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Fragility curves for low- and mid-rise buildings in Malaysia

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Abstract

In this paper, a study is presented on development of fragility curve for Malaysian low- and mid-rise buildings that are reinforced concrete and steel moment–resisting frames. Two prototype models, which include three- and six-story frame structures with different types of material, were designed based on Eurocodes. Incremental dynamic analysis (IDA) was conducted under seven sets of ground motion records, and scaling peak ground acceleration increased every 0.05 g until it achieved 0.6 g. The software SAP2000 was used to perform IDA. Five levels of performance based seismic designs, namely, operational phase, immediate occupancy, damage control, life safety, and collapse prevention, were considered to assess structural performance. Seismic fragility curves were developed for structural models with different types of material and height.

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Keywords: fragility curve; drift; incremental dynamic analysis; performance level; ground motion records.

1. Introduction

Malaysia belongs to low-seismicity group because itis tectonically located within the relatively stable Sunderland. The one exception is Sabah, which is categorized under moderate seismicity group [1]. This finding proves that the country is also at high risk for earthquake load. Thus, this finding should be considered in the future design for buildings in Malaysia.

The majority of construction in Malaysia uses reinforced concrete and steel structure. Moreover, buildings in Malaysia are usually categorized based on height as low- and mid-rise structure. Therefore, two types of structural materials and height were used as the main reference to conduct the analysis.

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In this new research, fragility curve was introduced to provide improved prediction in damage to structure and nonstructure. Fragility curve is defined as a conditional probability that provides a possibility that a structure will meet or exceed a specified damage level for a given ground motion [2]. It is a unique curve because every curve is developed depending on ground motions.

Fragility curves have been developed by many researchers for different structure types [2]. Although Malaysia is categorized under low-seismicity group, the possibility of earthquake should be taken seriously. Therefore, this study has been conducted to develop fragility curve for low- and mid-rise buildings reinforced concrete and steel moment–resisting frames.

2. Structural model

Two types of structural model were used, namely, three- and six-story frames that can be categorized as low- and mid-rise buildings. These two frames were chosen to represent typical buildings in Malaysia. Two sets of moment-resisting frame with different types of material and height are designed following Eurocode 2 (EC2) [3], Eurocode 3 (EC3) [4], and Eurocode 8 (EC8) [5].

Each frame has two 6 m bays and same story height of 3 m for three and six stories of concrete and steel frame. The type of ground in type A, which is rock or other rocklike geological formation, mostly includes 5 m weak material at the surface with shear wave velocity, V_s, that exceeds 800 m/s. The peak ground acceleration (PGA), a_g, was assumed 0.5 g or 5 m/s^2. The importance value used was 1, and the behavior factor, q, was 4 for moment-resisting frame with medium ductility class.

All frames were designed under the effect of dead, live, and lateral loads. The design and section model of beams and columns used are clearly discussed in the following section.

2.1. Moment-Resisting Concrete Frame and Steel Frame

EC2 and EC8 were used to design moment resisting concrete frame (MRCF). Compressive stress of concrete was 30 N/mm^2, and yield stress of reinforcing steel was 460 N/mm^2. The natural period of three- and six-story frames was 0.39 s and 0.66 s, respectively.

For moment resisting steel frame (MRSF), the designs were based on EC3 and EC8. The steel frames used were assumed steel grade S275. The natural period for three stories was 0.44 s, and that for six storieswas 0.74 s. Table 1 shows the crosssection of beam and column for MRCF, whereas Table 2 shows the size of beam and column for MRSF.

