Asian Journal of Civil Engineering
https://doi.org/10.1007/s42107-023-00600-w

RESEARCH

Development of elastic design response spectra with emphasis on far-source earthquakes for low to moderate seismic region

Abu Bakar Nabilah[1] · **Raudhah Ahmadi**[2] · **Noor Sheena Herayani Harith**[3] · **Azlan Adnan**[4] · **Meldi Suhatril**[5]

Received: 9 December 2022 / Accepted: 2 February 2023

Abstract

The development of design response spectra is crucial for earthquake design of structures. However, there are disagreements from the engineering community on the suitability of design values proposed by the existing design code which underestimates the long-period responses for flexible soils, typical of far-source earthquakes. This study uses soil response analysis to investigate the effect of near and far sources' earthquakes on the response spectral acceleration of Malaysia in three seismically different regions, namely Peninsular Malaysia, Sabah and Sarawak. 1923 borehole data have been collected and analysed under 5 near and 4 far sources earthquakes, subjected to the intensity from the probabilistic seismic hazard analysis. The results show that for Peninsular Malaysia, the far-source earthquake will govern the response at a period of more than 1 s, indicating its importance for structures with long periods such as tall buildings. It is also found that the corner period T_C is slightly higher than the code recommended and is dependent on the soil property, while T_D is significantly higher for far-source earthquakes due to the larger magnitudes. The finding of this research shows that the Eurocode 8 supplemented by the Malaysian National Annex (MS-EN1998-1, 2017) can be used to design structures in Malaysia, with some adjustments to the longer period motion for Peninsular Malaysia. Finally, it is recommended to perform an enhanced analysis for important structures of long periods to ensure their loadings are not underestimated.

Keywords Response spectral acceleration · Code · National Annex · Far-source earthquakes

Introduction

Malaysia is located on a stable Sunda plate, surrounded by countries of high seismicity, namely Indonesia and the Philippines. Based on the probabilistic seismic hazard analysis (PSHA) conducted, Malaysia is a country of low to moderate seismicity, depending on the region. Malaysia consists of 3 geographically different regions, namely Peninsular Malaysia, Sabah, and Sarawak as shown in Fig. 1. The seismic threats in Peninsular Malaysia are from local and far-source earthquakes, while Sabah and Sarawak are mainly from local earthquakes.

Recently, Malaysia adopted Eurocode 8 (EN, 2004) for the seismic design of structures. However, the seismicity of the region is much different from the recommended values in the code, triggering the need to develop Malaysia National Annex (MS EN, 2017) for the regional design values. Due to the lack of recorded regional data for local and far-source earthquakes, the development of response spectra based on statistical analysis is not possible and could cause large over predictions of the potential hazard (Gao et al., 2021).

The seismic hazard in Malaysia is coming from two main sources, (1) near-source earthquakes of small to moderate magnitudes (maximum 5.3 M_w for Peninsular Malaysia and Sarawak, and 6.5 M_w for Sabah) with epicentral distances ranging from 5 to 30 km, and (2) far-source earthquakes from strike-slip and subduction zones with large magnitudes (7–9.2 M_w) and distances (200 to 500 km). The former causes larger amplitude at smaller periods, while the latter

✉ Abu Bakar Nabilah
nabilah@upm.edu.my

[1] Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

[2] Faculty of Engineering, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia

[3] Faculty of Engineering, Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia

