FRAGILITY EVALUATION OF TYPICAL RC GOVERNMENT QUARTERS BUILDINGS DESIGNED BY BS 8110 IN SABAH, MALAYSIA

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ABSTRACT

A study to evaluate the performance of the existing building by the development of fragility curves was introduced in this paper. A typical five-story residential government RC building becomes the target building, designed based on BS 8110 without incorporating any seismic action. It consists of plan and elevation irregularities. The target building was analyzed by performing Incremental Dynamic Analysis (IDA) and excited by several ground motion records through equally scaling from 0.1 g to 0.8 g with every 0.1 g increment. Nonlinear time-history analysis was executed using STERA 3D software and recorded the structural response in terms of maximum inter-story drift ratio (IDR_{max}). This study initiated two different methods of developing fragility curves: (1) using a limit state of five levels of performance-based seismic designs, and (2) the conditional probability of IDR_{max} exceeded the specified limit state of *IDR* with the aid of static pushover analysis. Both X- and Y-directions were examined to investigate the irregularity effect of the target building. Findings indicated that X-direction is weaker than Y-direction for both methods to reach or exceed specific performance levels and for the conditional probabilities of exceeding the targeted limit state at a given peak ground acceleration (PGA).

Keywords: Fragility curve, performance levels, limit state, incremental dynamic analysis.

1. INTRODUCTION

Malaysia is categorized as the low-seismicity zone and tectonically located within a region that is relatively stable Sundaland (Saruddin & Nazri, 2015). Unfortunately, Sabah state, which is situated at Kalimantan Island, is categorized as a moderate-seismicity zone. The Ranau Earthquake on June 5th, 2015, changed the Earthquake Engineering landscape in Malaysia, which seismic action should be incorporated in the building design. Government buildings constructed before 2017 are mainly designed based on the conventional BS 8110 reinforced concrete (RC) building code without integrating seismic action. Additionally, most buildings in Malaysia, particularly apartments and office buildings, had an irregularity in plan and elevation, which tend to cause seismic hazards. Hence, there is a need to evaluate the performance of existing Government buildings which fragility evaluation is one of the best approaches, thus initiating this research topic.

Therefore, this study intended to develop and evaluate fragility curves for five-story RC Government quarters buildings with typical plan and elevation irregularities. Furthermore, this study aims to assess the seismic performance of the target RC structure designed by BS 8110 code and identify the size of an earthquake the building can withstand.

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2. DATA

The structural model was a five-story frame categorized as a typical mid-rise building for a residential government building in Malaysia. This structural model frame was classified as an RC moment-resisting frame designed by BS 8110 without incorporating seismic action. Additionally, it possessed irregularity in plan and elevation, which tend to have various columns and beams. The height of each floor of the target building is 3.3 m, with an overall dimension is 30.6 m (longitudinal) by 25.8 m (transverse). Characteristics of material strength are: 1) concrete compression strength, f_C is 35 N/mm^2, 2) characteristic yield strength, f_{yk} for main bars is 460 N/mm^2, and 3) f_{yk} for shear links is 260 N/mm^2. There was no shear wall for the target building.

Table 1. Examples of detailing for structural elements for beam and column.

Parameters	Beam name: B11	Beam name: B17	Column
Size (mm)	250 × 475	250 × 375	250 × 350
Reinforcement	Top: 3T16 Bottom: 3T16	Top: 3T16 Bottom: 2T16	4T25
Shear link	R10-200	R10-200	R10-200

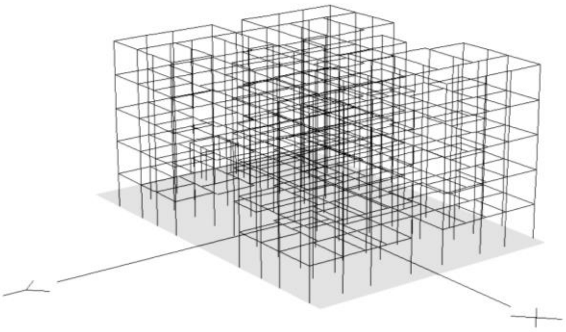

Figure 1. Analytical model of the target building performed by STERA 3D software.

