values of 33km have been excluded from the depth distribution analysis. The focal depth distribution is found to be wide with focal depths extending to greater than 500km. The deeper earthquake events are associated with the regional tectonic features in the region. Table 1 summarises the focal depths and weightings adopted in this preliminary assessment.

3.7 Attenuation relationships

No attenuation relationship for response spectral values has been specifically developed for Malaysia or the surrounding region. In this study, the attenuation relationships for the distant plate boundary earthquakes in the subduction zones and major fault zones in Indonesia and the Philippines, the attenuation relationships recently developed by Pan et al. (2007) from NTU have been adopted. These relationships are based on the seismological stochastic simulations on a fault rupture source model and have been verified by the recorded distant earthquakes from the Sumatra Subduction Zone and the Sumatra Fault.

While the attenuation relationships described above are appropriate for distant large events that may affect Malaysia, they are not suitable for the few events that may occur in the immediate vicinity within the stable continental region. It is considered that the most appropriate relationship for this area is one similar to that developed for eastern North America. This area has a rigid crustal structure and is likely to be similar to that of Malaysia. The most recent relationship derived for eastern North America by Atkinson and Boore (2006) has been used for these local areas (Zones 10, 11, 18 and 30 on Figure 2).

4. RESULTS OF THE SEISMIC HAZARD ASSESSMENT

Design response spectra for horizontal bedrock motions have been determined for various locations in Malaysia for seismic ground motion having a probability of 10% of being exceeded in the next 50 years for structural periods up to 5 seconds. The spectra are suitable for a structural damping of 5% and are shown in Figure 5. It is to be noted that these design spectra have the same probability of occurring at all structural periods and do not necessarily match the seismic ground motion that may arise from a particular individual future earthquake.

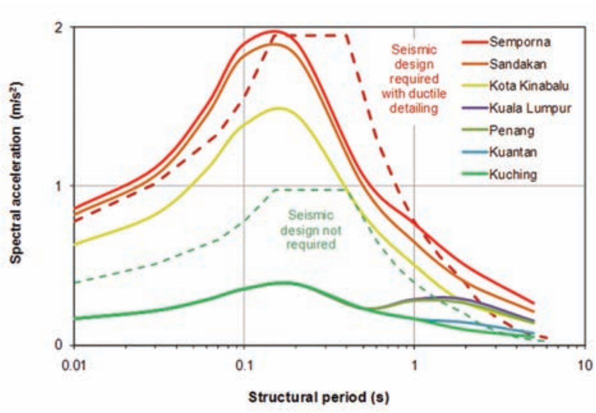


Figure 5: Design response spectra for horizontal bedrock motion

It should be noted that the peak ground acceleration values are plotted at a structural period of 0.01 seconds and shows that the three locations in Peninsular Malaysia, namely, Kuala Lumpur, Pulau Pinang and Kuantan, all have very low peak ground acceleration values of about 0.2m/s^2, or about 2% of gravity. Kuching in Sarawak has a similar value, however, the three locations in Sabah, namely, Kota Kinabalu, Sandakan and Semporna, have significantly higher peak ground accelerations of between 0.7m/s^2 and 0.9m/s^2, or about 7% to 9% of gravity.

5. IMPLICATIONS TO THE DESIGN OF STRUCTURES IN MALAYSIA

5.1 Where is seismic design required?

The earthquake design criteria implied by Eurocode 8 and shown previously in Figure 1 are also shown on Figure 5. On the basis of peak ground acceleration, only the locations in Sabah should consider seismic loading in the design of new buildings. While western Sabah (i.e. Kota Kinabalu) could use simplified design rules that avoid the use of ductile detailing, eastern Sabah (i.e. Sandakan and Semporna) is marginally over the 8% of gravity criterion, as such, ductile detailing should be used. If the whole response spectrum for each location is considered, similar conclusions can be drawn for these locations in Sabah. For Sandakan and Semporna, the spectra imply that ductile detailing should certainly be considered for longer period structures having fundamental periods above about 1 second. For lower rise shorter period buildings, ductile detailing could be ignored but at the expense of using a lower behaviour factor, q, which will result in higher seismic design forces.

