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COST COMPARISON FOR NON-SEISMIC (EC2) AND SEISMIC (EC8) DESIGN IN DIFFERENT DUCTILITY CLASS

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A B S T R A C T

Earthquakes in Malaysia, such as 2008 Bukit Tinggi and 2015 Ranau Earthquake, have caused Malaysian authorities to look into the importance of seismic design for their buildings and bridges. The lack of information in British Standard (BS) about seismic activity is because the seismic hazard is very low in the British region, hence, the design of bridge structures resistant to earthquake are ignored. However, Malaysia faces a different situation regarding the seismic point of view. Peninsular Malaysia is located only300 kilometres away from the Sumatra faults, where the probability of 8 Magnitude in Richter Scale has shown that the long-distant earthquake effect cannot to be neglected. Eurocode 8 (EC8) gives meaningful guidelines to engineers on how to design their structures with seismic considerations, and the impact of rising costs is still an important agenda item that needs to be discussed. This study estimates the requirement of reinforcement between non-seismic (Eurocode 2, EC2) and seismic design by using EC8 with different ductility class. Three zones with different Peak Ground Acceleration (PGA) value has been chosen, namely Kedah or Johor (low ductility 0.06g), Penang or Kuala Lumpur (medium ductility 0.08g) and Lahad Datu (medium ductility 0.14g). The results shows that the quantity of reinforcement requirement for beams had increased between 7% to 32.4%, while columns increased between 28% to 420.3% for different ductility class. In addition, the cost of construction is becoming more expensive because the cost of reinforcement requirement is increasing with the increase of ductility class from low to Medium.

1. Introduction

Eurocodes (EC) is a code of practice that was recently introduced in Europe and the aim of the codes is to set standardization procedures and specify how structural design should be conducted within the European Union (EU). Malaysia is currently using British Standard (BS) as design codes, but will enforce the use of EC in their structural designing starting in 2017. However, most of the structural engineers are still not prepared for it.

Eurocode 2 (2004) is a design code of practice for concrete structures. In general, Eurocode 2 (2004) deals with phenomena like flexure, shear, crack control, deflection control, detailing of beams, slabs, columns, walls, foundations, tying systems and the design of precast, lightweight and plain concrete. Eurocode 8 (2004) is a design code of practice for earthquake resistance design of structures. The main objective of these codes is to ensure that the design of the structure can save lives, minimize damage or ensure that the structures can still function during and after earthquake events.

While Malaysia has not experienced a very critical earthquake, it is influenced by the earthquakes of adjacent countries. Seismic design for high-rise buildings, bridges and others structures has not been practiced in Malaysia, although Malaysia experiences minor to moderate earthquakes across the country. The aim of this study is to give some idea of the costing impact to structural designers with the adoption of

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Eurocode 8 (2004) in their designs. The comparison is made in terms of total reinforcement requirements between design practice using Eurocode 2 (2004) and similar design including requirements in Eurocode 8 (2004) with different ductility class and Peak Ground Acceleration (PGA). The analysis and design is based on structure frame element (beams and columns) for five and ten storey buildings using ETABS computer software. To validate the input data such as geometric, material properties and mass assignment of the model, the Free Vibration Analysis (FVA) is conducted and the comparison is made between non-seismic design (Eurocode 2, 2004) and seismic design (Eurocode 8, 2004) with different ductility class.

At the-end of analysis phase for every ductility class, the suitable quantity of reinforcement requirements from all designs are calculated. In Eurocode 8 (2004), the response spectrum design procedure is implemented.

2. Literature Review

As Eurocode 8 (2004) prescribes the shape of the response spectra, defines ground categories and relevant amplifications but not the absolute numerical values of quantities defining earthquake hazard, new seismological map as a part of the National Annex shall include this hazard at the level of the base rock. New seismological map will follow the Eurocode 8 (2004) requirements completely: 475 years of return period, 10 percent of probability, and 50 years of design life of structure. It may be expected that according to the recent development in seismology and increased number of strong motion records, some changes in the earthquake zoning will occur, since valid maps of intensity based earthquake zones are about 20 years old. One of the fundamental requirements that a building must meet is the no collapse requirement, which means that the structure is able to retain its structural integrity and a residual load bearing capacity after the seismic event has occurred; thus, the global or local collapse must be prevented. For this requirement, the design of seismic action has a return period of 475 years probability to exceed (Eurocode 8, 2004).

