

SEISMIC FRAGILITY EVALUATION OF TYPICAL REINFORCED CONCRETE SCHOOL BUILDING IN MALAYSIA

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ABSTRACT

The purpose of this study is to evaluate the seismic performance level of a typical four-story RC school building designed as per Eurocode (EC) that does not cooperate with seismic consideration was analyzed. Incremental dynamic analysis (IDA) corresponding to 40 selected ground motion records were used to produce maximum inter-story drift ratio (IDR_{max}) that is used to obtain fragility curve representing the seismic performance level of the building. Four cities with different peak ground accelerations (PGAs) values based on the seismic hazard map of Malaysia were selected, and a limit state of five performance level used to evaluate the performance level of the target building. The seismic performance levels of target building and an additional school building (SMK Ranau) designed as per British Standard (BS) were compared. Results show that the structural strength of the target building was sufficient to withstand a certain levels of ground motion based on the seismic hazard map. Moreover, the damage probability increased with increasing PGAs, particularly in the X-direction. The aforementioned comparison also showed that the building designed as per the BS was weaker than the target building designed as per the EC, particularly in the X-direction.

Keywords: Fragility curve, performance level, maximum inter-story drift ratio, incremental dynamic analysis.

1. INTRODUCTION

Malaysia, located in Southeast Asia, comprises West Malaysia (Peninsular Malaysia) and East Malaysia separated by The South China Sea. It is located outside the Pacific Ring of Fire and is therefore not prone to earthquakes. However, its close proximity to two seismically active plates, i.e., Indo-Australian plate and Eurasian plate, earthquakes have periodically occurred in the country. After several series of earthquakes, particularly in 2015 (Ranau Earthquake), Malaysia has undertaken major steps in improving the Malaysian Management Disaster Plan. Until 2010, Malaysia used the British Standard (BS) design code as a national design code. After this code was withdrawn by the UK, Malaysia used Eurocode (EC) as a guide to design buildings and infrastructure. BS did not implement the seismic design; however, EC contained a specific code in seismic design. However, buildings and infrastructure before 2020 in Malaysia were constructed without seismic consideration. Therefore, the seismic performance level of the target building after an earthquake was reviewed herein.

2. DATA

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The target building was a four-story school building with the dimensions shown in Figure 1. The main members considered in this research were the column, beam and shear wall.

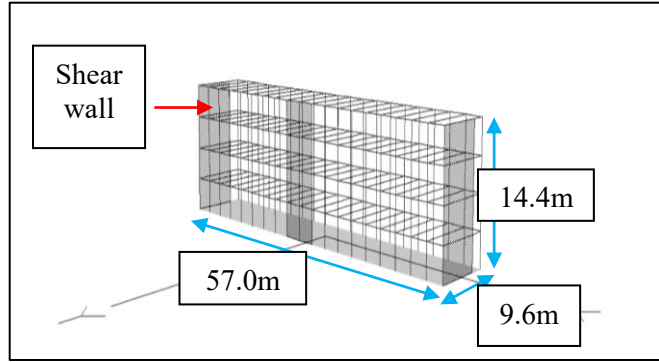
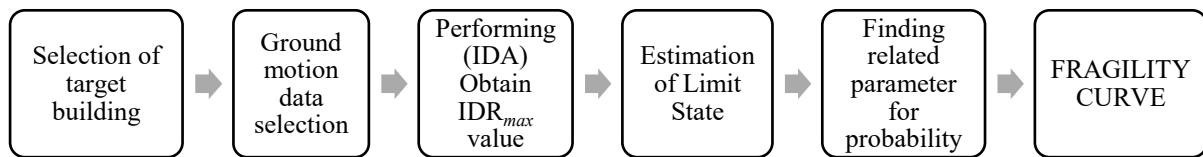


Figure 1: 3D modelling of target building by STERA 3D

3. METHODOLOGY

3.1. Introduction

The evaluation of the performance level of target building involves several processes as stated in the flow chart below:



3.2. Incremental dynamic analysis (IDA)

IDA as an analysis method to predict capacity capability using nonlinear dynamic analysis under a multiple scale of ground motion (Vamvaticos and Cornel, 2002). In this study, 40 ground motion were scaled to different intensity levels starting from 0.1g until 0.8g (0.1g interval) to determine the relationship between the ground motion intensity and response of the structure.

