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Article

Developing Earthquake-Resistant Structural Design Standard for Malaysia Based on Eurocode 8: Challenges and Recommendations

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Abstract: In late 2017, the Malaysian National Annex (NA) to Eurocode 8 (EC8) was released and enacted following some 13 years of deliberations and preparations. The authors of this paper aim to use this article to share their experiences and reflections during this period of developing the first national standard for the seismic design of buildings for Malaysia. To begin with, there were major challenges in implementing the 20-year-old EC8 framework for a country so far away from Europe. The first challenge was adapting the probabilistic seismic hazard assessment (PSHA) methodology in a low-to-moderate seismicity region where the paucity of representative seismic data presented a great deal of uncertainties. To address this situation, imposing a minimum level of seismic hazard was recommended. The second challenge was about dealing with the outdated EC8 site classification scheme, which poorly represents the potential effects of soil amplification in certain geological settings. To address this situation, an alternative site classification scheme in which the site natural period is an explicit modelling parameter was introduced. The third challenge was concerned with difficulties generated by the EC8 provisions mandating Ductility Class Medium (DCM) detailing in certain localities where the level of seismic hazard is predicted to exceed a certain threshold. To address this situation, the viable option of using strength to trade off for ductility was recommended, or in cases where ductility design is needed, a simplified set of code-compliant DCM designs was presented. The fourth challenge was about handling the requirements of EC8 that the majority of buildings are to involve dynamic analysis in their structural design when the majority of practising professionals did not have the skills of exercising proper use of the requisite software. To address this situation, a generalized force method was introduced to control the use dynamic analysis in commercial software. It is hoped that, through sharing the lessons learnt, code drafters for the future would be able to find ways of circumventing the multitude of challenges with clear thinking and pragmatism.

Keywords: Eurocode 8; PSHA; site period parameterisation; DCM detailing; dynamic analysis; low-to-moderate seismicity regions

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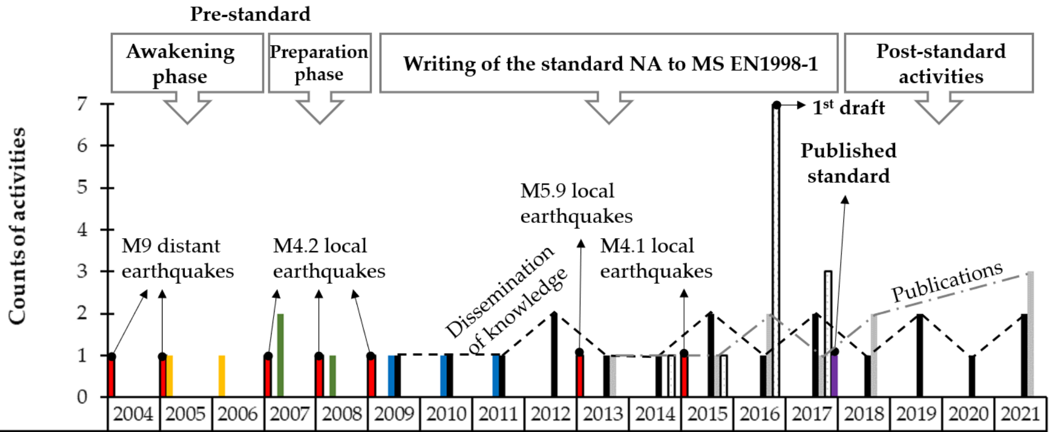
1. Introduction

Malaysia 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, or officially named as MS EN1998-1) in late 2017 [1,2]. The authors were among the most active hands-on participants in the preparation of the standard since 2008. This paper is written to present the experience and reflections of the authors gained during this period of standard writing. To begin with, the authors encountered major challenges in the drafting of the NA for Malaysia where practising structural design professionals had no prior seismic design experience. This problem was compounded by the distance of Malaysia from the European continent. Whilst some of the challenges were presented briefly in a regional conference [3], this paper presents an opportunity to discuss the key issues elaborated.

There are many facets of activities that are related to the endeavour of standard drafting. To put the readers into context, Figure 1 presents a collated summary of the relevant key activities in chronological order since 2004. A detailed listing of the individual activities can be found in Appendix A. Broadly speaking, there were three phases in the development of the Malaysia NA to EC8 [2], namely, the pre-standard phase (of awakening and preparation), the standard-writing phase and the post-standard phase.



	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
🟥 Seismic events	1	1		1	1	1				1		1						
🟨 Concern of engineers		1	1															
🟩 Setting up of standard writing committees				2	1													
🟦 Important initial publications						1	1	1										
⬛ Disseminations of knowledge						1	1	1	2	1	1	2	1	2	1	2	1	2
▨ Documentations in publications										1		1	2	1	2			3
☐ Major meeting/forum with stakeholders *											1	1	7	3				
🟪 Published standard														1				

*These are major meetings/forums. Frequent communications between group members took place throughout the whole process.

Figure 1. The roadmap of the drafting of the Malaysia NA of EC8 [1,2].

1.1. Pre-Standard: The Awakening and Preparation Phases (2004–2009)

Moderate size seismic events of magnitude 5 to 6 (M5–M6) occurring in Malaysia in the 1900s had been documented. The affected areas were mostly not so densely populated areas in Sabah (e.g., M5.3 in 1966 near Ranau, M6.2 and M5.7 in 1976 and 1994, respectively, near Lahad Datu). These early events had not drawn significant attention because of the sparse population in the affected areas where there were very few engineered building structures of significance. Memories of those events had faded away over time. However, there were also a few notable events, such as the Aceh M9.1–9.3 and Nias M8.6 megathrust subduction (interplate) earthquakes, which occurred offshore of Sumatra in 2004 and 2005, respectively. The epicentres of these earthquakes were at a far distance of about 600 km from Peninsular Malaysia, but many residing along the west coast of the Peninsular felt the shaking. Given the concern raised by the public, the Civil and Structural Engineering Technical Division of the Institution of Engineers Malaysia (IEM) took the initiative to write a position paper which was published in 2008 [4]. The position paper raised concern over the lack of preparedness of the Malaysian engineering industry in seismic design. Some short- and long-term measures to address the potential risks are recommended.

In 2008, IEM was appointed by the Department of Standards Malaysia as the standards-writing organisation for the Malaysia NA to EC8. Working Group 1 (WG1) was formed under a Technical Committee (TC) on Earthquakes to study the seismic hazard in Malaysia [5]. Whilst the initial focus was on distant interplate earthquakes generated from offshore sources, attention has also been drawn onto local intraplate earthquake events which had been recorded within the peninsular. Such events include the M4.2 earthquake tremor which occurred in 2007–2009 at Bukit Tinggi, which was about 30 km away from Kuala Lumpur, the capital city of Malaysia. The TC adopted the approach of addressing seismic risks holistically, and both local intraplate earthquakes and distant interplate earthquakes deserved an equal amount of attention.

1.2. The Standard-Writing Phase (2009–2017)

WG1 members acknowledged the challenges of dealing with seismic risks in a low-to-moderate seismicity region where representative locally recorded earthquake data were so lacking that undertaking seismic hazard assessments in a conventional manner would not be delivering any meaningful predictions. Hence, international experts in the low-to-moderate seismicity regions (the second and last authors of this paper) were invited to join the special study group under WG1 in June 2010. The first author was the candidate selected by WG1, trained under an apprenticeship program in grooming local talents for seismic engineering [5]. At a time when there was no existing ground motion model that could be applied to predict subduction earthquakes of mega magnitude (of the order of M9), the study put the focus on three key publications for the prediction of ground motions generated by distant interplate earthquakes [6–8]. Publications cited in the review laid the foundation of the seismic hazard study for Malaysia.

The main development activity was the drafting of the Malaysia NA to EC8 and was paralleled by sourcing input from international experts in the field, as well as working alongside local authorities and influential groups to resolve differences and to disseminate knowledge to local practising professionals through workshops and publications. All these knowledge dissemination activities have been conducted on a regular basis since 2009, long before the first draft of the national annex was presented for the first round of public comments in 2016 [9]. The standard-writing activities became most intensive in 2016. Around that time, the authors and co-workers travelled to different parts of Malaysia for various meetings, forums and discussions with stakeholders. These activities lasted until the standard was officially published in 2017 [2].