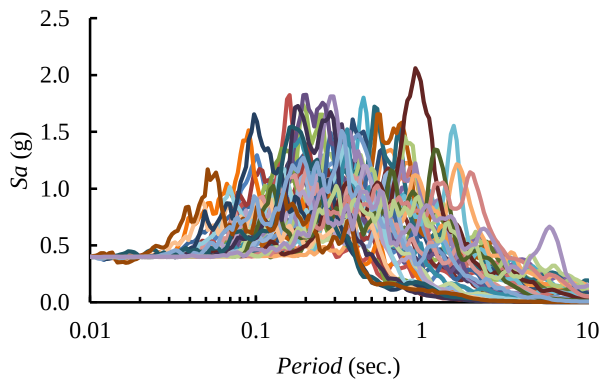

Figure 2. Ground motions records scaled at PGA of 0.4 g.

The target area, Sabah state, was used as a reference for selecting ground motion records. The Sabah state area was mainly affected by distance earthquakes, and the choice of far-field record sets was essential for collapse assessment by nonlinear dynamic analysis. Criteria selection of ground motion records set referred to FEMA P695. Totally 40 ground motion records consisting of horizontal components were selected with the distance of sites 10 km or greater than that from the fault rupture that was considered. These characteristics of ground motion records selection were used to develop fragility curves corresponding to the limit state of building failure.

The 40 ground motion data were obtained from the Pacific Earthquake Engineering Research Center (PEER). Selection criteria of source magnitude based on large magnitude events can cause building collapse even for new structures. Ground motions with a moment magnitude range between 6.5 to 6.9 were selected for this study, as detailed in FEMA P695. Most of the site conditions were in site class D (stiff soil). Figure 2 shows 40 sets of motion records scaled at peak ground acceleration (PGA) of 0.4 g.

Furthermore, for developing fragility curves by using a limit state of five levels of performance-based seismic designs, it required seven or more time-history analyses to record the structural response. Then, selected seven sets of ground motion records (Table 2) will limit the state of performance level in developing the fragility curves for this study.

Table 2. Selective ground motion records for IDA.

No.	Name Record	Event	Station Name	Year	Earthquake Magnitude (M_W)
1	GMC 1400	Imperial Valley-06	El Centro Array #12	1979	6.53
2	GMC 0001	Superstition Hills-02	El Centro Imp. Co. Cent	1987	6.54
3	GMC 0901		Westmorland Fire Station	1987	6.54
4	GMC 2700	Loma Prieta	Sunnyvale - Colton Ave.	1989	6.93
5	GMC 0902	Northridge-01	Lake Hughes #1	1994	6.69
6	GMC 0002	Kobe, Japan	Fukushima	1995	6.90
7	GMC 0003		Kobe University	1995	6.90

3. METHODOLOGY

3.1. Incremental dynamic analysis (IDA)

A method or technique to identify the structural limit state in the series of the amplified intensity of ground motion has been discovered by the IDA to determine the level of shaking that will cause a structure to exceed a specified limit state, thus failing a given performance objective (Vamvatsikos & Allin Cornell, 2002). IDA was developed by performing a series of nonlinear time-history analyses under a suite of ground motion records by equally scaling each record to several intensity levels and recording the structural responses. Ground motions records can be from real earthquakes or generated artificially.

This research used two different methods: by limit state of performance levels and conditional probability under static pushover analysis (SPOA) approach. Both ways were conducted using seven and 40 ground motion records for limit state by performance levels and conditional probability, respectively. The IDA was carried out by nonlinear time-history analysis that was performed by STERA 3D (Saito, 2020) software. The seismic intensity was amplified from 0.1 g to 0.8 g for every 0.1 g increment.

