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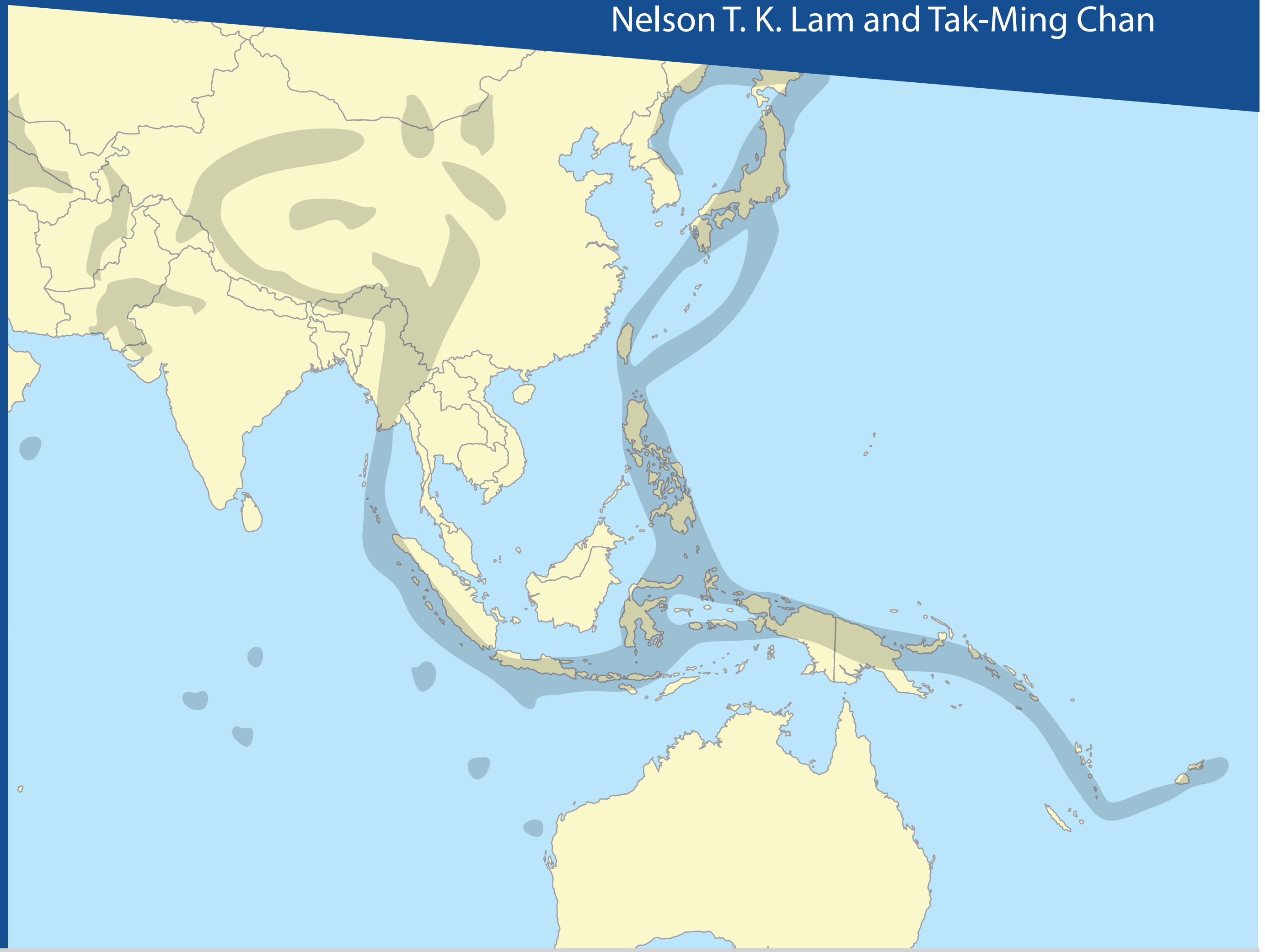
Chinese National Engineering Research Centre
For Steel Construction (Hong Kong Branch)