[4] Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

[5] Faculty of Engineering, Universiti Malaya, 50603 Kuala Lumpur, Malaysia

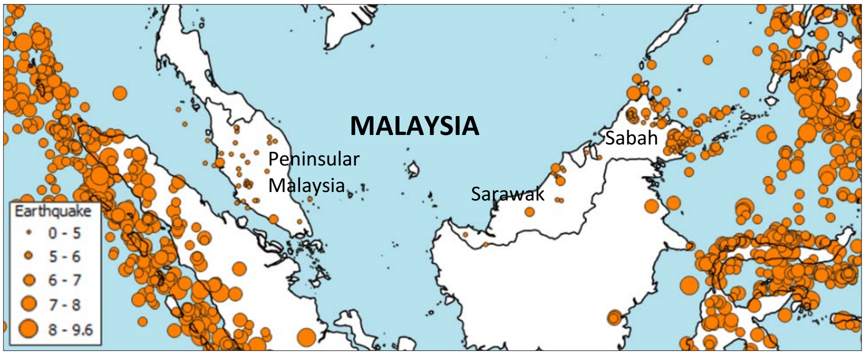

Fig. 1 Past earthquakes around Malaysia

controls the maximum displacement range at the higher periods. The effects of the sources on the seismic demand must be investigated due to the unique nature of this region. Tremors from far-source earthquakes have been felt especially in Peninsular Malaysia (example: 6.1 M_w West Sumatra earthquake on 25 February 2022). The need to distinguish and emphasise the importance of far-source earthquake effects must be done to ensure the proper design of medium to high-rise buildings.

Far-source earthquakes

The far-source long-period earthquake is characterised by its later-arriving surface waves, having long-period motion (Dai et al., 2019). The long-period motion tends to attenuate slowly at a longer distance due to the path effect. In the paper by Koketsu and Miyake, (2008), the velocity time-history of far-source long-period earthquakes exhibits a longer duration compared to the near-source long-period earthquakes. In addition, the values of the velocity response spectra of the far-source earthquake are comparable to the near-source earthquake, despite the smaller amplitude of the former. The 1968 Tokachi-Oki earthquake in Japan with 8.2 M_w is an example of such an earthquake, where the predominant period is 2.5 s and the motion was measured in a high-rise building 650 km from the epicentre. As highlighted by Dai et al., (2019), near-source earthquakes are earthquakes with an epicentral distance of fewer than 50 km. In their study, there is no clear definition of far-source earthquake as the far-source long-period ground motions were selected based on visualisation of the waveforms of the velocity–time series. However, it is implied that earthquakes with distances of more than 100 km are taken as far-source earthquakes (Saman et al., 2021).

The motion of far-source long-period earthquakes can also be amplified due to the site condition, causing the greatest effects to the medium to high-rise structures (1 to 10 s periods). The effect of far-source long-period motion on flexible soil is evident in the case of the famous Michoacan earthquake in 1985. Mexico City, located 400 km from the epicentre, is heavily damaged compared to locations that are much closer to the epicentre. The field report by EEFIT (Booth et al., 1986) concluded that the motion amplified by the local site condition is very large, even though the motion attenuated by the distance is considered to be harmless. The amplification is found to be 10 times of rock site, at a period of about 2 s. Nabilah et al. (2019) in their research, discovered that sites with soft, flexible soil yield higher spectral acceleration at longer periods, and up to 2 to 3 times larger than that recommended by Eurocode 8.

Soil response in Eurocode 8 and its application in low to medium seismic regions

Soil classification

The soil classification in Eurocode 8 (EN, 2004), EC8, is quite descriptive, which takes into account the soil profile for limited depths of soil. EC8 uses the average shear wave velocity of the top 30 m of soil ($V_{s,30}$), where the classification generally goes from stiff (soil A) to soft (soil D) soil as given by other seismic codes. Soil type E, on the other hand, deals with shallow soft soil (soil C or D) underlain by bedrock, which will cause large amplification due to the impedance contrast between bedrock and the overlain soil. However, soil classification based on $V_{s,30}$ might not represent the actual soil behaviour, which could lead to errors in the determination of earthquake loads for deep soil conditions (Barani et al., 2008; Looi et al., 2021; Pitilakis et al., 2004).

For areas with low to moderate seismicity, direct shear wave velocity measurement using the in situ test is very rarely conducted, if any. Hence, an indirect measurement through a standard penetration test (SPT) is used. These tests are usually terminated when the number of blows exceeded 50 within 15 cm depth for three consecutive times. Usually, the soil test rarely reaches bedrock due to the high soil depth.