Seismic analysis in the low to moderate seismicity region of Malaysia based on the draft handbook

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ABSTRACT: This paper introduces the draft handbook for the analysis of seismic actions for Malaysia which serves as the commentary for the debut EC8 National Annex and makes seismic design more user-friendly for practitioners. For loading specification, comprehensive spectral shape tables are presented according to the location of Malaysia (Peninsular, Sabah and Sarawak) for different ground conditions and the site natural period is taken as the controlling parameter. Example is given to guide designers on the method of calculating site natural period from boreholes record, particularly for flexible soil site. A quasi-static method of analysis which circumvents issues generated by uncertainties in the natural period properties of real building structures is introduced along with examples. The handbook is foreseen to be an extremely useful document for engineers in low to moderate seismicity region especially for countries like Malaysia which did not consider seismic action in the past.

1 INTRODUCTION

In alignment with the withdrawal of British Standards (BS) in the UK, Eurocodes (EC) were proposed for adoption in Malaysia which has been practising the BS. The National Annex (NA) of EC8 Part 1 (CEN, 2004) for Malaysia is in its fully drafted stage. A handbook to explain the background and demonstrate with examples using real sites and practical reinforced concrete (RC) buildings is in the drafting stage in order to fill in the gaps of current state of knowledge in seismic actions and analysis among Malaysian Engineers (who did not consider seismic actions in structural design in the past). This paper introduces the highlights of the NA through examples to be incorporated in the draft handbook for the analysis of seismic actions.

1.1 Response Spectrum on Rock Site

Elastic horizontal response spectrum (RS) models on rock sites have been developed for Peninsular Malaysia, Sarawak and Sabah, respectively, in the NA. It is worth noting that the RS models of Malaysia do not follow the generic EC8 code which stipulates Type 1 and Type 2 spectrum, as per Cl. 3.2.2.2 (2)P of EC8. The model proposed for Peninsular is a composite model which encapsulates results from the probabilistic seismic hazard assessment (PSHA) of recorded regional earthquakes as well as from the predictions of the local earthquakes based on broad source zone modelling. This approach best capitalises on the benefits of abundant data of distant events, whilst obtaining robust estimates of locally generated hazards. Details of the modelling methodology have been published internationally (Lam *et al.*, 2009 & 2015) and also presented locally in a recent Institution of Engineers Malaysia (IEM) workshop (Lam *et al.* 2014; Looi *et al.* 2014) as summarised in the IEM monthly magazine *JURUTERA* (Hee 2014).

1.2 Response Spectrum on Soil Site

All the RS models in the NA developed for rock sites (bedrock) conditions is to be combined with the site amplification model to be introduced in the companion paper (Tsang *et al.* 2015) for defining the design seismic actions on a building for given site conditions. In the EC8 NA for Malaysia, the small-strain site natural period of the soil layer (T_S) has been incorporated as a parameter in the construction of the RS for structures. The elastic response spectrum model can be constructed using Eq. (1) in the displacement (S_{De}) format, as expressed in terms of four spectral parameters, $S_D(T_D)$, T_C, T_D and m. Figures 1a & 1b are schematic diagrams showing the form of the response spectrum for rock sites, stiff soil sites and flexible soil sites. A summary of the proposed models for these site classes are presented in Table 1, and the key regional-dependent hazard parameters are listed in Table 2.

$$\begin{aligned} T \le T_C: &\quad S_{De}(T) = S_D(T_D)\left(T^2/T_C T_D\right) \\ T_C \le T \le T_D: &\quad S_{De}(T) = S_D(T_D)\left(T/T_D\right) \\ T_D \le T \le 4: &\quad S_{De}(T) = S_D(T_D) + m \times \left(T - T_D\right) \end{aligned} \tag{1}$$

The RS model in the acceleration (S_e) format can be conveniently obtained by direct transformation from the displacement format using Eq. (2).

$$S_e(T) = S_{De}(T) \times \left(2\pi/T\right)^2 \tag{2}$$

Table 1. Proposed spectral parameters, $S_D(T_D)$, T_C, T_D and m.