Design of Buildings and Structures in Low to Moderate Seismicity Regions

Professional Guide: PG-002

Nelson T. K. Lam and Tak-Ming Chan



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This Professional Guide represents CNERC's continued contribution towards the building of a resilient world community. The underlying objective is to maintain living standards and improve safety in the face of natural disasters such as earthquakes. The scope of the undertaking in its entirety is broad, drawing expertise from many allied disciplines. Managing natural disasters entails developing adequate mitigation measures and preparedness levels. This Professional Guide is concerned specifically with mitigating the impact of future disasters by improving the robustness of newly constructed buildings in regions of low to moderate seismicity through a better understanding of hazard assessment and design methodology. The targeted readers are designers of building structures and policy makers in these regions.

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Site Classification Scheme and Response Spectrum Models for Malaysia

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The original site classification scheme written into the main body of Eurocode 8 is out of date and unsuitable for use in low to moderate seismicity regions such as Malaysia because of its failure to model the phenomenon of soil resonance. In addressing this shortcoming, the National Annex to Eurocode 8 for Malaysia stipulates that this conventional site classification model can only be applied to sites that are covered by soil sediments not exceeding 30 m. An alternative site classification scheme which involves calculation of the natural period of the site provides more accurate predictions of real behaviour and without restriction as to soil depth. Details of the two site classification schemes and comparisons of their associated response spectra are presented in this chapter with the aim of helping designers to interpret the National Annex correctly and to adopt the less conservative (more economical) site classification scheme and response spectrum model.

Keywords: Eurocode 8, National Annex, site classification, response spectrum, site period parameterisation

1. Introduction

The National Annex (NA) to Eurocode 8 (EC8) for Malaysia (NA-2017) stipulates two site classification schemes alongside their respective response spectrum models. These two schemes are represented by Models A and B (Figures 1 and 2). The common feature of the site classification scheme across the two models is that five ground types are defined, each with its own definition. Apart from ground type A, which refers to rock sites, all others refer to soil sites which are classified differently in the two models. This dual classification system, which is atypical of seismic codes of practice generally, easily causes confusion. For example, ground type D refers to very different types of site conditions in Models A and B. The writing of this chapter was motivated by the need for a site classification system and the associated response spectra, to be well explained, if there is to be no risk of misinterpretation by designers.

The response spectrum of Model A is not in accordance with that stipulated by the main body of EC8. It is understood to have been derived from analyses made by local investigators. Details of these analyses justifying their model, have not been published in any international archival source. It is stated in the NA that Model A is only applicable if the total depth of the overlying rock soil sediments does not exceed 30 m. With deeper soil sediments Model B has to be adopted.

The inability of the current site factor model in EC8 to properly address deep site geology is a matter of concern, in view of the potential occurrence of resonance with non-ductile construction in deep soil sites in particular. This message came across very strongly in the speech by Professor Pitilakis in a forum of experts hosted by the *Institution of Engineers Malaysia* on 11-12 April 2017. Professor Pitilakis is the Vice President of the *European Association of Earthquake Engineering (EAEE)* and has been a leader in drafting EC8 in relation to geotechnical matters. The next edition of EC8 is to be revised to the form proposed in numerous publications by Pitilakis et al. (2012 & 2013) and by Riga et al. (2016). The proposal is consistent in form to the site factor model founded on displacement principles, and once incorporated into the draft NA to EC8 for Malaysia (NA-2016), the draft circulated for the first round of public comments in 2016. The displacement-based site factor model was subsequently modified to achieve consistencies in format with Model A (NA-2017). The basis and justification of the displacement-based site factor model, and its modified form (i.e. Model B) can be found in numerous prestigious international peer reviewed archival sources (e.g. Tsang et al., 2006 & 2017). This modified site factor model that takes into account the phenomenon of soil resonance is denoted herein as Model B.

In summary, Model B was introduced to address the concern that the site response behaviour of deep soil sediments (where the total thickness of the soil sedimentary layers overlying bedrock exceeds 30 m) cannot be modelled accurately by Model A. The key feature of Model B is the incorporation of the site natural period which takes into account depth of the soil sediment to bedrock as a modelling parameter. It should be noted that Model B, which is generic in nature and derived using sound theoretical principles, more consistently emulates real behaviour than Model A for all soil conditions (including both shallow and deep soil sites). Model A is out of date. The stipulation of the dual model approach was purely a pragmatic decision to address political issues in the regulatory process.

