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The Malaysian seismic design code: lessons learnt

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ABSTRACT

Malaysia has enacted its first national code of practice for the seismic design of buildings following the release of the Malaysian National Annex (NA) of Eurocode 8 (EC8) in late 2017. The authors are key contributors to the drafting of the NA spanning a period of around 8 years. The authors experienced major issues in implementing the 20 years old EC8 framework for a country which is very far away from Europe. This paper is aimed at sharing the lessons learnt in order to give good pointers to code drafters who lack seismic codification experience. The first theme is the uncontrolled use of probabilistic seismic hazard assessment (PSHA) technique for use in a low-to-moderate seismicity region which has a paucity of representative earthquake data of any form (and this has resulted in some “fancy looking” PSHA contour maps featuring hotspots which are not far away from areas that have close to zero hazard). The second theme is to do with the out-of-date EC8 site classification scheme which has not incorporated the natural period of the site as a design parameter. The third theme is to do with mandating Ductility Class Medium (DCM) detailing in areas which has been stipulated with a higher level of hazard as shown on the PSHA contour map. Given that the use of strength to trade off ductility is not allowed; ductile design requirements vary with stipulations by the contour map. In this article, ways of pragmatically circumventing around these challenges are presented.

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1 INTRODUCTION

This paper was written with the purpose of sharing the recent experience of the authors who have spent many years in preparing Malaysia which was without any prior experience of seismic design and is well away from the European continent to adopt *Eurocode 8* (EC8). There are many facets of activities that are related to this endeavour. The drafting of the National Annex (NA) which was the main activity had to be paralleled by seeking advice from international experts in the field, working alongside with local authorities and influential groups to resolve differences and to disseminate knowledge to local practising professionals through workshops and publications. Three key issues have been experienced by the authors in the drafting process. This paper is structured to discuss these issues and to make recommendations under separate headings. The uncontrolled use of probabilistic seismic hazard assessment (PSHA) methodology in a low-to-moderate seismicity environment is the first item to address. The out-of-date EC8 site classification scheme would also need to be modified to introduce the natural period of the site as a design parameter. The current out-dated practice of mandating Ductility Class Medium (DCM) detailing in areas which has been stipulated with a higher level of hazard would need to be phased out to incorporate provisions for allowing the use of strength to trade-off for ductility. A list of recommendations which is not as onerous as that stipulated for areas of high seismicity is provided at the end of the paper for improving ductile behaviour in regions of lower seismicity.

2 UNCONTROLLED USE OF PROBABILISTIC SEISMIC HAZARD ASSESSMENT (PSHA) TECHNIQUE

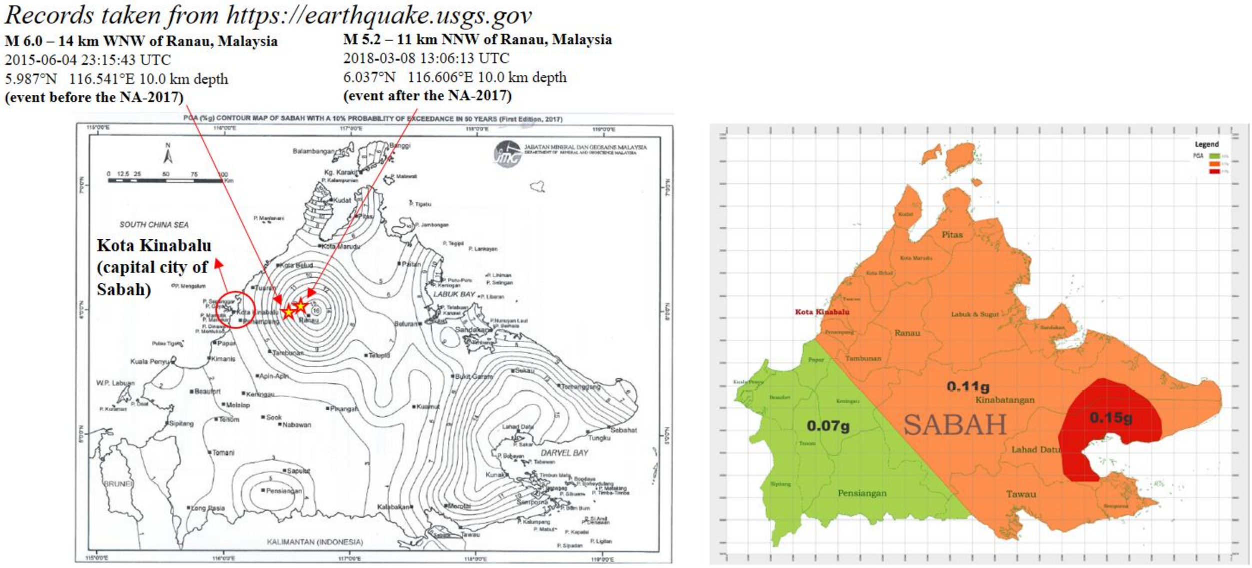
Probabilistic seismic hazard assessment is a popular seismic hazard modelling technique which is introduced in almost every textbook on earthquake engineering and seismic risks modelling (e.g. Dowrick, 2009). The modelling methodology is perceived by many as being unbiased and scientific. However, in stable areas away from tectonic plate boundaries, active fault sources are very difficult to identify. Seismic sources are usually areal sources, the location of which are simply mapped in accordance with the epicentres of historical earthquakes, whilst knowledge on faulting activities are sometimes taken into considerations at the discretion of the person(s) operating on the PSHA.