1.3. Post-Standard Phase (2017 to Current)

Standard writing is in itself a time-consuming activity. In addition, related work may be prolonged even after the standard is published as it is a natural continuation of obligations of the code drafters. In the case of the Malaysia NA to EC8, substantial knowledge dissemination activities are warranted to ensure that the intention of the standard is well understood by practising engineers. Hence, the authors (together with other local and international team members) have relentlessly dedicated themselves to achieve the goal of the standard following its release in 2017. A notable milestone was the setting up of a public access website (quakeadvice.org, last assessed on 28 October 2021) with free online lectures and software, which is aimed at educating engineers and guiding them into making proper use of the newly launched standard in a low-to-moderate seismicity region [10].

2. Technical Challenges Faced during the Drafting of the Standard

During the course of drafting the National Annex, the authors managed to gain highly valuable experiences, which are elaborated in this section. Four main technical challenges were encountered when implementing the EC8 framework into Malaysia. The first challenge was over the prediction of seismic hazards when representative data required for input into a probabilistic seismic hazard assessment (PSHA) were lacking. The second challenge was to do with the need to modify the outdated EC8 site classification scheme, which in its current form could poorly represent the conditions of the site in an earthquake.

The third challenge was to deal with EC8 mandating Ductility Class Medium (DCM) detailing in localities where the predicted level of seismic hazard exceeds a certain threshold. The fourth challenge was to deal with the requirement of EC8 to involve dynamic analysis of the majority of building structures when most engineers were not familiar with the requisite software. Each of these challenges, along with recommendations on how to best handle them, will be discussed in detail below under separate sub-headings.

2.1. Challenge 1: The Uncontrolled Use of Probabilistic Seismic Hazard Assessment (PSHA) Methodology

PSHA is a widely adopted seismic hazard modelling technique introduced in almost every textbook on earthquake engineering and seismic risk modelling [11]. The modelling methodology is perceived by many as being unbiased and scientific. When PSHA was first developed, it was intended for use in areas where data were abundant. In stable areas away from tectonic plate boundaries (i.e., intraplate regions), instrumented data are usually by far too inadequate to inform the spatial and temporal distribution of seismic activities. The use of aerial surveys to identify the location of active fault sources can be problematic because of the existence of blind faults (the location of which has been blurred by erosion or masked by sedimentary deposits). Seismic sources are usually represented as areal sources and are based on mapping the position of the epicentre of historical earthquakes. However, guidance is lacking on how to delineate the boundary of an areal source. Amid a lack of information and guidance, much can be left to the discretion of the operator of PSHA in addressing the unknowns. Thus, predictions derived from the same set of data can be non-unique. In an area where data are sparse, the modelled level of hazard in the vicinity of a historical earthquake would always be higher than before. This implied phenomenon of thePSHA as a predictive tool is an irony given that predictions so derived from it cannot be repeated over time [12]. The standard practice to resolve differences in opinion is to employ the so-called logic tree (decision making by "show of hands") procedure. This is another irony of the PSHA as a scientific procedure, as the outcome of the modelling is susceptible to influence by personal, commercial and political interests.

In EC8, the no collapse performance objective is based upon a recommended design return period (RP) of 475 years, which corresponds to a probability of exceedance of 10% in a 50-year design lifespan of a building. The concept of the Maximum Considered Earthquake (MCE) has not been incorporated into its underlying design philosophy, given that the code was drafted in the mid-1990s, at which time it was still the norm to design the majority of building structures for a return period of up to 500 years. Seismic design provisions around the world have evolved since that time. Notably, at present, there is a general consensus amongst earthquake engineers that an MCE event for normal buildings should have a RP of around 2500 years, which is consistent with a probability of exceedance of 2% in 50 years [13]. Importantly, structural designers operating in low seismicity regions are cautioned, herein, that the amount of increase in the ground motion intensity (corresponding to an increase in the RP from 500 to 2500 years) can exceed the default factor of 1.5 by a wide margin. A factor varying between 2.4 and 5 is predicted for intraplate earthquakes, as shown in Figure 2 [14–16]. As a result, designing a building to the no collapse performance limit state for a RP of 500 years would not in itself be able to offer the building adequate protection from the near-collapse limit state in an MCE. The trend of moving away from the conventional practice of designing to a return period of 500 years was initiated by the influential FEMA450 document [17] to guide the design of new buildings in the United States. The design seismic action was recommended based on an MCE of 2500 years scaled down by a factor of two thirds (reciprocal of 1.5). This scaling factor can be interpreted as the margin between the limit state of no collapse, and collapse prevention, in order that code-compliant buildings can always be assured of their ability not to collapse in a very rare earthquake event [18].

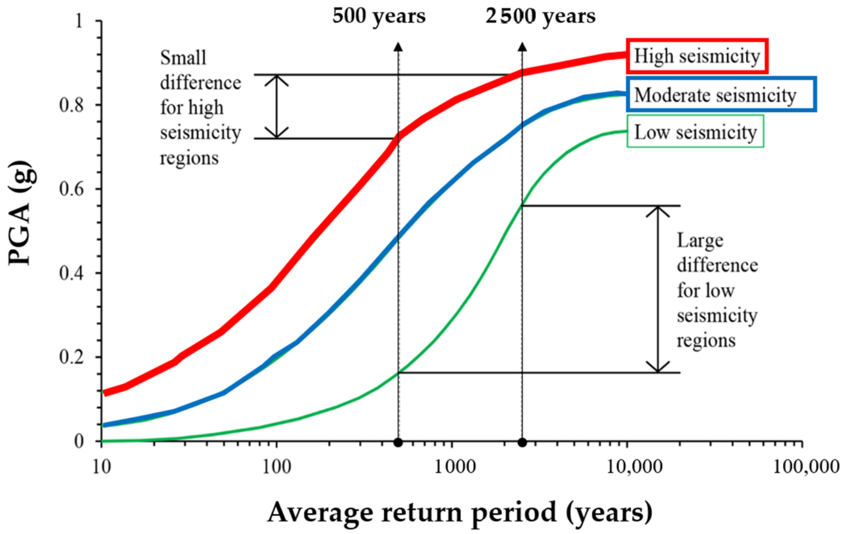


Figure 2. PGA-return period correlation with reference to low-, moderate-, and high-seismicity regions [14].

On recommendations made by WG1 in the draft Malaysia NA to EC8 for public comments [9], a minimum level of the reference peak ground acceleration (PGA) on rock (a_{gR}) of 0.07 g was considered to be specified for Peninsular Malaysia and Sarawak and 0.12 g for most of Sabah. The recommended minimum hazard requirements can be justified by referring to results from PSHA, assuming a uniform spatial distribution of seismic activities and observations on the frequency of occurrence of M > 5 earthquake events over an extensive area [19]. The a_{gR} value of 0.07 g and 0.12 g, as quoted above for a notional return period of 500 years, was two-thirds of the values (0.10 g and 0.18 g, respectively), corresponding to a return period of 2500 years, i.e., MCE [20]. The modelling concept as described is likened to that of background seismicity (which is a well-established 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 0.03 g for a design return period of 500 years.

The requirement of a minimum seismic hazard design factor (Z, known as the effective PGA) of 0.08 for a return period of 500 years was implemented in the 2018 revision to the Australian Standard for seismic actions [21]. Thus, in most parts of Australia $Z = 0.08$ is specified in the new seismic hazard map, superseding an old model 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. However, unlike the Australian Standard [21], recommendations in the draft Malaysia NA [9] for imposing a minimum seismic loading of 0.07 g and 0.12 g to different parts of Malaysia have not been taken up by the enacted version of the Malaysia NA to EC8 [2], which was completed through a decision process based on voting. One of the consequences of the decision is that an unacceptably low a_{gR} value of 0.04 g has been stipulated for Kota Kinabalu (the capital city of Sabah), which was only some 50 km from the epicentre of the M5.9 Ranau earthquake of 2015 (see Figure 3). In addition, given that the modelling has not been subject to any independent audit by a third party, the modeller did not have to abide by any rules nor any form of control. A small interval of 0.01 g PGA contour was created (as shown in Figure 3) even when such a high-resolution seismic hazard map cannot be justified (given that seismic data has only been recorded from one earthquake event).