2. Site classification systems

In Model A, only ground types A, D and E are valid ground types and applicable to Malaysian conditions. This is because NA-2017 limits the application of this model to soil sites where the total depth of the soil sediments overlying bedrock does not exceed 30 m. Given that ground types B and C in EC8 were intended to represent deep sedimentary layers, for these two ground types Model A cannot be used, for reasons explained above. Ground types S1 and S2 of Model A are also irrelevant to Malaysia. In summary, Model A has provisions for ground type A which refers to rock or very shallow soil sites overlying bedrock; ground type D for soft shallow soil sites; and ground type E for stiff shallow soil sites. Refer to Figure 1 for the ground type descriptions based on Model A.

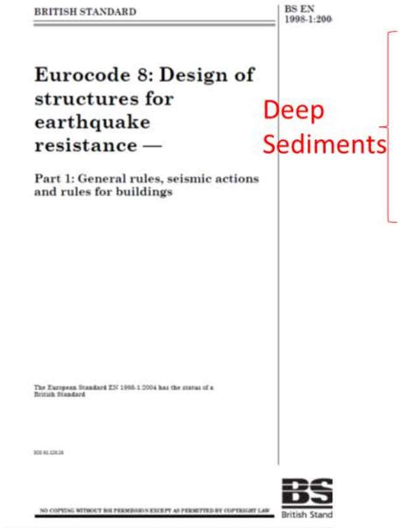

Table 3.1: Ground types

Ground type	Description of stratigraphic profile	Parameters		
		$v_{s,30}$ (m/s)	N_{SPT} (blows/30cm)	c_u (kPa)
A	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.	> 800	_	_
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of metres in thickness, characterised by a gradual increase of mechanical properties with depth.	360 – 800	> 50	> 250
C	Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of metres.	180 – 360	15 - 50	70 - 250
D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.	< 180	< 15	< 70
E	A soil profile consisting of a surface alluvium layer with v_s values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with v_s > 800 m/s.			
S_1	Deposits consisting, or containing a layer at least 10 m thick, of soft clays/silts with a high plasticity index (PI > 40) and high water content	< 100 (indicative)	_	10 - 20
S_2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A – E or S_1			

Figure 1. Site Classification System of Model A

In Model B, site classes are dictated by the site natural period parameter (T_S) which is proportional to the total depth of the soil sediment and is inversely proportional to the average value of the shear wave velocity of the soil material (V_S). Ground types A to E correspond to T_S values ranging from low to high, and with transitions at T_S = 0.15 s, 0.5 s, 0.7 s and 1.0 s as listed in Figure 2. The calculation of the value of T_S is illustrated with an example borehole record as shown in Figure 3. More detailed descriptions of the calculation can be found in Chapter 7 in this technical guidebook on a case study of code compliant design of buildings.

Table AA.1 Ground classifications scheme in accordance to site natural period

Ground Type	Description and Range of Site Natural Period, T_s (s)*
A	Rock site, OR a site with very thin sediments and T_s < 0.15 s
B	A site not classified as Ground Type A, C, D or E
C	A site with sediments of more than 30 m deep to bedrock AND T_s = 0.5 – 0.7 s
D	A site with sediments of more than 30 m deep to bedrock AND T_s = 0.7 – 1.0 s
E	A site with sediments of more than 30 m deep to bedrock AND T_s = > 1.0 s, OR deposits consisting of at least 10 m thick of clays/silts with a high plasticity index (PI > 50)

Figure 2. Site Classification System of Model B (taken from Table AA.1 in the NA-2017)