3.2. The limit state of a structural model

The FEMA 356 and a research study from Xue et al. (2008) stated the limit state in performance level conditions. Table 3 shows IO and LS having similar performance levels between FEMA 356 and suggested values by Xue et al. (2008). Damage Control (DC) lies in between Immediate Occupancy (IO) and Life Safety (LS), while an Operational (OP) is at the beginning of performance level. Additionally, the Collapse Prevention (CP) value suggested by Xue et al. (2008) is more conservative compared to FEMA 356 (Ibrahim & El-Shami, 2011).

Nonlinear static pushover analysis (SPOA) was carried out to evaluate the lateral deformation of the building in determining the conditional limit state for the second method of fragility curves development. In SPOA, the lateral force will be statically applied to the building, whichever in X or Y direction. An applied force will gradually increase until the sequenced failure mode occurred. These failure modes will start from flexural until shear failure occurs. Hinges between the connection of the structural members will develop from the formation of the elastic state, followed by the yield point until plastic hinges occur. In addition to this, the ductility of the structural members can be obtained, and the load at which the failure modes occur is recorded. The incremental load will push the building until it reaches global collapse or a predefined drift limit.

Additionally, output data from SPOA such as capacity curve and drift-shear relation curve will be used in these studies to determine the limit state of the building. The estimation of the limit state of the structural model in the weaker direction and the weakest floor regarding the failure mode was calculated in terms of the IDR_{max}.

Table 3. The IDR_{max} for different phases of performance level between FEMA 356 and Xue et al. (2008) proposed values.

Description	FEMA 356 (elements: concrete frames)			Xue et al. (2008) (suggested values)				
Limit state parameter	Maximum inter-story drift ratio			Maximum inter-story drift ratio				
Performance level	IO (1.0%)	LS (2.0%)	CP (4.0%)	OP (0.5%)	IO (1.0%)	DC (1.5%)	LS (2.0%)	CP (2.5%)
Where: OP – Operational, IO – Immediate occupancy, DC – Damage control, LS – Life safety, and CP – Collapse prevention.								

3.3. Statistical analysis for fragility curves development

The conditional probability of a structure to reach or exceed a specific damage state corresponding to the PGA is expressed in Eq. (1) as below:

$$P[\,^{D}/_{PGA}] = \Phi\left[\frac{ln(PGA) - \mu}{\sigma}\right] \tag{1}$$

where Φ is the standard normal cumulative distribution function, μ is the mean value, and σ is the standard deviation of the natural logarithm of PGA at which the structural model reaches the limit state of performance levels. Furthermore, the mean and standard deviation log-normal functions were suited for different performance levels: OP, IO, DC, LS, and CP related to the structural model.

Differing from the method of defining the conditional probability that maximum inter-story drift (IDR_{max}) exceeds the specific limit state of IDR at a given PGA, the equation is expressed as Eq. (2) below:

$$\begin{aligned} P[IDR_{max} > IDR] &= 1 - P[IDR_{max} \leq IDR] \\ &= 1 - \Phi\left(\frac{ln(IDR) - ln(IDR_{max})^{50\%}}{\delta_{eq}}\right) \end{aligned} \tag{2}$$

where $(IDR_{max})^{50\%}$ is equal to mean value (μ), while δ_{eq} is standard deviation and expressed as Eq. (3) below:

$$\delta_{eq} = \frac{\ln(IDR_{max})^{84\%} - \ln(IDR_{max})^{16\%}}{2} \tag{3}$$

where δ_{eq} can be represented as the equivalent dispersion of the 16th and 84th percentile data of IDR_{max} in the normal distribution of statistical data for specified ground motion intensities.

The probability of exceedance is indicated in the fragility curve by means is the damage parameters representing by IDR_{max}, lateral drift, and base shear of the structural model under predefined limiting value at a given intensity measure (IM) of ground motion. In other words, if a predetermined PGA value of 0.5 g is occurring, it will provide a percentage of damage measure at which the line was crossing the fragility line.