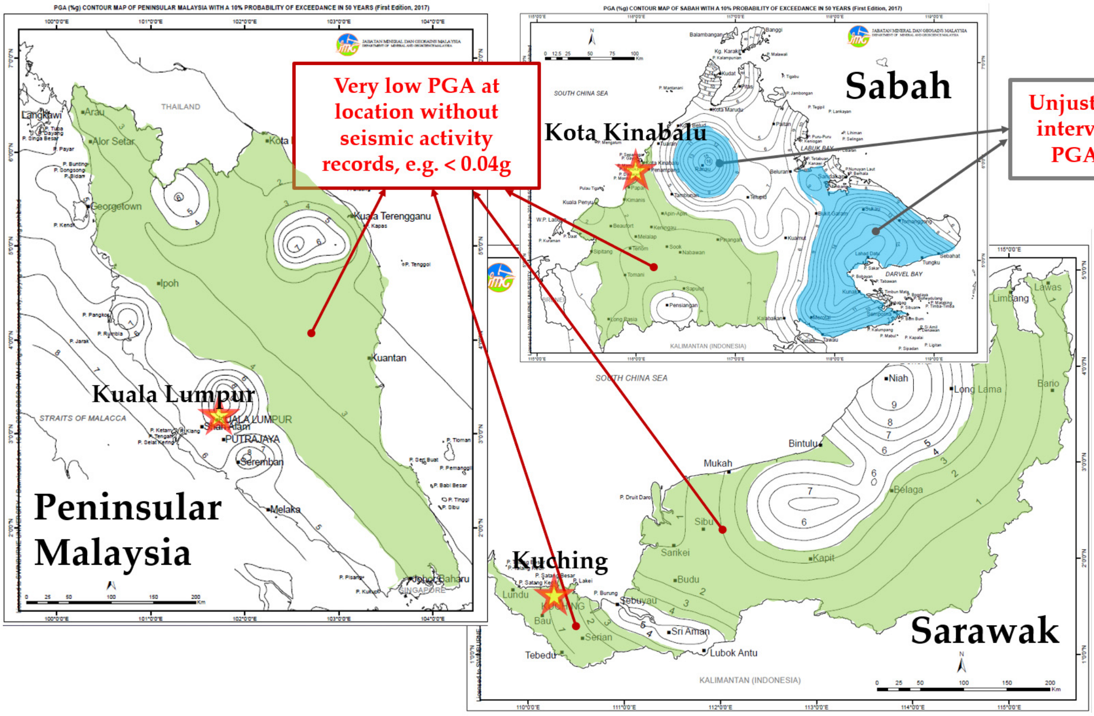


Figure 3. Challenge 1: The uncontrolled use of PSHA methodology in the enacted version of the Malaysia NA to EC8 [2].

The authors pledge all major codes of practice, including EC8, to require seismic hazard maps to be subject to proper auditing and to impose adequate minimum design requirements so that maps such as that shown in Figure 3 do not become part of a legal document for safeguarding the public. The authors recommended adopting a more robust model such as the one depicted in Figure 4. Although the recommended PGA values were originally 0.12 g for most of Sabah, the stipulated level of hazard has been harmonised to 0.11 g to have a smooth interval of 0.04 g across the country (i.e., minimum level of 0.07 g, intermediate level of 0.11 g and the highest level of 0.15 g).

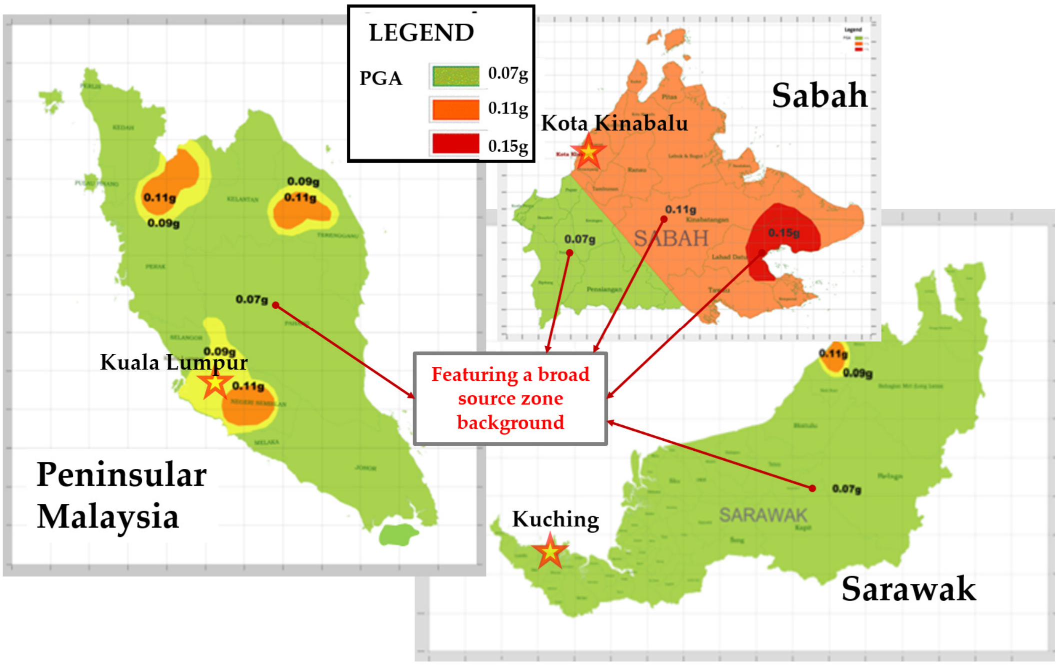


Figure 4. Proposed seismic hazard maps that circumvent Challenge 1.

2.2. Challenge 2: The Incomplete EC8 Site Classification Scheme

In EC8, a site can be classified into a few pre-defined site classes. Site effects are commonly related to a reference site class, i.e., ground type A for rock sites. The inability of this site classification scheme in EC8 to adequately address deep site geology is a matter of concern (see Figure 5). The potential occurrence of resonance 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 with site natural period parameterisation proposed in numerous publications by Pitilakis et al. [22–24]. The basis and justification for incorporating the site natural period as a parameter in the classification scheme and the effects of site resonance in the site amplification factor can be found in earlier studies conducted globally [25–28].

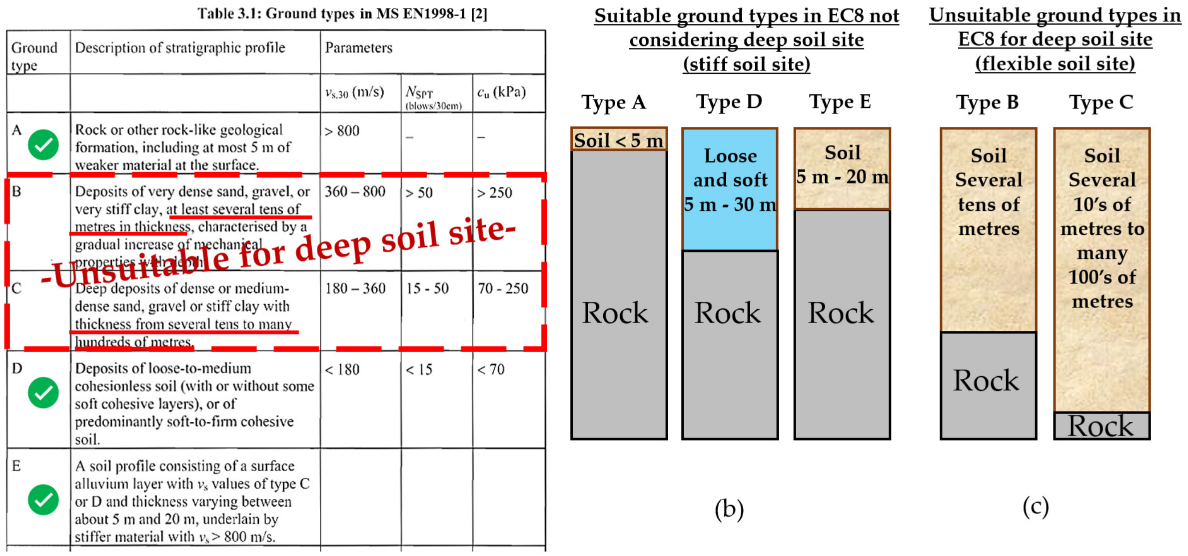


Table 3.1: Ground types in MS EN1998-1 [2]

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.			