Table 1 Cross section of beam and column for MRCF

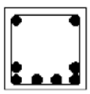
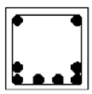
	Three Stories		Six Stories	
	Beam	Column	Beam	Column
Size (mm)	300 × 700	500 × 500	300 ×700	500 × 500
Reinforcement	6T25	6T32	4T32	6T32
				
Shear link	8 mm link at 150 mm c/c		8 mm link at 150 mm c/c	

Table 2 Size of beam and column for MRSF

	Three Stories		Six Stories	
	Beam	Column	Beam	Column
	(D x B x kg/m)	(D x B x kg/m)	(D x B x kg/m)	(D x B x kg/m)
Size (mm)	533 × 210 × 109	305 × 305 ×198	533 × 210 × 82	305 × 305 × 198

3. Incremental dynamic analysis (IDA)

IDA is used in performance-based earthquake engineering to determine the expected structural response, damage, and financial loss under earthquake. According to IDA curve, the relationship between drift ratio and ground motions can be determined. Then, this relationship is utilized to determine performance level of a structure. This relationship also shows a range of behavior with large variation from each record. IDA must be considered the first step before developing fragility curves.

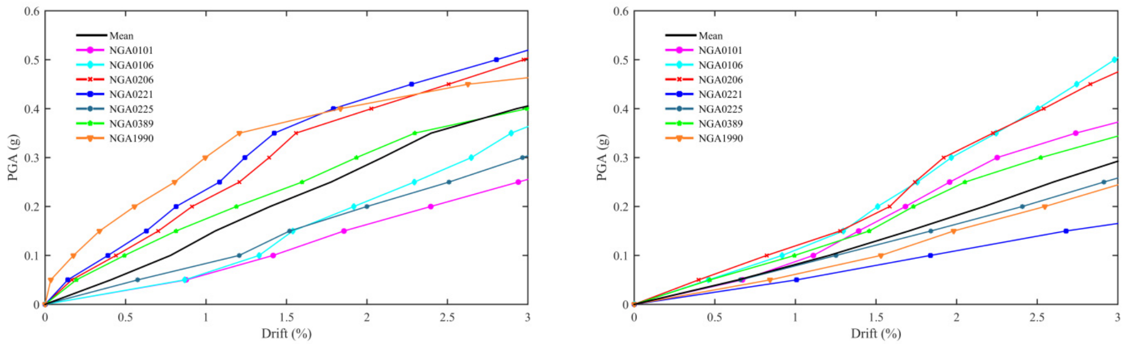
A suitable set of ground motion records are needed to conduct IDA. Few parameters, such as event magnitude, PGA, distance, and soil type, must be considered in selection of ground motions [6]. For set of ground motions, most codes [7-9] recommended a minimum of three or seven sets of ground motions. Thus, seven sets of ground motions were used in this study, as shown in Table 3. These ground motions was chosen based on the following criteria; (i) Joyner-Boore distance is more than 20 km and (ii) magnitude range from 7 to 8. Then, ground motions were scaled to response spectra. The elastic response spectra were incrementally developed from 0.05 g to 0.6 g every 0.05 g. Nonlinear time history analysis was carried out under each ground motionand it was performed with SAP2000 software.

Every structure with different characteristics and ground motions recorded a different pattern of IDA curve. These IDA curves indicate a relationship between drift and PGA. The only focus for this analysis was drift until it achieved 3% because the maximum drift limit given by performance level was referred to develop fragility curve [10].Fig. 1 presents IDA curve for three- and six-story MRCFs.

Five performance levels were referred to assess structural performance. The vertical gridlines at drift 0.5%, 1%, 1.5%, 2%, and 2.5% were represented as operational phase (OP), immediate occupancy (IO), damage control (DC), life safety (LS), and collapse prevention (CP), respectively [10].

Table 3 Selective ground motion records

Name Record	Earthquake Location	Year
NGA 0101	Northern Calif-07	1975
NGA 0106	Oroville-01	1975
NGA 0206	Imperial Valley-07	1979
NGA 0221	Livermore-02	1980
NGA 0225	Anza (Horse Canyon)-01	1980
NGA 0389	Coalinga-02	1983
NGA 1990	Gulf of California	2001