Ground Type	**T_S (s)**	**$S_D(T_D)$ (mm)**	***Slope m***	**T_C (s)**	**T_D (s)**
Rock (R)	$T_S < 0.15$	$S_{DR}(1.25)$	m_R	0.3	1.25
Stiff Soil (SS)	$0.15 \le T_S < 0.5$	$S_{DR}(1.25) \times 1.5$	m_R		
Flexible Soil (FS)	$0.5 \le T_S \le 1.0$ *	$S_{DR}(1.5T_S) \times 3.6$	m_F	$1.2T_S$	$1.5T_S$

Notes: For T_S beyond 1.0 s, or deposits consisting of at least 10 m thick of clays/silts with a high plasticity index (PI > 50), the NA suggested to perform dynamic site response analyses. Alternatively, EC8 Type 1 elastic response spectrum for ground type D shall be adopted.

Table 2. Proposed regional-dependent hazard parameters, a_g, $S_{DR}(1.25)$, m_R and m_F for 2475 years return period.

Region	**a_g (g)**	**$S_{DR}(1.25)$ (mm)**	**m_R**	**m_F**
Peninsular Malaysia	0.1	24	10	0
Sarawak	0.1	24	0	0
Sabah	0.18	42	60	40

For rock (R) sites, $S_D(T_D)$ is the region-specific spectral displacement on rock $S_{DR}(T)$ at T = 1.25 s. This value is 24 mm for Peninsular Malaysia and Sarawak, and 42 mm for Sabah, for a return period of 2475 years. For stiff soil (SS) sites, a uniform *S*-factor of 1.5 shall be applied across the whole response spectrum on rock. This recommendation is consistent with that for ground type D of EC8 Type 2 spectrum (for regions of lower seismicity). The values of the two corner periods T_C and T_D are taken as the same as that for rock sites, which are equal to 0.3 s and 1.25 s respectively. T_B is fixed as 0.1 s for all ground types in the proposed scheme.

For flexible soil (FS) sites, the two corner periods T_C and T_D are taken as $1.2T_S$ and $1.5T_S$ (Tsang *et al.* 2006a) and *S* is the site amplification factor of 3.6 (Tsang *et al.* 2006b), which is applied at the constant-velocity range (intermediate period range). In fact, the largest amplification ratio at the low-period range would be 1.8, which is consistent with that for ground type D of EC8 Type 2 spectrum. The parameters slope m_R and m_F are aimed to capture the long period spectral shape of distant events. A schematic diagram of the proposed response spectrum models for the three ground types (in displacement RS format) are shown in Figure 1.

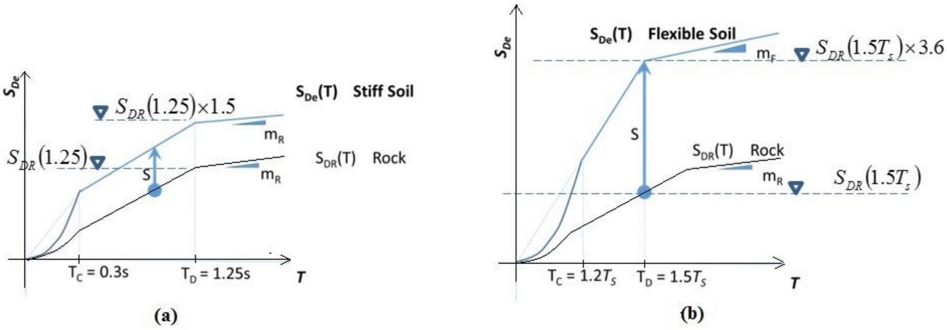


Figure 1. Schematic diagram of the proposed model for (a) rock and stiff soil sites, (b) flexible soil sites (in displacement RS format)

2 SPECTRAL SHAPE SHEETS

The draft handbook features a chapter showing 24 sheets of spectral shape tables and charts for *Peninsular Malaysia*, *Sabah* and *Sarawak* (for *R*, *SS* and *FS* site classes at intervals of 0.1 s site natural period). The idea of providing spectral tables and charts (which was inspired by the much well-known concrete column axial-moment interaction charts in BS 8110: Part 3; BSI 1985) is to make it easier for the engineers to identify the correct RS to be adopted for their design. These tables and charts circumvent the need on the part of the design engineer to construct the design RS in accordance with the regional seismicity parameter and site parameters.