(a) (b) (c)

Figure 5. Challenge 2: The incomplete EC8 site classification scheme. (**a**) Table 3.1 in MS EN19981-1 [2]. (**b**) Suitable ground types. (**c**) Unsuitable ground types.

A site classification scheme which incorporates the site natural period as a parameter was clearly much preferred to the then existing classification scheme of EC8 and was considered as the next generation classification scheme [22]. However, the transition to the new scheme had not occurred officially at the time when the Malaysian NA to EC8 [2] was drafted. It was decided that the NA adopted the (atypical) approach of having a dual classification scheme. The two schemes are, namely, Model A and Model B. This was purely a pragmatic decision to address political issues in the regulatory process. Model A can be used for shallow soil sites covered by soil sediments of thickness H_S not exceeding 30 m (Figure 5b), whereas Model B is mandatory for deep soil sites exceeding 30 m (Figure 6). The response spectrum associated with Model A was not stipulated by the main body of EC8 but was derived from analyses made by local investigators and was without justifications that have not been published in an international archival source. By contrast, Model B has a theoretical basis validated by site response analyses and field data from the 1994 Northridge earthquake [27,29–31]. As descriptions for the same ground type in the two classification models are totally different, code users can easily be confused. In comparison between the two models, Model B provides more accurate predictions of the real behaviour of a soil column in an earthquake. Model B is free of limitations in relation to the depth of the soil sediments, i.e., it can be applicable to soil sediments of any depth. Model B is recommended by the authors because of the deficiencies of Model A in covering for deep geology and more so where there is a distinct soil–rock interface.

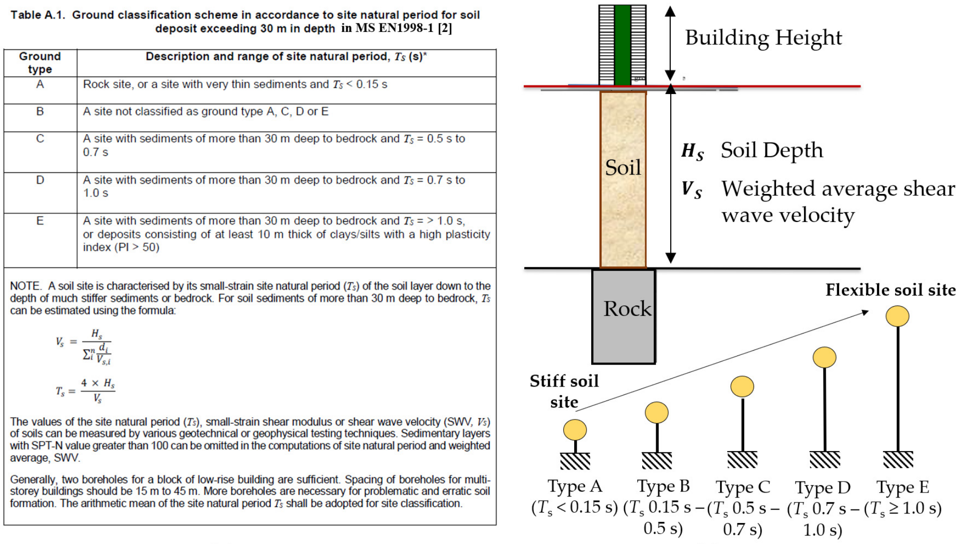


Table A.1. Ground classification scheme in accordance to site natural period for soil deposit exceeding 30 m in depth in MS EN1998-1 [2]

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 s to 0.7 s
D	A site with sediments of more than 30 m deep to bedrock and T_S = 0.7 s to 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)

NOTE. A soil site is characterised by its small-strain site natural period (T_S) of the soil layer down to the depth of much stiffer sediments or bedrock. For soil sediments of more than 30 m deep to bedrock, T_S can be estimated using the formula:

$$V_s = \frac{H_s}{\sum_i^n \frac{d_i}{V_{s,i}}}$$

$$T_s = \frac{4 \times H_s}{V_s}$$

The values of the site natural period (T_S), small-strain shear modulus or shear wave velocity (SWV, V_S) of soils can be measured by various geotechnical or geophysical testing techniques. Sedimentary layers with SPT-N value greater than 100 can be omitted in the computations of site natural period and weighted average, SWV.

Generally, two boreholes for a block of low-rise building are sufficient. Spacing of boreholes for multi-storey buildings should be 15 m to 45 m. More boreholes are necessary for problematic and erratic soil formation. The arithmetic mean of the site natural period T_S shall be adopted for site classification.

(a) (b)

Figure 6. Solution to circumvent Challenge 2 with a new site classification scheme. (**a**) Definition for Model B from the Malaysia NA to EC8 [2]. (**b**) Analogy of stiff soil and flexible soil sites according to single-degree-of-freedom lumped mass oscillators.

With Model B, the rock–soil amplification ratio has its maximum value occurring at the site natural period (T_S). Figure 6a shows the five ground types as defined by the range of values of T_S. Apart from ground type A, which refers to rock sites (or very stiff soil sites), all 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, which can be viewed in analogy with a series of single-degree-of-freedom lumped mass oscillators model as shown by Figure 6b. The value of T_S is based on the conditions of small shear strains in the soil. The shear wave velocity (SWV, V_S) of soils can therefore be estimated based on geophysical or geotechnical measurements involving the use of Equation (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:

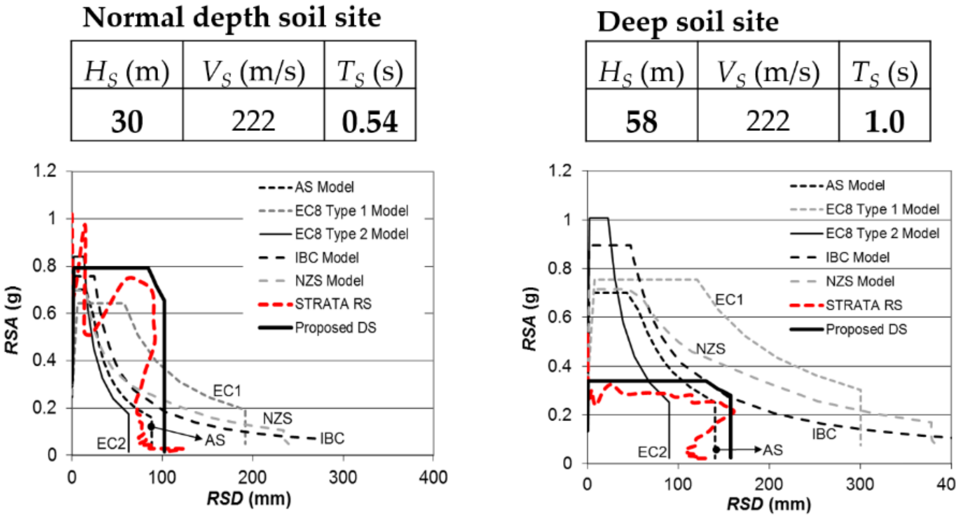
$$T_s = 4 \times \sum\nolimits_{i=1}^{n} \frac{d_i}{V_i} = \frac{4H_s}{V_s}, \tag{1}$$

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 the site natural period and weighted average SWV. The authors proposed effective ways to choose the empirical equations to convert SPT-N to SWV [32] based on recommendations presented in a PEER report [33].

Model B has been reviewed and endorsed by Professor Kyriazis Pitilakis—current President (2018–2022) of the European Association of Earthquake Engineering (EAEE), who has been the Coordinator of the EAEE Working Group 6 on Geotechnical Earthquake Engineering, leading the future revision to EC8 concerning geotechnical matters [34].