Whenever the seismic hazard map is updated to incorporate the occurrence of a recent earthquake event in an area where data is sparse, the modelled level of hazard surrounding the epicentre would always be higher than before. This implied phenomenon is not based on any scientific principles or a consensus of opinion amongst earth scientists (Mulargia et al., 2017). A major cause for concern is that in areas where no earthquake activity has been detected during the period of observation, the design hazard level can be very low and much depends on the disposition of the mapped seismic sources. No definitive guidance exists on how to delineate the boundary of an areal source, and much is left to the discretionary judgement of the analysts. The standard practice to resolve differences in opinion is to employ the so-called logic tree (i.e. decision making by “the show of hands”) procedure. No doubt the modelling process of PSHA can be very susceptible to influences by commercial and political interests.

In recommendations made by the working group formed within the *Institution of Engineers Malaysia* (IEM) in the *Draft NA to EC8* for public comments (2016), a minimum level of the reference peak ground acceleration on rock (a_{gR}) of 0.07g was specified for *Peninsular Malaysia* and *Sarawak*, and 0.12g for most of *Sabah*. The recommended minimum hazard requirements can be justified by referring to results from PSHA assuming uniform spatial distribution of seismicity activities and observations on the frequency of occurrence of M > 5 earthquake events over a very large area (Lam et al., 2015 & 2016). The a_{gR} value of 0.07g and 0.12g as quoted in the above for a notional return period of 475 years was two-thirds of values (0.10g and 0.18g respectively) corresponding to a return period of 2475 years (refer Looi et al., 2018a for a presentation of the rationale behind the recommendations). The modelling concept as described can be likened to that of background seismicity (which is not a new concept). However, background seismicity models that have been employed in the past for PSHA did not prevent the value of a_{gR} to go as low as 0.03g for a design return period of 475 years.

In the 2018 revision to the Australian Standard for seismic actions, AS1170.4-2007 (R2018), the requirement of a minimum seismic design factor (Z) of 0.08 for a return period of 500 years has been imposed. Thus, in most parts of Australia Z = 0.08 is specified in the new seismic hazard map, superseding an old model that was derived originally from conventional PSHA (based on information from documented historical seismic activities). In contrast to the new stipulation, the value of Z in the old map could be as low as 0.03 for areas where no historical activities had been recorded within the period of seismic activity observation. Unlike the Australian Standard, recommendations for imposing a minimum threshold of 0.07g, and 0.12g, to different parts of Malaysia have not been taken up by the enacted version of MS EN 1998-1:2015 (National Annex 2017) through a decision process based on voting. One of the consequences of the decision is that an unacceptably low a_{gR} value of 0.04g has been stipulated for *Kota Kinabalu* (capital city of *Sabah*) which was only some 50 km from the epicentre of the M5.9 *Ranau* earthquake of 2015 (see Fig. 1a, where the *Ranau* earthquake epicentre is superimposed).

The authors pledge all major codes practices like EC8 to require seismic hazard maps to be subject to proper auditing and to impose adequate minimum design requirements in order that maps such as that shown in Figure 1a cannot become part of a legal document for safeguarding public safety. It was recommended by the authors to adopt a more robust model like the one depicted in Figure 1b.