An example of the spectral shape sheet is shown in Figure 2. A single sheet of the spectral shape contains all the necessary information in a table to construct the acceleration and displacement RS chart. Simplified equations to build the RS (translated from the generic equations in the NA) have been included. The clear diagrams, i.e. site location and charts are intended to simply make the sheets as self-explanatory as possible. The spectral shape sheets resemble the elastic horizontal RS based on design peak ground acceleration (PGA) of importance class IV building. Further reduction in the non-linear range is permitted through the behaviour factor (*q*) to convert the elastic RS into design spectrum for elastic analysis.

RS sheet no. 1.3

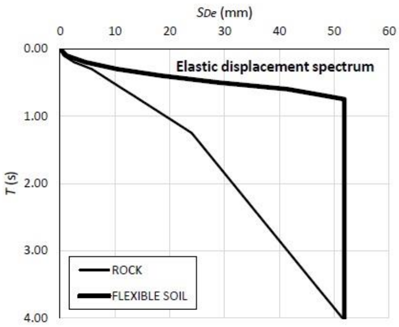
T (s)	S_e (g)	S_{De} (mm)
0.00	0.46	0.00
0.10	0.46	1.15
0.20	0.46	4.61
0.30	0.46	10.37
0.40	0.46	18.43
0.50	0.46	28.80
0.60	0.46	41.47
0.70	0.40	48.38
0.75	0.37	51.84
0.80	0.33	51.84
0.90	0.26	51.84
1.00	0.21	51.84
1.10	0.17	51.84
1.20	0.14	51.84
1.30	0.12	51.84
1.40	0.11	51.84
1.60	0.08	51.84
1.80	0.06	51.84
2.00	0.05	51.84
2.20	0.04	51.84
2.40	0.04	51.84
2.60	0.03	51.84
2.80	0.03	51.84
3.00	0.02	51.84
3.20	0.02	51.84
3.40	0.02	51.84
3.60	0.02	51.84
3.80	0.01	51.84
4.00	0.01	51.84

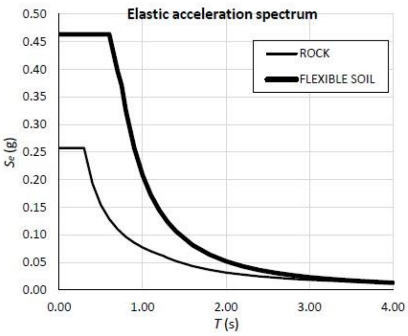
Location: Peninsular Malaysia

Site condition: FLEXIBLE SOIL
Site period: T_s = 0.5 s
Notional pga: 0.19 g (= $S_{e\,max}$/2.5)

Equations for spectra		
T (s)	S_e (g)	S_{De} (mm)
$T \le T_C$	0.46	$115.2\,T^2$
$T_C \le T \le T_D$	$0.278/T$	$69.1\,T$
$T \ge T_D$	$0.208/T^2$	51.84

where T_C = 0.60 s
and T_D = 0.75 s





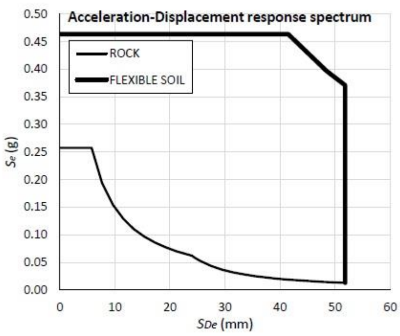
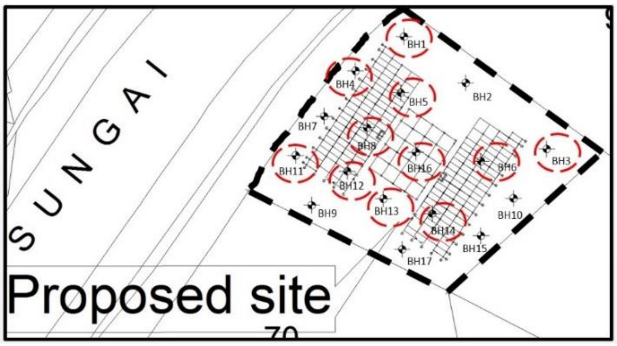