In summary, site classification 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. The key feature of this classification model is the incorporation of the site natural period as the key modelling parameter. Model B is therefore generic in nature and is found on sound theoretical principles to emulate real response behaviour of soil sediments of different depths.

In a case study of a normal stiff soil site of 30 m depth (see Figure 7a) and a deep soil site of 58 m (see Figure 7b), the soil sediments had a common weighted average shear wave velocity of 222 m/s. The soil response spectra in both cases as obtained from the 1D site response analyses using STRATA [35] are presented in the format of Acceleration-Displacement Response Spectrum (ADRS) diagrams. It is shown that the proposed design response spectrum (DS) models adopted as Model B in the Malaysia NA to EC8 match the site response analysis results very well [31].



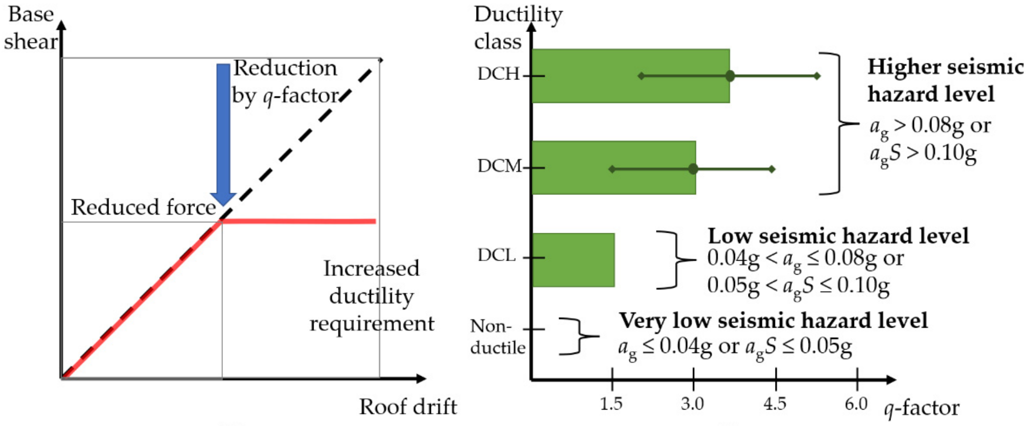
(a) (b)

Figure 7. Proposed design response spectrum (DS) model based on Model B in the Malaysia NA to EC8 for (**a**) a normal 30 m depth soil site with T_S = 0.54 s and (**b**) a flexible deep soil site having the same weighted average shear wave velocity with T_S = 1 s [31]. The proposed model matches site response analysis results from STRATA [35].

2.3. Challenge 3: EC8 Mandated the Use of DCM Ductile Detailing for Higher Seismic Hazard Level

The third challenge was that EC8 had mandated Ductility Class Medium (DCM) detailing, which was about designing the structure to develop an inelastic response mechanism to dissipate energy in seismic conditions. This design approach is common in areas that are stipulated with a high level of hazard. EC8 recommended a set of pre-defined thresholds for very low, low and high seismic hazard levels as informed by Nationally Determined Parameters (NDPs). Introducing EC8 as an independent document instead of imposing seismic design provisions into various material standards was to make it easier for countries with a very low level of seismic hazard to opt out of adopting EC8 at all [36]. However, there has not been much guidance for regulators in low-to-moderate seismicity regions on how best to optimise the design and detailing requirements of building structures.

Figure 8a shows the concept of a force-based seismic design approach in which a behaviour factor (q-factor in EC8 [1]), or a similar set of factors, is introduced to lower the design strength of the seismic action whilst allowing the structure to experience post-elastic deformation in a ductile manner; the higher the level of ductility and/or overstrength, the higher the q-factor. Figure 8b shows the range of q-factor values recommended in EC8 according to ductility classes. Areas where the value of the design ground acceleration on rock (a_g, being the product of a_{gR} with an importance factor, γ_I) is lower than 0.08 g, or where a_gS is lower than 0.10 g (where S is the soil factor), the condition of seismicity is classified as "low". Structures located in these areas can be designed to Ductility Class Low (DCL) in alignment with design compliance with the respective material-specific design standard. For example, structures built of reinforced concrete (RC) are designed to requirements stipulated by Eurocode 2 (EC2) [37], which is without any seismic detailing provisions. In areas where the hazard level is above the "low" threshold (including borderline cases, say a_g is 0.09 g), designers are compelled to comply with ductile design and detailing practices consistent with requirements in areas of high seismicity. This approach to seismic design may seem logical to some. However, the authors experienced major issues when implementing it in Malaysia.



(a) (b)

Figure 8. Challenge 3: The mandated use of DCM at the pre-defined threshold of seismic hazard level (**a**) the use of q-factor to trade-off strength with ductility in force-based methods (**b**) the pre-defined threshold in EC8.

In regions of low-to-moderate seismicity, such as Malaysia, practising engineers typically lack knowledge and experience in incorporating ductility into the design of a structure. The authors faced difficulties communicating the practice of ductile detailing (which was not the only viable way to counter seismic actions [38]) to the Malaysian engineering community in various seminars or events held for knowledge dissemination purposes. Dialogues with local structural design practitioners revealed the sentiment that DCM design should never be made compulsory, given that strength could be traded off with ductility. In the original draft of Malaysia NA to EC8 [9], which was prepared by the authors, building structures should have the option of adopting DCL irrespective of its location. This regulatory approach could be accomplished by altering the NDP for the low seismic hazard level so that no structure is compelled to be designed to DCM requirements (noting that DCH is overly complicated [38] and is only suitable for use in high seismic areas).

However, given the lack of justifications from the literature, the recommendations made by the authors in the original draft were challenged by a group of local investigators. As a result, the published Malaysia NA to EC8 [2] does not provide the option of adopting DCL for all building structures. Instead, the NA was to simply go by the recommended seismic hazard thresholds of EC8 when deciding if the design is to adopt DCL or DCM design and detailing. The authors strongly advocate improving current building design practices in low-to-moderate seismicity regions which are proliferated with structures lacking considerations of the performance of the structure in seismic conditions. However, linking the seismic hazard level of an area to ductile design classification is an outdated concept, gives little regard to local practices and is ineffective in ensuring a safe and sustainable built environment. Blindly imposing DCM design requirements would not deliver the desired outcomes.

The published Malaysia NA to EC8 [2] may result in many areas in the country being subjected to DCM design requirements. In anticipation of this challenge to engineering practice, the authors took the proactive initiative to assist practising engineers in coping with DCM design in RC buildings. Looi et al. [39] summarised the steps and developed EC8 DCM tools for rectangular RC columns (see Figure 9 for a snapshot) and RC shear walls (see Figure 10 for a snapshot). Designing RC columns and shear walls to DCM requirements requires determining the ductility demand (Step 1) and the associated confinement requirements (Step 2), which are to be compared against the confinement capacity (Step 3).