For locations on the western side of Peninsular Malaysia, however, it can be seen that the spectra for Kuala Lumpur and Pulau Pinang increase and is above the Eurocode seismic design threshold criterion at periods above about 1.5 seconds. This increase in seismic hazard is due to the significant seismic activity under Sumatra and implies that, for long period structures having fundamental periods above 1 second, seismic loading should be considered as part of their design. This leads to the important conclusion that buildings above about 10 storeys, especially those founded on deep or soft soil deposits on the western side of Peninsular Malaysia, should consider seismic loading as part of their design. While the level of seismic loading is sufficiently small that ductile detailing could be avoided, the designer may still wish to use ductile detailing to take advantage of the lower seismic design forces that result as a consequence of using a higher behaviour factor, q, appropriate to buildings incorporating ductile detailing.

5.2 Site response effects

The spectra shown in Figure 5 are for horizontal seismic ground motion for a rock outcrop site. It is well known that local soil conditions can have a significant effect on the ground surface seismic ground motion and this effect needs to be considered in design. Eurocode 8 achieves this by specifying different spectral shapes for site soil profiles that are assigned to a specific soil class on the basis of the geometric average of the soil shear velocity in the upper 30m of the soil deposit. Table 2 summarises the soil profile classification system. Eurocode 8 should be referred to for full details of the averaging methodology. Eurocode 8 has special rules for liquefiable sites and very deep soft day sites that require site specific dynamic site response analyses as discussed later.

Eurocode 8 cannot be used directly to determine the effect of the soil profile site response effects as it gives different spectral shapes rather than amplification factors. This is potentially directly applicable to sites in Sabah as the spectral shape for a bedrock outcrop site is similar to that in Eurocode 8 as shown in Figure 5. It is not helpful for the western side of Peninsular Malaysia, however, as the underlying spectral shape is so different for a bedrock site. To overcome this problem, site response amplification factors implied by the Eurocode curves have been derived for the various site classes as a function of the fundamental structural period. They are shown in Figure 6.

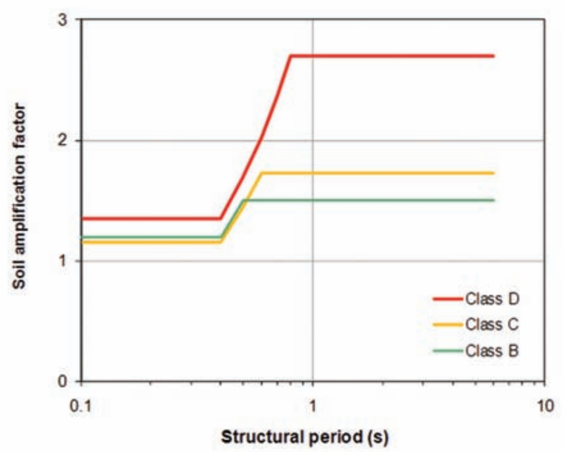


Figure 6: Site response amplification factors implied by Eurocode 8 as a function of structural period

Table 2: Summary of Eurocode 8 soil profile classification

Site Class	Soil Profile Name	Average Properties in the upper 30m		
		Shear-Wave Velocity, V_S, (m/s)	SPT, N (blows/300mm)	Undrained Shear Strength, S_U, (kPa)
A	Rock or thin (<5m) soil	$800 < V_S$	Not applicable	Not applicable
B	Very dense or stiff soil	$360 < V_S \le 800$	$N > 50$	$S_U > 250$
C	Dense or stiff soil	$180 < V_S \le 360$	$15 < N \le 50$	$70 < S_U \le 250$
D	Loose or soft to firm soil	$100 < V_S \le 180$	$5 < N \le 15$	$20 < S_U \le 70$

The period dependent factors shown in Figure 6 could be directly applied to the bedrock spectra shown in Figure 5 for any of the locations in Malaysia. Alternately, if the shear wave velocity profile can be determined for the site being investigated, conventional dynamic site response analyses could be used to determine the ground surface spectrum. Many computer programs are available to do this (see Visone et al. 2010 for various examples). These programs all require the input of earthquake time histories that are compatible with the appropriate bedrock outcrop response spectrum, but the selection and scaling of these is beyond the scope of this paper. ■

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