Figure 2. Elastic spectral shape sheet 1.3 (Peninsular Malaysia, T_S = 0.5 s, Class IV)

3 SITE NATURAL PERIOD

3.1 Boreholes records

In order to demonstrate the RS model in the NA, a site in Peninsular Malaysia with typical engineering borehole records was taken as example (Fig. 3). The site has dimensions of approximately 140 m×140 m (19,600 m^2) and is intended for the construction of two blocks of eight-storey building forming part of a hospital. A general rule of thumb specifies that two boreholes for a block of low-rise building is sufficient, and the spacing of boreholes for multi-storey buildings should be 15 m to 45 m. More boreholes are necessary for problematic and erratic soil formations (Sowers 1979). In this site example, a total of 11 boreholes records have been selected, spread as evenly as possible covering the site area, based on one borehole per 1800 m^2 approximately.



Borehole no.	T_S, (s)	Borehole no.	T_S, (s)
1	0.46	11	0.63
3	0.51	12	0.56
4	0.37	13	0.58
5	0.43	14	0.48
6	0.49	16	0.58
8	0.42	Mean	0.5

Figure 3. A site in Peninsular Malaysia with typical engineering borehole records

3.2 Computation of T_S

The site natural period (T_S) is estimated by the use of the correlation of Standard Penetration Test (SPT-N) values to shear wave velocity (SWV). In view of the lack of local studies, empirical formulas that are applicable to all types of soils as summarised in Wair *et al*. 2012 were referenced. Equivalent values of SPT-N > 50 for certain soil layers which is above the normally considered "saturated limit" of 50 should be carried out by proportion of N < 300 blow count, e.g. N = 50x300/270 = 55.6.

The individual soil layers thickness (d_i) divided by the respective initial SWV ($V_{s,i}$) ratio were calculated to obtain the weighted average SWV (V_S) by the use of Eq. (3).

$$V_s = \sum_{i=1}^{n} d_i \Big/ \sum_{i=1}^{n} \frac{d_i}{V_{s,i}} \tag{3}$$

where $V_{s,i}$ = The SWV in m/s; d_i = The thickness of any layer.

The value of T_S can be expressed in terms of the total thickness of the soil layers (H_S) and its weighted average SWV (V_S) via the use of Eq. (4).

$$T_S = \sum_{i=1}^{n} \frac{d_i}{V_{s,i}} \times 4 = \frac{4H_S}{V_S} \tag{4}$$

It is suggested that the arithmetic mean of the site natural period (T_S) from all the boreholes shall be adopted for site classification. In this site example, the mean value of T_S is computed as 0.5 s (Fig. 3) which corresponds to spectral shape sheet 1.3 in the draft handbook (Fig. 2).

4 STATIC ANALYSIS FOR A RC HOSPITAL BUILDING

EC8 makes reference to the lateral force method of analysis and the dynamic modal RS method of analysis. The lateral force method is essentially a static analysis method based on a pre-determined lateral force which is representative of the design seismic actions. The dynamic analysis method is particularly encouraged in EC8 and is regarded as the "reference method" in view of the availability of commercial packages possessing dynamic analysis capability in most structural design offices in Europe and other advanced economies in other parts of the globe. Although most design offices possess software having dynamic analysis capability, the average engineering graduate may not have adequate knowledge and training to review dynamic analysis results generated by the computer and have them incorporated in the calculation of design actions (i.e. bending moment and shear force) at the member level. Enforcing dynamic analysis on structures can be counter-productive when the underlying principles are not well understood. A static analysis despite its shortcomings of not allowing for higher mode effects in a dynamic response has the merit of being easy to comprehend by the average structural engineering designer.