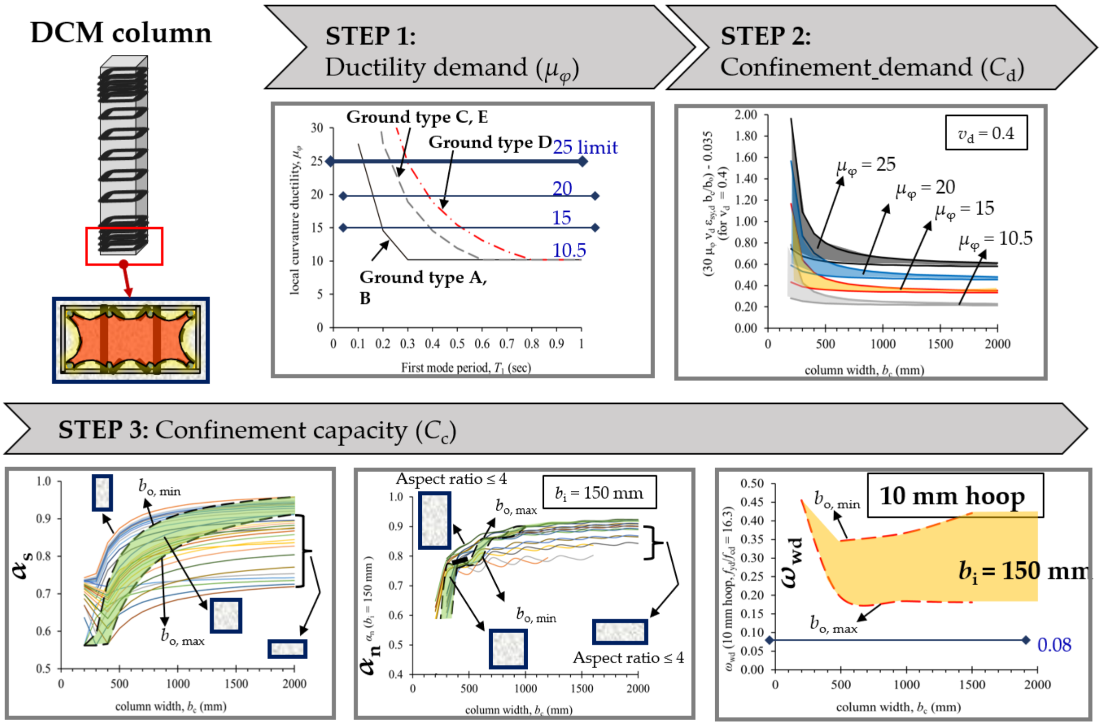
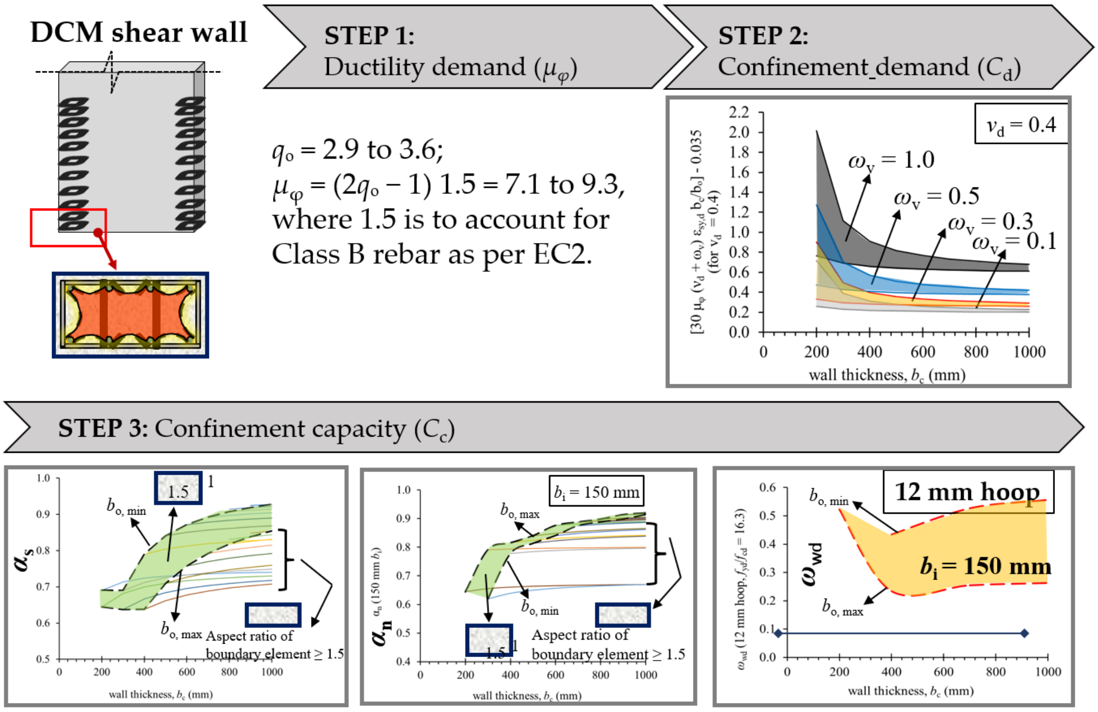


Figure 9. Developed DCM tools for rectangular RC columns to circumvent Challenge 3 [39].



$q_o = 2.9$ to 3.6;
$\mu_\varphi = (2q_o - 1)\ 1.5 = 7.1$ to 9.3,
where 1.5 is to account for Class B rebar as per EC2.

Figure 10. Developed DCM tools for RC shear walls to circumvent Challenge 3 [39].

A summary of the design recommendations is listed in Table 1. The length of the boundary elements is either 0.15 times the wall length or 1.5 times the wall thickness, whichever is higher. The rather complex and tedious confinement design procedure is hence circumvented. Interestingly, the presented design solutions are consistent with the draft provisions of the second generation of EC8 [40].

Table 1. Summary of recommendation for simplified DCM for RC buildings.

RC Elements	Parameters	Recommended Values
Beam	Depth	600 mm
	Hoop diameter	10 mm
	Hoop spacing	150 mm
	Longitudinal rebar diameter	20 mm
Rectangular columns	Size	500 mm × 500 mm
	Hoop diameter	12 mm
	Hoop spacing	150 mm
	Longitudinal rebar diameter	20 mm
	Longitudinal rebar spacing	150 mm
	α_n	0.78
	α_s	0.73
Shear walls	Thickness	400 mm
	Boundary length	600 mm [1]
	Hoop diameter	16 mm (or bundled rebars)
	Hoop spacing	150 mm
	Longitudinal rebar diameter	20 mm
	Longitudinal rebar spacing	150 mm
	α_n	0.80
	α_s	0.70

[1] The confined boundary element length has not considered the confined compression zone x_u at ultimate curvature estimated from equilibrium.

EC8 has imposed what is widely perceived as strict and complex rules for RC design and detailing. Preparing a full-fledge DCM based design calculation could be a daunting task to many engineers practicing in low-to-moderate seismicity regions. To circumvent around this challenge to Malaysian engineers, the authors have developed simple deemed-to-comply rules for achieving DCM compliance for the seismic design of RC beams, columns and shear walls. Meanwhile, it was revealed from past experimental research on RC columns [41,42] and RC shear walls [43,44] that deformability was severely degraded in conditions of high axial compression. Practitioners are urged to control the amount of axial compression on RC members irrespective of confinement provisions for ductility.

2.4. Challenge 4: EC8 Imposes Modelling of Irregular Buildings for Dynamic Analysis

EC8 provides a code-based lateral force method to emulate seismic behaviour by applying equivalent static forces to the building. However, this code-stipulated simplified analysis method is subject to stringent pre-qualification criteria which are concerned with vertical and horizontal regularity. Most of the building stocks in Malaysia feature irregularities in planning, such as asymmetrically disposed structural walls around the building, resulting in a significant eccentricity of the centre of rigidity from the centre of mass of the building. This form of irregularities can be compound with other forms of irregularities such as setbacks, discontinued load paths and transfer structures. EC8 prohibits the use of the lateral force method on a building that possesses any of these irregularity features. EC8 stipulates three-dimensional (3D) dynamic analysis (or modal response spectrum analysis) as the default analysis procedure. Executing dynamic analysis in a controlled manner requires expertise and experience in structural dynamics, and such engineering skills can be scarce in a country where seismic design practice has yet to be established. This type of challenge in Malaysia is common to other countries of low-to-moderate seismicity. To circumvent the challenge, the authors have devised a simple and yet accurate method of structural analysis (referred herein as the Generalised Force Method, GFM) that can be applied to multi-story buildings featuring horizontal and vertical irregularities. A key feature of GFM is that it does not rely on any code-based empirical formula to predict the natural period of vibration of the structure. The GFM may be applied at three different levels depending on the building (see Figure 11): GFM-1 is suitable for use in the 2D analysis of low-rise buildings; GFM2 has been enhanced to handle taller buildings, as higher mode effects have been taken into account (whilst generalised mode shapes and default modal period ratios are made use of to eliminate the need of modal analysis); and GFM3, which is structured into three tiers (Quick, Refined or Detailed methods), has been enhanced further to handle 3D phenomena [45]. Interested readers are recommended to read into recent publications presenting the GFM [45–47].