3.3. Seismic performance level and fragility curve

The seismic performance level of buildings exhibits the expected performance and condition of structures during and after an earthquake event. It defines their functionality and damage states (limit states) based on the specified earthquake. Table 1 shows the limit state criteria between FEMA and Xue et al. (2008). IDR was used to assess the structure seismic performance level. While fragility curve can be defined as a probability of a structure reaching certain limit of damage states. Regarding the seismic hazard map of Malaysia that use PGA format, therefore the conditional probability of structure to reach or exceed specific damage state will be corresponding to the PGA value.

Table 1: FEM 356 and Xue et al. (2008) proposed value for different phases of performance level.

Performance Level	FEMA 356			Xue et al. (2008)				
	IO	LS	CP	OP	IO	DC	LS	CP
Limit State	1.0%	2.0%	4.0%	0.5%	1.0%	1.5%	2.0%	2.5%

OP – Operation, IO – Immediate Occupancy, DC – Damage Control, LS – Level of Safety, CP – Collapse Prevention

The probability function is as below (Eq. (1)):

$$P[D/PGA] = \phi[\ln(PGA) - \mu]/\sigma] \quad (1)$$

where ϕ is standard normal cumulative distribution function, μ is the mean value and σ is the standard deviation of natural logarithm of PGA.

Equation to define the conditional probability of IDR_{max} exceeds the limit state at given PGA is expressed as Eq. (2) below:

$$P[IDR_{max} > IDR] = 1 - P[IDR_{max} \leq IDR] = 1 - \phi\left[\frac{[\ln(IDR) - \ln(IDR_{max})^{50\%}]}{\delta eq}\right] \quad (2)$$

Where $(IDR_{max})^{50\%}$ is equal to mean value (μ) while δeq is the standard deviation.

3.4 Selection of study location

Damage measure and performance level for the target building that located in four cities in different zones with the specific level of PGA (based on seismic hazard map of Malaysia with 10% of POE in 50 years) will be determined and also with estimated PGA value (2% of POE in 50 years).

Table 2: PGA values for return period of 475 years and 2475 years.

Zone	City	PGA (g)	
		Malaysia Seismic Hazard Map 10% of POE in 50 years	ASCE/SEI 41-06 2% of POE in 50 years
		475 years	2475 years
1	Kota Bharu	0.02	0.05
2	Alor Setar	0.05	0.13
3	Kuala Lumpur	0.09	0.23
4	Ranau	0.16	0.41

3.5 Performance level comparison

The seismic performance levels of the target building and another building in Ranau, Sabah were compared. SMK Ranau was built and design as per the BS in 2004 before Malaysia revised the building code to EC in 2010. The dimensions of SMK Ranau are shown in Figure 2.

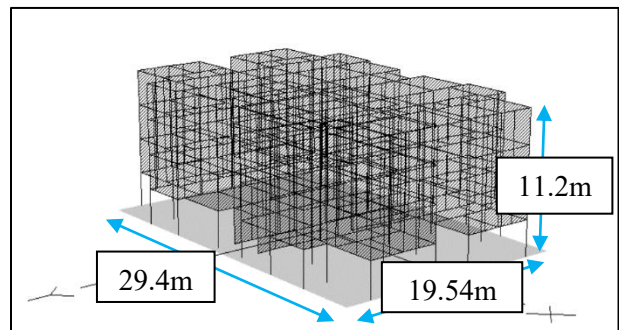


Figure 2: 3D modelling of SMK Ranau by STERA 3D

4. RESULTS AND DISCUSSION

Figure 3 indicated the performance level of the target building in these cities based on 10% of POE in 50 years and FEMA 356 criteria. The figure shows, for Ranau with PGA of 0.16g, the target building will experience the probability of damage in IO level on both X- and Y- direction with value of 3.1% and 1%, respectively. Figure 4 represents the seismic performance level of target building based on the criteria by Xue et al. 2008. Kuala Lumpur with 0.09g PGA will experience the probability of reaching or exceeding OP level with the value of 4% for in X- direction. The target building in Ranau experienced the probability of damage by 19% for OP level, 3.1% for IO level and 1% for DC level in X- direction. In the Y-direction, the target building experienced 5% of damage probability in OP level and 1% in IO level.