Records taken from https://earthquake.usgs.gov

M 6.0 – 14 km WNW of Ranau, Malaysia
2015-06-04 23:15:43 UTC
5.987°N 116.541°E 10.0 km depth
(event before the NA-2017)

M 5.2 – 11 km NNW of Ranau, Malaysia
2018-03-08 13:06:13 UTC
6.037°N 116.606°E 10.0 km depth
(event after the NA-2017)

(a) Enacted version in National Annex (2017)

(b) Recommended model

Figure 1: Seismic hazard models for Sabah

3 CURRENT OUT-OF-DATE EC8 SITE CLASSIFICATION SCHEME

The inability of the current site classification scheme and the site factor model in EC8 to properly address deep site geology is a matter of concern, in view of the potential occurrence of soil-structure resonance, the conditions of which can be particularly acute in buildings of limited ductility and more so on deep soil sites. The next edition of EC8 is to be revised to the form proposed in numerous publications by Pitilakis et al. (2012, 2013, 2018). The basis and justification for the incorporation of site natural period and the effects of site resonance in the new site factor model can be found in earlier studies conducted globally and also by the authors (e.g. Seed et al. 1976, Lam et al. 2001, Tsang et al. 2006a).

In a low seismicity environment, a site factor model which has not taken into account the likely occurrence of soil-structure resonance, represents a significant shortcoming. In addressing this shortcoming, the NA to

EC8 for Malaysia stipulates that the conventional site classification scheme stipulated by EC8 can only be applied to shallow soil sites that are covered by soil sediments of thickness H_s not exceeding 30 m. An alternative site classification scheme which involves calculating the natural period of the site (T_s) provides more accurate predictions of real behaviour and without any limitations in relation to the depth of the sediments. Details of the latter site classification scheme are presented in this section.

Five ground types are defined, each with its own simple definition based mainly on the range of T_s. Apart from ground type A, which refers to rock sites or a site with very thin sediments, all the other ground types refer to soil sites. 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.

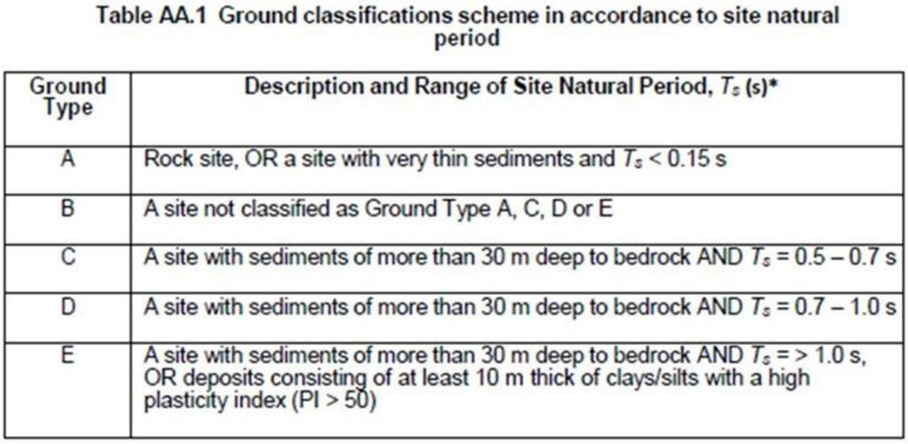


Table AA.1 Ground classifications scheme in accordance to site natural period

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 Scheme taken from Table AA.1 in the Malaysian NA-2017

The values of the site natural period (T_s), small-strain shear modulus or shear wave velocity (SWV, V_s) of soils can be estimated based on geophysical, or geotechnical, measurements with the use of Eq. (1). The value of T_s can be taken as four times the travel-time taken by seismic waves traversing the sedimentary layers overlying bedrock. Eq. (1) can be used for estimating the value of T_s.

$$T_s = 4 \times \sum_{i=1}^{n} \frac{d_i}{V_i} = \frac{4H_S}{V_S} \qquad (1)$$

where d_i is the thickness, V_i is the initial SWV of the i^{th} soil layer, H_S is the total thickness of the soil layers and V_S is the weighted average SWV.

Sedimentary layers with SPT-N values greater than 100 can be omitted in the computation of site natural period and weighted average SWV.

The response spectrum models for different ground types in *Peninsular Malaysia* stipulated in the Malaysian NA-2017 as shown in Figure 3 were developed based on a theoretical model that had been validated by 1-D site response analyses and field data from 1994 Northridge earthquake (Tsang et al. 2006a, 2006b, 2012, 2017). The proposed model was reviewed and endorsed by Professor Kyriazis Pitilakis in a forum of experts hosted by the Institution of Engineers Malaysia (IEM) on 11-12 April 2017. Professor Pitilakis is the President (2018-2022) of the European Association of Earthquake Engineering (EAEE) and has been the Coordinator of the EAEE Working Group 6 on Geotechnical Earthquake Engineering, leading the future revision to EC8 in relation to geotechnical matters.