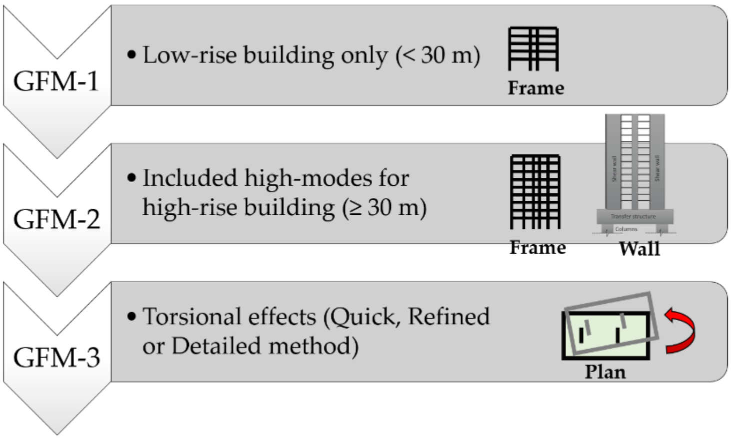
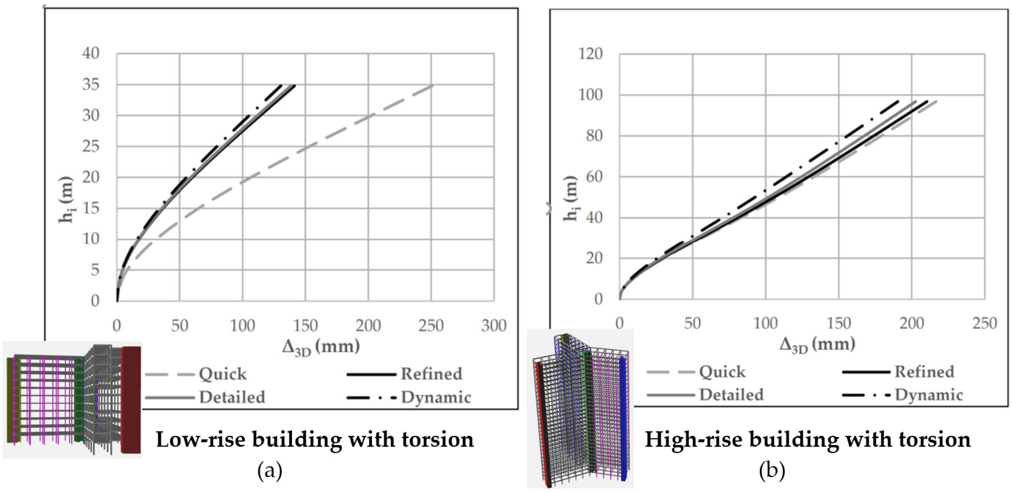


Figure 11. GFM methods to check dynamic analysis results.

The GFM has been demonstrated to provide reliable predictions on the deflection behaviour in buildings, including high-rise buildings and torsion-sensitive buildings (see Figure 12). GFM can be used as a tool to benchmark results generated by the computer in order to exercise control over the use of commercial software in undertaking complex analyses and to enable the design engineers to gain better understanding of the seismic response behaviour of the building.



(a) (b)

Figure 12. Validated examples of displacement profiles using the GFM methods: (**a**) asymmetrical low-rise building (**b**) asymmetrical high-rise building.

3. Future Outlook of the Second Generation of EC8 and Beyond

Standard drafting can be very time-consuming and baffled by many challenges. Take EC8 as an example: The first version was published in 2004 following a gestation period of nearly 20 years [48]. Revision to EC8, which is still underway, has been discussed in a few publications [36]. The second generation of EC8 was originally expected to have been concluded around 2020 [48] but had to be postponed to the end of 2021 and, subsequently, postponed further to 2022 (noting that its release is affected by the schedule of releasing a few related codes) [38]. Several key features in the revision as reported in the literature are summarised as follows [36,38,48]:

1. The number of NDPs is reduced by harmonisation, and this requires international consensus among the European member states.
2. The second generation of EC8 aims to improve its clarity by simplifying clauses and removing rules with limited practical utilities (i.e., overly "academic" provisions). For instance, the dependence on ductility classes to the level of seismicity is under review. The conditions of low-to-moderate seismicity areas require special considerations [38]; the number of ductility classes is consolidated from three to two [36,38]; the use of two spectral shapes Type 1 and Type 2 is to be abandoned [38]; the soil classification scheme and the associated site-factor models are to be revised [22–24]; methods of analysis for handling irregularities in buildings are also under review [38].
3. Research findings to fill the voids of knowledge and include introducing new methodologies for handling post-tensioned buildings, flat slab buildings and high-strength concrete.
4. Allow changes to evolve gradually. Engineers who have been trained to operate with the existing version of EC8 should not have much difficulty adapting to the new version. On a separate note, earthquake engineering is a fast-evolving discipline (e.g., the use of conditional mean spectrum [49] and risk-targeted hazard spectra [50] with the considerations of community resilience [51]). Hence, the EAEE has set up a working group entitled 'Future direction for EC8' to oversee the long-term development of EC8 through establishing broad guiding principles that are in alignment with the latest development and to gradually phase out outdated practices which are founded on technologies developed as far back as the 1990s or earlier [52].

4. Conclusions

This paper aims to record important milestones achieved by the authors and co-workers, who have been engaged for over a decade in developing the first seismic design standard for Malaysia in the form of a NA to EC8 [1,2]. NDPs were introduced in EC8 to resolve differences where consensus could not be reached amongst the European Commission member states during the drafting of EC8 [36]. Ironically, the authors encountered similar challenges as consensus over the NDP of the nation could not be reached. In addition, four major technical challenges stemming from outdated clauses in EC8 and their lack of fit for use in a low-to-moderate seismic environment were highlighted, discussed, and critiqued. A few key challenges have been brought up for detailed discussions, as summarised below:

1. There was a lack of control in applying the PSHA methodology to areas with a paucity of representative and reliable seismic data. To address this situation, imposing a minimum level of seismic hazard was recommended.
2. Areas typified by limited ductile building construction can be susceptible to soil-structure resonance, and more so on deep soil sites [31]. A conventional site factor model, such as that stipulated in EC8, would not cater for resonance conditions as described. An alternative site classification scheme in which the site natural period is an explicit modelling parameter was introduced.
3. The regulatory approach of mandating DCM ductile detailing requirements following the level of seismic hazard of the area (as shown on the seismic hazard maps) is an outdated practice. The viable option of using strength to trade off for ductility was

recommended. In addition, a simplified set of code-compliant DCM designs for RC columns and walls has been developed by the authors to circumvent the need to apply the complex design procedures as stipulated by EC8.

4. Amid the proliferation of commercial structural analysis software, EC8 mandates the use of dynamic analysis in the design of the majority of buildings. Dynamic analysis necessitates engineering skills and experiences that are scarce among engineers in Malaysia and other low-to-moderate seismicity regions. GFM methodology was introduced by the authors to exercise control of the use of commercial software avoiding the "black box" syndrome.

The future development of EC8 has been actively discussed in the literature in recent times [38]. Some of the new features are interestingly aligned with recommendations by the authors in relation to the four challenges discussed in this paper. The authors concur with the view that an effective standard should feature stability, simplicity and harmonisation [36,38,48]. Hence, it is also hoped that the next generation of EC8 contains well-defined provisions, free of grey areas and overly constrained clauses. Future developments of regulatory control for seismic design in low-to-moderate seismicity regions need to be approached in context with existing structural design practices in these regions.

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Appendix A

Table A1. The details of the chronological activities from 2004 to current year 2021 in the writing of the Malaysia NA to EC8.