An eight-storey RC hospital building (Fig. 4) corresponding to Class IV importance level situated at the site in Figure 3 is chosen as example to demonstrate the use of the static analysis method under Malaysian seismic actions. The building measures 31.2 m×93.8 m on plan and stands at a height of 25.6 m above ground. The lateral force resisting system is contributed by wall-frame interaction. The typical storey height is 3.2 m, typical span is 7.8 m with 600 mm×600 mm secondary beams separating the 150 mm thick slabs into one-way action. The main beams are sized at 450 mm×450 mm. The thickness of walls is 250 mm, dimension of major columns is 850 mm×800 mm, except for the 450 mm×450 mm corner columns at the two wings. For gravity load, a superimposed dead load of 5.2 kPa is estimated for partitions, finishes and ceilings, and an average live load of 5 kPa is adopted. The elastic spectrum is shown in Figure 2, after incorporating the importance factor (γ_I) 1.5 to elevate the demand from Class II (ordinary structure) to Class IV (lifeline structure). The building is subjected to the design spectrum with a behaviour factor (q) 1.5 to account for limited ductility.

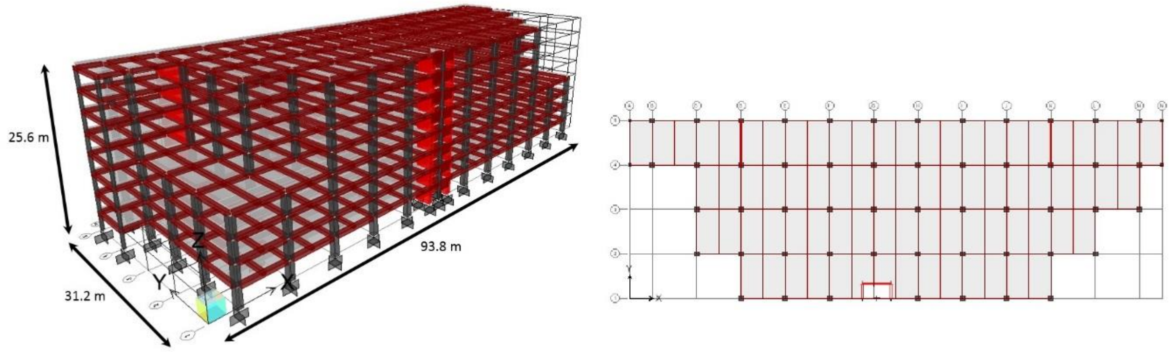


Figure 4. An eight-storey RC hospital building

4.1 **Lateral force method of analysis**

The lateral force method of analysis as stipulated in EC8 entails the determination of the natural period of vibration, T_1, using Eq. (5a), the determination of the design base shear, F_b, using Eq. (5b) and the determination of lateral forces, F_i, applied to individual floor levels in the building using Eq. (5c).

$$T_1 = 0.05H^{0.75} \quad \text{where } H \text{ is the building height.} \tag{5a}$$

$$F_b = S_d(T_1)\,\lambda m \tag{5b}$$

where $S_d(T_1)$ is the design RS acceleration at period T_1, and

λm is the effective mass of the building and λ can be taken as 80% of the total mass.

$$F_i = F_b \frac{\delta_i m_i}{\sum_j \delta_j m_j} \tag{5c}$$

where δ_i (or δ_j) is the deflection at floor level i (or j) of the building when subject to the lateral force and m_i (or m_j) is the floor mass.

Step One – Identifying building height (H), calculating codified natural period of vibration (T_1) using Eq. (5a) and identifying the RS acceleration (S_d) from spectral shape sheet in Figure 2.