The design of ground-motion accelerations on rock sites of Peninsular Malaysia is with 2% and 10% Probability of Exceedance (PE). The previous seismic hazard maps based on the Peak Ground Acceleration (PGA) and Modified Mercalli Intensity (MMI) presented by Adnan et al., (2006), U.S. Geological Survey (USGS), and Malaysia Meteorological Department (MMD) are also need to study for comparison with the new obtained results.

East Malaysia is located at the triple junction of the Pacific (through the Philippine plate), Indo-Australian and Eurasian Plates. The interactions among the plates are very complex and active. According to the seismic-tectonic map published by the Mineral and Geoscience Department, Malaysia (MGDM, 1994) the seismicity around this location is affected by the low seismic active level of stable Sunda tectonic plate and moderately active seismic level of East Malaysia, Kalimantan and Sulawesi.

3. Methodology

The target location of the project and architect drawings were acquired in advance. The study was performed on residential buildings of five (5) and ten (10) stories. After the architect drawing was obtained, modelling of the buildings was conducted before full analysis began.

Free vibration analysis is performed to obtain the natural frequencies and periods. The natural periods and mode shapes are the most important factors to determine the dynamic characteristic. In order to implement the response spectrum analysis, natural vibration periods of the building were first determined using an eigenvalue analysis. The number of modes chosen is based on mass participation factor of more than 90%. ETABS software was used in the analysis and design stage. Two conditions that was used for comparison are design using Eurocode 2 (2004) only and design inclusive of Eurocode 8 (2004). ETABS can handle the largest and most complex building models, including a wide range of nonlinear behaviors, making it the tool of choice for structural engineers in the building industry.

The response spectrum analysis is used and the multiple modes of response of a building are taken into account. This method has been adopted by most of the building codes except for very simple or very complex structures. The response of a structure can be taken from combination of multiple modes. Numerical analysis can be used to determine these modes for a building. For each mode, a response is read from the design spectrum based on the modal frequency and the modal mass, and they are then combined to provide an estimate of the total response of the structure.

Design data form ETABS is used as input data for spreadsheet (Excel) to calculate quantity of reinforcement requirements for every ductility class. Figure 1 shows the stages of analysis, design and determining the quantity of reinforcement. Table 1 shows the loading classification for static loads.

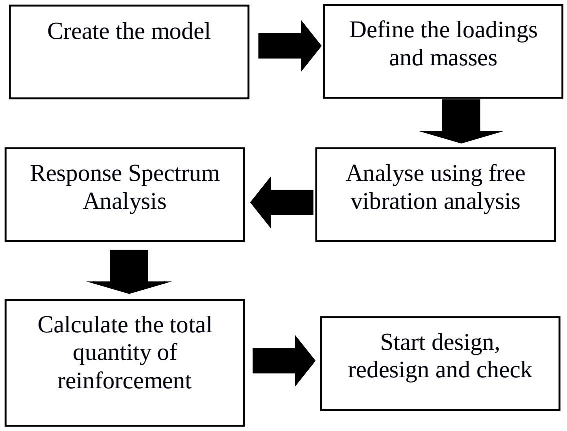


Figure 1: Flowchart of the stages to calculate the total quantity of reinforcement in this study

Table 1: Static load determination

Floor level	Live Load (kN/m)	Dead Load (kN/m)
Top floor	98.11 (for beam with water tank)	2.05
Other floor	2.00 (for quarters)	14.55 (middle of beam) & 7.21 (edge of beam)

Load case and load combination fora non seismic design (EC2) : 1.35 DL+1.5LL

The concrete buildings are regular in elevation and analysed under frame system. The parameter data for response spectrum and structural types for both buildings are shown in Table 2.