No.	Events	Location	Year	Remarks
1	Sumatran subduction M9 earthquake	Acheh, Indonesia	2004	Seismic event (1)
2	Sumatran subduction M8.6 earthquake	Nias, Indonesia	2005	Seismic event (2)
3	IEM Civil and Structural Technical Division's position documents	Kuala Lumpur	2005–2006	Concern of engineers in Malaysia
4	Sumatran subduction M8.4 earthquake	Bengkulu, Indonesia	2007	Seismic event (3)
5	IEM appointed by Department of Standards Malaysia to be the Standards Writing Organisation (SWO) for NA to EC8.	Kuala Lumpur	2007	Initiation of standard writing
6	IEM set up a Technical Committee (TC) on Earthquakes and established Working Group 1 (WG1)	Kuala Lumpur	2008	Setting up TC and WG for standard writing

Table A1. *Cont.*

No.	Events	Location	Year	Remarks
7	Local M4.2 seismic activities detected	Bukit Tinggi, Selangor	2007–2009	Seismic event (4)
8	A journal paper "Seismic load estimates of distant subduction earthquakes affecting Singapore" in *Engineering Structures* [6]	-	2009	Important publication (1)
9	Two-Day Course on Earthquake Resistant Design and Analysis of Buildings and Structures	Kuala Lumpur	2009	Dissemination of knowledge (1)
10	A journal paper "Ground-motion attenuation relationship for the Sumatran megathrust earthquakes" in *Earthquake Engineering and Structural Dynamics* [7]	-	2010	Important publication (2)
11	Symposium on Earthquake Ground Motions and Responses of RC Buildings	Kuala Lumpur	2010	Dissemination of knowledge (2)
12	Two-Day Course on Analysis and Design to EC8 Demystified	Kuala Lumpur	2011	Dissemination of knowledge (3)
13	An article "An Approach for Seismic Design in Malaysia following the Principles of Eurocode 8" in the *IEM JURUTERA Monthly Bulletin* [8]	-	2011	Important publication (3)
14	Sequel to Two-Day Course on Analysis and Design to EC8 Demystified	Kuala Lumpur	2012	Dissemination of knowledge (4)
15	Two-Day Symposium and Workshop on Earthquake Engineering in Malaysia and Asia Pacific Region	Kuala Lumpur	2012	Dissemination of knowledge (5)
16	Local M4.1 seismic activities detected	Temenggor Lake, Perak	2013	Seismic event (5)
17	An article "Recommended Earthquake Loading Model for Peninsular Malaysia" in the *IEM JURUTERA Monthly Bulletin* [53]	Kuala Lumpur	2013	Documentation in publication (1)
18	Two-Day Symposium and Workshop on Earthquake Engineering in Malaysia and Asia Pacific Region	Kuala Lumpur	2013	Dissemination of knowledge (6)
19	Two-Day Workshop on Recommended Earthquake Loading Model in the Proposed NA to EC8 for Sabah, Sarawak and Updated Model for Peninsular Malaysia	Kuala Lumpur	2014	Dissemination of knowledge (7)
20	IEM meeting and Standard writing workshop	Kuala Lumpur	2014	Major meeting/forum with stakeholders (1) *
21	Two-Day International Seminar and Workshop on Presentation and Reviewing of the Draft Malaysia NA to EC8	Kuala Lumpur	2015	Dissemination of knowledge (8)
22	IEM meeting and Standard writing workshop	Kuala Lumpur	2015	Major meeting/forum with stakeholders (2) *
23	Two-Day Course on How to Utilise Our Proposed EC8 Malaysia NA to Our Practising Consulting Engineers	Kuala Lumpur	2015	Dissemination of knowledge (9)
24	Special issue "Developing Malaysian Design Standards for Earthquake Resistance" in *IEM JURUTERA Monthly Bulletin* [54]	-	2015	Documentation in publication (2)
25	Local M5.9 earthquake	Ranau, Sabah	2015	Seismic event (6)
26	Kota Kinabalu, Sabah Town Council, mandated seismic design with PGA of 0.12 g	Kota Kinabalu, Sabah	2015	Interim enforcement of seismic design
27	Special issue "Public Safety in Earthquake Event" in *IEM JURUTERA Monthly Bulletin* [55]	-	2016	Documentation in publication (3)

Table A1. *Cont.*

No.	Events	Location	Year	Remarks
28	IEM Standard meeting to go through the public comments	Kuala Lumpur	2016	Major meeting/forum with stakeholders (3) *
29	A journal paper “Minimum loading requirements for areas of low seismicity” in *Earthquakes and Structures* [19]	-	2016	Documentation in publication (4)
30	Dialogue on The Proposed NA to MS EC8 on Design of Structure for Earthquake Resistance	Kota Kinabalu, Sabah	2016	Major meeting/forum with stakeholders (4) *
31	Special meeting with Sabah seismologist/geologist	Kota Kinabalu, Sabah	2016	Major meeting/forum with stakeholders (5) *
32	Draft Malaysian EC8 NA for public comments [9]	Kuala Lumpur	2016	Major meeting/forum with stakeholders (6) *
33	WG1 meeting with Department of Standards Malaysia (DSM)	Shah Alam, Selangor	2016	Major meeting/forum with stakeholders (7) *
34	National Consultation of the Draft Malaysian EC8 NA by DSM	Shah Alam, Selangor	2016	Major meeting/forum with stakeholders (8) *
35	Seminar on Analysis of Torsional Actions in Buildings	Kuala Lumpur	2016	Dissemination of knowledge (10)
36	WG1 study group meeting with Minister of Science, Technology and Information	Kota Kinabalu, Sabah	2016	Major meeting/forum with stakeholders (9) *
37	A journal paper “A design spectrum model for flexible soil sites in regions of low-to-moderate seismicity” in *Soil Dynamics and Earthquake Engineering* [31]	-	2017	Documentation in publication (5)
38	Special four seismic experts meeting	Kuala Lumpur	2017	Major meeting/forum with stakeholders (10) *
39	Two-Day Workshop on Proposed Seismic Analysis Methods for Regions of Low to Medium Seismicity	Kuala Lumpur	2017	Dissemination of knowledge (11)
40	A conference paper “Intricacies of addressing distant and local earthquakes in Malaysia in the official design standard EC8 Malaysia NA” at AEES 2017 [56]	Australia	2017	Documentation in publication (6)
41	Finalised Malaysian EC8 NA for public comments	Kuala Lumpur	2017	Major meeting/forum with stakeholders (11) *
42	Publication of MS NA EN 1998-1: 2015 (2017) [2]	-	2017	Published standard
43	Public forum on Malaysia NA to EC8 by DSM	Shah Alam, Selangor	2017	Major meeting/forum with stakeholders (12) *
44	A journal paper “Seismic Hazard and Response Spectrum Modelling for Malaysia and Singapore” in *Earthquakes and Structures* [20]	-	2018	Documentation in publication (7)
45	Two book chapters in *Guideline on Design of Buildings and Structures in Low-to-moderate Seismicity Countries* [46,47]	Hong Kong	2018	Documentation in publication (8)
46	Two-Day Symposium on Earthquake Resistant Design of RC Buildings based on the EC8 Malaysia NA: From Loading Characterisation to RC Detailing	Kuala Lumpur	2018	Dissemination of knowledge (12)
47	Two-Day Symposium on Earthquake Resistant Design of RC Buildings based on the EC8 Malaysia NA: From Loading Characterisation to RC Detailing	Kuching, Sarawak	2019	Dissemination of knowledge (13)

Table A1. *Cont.*

No.	Events	Location	Year	Remarks
48	A conference paper “The Malaysian Seismic Design Code: Lessons learnt” at NZSEE 2019 Pacific Conference on Earthquake Engineering (PCEE) [3]	Auckland, New Zealand	2019	Dissemination of knowledge (14)
49	Launching of www.QuakeAdvice.org website (last assessed on 28 October 2021) [10]	-	2020	Dissemination of knowledge (15)
50	One-Day webinar on Online Tools for Earthquake Resistant Design of RC Buildings based on the EC8 Malaysia NA	Malaysia, Australia	2021	Dissemination of knowledge (16)
51	A journal paper “Fast Checking of Drift Demand in Multi-Storey Buildings with Asymmetry” in *Buildings* [45]	-	2021	Documentation in publication (9)
52	A journal paper “Site-Specific Response Spectra: Guidelines for Engineering Practice” in *CivilEng* [32]	-	2021	Documentation in publication (10)
53	4-half day webinar on Analysis and Design of Building Structures for Seismic Environment in Malaysia	Malaysia	2021	Dissemination of knowledge (17)
54	A conference paper “Simplifying Eurocode 8 Ductile Detailing Rules for Reinforced Concrete Structures” at 17th World Conference of Earthquake Engineering [39]	Sendai, Japan	2021	Documentation in publication (11)

* These are major meetings/forums. Frequent communications between group members took place throughout the whole process.

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