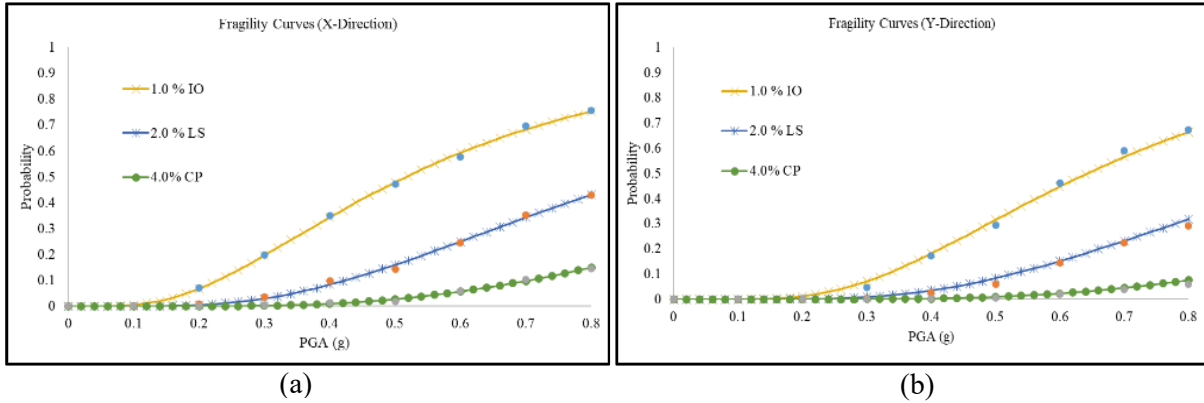


Figure 3: Fragility curve based on criteria by FEMA 356 (Target building). (a) Fragility curve for X- direction, (b) Fragility curve for Y- direction.

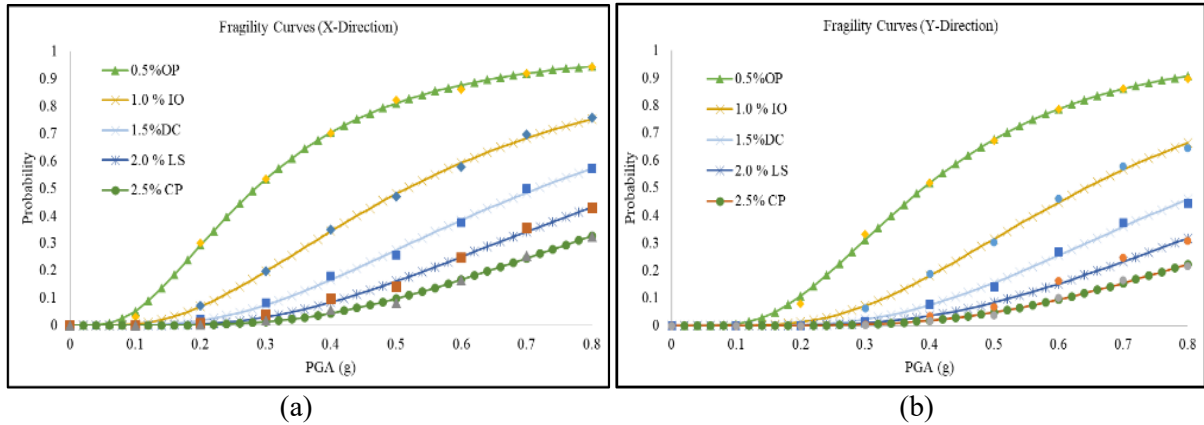


Figure 4: Fragility curve based on criteria by Xue et al. (2008) (Target building) (a) Fragility curve for X- direction, (b) Fragility curve for Y- direction.