Type	*Thickness (m)*	*N*	V_i *(m/s)*	
Fill	5.2	13	217	
MD	2	11	206	
MD	2	11	206	
MD	2	6	170	
MD	2	7	179	
Alluvium	2.14	14	222	
Alluvium	1.86	13	217	
Alluvium	1.9	17	236	
	H_S = **19.1 m**		$V_{S,i}$ = **206 m/s**	T_i = **0.370 s**

$$T_s = \frac{4H}{V_s} = \frac{4 \times 19.1}{206} = 0.37s$$

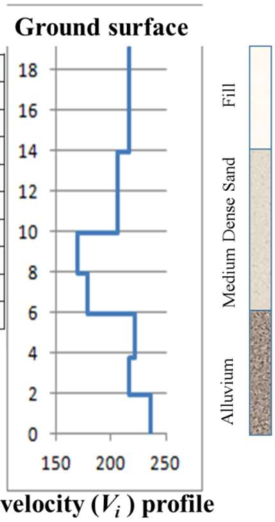

Figure 3. Example calculation of site natural period

3. Response spectrum models

The general construct of the ground type dependent response spectrum is shown in the schematic diagram of Figure 4 which is annotated with values for the various corner periods to characterise the shape of the spectrum. The value of each corner period and the site amplification factor S are listed in Figures 5a and 5b for Models A and B for Peninsular Malaysia respectively.

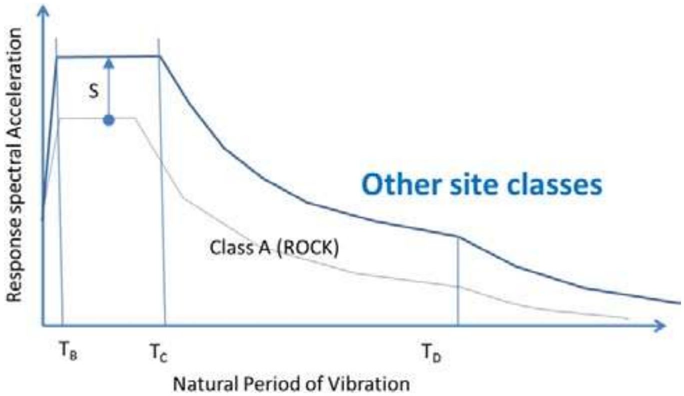

Figure 4. Basic construct of the response spectrum model

4. Guidance over selection of response spectrum model

The purpose of this section, in making comparisons between Models A and B, is purely to assist designers in selecting the lower of the values provided by the two models to achieve a more economical design. The response spectra presented in this section are based on a reference peak ground acceleration for rock sites (a_{gR}) of 0.07g which is the recommended minimum design PGA values across the whole of Malaysia (a higher value of 0.12g is recommended for Central and Eastern Sabah) for important Class II structures

Note: Figure 5 was missed out in the book publication and is added here.

Peninsular :

Ground	S	T_B	T_C	T_D
A	1	0.05	0.2	2.2
D	1.35	0.3	0.8	2.2
E	1.4	0.15	0.5	2.2

Ground type B and C are not applicable

(a) Model A – shallow soil

Peninsular :

Ground	S	$T_B(s)$	$T_C(s)$	$T_D(s)$
A	1	0.1	0.3	2
B	1.5	0.1	0.3	1.5
C	1.8	0.1	0.6	1.0
D	1.35	0.1	0.8	1.5
E	1.8	0.1	0.6	2.0

(b) Model B – deep soil

Figure 5**:** Dual Response Spectrum Model for Peninsular Malaysia in NA-2017

in Peninsular Malaysia. Response spectra in areas within Peninsular Malaysia that have a different value of a_{gR} to 0.07g may be derived by scaling from the response spectra presented herein.

4.1 Rock sites or very shallow soil sites (T_S < 0.15s)

This site category refers to rock outcrops or sites in which the thin layer of soil overlying bedrock does not exceed 5 m. The dual response spectra of ground type A, given by Models A and B are shown on the same graph for comparison purposes, in Figure 6. The designer is free to choose between the two models shown.