(a)Three stories (b)Six stories

Fig. 1 IDA curves for (a) three-story MRCF and (b) six-story MRCF

4. Fragility Curve

Fragility curve shows probability to express level of damage at specified ground motion records. Some parameters, such as PGA, spectral acceleration, and peak ground velocity, can be used to develop fragility curve. PGA was selected because it is used to conduct nonlinear history analysis. Fig.2 shows the step to develop fragility curve in this study. Mean and standard deviation of PGA are necessary to develop fragility curve. These parameters were calculated for every point, which are across the limit state vertical gridlines at drift 0.5%, 1%, 1.5%, 2%, and 2.5%. Calculated parameters are tabulated in Table 4. For this study, Equation 1 by Ibrahim and El-Shami [2]was used to develop fragility curve.

$$P[\mathrm{D/PGA}]=\Phi((\ln(\mathrm{PGA})-\mu)/\sigma), \quad (1)$$

where D is damage; Φ is standard normal cumulative distribution; μ is mean; and σ is standard deviation of the natural logarithm of PGA.

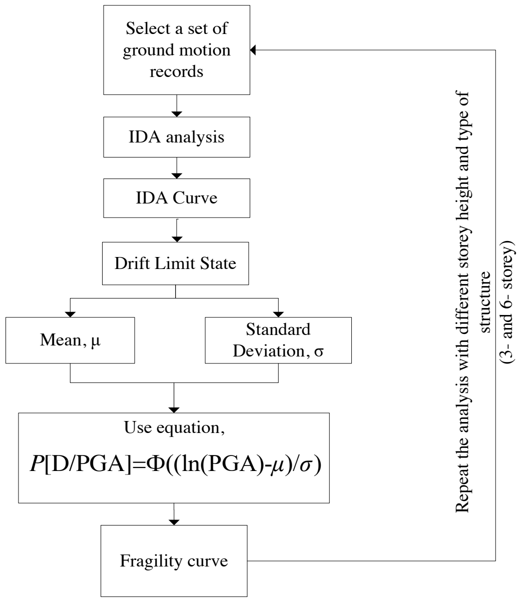


Fig.2 Fragility curve procedure

Table 4 Parameters of log-normal distribution for MRCF and MRSF

No. of story	OP		IO		DC		LS		CP	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
					MRCF					
3	−2.515	0.740	−1.876	0.639	−1.518	0.517	−1.249	0.395	−1.079	0.323
6	−3.245	0.407	−2.489	0.321	−1.991	0.342	−1.574	0.401	−1.333	0.396
					MRSF					
3	−1.536	0.716	−1.427	0.378	−1.013	0.380	−0.993	0.372	−0.772	0.372
6	−2.754	0.573	−2.041	0.454	−1.543	0.422	−1.205	0.415	−1.128	0.407

Fig. 3 presents all sets of fragility curves. This figure illustrates that when weak ground motion, which was 0.2 g, was exposed, the probability of reaching or exceeding OP is approximately 89% and 46% for three-story concrete and steel frame. This probability is approximately 100% and 93% for six-story concrete and steel frame. Moreover, probability of reaching or exceeding CP level is approximately 5% and 0.9% for three-story concrete and steel frame, and approximately 24% and 12% for six-story MRCF and six-story MRSF.

When the ground motion with 0.5 g was exposed, the probability of reaching or exceeding OP level was approximately 98% and 88% for three-story concrete and steel frame and approximately 100% for six-story concrete and steel frame. However, the probability of reaching or exceeding CP level is approximately 89% and 59% for three-story MRCF and MRSF, whereas that for six-story MRCF and MRSF is approximately 95% and 86%, respectively.

The analysis indicated that six stories have high probability of reaching or exceeding OP and CP performance level. However, based on the material, concrete frame has increased probability to reach or exceed OP and CP level during weak and strong ground motions. Thus, steel material can provide better performance than concrete material. This result shows that the height and type of material play an important role in structure behavior and fragility curve pattern.