Performance level of target building corresponds to the prediction or estimated value of PGA by 2% of POE in 50 years also can be refer to Figure 3 and Figure 4. The estimated value of PGA for the four cities was twofold from the original value. Based on FEMA 356 criteria, the target building started to show the probability of damage when ground motion reaches 0.13g in Alor Setar city. The probability of damage is 1.5% for IO level in X- direction. Target building in Kuala Lumpur for a ground motion of 0.23g exhibited the probability of damage 10% for IO and 1% of LS in X- direction, respectively, and only 2% of IO level in Y- direction. Ranau city is in the most critical zone with the highest PGA of 0.41g. The probability of reaching or exceeding the IO level is around 36% and 19% in X- and Y-direction, respectively. In addition, the probabilities for the LS level in both X- and Y-direction is 9% and 4%, respectively. Meanwhile the CP level of 1% is only observed in the X- direction.

Referring to the criteria by Xue et al. 2008. For Alor Setar city with 0.13g of PGA, the probability of target building will be experiencing the OP and IO levels in X- direction are 7% and 1%, respectively. In the Y-direction, the target building only experienced probability of damage in OP level which is 1%. Kuala Lumpur with the PGA of 0.23g will be experiencing the probability of damage in OP, IO and DC level with the value of 31%, 8% and 2% for X- direction, respectively. 12.5% of damage probability for OP level and 1.5% probability in IO level for the Y- direction. Ranau city with the highest PGA of 0.41g experienced all five elements of damage level. In the X- direction, the target building recorded 72% of OP, 36% of IO, 18% of DC, 9% of LS and 5% of CP level. Meanwhile in the Y- direction, OP level is 53%, IO level is 19.5%, DC level is 8%, LS is 4% and 2% for CP level.

Seismic performance levels of buildings with different structural designs (design as per EC and BS) were also compared. The building that was design as per BS is SMK Ranau. The performance was compared based on the original PGAs in official seismic hazard map of Malaysia. Figure 5 shows the performance level of the comparison building which is SMK Ranau based on FEMA 356 criteria. When the intensity reached 0.09g for Kuala Lumpur, SMK Ranau experienced two limit states of 11% and 2% in the IO and LS level, respectively in X- direction. If the building was constructed in Ranau with a PGA of 0.16g, the probabilities were 38%, 12% and 2% in the IO, LS and CP levels, respectively, in X- direction. Figure 6 shows the performance level for SMK Ranau with criteria defined by Xue et al. (2008). Kota Bharu with a PGA of 0.02g recorded a probability of 4% in OP level, whereas Alor Setar with PGA of 0.05g exhibited probabilities of 15% and 1% in the OP and IO levels, respectively. A higher zone in Kuala Lumpur (0.09g) projected a probability of 34%, 11%, 5%, 2% and 1% in the OP, IO, DC, LS and CP levels, respectively, in X- direction. In Ranau with a PGA of 0.16g, the probabilities of OP, IO, DC, LS and CP levels were 68%, 37%, 21%, 12% and 7%, respectively.

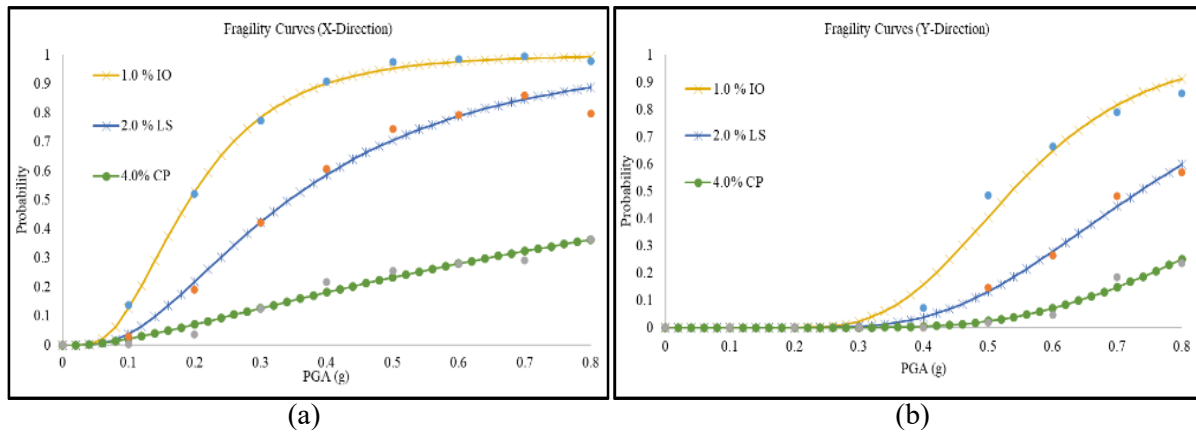


Figure 5: Fragility curve based on criteria by FEMA 356 (SMK Ranau). (a) Fragility curve for X-direction, (b) Fragility curve for Y- direction.