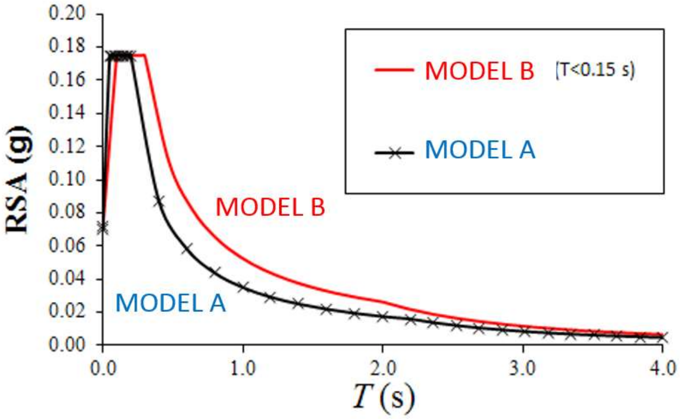

Figure 6. Model A (ground type A) versus Model B (ground type A)

4.2 Stiff soil sites (0.15 s < T_S < 0.5 s)

This site category refers to conditions where the soil material is stiff enough for the value of T_S to lie within the range 0.15 s - 0.5 s. If the total thickness of the soil is less than 30 m the designer is free to choose between the response spectrum of ground type E of Model A and ground type B of Model B which are plotted on the same graph for comparison in Figure 7. The response spectrum stipulated for ground type B of Model B is shown to be less conservative than that for ground type E of Model A in most cases. If the total thickness of the soil exceeds 30 m then ground type B of Model B has to be adopted.

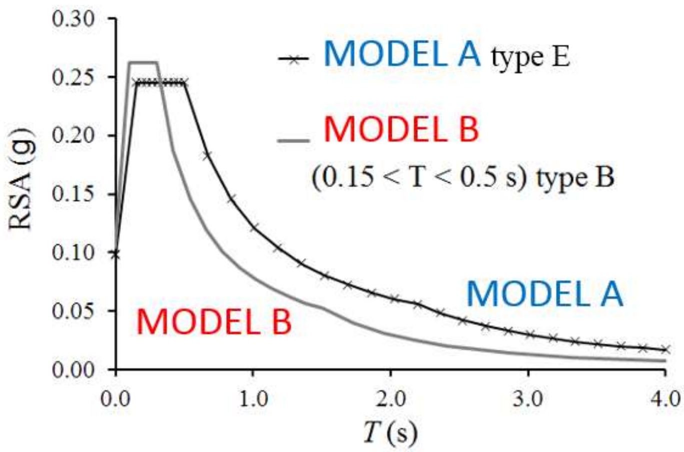

Figure 7. Model A (ground type E) versus Model B (ground type B)

4.3 Medium soft soil sites (0.5 s < T_S < 0.7 s)

This site category refers to conditions where the soil layer consists of soft materials and/or is of a thickness which results in the value of T_s to be in the range 0.5 s - 0.7 s. If the total thickness of the soil is less than 30 m the designer is free to choose between the response spectrum for ground type D of Model A and ground type C of Model B which are plotted on the same graph for comparison in Figure 8. The response spectrum stipulated for Ground type C of Model B is shown to be higher than the response spectra stipulated by ground type D of Model A in the low period range (T < 0.8 s approximately) to account for amplification associated with the resonance phenomenon. Response spectra stipulated by Model B are less conservative than those for Model A in the higher period range. If the total thickness of the soil exceeds 30 m then ground type C of Model B has to be adopted.

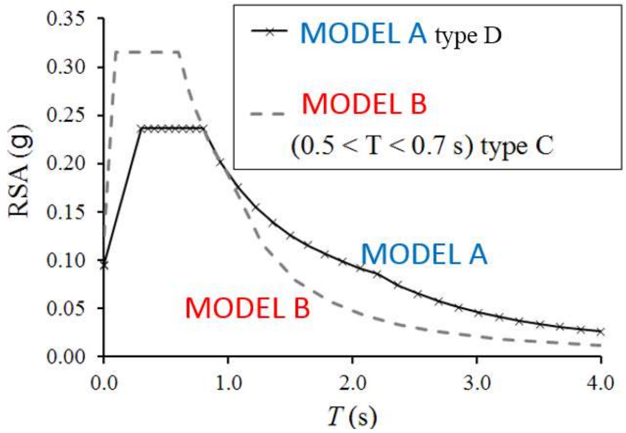

Figure 8. Model A (ground type D) versus Model B (ground type C)

4.4 Flexible soil sites (0.7 s < T_S < 1.0 s)

This site category refers to conditions where the soil layers are sufficiently deep and/or soft to result in values of T_S in the range 0.7 s - 1.0 s. The total depth of the soil layers should exceed 30 m in most cases and hence Model A would be irrelevant. Thus, designers do not have an option and have to adopt the response spectrum for ground type D of Model B as shown in Figure 9.