$T_1 = 0.05\ (25.6)^{0.75} = 0.57$ s

From Figure 2, $S_d = S_e\ \gamma_I\ /\ q = 0.46g\ /\ 1.5 = 0.31g$, where γ_I is the importance factor (1.5 for Class IV) and q is the behaviour factor (1.5 proposed in the NA)

Step Two – Finding base shear (F_b) using Eq. (5b)

Mass, m = 76,862 ton

$F_b = 0.31g\ (0.8)(76,862) = 186,996$ kN

Step Three – Distributing the base shear into equivalent static force at each storey using Eq. (5c) by replacing lateral displacement (δ) with heights (z) of the masses, assuming fundamental mode shape is approximated by δ increasing with z (see Table 3). The static load should be applied to two orthogonal directions on plan. The lateral force method as required by EC8 is completed at this point. Analysis may continue with the quasi-static method for obtaining improved estimates.

4.2 Quasi-static method of analysis

Uncertainties stem from inconsistencies in the natural period value calculated by Eq. (5a) and that reported by the computer analysis of the structural model of the building. This problem can be circumvented by introducing the capacity spectrum method (in a linear elastic analysis setting) which makes use of the calculated static deflection of the building to infer on an improved estimate of the fundamental natural period of vibration of the building. The revised lateral forces and the corresponding deflection can be significantly lower than that estimated by Eqs. (5a – 5c). Only static analyses are involved and is easy to comprehend by the average structural engineer.

ETABS (CSI 2003) was used to model the hospital, nonetheless any suitable commercial structural software can be used for static linear analysis. Frames are modelled as line elements, shear walls as membrane elements and typical floor slabs as shell elements. Rigid diaphragm behaviour is assumed for all the floors. The supports are modelled as fixed. C30/37 grade concrete is used in the construction.

Step Four – Structural analysis to obtain the force at each floor (F_i), displacement at each floor (δ_i) (see Table 3) and effective displacement value (δ_{eff}) are calculated using Eq. (6).

Table 3. Force and displacement at individual floors in lateral Y direction.

Flr. no.	**Mass m_j, (*ton*)**	**z_j cumulative, (m)**	**$m_j\ z_j$**	**F_j, (kN)**	**δ_j, (mm)**	**δ_j^2, (mm^2)**	**$m_j\ \delta_j$**	**$m_j\ \delta_j^2$**
8	8700	25.6	222,720	39,080	68.5	4690.4	595,830	40,806,128
7	8864	22.4	198,554	34,840	63.1	3981.1	559,280	35,288,181
6	8864	19.2	170,189	29,863	56.0	3132.0	496,068	27,762,073
5	8864	16	141,824	24,885	47.3	2239.8	419,506	19,853,902
4	10,370	12.8	132,736	23,291	37.4	1397.0	387,589	14,486,531
3	10,400	9.6	99,840	17,519	27.4	749.8	284,780	7,798,047
2	10,400	6.4	66,560	11,679	17.1	293.8	178,251	3,055,130
1	10,400	3.2	33,280	5,840	7.4	54.5	76,790	566,998
Sum	76,862		1,065,702	186,996			2,998,094	149,616,990

$$\delta_{eff} = \left(\frac{\sum m_j \delta_j^2}{\sum m_j \delta_j} \right) = \frac{149{,}616{,}990}{2{,}998{,}094} \approx 50\ mm \qquad (6)$$

Step Five – Calculating effective mass (m_{eff}) and improved estimate of RS acceleration (S_d) from Eq. (5b)

$$m_{eff} = \left(\frac{\left(\sum m_j \delta_j\right)^2}{\sum m_j \delta_j^2} \right) = \frac{(2{,}998{,}094)^2}{149{,}616{,}990} \approx 60{,}077 \text{tons} \tag{7}$$

$$S_d = \frac{F_b}{\lambda m} = \frac{186{,}996}{60{,}077} \Big/ 9.81 \approx 0.32g$$

<u>Step Six</u> – Calculating effective stiffness (k_{eff}), natural period of vibration (T_{eff}) and drawing acceleration-displacement diagram for the building structure.

$$k_{eff} = 186{,}996/0.05 = 3{,}747{,}112 \text{ kN/m}$$

$$T_{eff} = 2\pi \sqrt{\frac{m_{eff}}{k_{eff}}} = 2\pi \sqrt{\frac{60{,}077}{3{,}747{,}112}} = 0.8\ s$$

Compared to the results obtained from ETABS simulation, the first mode shape period is 0.81 s in the X direction and second mode shape period is 0.80 s in the Y direction.