Table 2: Response Spectrum and Building Design Parameters in Eurocodes 8 (2004)

Parameters	Value
Spectrum Type	1
Ground Type	D
Behaviour Factor, q	3.90
Correction Factor, λ	0.85

This study involved four types of design that started with the non-seismic (EC2) and three other seismic designs (EC8) according to the PGA seismic hazard zones on Peninsular Malaysia (Adnan et al., 2008) and East Malaysia (Harith et al., 2015). Table 3 shows the value of PGA selected in this study.

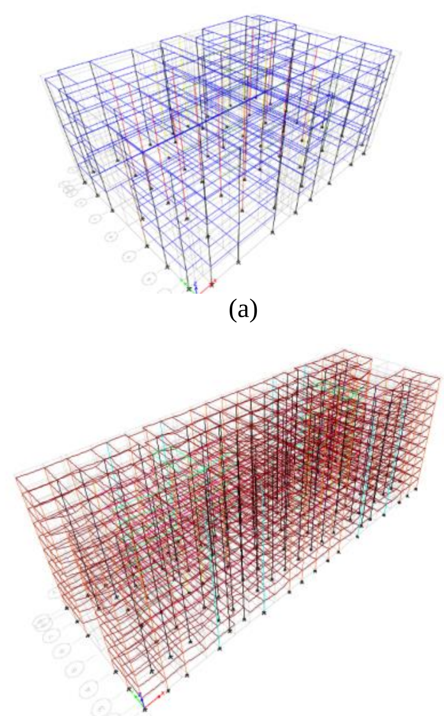
For medium ductility class, two site are chosen with two different values of PGA, 0.08g and 0.14g. For a design based on Eurocode 2 (2004), only live load and dead load were imposed. For Eurocode 8 (2004), the values of peak ground acceleration (PGA) such as DCL 0.06g, DCM 0.08 and DCM 0.14 should be considered in the analysis under response spectrum analysis. This study considered two classes of ductility because Ductility Class High (DCH) is not practical in Malaysia.

Table 3: Different ductility class and different PGA value

Design Type	PGA (g)	Zone/Location
EC2	none	None
Low (DCL)	0.06	Johor or Kedah
Medium (DCM)	0.08	Kuala Lumpur or Pulau Pinang
Medium (DCM)	0.14	Lahad Datu

Load case and load combination for the seismic design (EC8) : 1.20 DL+1.5LL+RS

The calculation is based on a steel bar requirement using computer aided design software, ETABS and Excel. Figure 2 shows the geometric model of both buildings.



(a)

(b)

Figure 2: Frame model (a) 5storey and (b) 10 storey

4. Results and Discussion

4.1 Analysis Results (Free Vibration Analysis)

Tables 4 and 5 show the time period with different ductility class and the first four modes of 5 storey and 10 storey buildings, respectively. It can be concluded that the mode is having a reduction in the period between -4.88% to -16.95%, according to seismic and non-seismic design for both buildings. Reduction of the period for EC2 to EC8 with different ductility class is due to an increasing in the stiffness of each building element, especially column. When the size of the structure was larger, the stiffness of the structure such as the column will increase due to the effect of the earthquake. The greater value of PGA caused changes in the size columns and beams, which meet the requirements for the increase in the quantity of reinforcement.

Table 4: Time Period with different ductility class and modes for 5 storey building

Ductility Class	Time Period			
	Mode 1	Mode 2	Mode 3	Mode 4
EC2	0.8200s	0.8040s	0.7380s	0.6040s
EC8 DCL0.06g	0.7800s	0.7480s	0.7200s	0.5970s
EC8 DCM 0.08g	0.6840s	0.6430s	0.6310s	0.5570s
EC8 DCM 0.14g	0.6810s	0.6420s	0.6300	0.5570s

Table 5: Time Period with different ductility class and modes for 10 storey building

Ductility Class	Time Period (s)			
	Mode 1	Mode 2	Mode 3	Mode 4
EC2	1.302	1.292	1.199	0.969
EC8 DCL0.06g	1.203	1.184	1.088	0.919
EC8 DCM 0.08g	1.203	1.184	1.08	0.918
EC8 DCM 0.14g	1.185	1.177	1.067	0.903