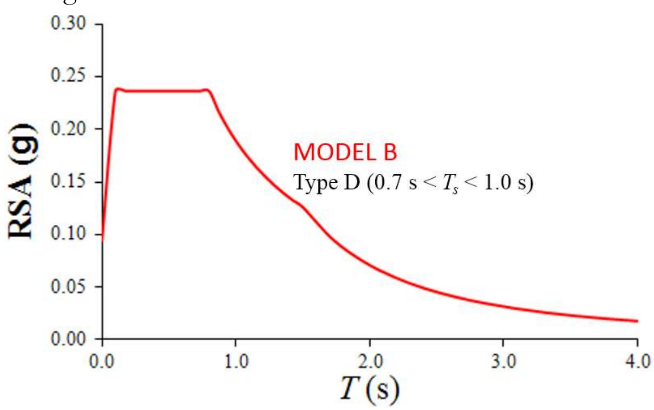

Figure 9. Model B (ground type D) for flexible soil site > 30 m (0.7 s < T_s < 1.0 s) (note: Model A is irrelevant in this case)

4.5 Very flexible soil sites (T_S > 1.0 s)

This site category refers to soil conditions where the soil layers are exceptionally deep and/or so soft that results in the value of T_S exceeding 1.0 s. The total depth of the soil must be well above 30 m. Thus, designers have to adopt the response spectrum for ground type E of Model B as shown in Figure 10.

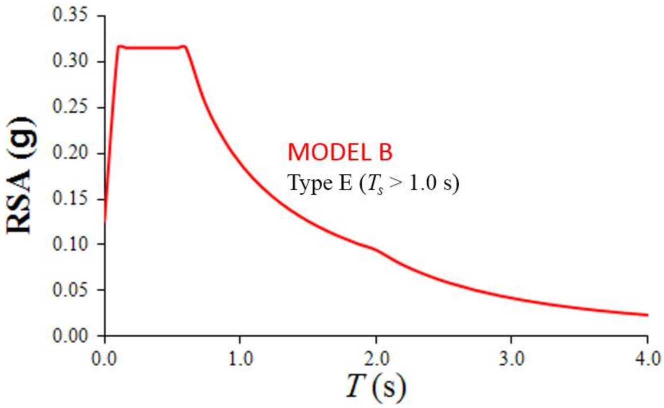

Figure 10. Model B (ground type E) for flexible soil site > 30 m (T_s > 1.0 s) (note: Model A is irrelevant in this case)

5. Conclusions

The site classification system of Model A is out of date as it fails to model the phenomenon of soil resonance. This is a significant shortcoming in regions of low to moderate seismicity where limited ductile construction is the norm. The alternative displacement-based site amplification model which had been developed to take into account the effects of soil resonance was circulated for the first round of public comment in 2016 (NA-2016).

The displacement-based model, which has a firm foundation as evidenced by publications in prestigious international archival sources has since been modified to conform to the format of Eurocode 8 and is referred to herein as Model B. Both Models A and B involve five ground types (A to E). Definitions of the ground types adopted by the two models are very different. Model A is restricted to rock or shallow soil sites which are less than 30 m deep. Model B, which does not have this restriction features the use of the site natural period as the criterion for classification. A key objective of this chapter is to assist engineers in deciding between Models A and B when identifying the response spectrum to be adopted in design. On the whole, Model B is preferred as it is less conservative (hence more economical) than Model A except for the following conditions: (1) rock sites or very shallow soil sites (ground type A) (2) the low period section (T < 0.8 s) of the response spectrum on a stiff soil site (ground type B of Model B).

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