<u>Step Seven</u> – Calculate seismic demand from spectral shape sheet

Since T_{eff} = 0.8 s > T_D = 0.75 s, the spectra equation is $S_d = (0.208/T^2)/q$ = 0.22g and $S_D = 51.84/q$ = 34.56 mm.

<u>Step Eight</u> – Repeat Step Two with the improved accuracy of demand

$$F_b = 0.22\text{g}\ (0.8)(76{,}862) = 132{,}707 \text{ kN}$$

Figure 5 shows the summary of the uncertainties in the natural period properties of the building using the coded empirical formula and the improved estimation via the quasi-static method. The exercise is repeated for a more flexible soil site (T_S = 1.0 s). Importantly, the site model in the NA predicts lower seismic demand on this medium rise (stiff) structure, contributing to some leverage in cost savings.

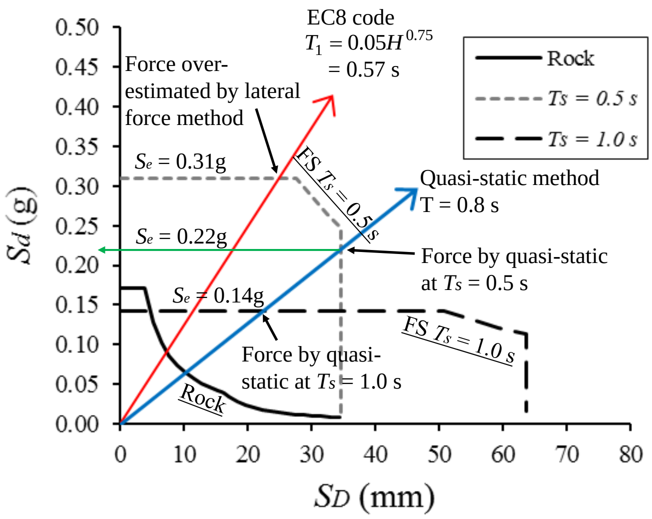


Figure 5. Comparison of natural period estimated by code and the quasi-static method

Considering most structures having some form of irregularity to fulfil architectural and functional requirements the criterion as stipulated in Cl. 4.2.3 in EC8 can be described as very stringent because this may preclude the majority of building structures from design by static analysis only. The vertical regularity prerequisite in EC8 should be relaxed in view of recent findings from the literature that buildings with T_1 < 1.5 s (which is fulfilled by most buildings with height of up to 50 m, or 16 storeys) are unlikely to experience any significant higher mode effects in their dynamic response to earthquake ground shaking. Analyses that have been reported to support this proposition include buildings possessing mass and stiffness irregularity in the elevation of the building (Su *et al.* 2011, Fardipour *et* *al*. 2011, Zhu *et al*. 2007). In Australia (AS 1170.4 2007, AEES 2009), dynamic analysis is only required for buildings exceeding 50 m (16 storeys) which are found on rock, or stiff soil. In Singapore (NA to SS EC8 2013, BC3 2013) only one of the two prerequisites for lateral force method listed in EC8 need be fulfilled. In view of findings reported from the literature and prerequisites imposed by codes of practices in other areas of low to moderate seismicity, it is recommended that buildings of up to 25 m in height may be subject to lateral force analysis method irrespective of its regularity conditions in elevation. Subsequent rigorous design check based on acceptance criteria of ultimate strength and serviceability drift in NA should be carried out accordingly.

5 **CONCLUSIONS**

This paper introduces the draft handbook for the analysis of seismic actions for Malaysia with EC8 NA. An example of the comprehensive spectral shape sheet is presented for a FS site in Peninsular Malaysia. A worked example of an eight-storey RC hospital is given, initiating from site period calculation of borehole records to a quasi-static method of analysis which circumvents issues generated by uncertainties in the natural period properties of a real building structure. The draft handbook (which contains more details than this paper) is foreseen to be an utmost useful document for engineers in low to moderate seismicity region especially for countries like Malaysia which has not until now considered seismic actions in the design of building structures.

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