4.2 Reinforcement Design Results

Tables 6 and 7 shows the difference between the quantity of reinforcement and the percentage increase of the non-seismic design and seismic design with different ductility class for the beam and column of 5 storey and 10 storey buildings, respectively. It is shown that the percent quantity of reinforcement increases with each ductility. Each value of ductility was compared to Eurocode 2 (2004) design. The quantity of reinforcement of DCL 0.06g, DCM 0.08g and DCM 0.14g increased because the value of peak ground acceleration was inserted in each analysis.

Table 6: Different quantity of reinforcement between non seismic and seismic for 5 storey building

Ductility Class	Quantity of Reinforcement (Tonne)			Increment (%)
	Beam	Column	Total	
EC2	117.0	8.6	125.6	-
EC8 DCL0.06g	127.5	11.0	138.5	+10.2
EC8 DCM 0.08g	154.0	31.8	185.8	+32.4
EC8 DCM 0.14g	155.9	32.1	188.0	+33.2

Total reinforcement requirement for beams and columns increased under considerations of seismic based on the determination of seismic zones in Peninsular Malaysia and Sabah. The requirement of the beam was increased from 117 tons to between 127.5 and 155.9 tons, which was between 9% to 33.2%.The requirement of the column increased from 8.6 tons to between 11 and 32.1 tons, which was between 28% and 273.3%.

Table 7: Different quantity of reinforcement between non seismic and seismic for 10 storey building

Ductility Class	Quantity of Reinforcement (Tonne)			Increment (%)
	Beam	Column	Total	
EC2	962.3	78.7	1041.0	-
EC8 DCL0.06g	1027.8	361.0	1388.9	+33.4
EC8 DCM 0.08g	1273.9	409.4	1683.3	+61.7
EC8 DCM 0.14g	1274.3	409.5	1683.8	+61.8

The requirement of the beam was increased from 962.3 tons to between 1,027.8 and 1274.3 tons, which was between 7% and 32.4%.The requirement of the column increased from 78.7 tons to between 361 and 409.5 tons, which was between 358.7% and 420.3%. According to the results from both buildings, the different quantities of reinforcement requirements showed big differences for column elements. This was due to the increasing of the shear reinforcements at critical region stated in each ductility class in Eurocode 8 (2004).

6. Conclusions

In the modal analysis, each modal case with different ductility class showed different mode shapes and time period. The analysis determined the undamped free vibration mode shapes and frequencies of the system. These natural modes provided an excellent insight into the behaviour of the structure. The period of the buildings for EC2 design took a longer time compared to buildings with DCL and DCM design. Ductility class design made the total stiffness of the buildings increase with the increase of column sizes. Larger column size gives more stiffness and reduces the period. The enlargement of column sizes is required due to the increment of reinforcement requirements of the systems.

Based on the total quantity of reinforcement shown in Tables 5 and 6, the quantity of reinforcement designed using Eurocode 2 (2004) was smaller than that of Eurocode 8 (2004). The design that was only based on Eurocode 2 (2004) did not take the value of ground acceleration compared to DCH 0.06g, DCM 0.08g and DCM 0.14g, which is causing many of the shear links needed to resist earthquake forces approaching from the horizontal direction.

Based on this case study, it can be concluded that, regarding the quantity of reinforcement requirement, the cost for civil and structure in the design phase had become more expensive. The higher value of peak ground acceleration will increase the total cost for the whole project. In this study, the states of Kedah and Johor showed the lowest cost (DCL 0.06g), followed by Penang and Johor (DCM 0.08g) and Lahad Datu (DCM 0.14g).

It is recommended that future construction, either building or any civil structure project, consider the risk of seismic hazard to protect elements of the structure from being damaged. Peak ground acceleration and ductility class values should be considered in analysis and design. The cost of a project will increase, but the cost of repair and maintenance maybe reduced, especially in the case of earthquakes.

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