4. RESULTS AND DISCUSSION

Through the development of fragility curves, the seismic performance of the target building can be evaluated. Both fragility curves of the X- and Y-directions will be obtained to assess the performance of the building in terms of plan and elevation irregularities effect. In addition, from observation of Figure 3, under weak ground motions, which is 0.2 g, the probability of the target building will be experiencing the OP and IO levels in the X-direction that is 83% and 32%, respectively. However, the likelihood of reaching LS and CP levels is 0%. Meanwhile, in the Y-direction for 0.2 g, the probability of getting the OP and IO levels is 72% and 17%, respectively.

Furthermore, when exposed to the strong ground motions with PGA equal to 0.5 g, the target building will experience approximately the probability of 67% for LS and 44% of CP in the X-direction. The probability of reaching or exceeding the IO level is around 97% and 94% in X- and Y-directions, respectively. In addition, the probability of reaching OP levels is 100% for both X- and Y-directions. Meanwhile, in the Y-direction, the probability of achieving or exceeding LS and CP levels is approximately 45% and 21%, respectively. Undoubtedly, the irregularities of the target building affected the behavior of the structure, which was illustrated in fragility curves. The effect of irregularities on the building was clearly shown at OP, IO, LS, and CP performance levels. The X-direction was seen as a weaker direction than the Y-direction.

Meanwhile, the fragility curve development by conditional probability limit state shows that the probability of damage increases as the level of intensities becomes large. Figure 6 (b) represents the different pattern of fragility curves between X- and Y-directions, which indicates the Y-direction of the target building performs better in seismic response than the X-direction for the conditional probabilities of exceeding 1/125 rad at a given PGA.

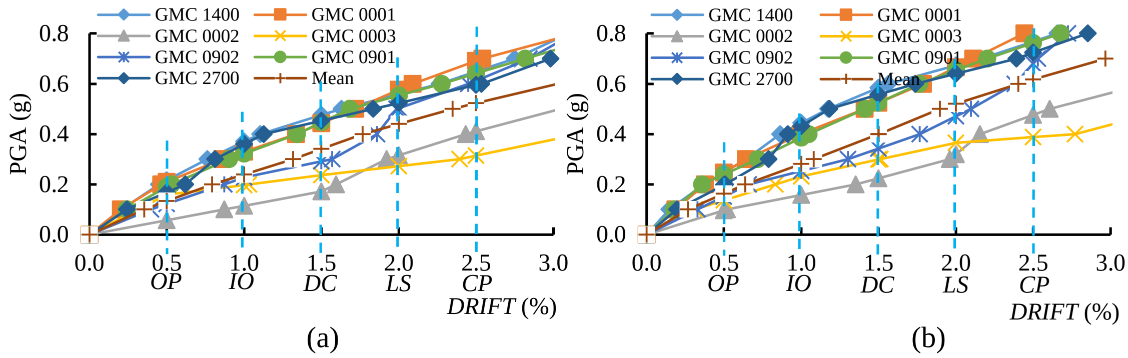

Figure 3. The IDA curves for: (a) target building in X-direction and (b) the target building in Y-direction.

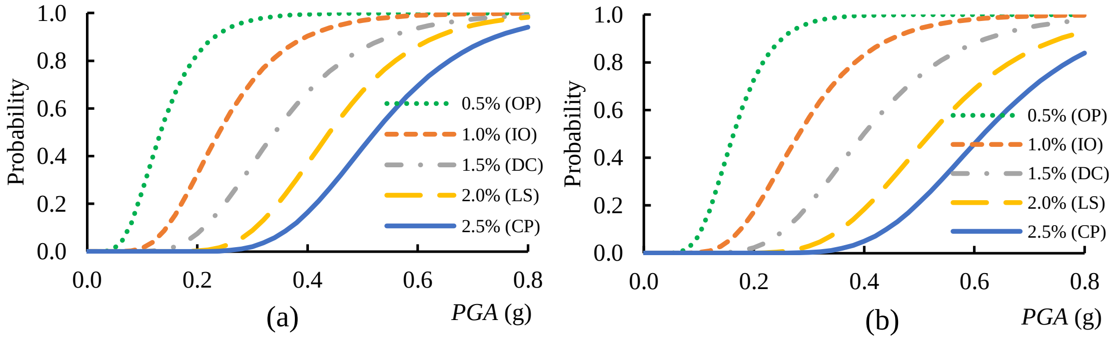

Figure 4. Fragility curves of the target building in (a) X – direction and (b) Y – direction.