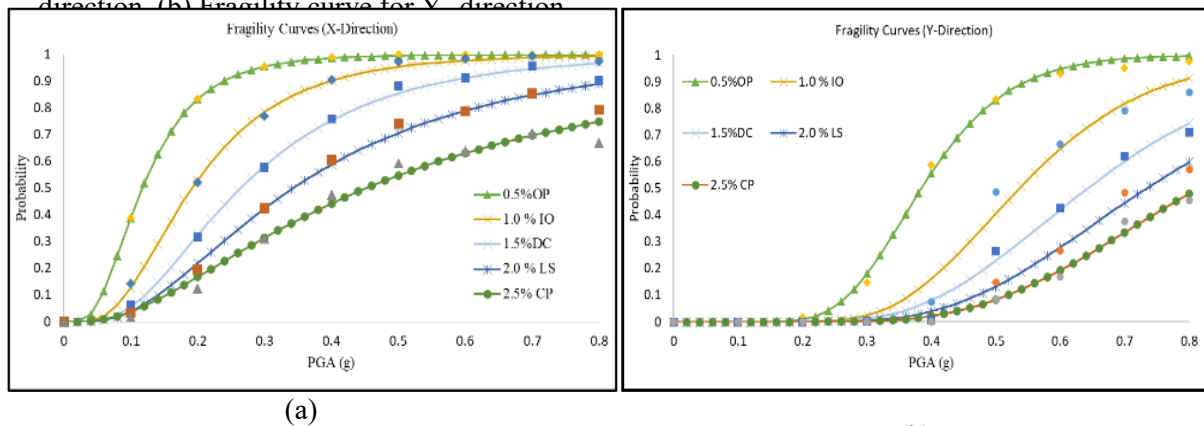


Figure 6: Fragility curve based on criteria by Xue et al. (2008) (SMK Ranau). (a) Fragility curve for X- direction, (b) Fragility curve for Y- direction.

5. CONCLUSIONS

Based on the original PGA (10% of POE in 50 years) from seismic hazard map of Malaysia, the target building that constructed as per EC could sufficiently to handle small intensity of ground motion in both X- and Y- directions. The probability of exceeding severe damage of 3.1% recorded in Ranau city (0.16g of PGA) for IO level in X- direction while in Y-direction only recorded 1% for IO level based on criteria defined by FEMA 356 criteria. Based on the criteria defined by Xue et al. (2008), probabilities of 19% and 5% for the OP level were recorded in the X- direction and Y- direction, respectively. Thus, although the target building could sufficiently withstand the intensity of earthquake based on the seismic hazard map, the structure still has risk of damage especially in X- direction (weaker than Y- direction).

The estimated PGA for 2% of POE in 50 years with a return period of 2475 years showed that the probability of damage to the target building increased. The city located in the second zone with a PGA of 0.13g (Alor Setar) began experiencing damage with a probability of 1.5% in the IO level, 10% of IO in third city and 36% of IO in the fourth city (Ranau) in the X- direction. These findings indicated the structure in X- direction was weaker than the Y- direction. Moreover, based on the criteria defined by Xue et al. (2008), the probability of damage will continue to increase with increasing PGA. The probability of damage increased more than ten times in the X- direction corresponding to the PGA of 2% of POE in 50 years.

A comparison of the seismic performance levels of the target building and SMK Ranau showed that the latter has a higher damage probability in the X- direction. The probabilities in the OP, IO, DC, LS and OP levels for SMK Ranau were higher than those for the target building. This indicated that SMK Ranau designed as per BS was weaker than the target building design as per the EC.

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