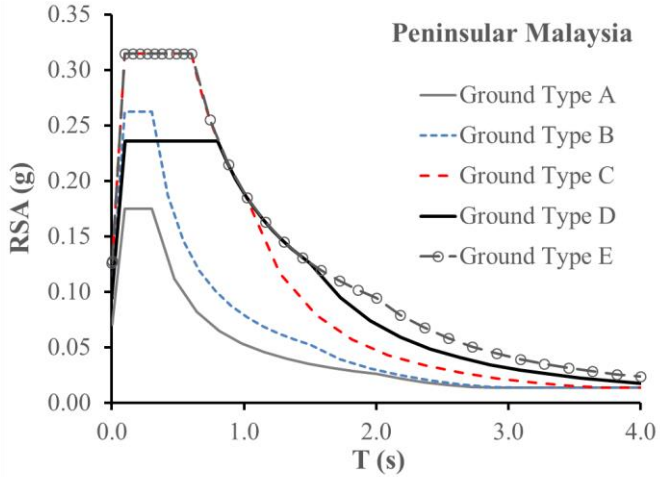


Figure 3: Response spectrum models for different ground types for Peninsular Malaysia stipulated in the Malaysian NA-2017

4 EC8 RIGID APPROACH OF MANDATING DUCTILITY CLASS MEDIUM (DCM) DETAILING BY TYING WITH SEISMIC HAZARD LEVEL

4.1 The challenge of mandating ductile detailing in low-to-moderate seismicity region

The third theme is to do with mandating Ductility Class Medium (DCM) detailing in areas which has been stipulated with a higher level of hazard as shown on the PSHA contour maps. In regions of low-to-moderate seismicity, such as Malaysia, practising engineers are typically lack in knowledge and experience in incorporating ductility into the design of a structure. To the majority of designers, the use of strength to trade off with ductility is the preferred option but EC8 does not provide such an option. In EC8, in areas where the value of design ground acceleration on rock (a_g, being product of a_{gR} with importance factor, γ_I), is lower than 0.08g or where $a_g S$ is lower than 0.10g (where S is the soil factor), the condition of seismicity is classified as “low”. Structures located in these areas can be designed with Ductility Class Low (DCL) in alignment with common practice of reinforced concrete (RC) design using Eurocode 2 (EC2) which is without any seismic design and detailing provisions. In areas where the level of hazard is above the threshold (including borderline cases where $a_g = 0.09$g, say) designers are forced to adopt ductile design and detailing practices consistent with requirements in countries of high seismicity. In the opinion of the authors, linking the level of seismic hazard level of an area to ductile design classification is an out-dated concept. This regulatory approach which gives little regard to local practices is not effective in ensuring a safe and sustainable built environment. The authors strongly advocate making improvements to current practices which can result in non-ductile behaviour of the structure. However, blindly imposing DCM design requirements might not deliver the desirable outcomes.

4.2 Proposed pragmatic approach of seismic detailing

The option of using strength to trade off ductility requirements should be made available to designers in countries like Malaysia. This approach can be facilitated by introducing simple rules to control the value of the behaviour factor (q) for reduction of the elastic seismic action. Meanwhile, additional provisions as listed in Table 1 can be incorporated to introduce the desirable amount of ductility in all structures irrespective of the level of hazard. Importantly, these detailing requirements are not strictly tied in with the seismic hazard level. The Ductility Class High (DCH) in EC8 is not recommended due to its overly complicated and stringent requirement that is only suitable for high seismic areas, and not feasible for use in Malaysia. Although limited ductile design is recommended, it does not refrain engineers from choosing a more ductile design (i.e. moderately ductile) for cautioned area such as the hot-spots of *Lahad Datu* in the east coast of

Sabah which is stipulated with a_{gR} of 0.15g (see Fig. 1). Table 1 shows the recommended detailing practice of RC building structure for use in countries like Australia and Malaysia based on recommendations by Menegon et al. (2017) and the authors (Looi et al., 2018b).

Table 1: Proposed simplified ductility classes and recommended detailing practice for RC structure