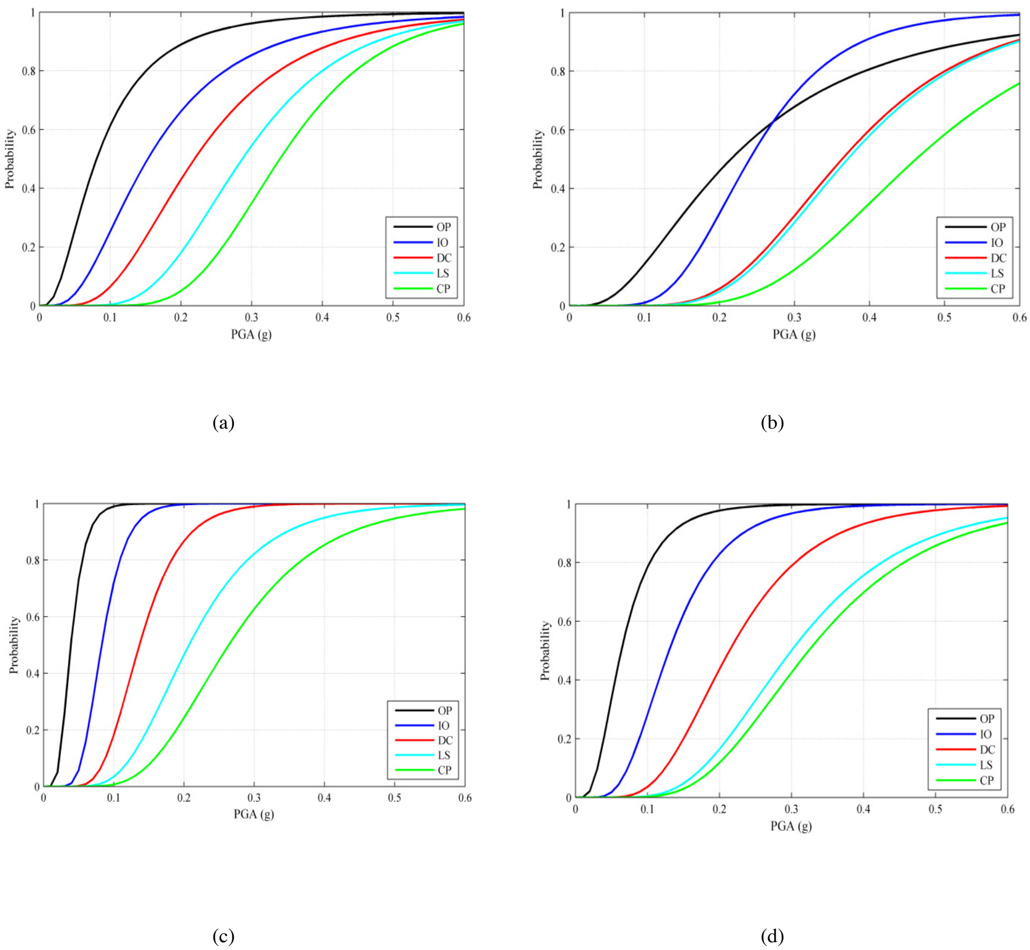


Fig. 3 Fragility curves of (a) three-story MRCF; (b) three-story MRSF; (c) six-story MRCF; and (d) six-story MRSF

5. Conclusion

Fragility curve was developed and presented in this paper. The structural models were designed based on Eurocodes for typical low- and mid-rise buildings in Malaysia. Three-story buildings with a height of 3 m per story were considered low-rise, whereas a six-story frame represented mid-rise buildings. IDA was performed with SAP2000 software under seven ground motion records. The results from IDA curves were compared with the limit state to develop fragility curve. Fragility curves were plotted because of different types of materials and height. The following are the conclusions:

- Based on CP level, both three- and six-story frames, MRSF has better performance than MRCF. Three-story frame can sustain until 0.55 g before collapse compared with concrete frame, which recorded 0.45 g. Meanwhile, six-story MRCF started to collapse at 0.4 g.
- The structural material that is appropriate for either for low- or mid-rise buildings can be obtained from this study. Fragility curve is a highly useful method in predicting the extent of probable damage.

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