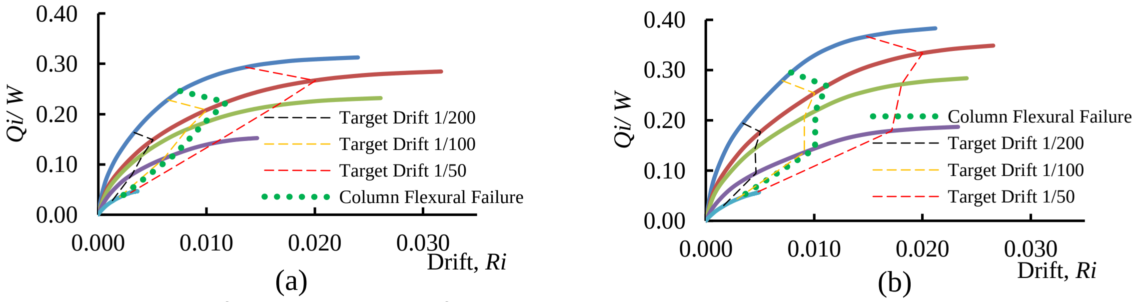

Figure 5. Drift-shear relation of the target building in the (a) X-direction and (b) Y-direction.

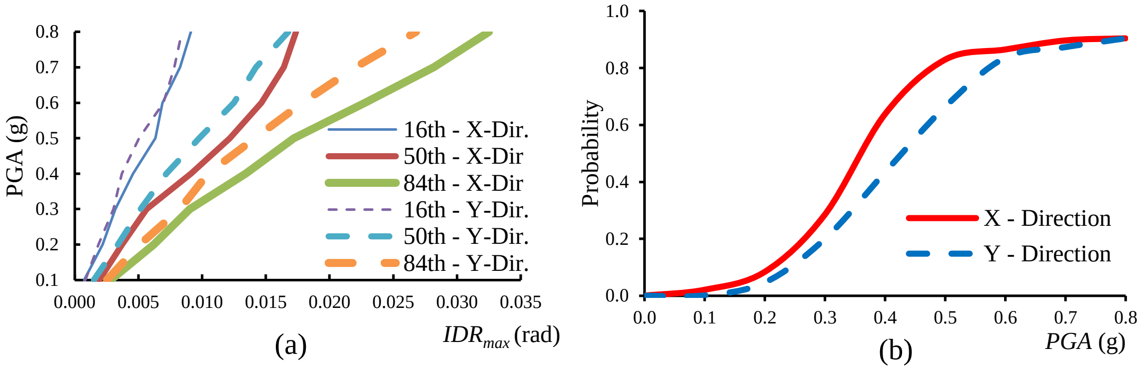

Figure 6. (a) The IDA curves for 40 sets of ground motion records equally scaled at every 0.1 g from 0.1 g to 0.8 g to record the structural response. (b) The fragility curves of conditional probabilities of exceeding damage measure at the first flexural failure of a column at 1/125 rad in X-direction and Y-direction.

5. CONCLUSIONS

Through the observation of OP, IO, LS, and CP performance levels, X-direction exhibits a weaker direction than Y-direction from the assessment percentage of probability of collapse. Furthermore, the fragility curves developed by the limit state method using specific *IDR* also show similar results, which is X-direction is weaker than Y-direction. An evaluation of the appropriate shape of the building under intensity measures in both X- and Y-directions can be obtained from this study. The performance of the building in a similar category can be evaluated by developing a single fragility curve.

Further research is recommended to determine or evaluate the structural vulnerability of different categories of the existing building at high seismicity zones. On the other hand, the retrofitting method of the existing building is also essential to enhance performance capacity and withstand the seismic load.

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