Criteria	Limited ductile	Moderately ductile
1. Behaviour factor (q)	1.5*	≥ 1.5, following Table 5.1 in EC8
2. Notes	Building must be designed elastically to EC2, with a strength design approach. Building must be detailed to EC8 DCL requirement.	Building must be detailed to a minimum DCM requirement.
3. Reinforcement class	Class A, B or C according to Table C.1 in EC2	Minimum Class B according to Table C.1 in EC2**
4. Reinforcement grade	Characteristic yield strength 400 MPa to 600 MPa	Characteristic yield strength 400 MPa to 600 MPa
5. Seismic **beam** in frame-dominated structure:		
(a) Size	Conform to EC2	Keep depth ≥ 600 mm
(b) Stirrup rebar diameter	Conform to EC2	≥ 10 mm
(c) Longitudinal rebar diameter	Conform to EC2	≥ 20 mm
(d) Stirrup spacing at critical length	Not applicable, shear links conform to EC2	≤ 150 mm
6. Seismic **column** in frame-dominated structure:		
(a) Size	Conform to EC2	Keep gross dimension ≥ 500 mm by 500 mm to achieve effective confinement
(b) Hoop rebar diameter at critical length	Not applicable, shear links conform to EC2	≥ 12 mm
(c) Longitudinal rebar diameter	Conform to EC2	≥ 20 mm
(d) Hoop spacing at critical length	Not applicable, shear links conform to EC2	≤ 150 mm
(e) Spacing between longitudinal bar engaged by links and ties (b_i)	Conform to EC2	≤ 150 mm
(f) Confinement effective factor for longitudinal engaged bar spacing (α_n) - Eq. 5.16a in EC8	Not applicable	0.78
(g) Confinement effective factor for stirrups spacing (α_s) - Eq. 5.17a in EC8	Not applicable	0.72
(h) Axial load ratio for columns***	Conform to EC2	≤ 0.33
(i) Capacity design	Not applicable	Conform to DCM requirement in EC8 (i.e. strong column weak beam, strong shear weak bending)
7. **Shear wall** in frame-dominated and wall-dominated structure:		
(a) Minimum shear walls slenderness ratio	Conform to EC2	Height/Thickness ≤ 16
(b) Axial load ratio for walls***	Conform to EC2	≤ 0.20
(c) Minimum vertical rebar ratio	Conform to EC2	Range from 0.7% to 1.0%****
(d) Capacity design	Not applicable	Design as elastic members

*1.5 is the value commonly accepted by the Malaysia local structural community, in view of the confidence level in quality control. It is noted that a higher value can be adopted, for example 2.6 is adopted for Australia.

**Class B rebar is commonly available in Malaysia.

***Axial load ratio is defined as $P_o/(f_c' A_g)$, where P_o is defined as the ultimate axial load using load combination for earthquake given in EC8, f_c' denotes the actual concrete cylinder strength and A_g is the gross area of section.

****Menegon et al. (2017) recommends reinforcement ratios of 0.7%, 0.8%, 0.9% and 1% for concrete grades C32, C40, C50 and C65 respectively. The vertical reinforcement ratio can be decreased at a rate of 15% per storey away from the plastic hinge regions.

It is noted that Table 1 features two provisions which represent a departure from EC8. First, the axial load ratios of columns and walls (see item 6(h) and 7(b)) are defined differently from EC8 (where EC8 refers as the normalised design axial force, v_d in Eq. 5.15). The difference is related to the need to refer to the work of Menegon et al. (2017) and essentially the limits are similar to EC8 in principles. Reducing the axial load ratio in columns (Wilson et al., 2015; Raza et al., 2018) and in shear walls (Menegon et al., 2017; Looi et al., 2017) is emphasized to be the most direct way to achieve adequate deformation capacity. Second, capacity design methodology is not recommended for the design of shear walls in view of the ductility requirements in a region of low-to-moderate seismicity like Malaysia. Minimum vertical reinforcement ratio requirement is also recommended to achieve desirable crack formation behaviour.

5 CONCLUSION

The lack of control in the application of the PSHA methodology to areas with a paucity of information on seismic activities has been identified as a cause for concern. In view of uncertainties with the underlying spatial and temporal distribution of seismic activities, the seismic hazard maps for Australia is subject to a minimum seismic design factor of $Z = 0.08$. It is recommended to impose similar requirements to Malaysia and other countries of low-to-moderate seismicity.

Areas typified by limited ductile building construction are susceptible to soil-structure resonance, and more so on deep soil sites. A conventional site factor model, such as that stipulated in EC8, would not cater for resonance conditions as described. In addressing this issue, the NA to EC8 for Malaysia has incorporated an alternative site factor model which features the natural period of the site as a design parameter. It is recommended to introduce similar code provisions in countries of low-to-moderate seismicity.

The regulatory approach of mandating DCM ductile detailing requirements in accordance with the level of seismic hazard of the area (as shown on the contour maps) is an out-dated practice. It is recommended to make available to designers the option of using strength to trade off for ductility, which is the preferred approach as it is more straightforward. A list of recommendations which is less onerous than the EC8 ductile design methodology has been put forward to improve the ductility behaviour of new buildings in low-to-moderate seismicity region.

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