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Damage and Loss Assessment of a Midrise RC Building in Downtown Area of Yangon Region

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ABSTRACT

Yangon is an earthquake-prone region and most of the low-rise to mid-rise residential reinforced concrete buildings are designed for gravity loads only. Therefore, evaluation of seismic vulnerability of buildings is essential in order to predict the probable damages and losses to this type of buildings. Damage assessment and earthquake loss estimation for gravity only design buildings should be performed to predict the damage probabilities and losses under the earthquake loading. In this study, seismic design and gravity design are accomplished for a five-story residential RC building. Nonlinear static pushover analysis is performed using SAP 2000 software and capacity curves and fragility curves are developed for both designs. Damage probability matrices (DPM) are formed for design basic earthquake DBE level and maximum considered earthquake MCE level and the damage states are compared. The expected annual loss of the both designs are evaluated by means of the fragility curves and seismic hazard curve. Expected annual loss (EAL) values are also estimated and compared for both designs for 475 years and 2475 years periods.

KEYWORDS: *Capacity Curve, Fragility Curve, Seismic Hazard Level, Probable Damage States, Expected Annual Loss*

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I. INTRODUCTION

While structures located near a seismically active geologic setting are at risk of being damaged during a potential seismic event, it is possible to mitigate future structural damage by identifying vulnerable structures and applying appropriate retrofit or replacement strategies. As such, seismic loss estimation is an important tool for developing a plan for seismic hazard mitigation. In particular, a significant seismic event affecting a densely populated area could lead to severe damage and significant economic losses. Seismic loss estimation provide a better understanding of the expected losses due to different seismic hazard levels for decision makers to expect structural damage and consider mitigation strategies in particular for concrete structures.[16]

There have been a number of studies related to seismic loss estimation framework and supporting software tools. For example, Porter (2003) developed a modular framework to assess seismic losses based on the performance-based earthquake engineering methodology. It includes four stages: hazard analysis, structural analysis, damage analysis, and loss analysis. This framework provides the frequency with which levels of decision variable are exceeded so that decision makers can determine whether the structural system is safe or has low expected damage for potential earthquakes. HAZUS-MH (2003) was developed by Federal Emergency Management Agency for estimating potential losses from natural disasters including floods, hurricane winds, and earthquakes.[16]

Several research studies have been conducted to assess the direct losses due to structural damage during a seismic event. The HAZUS (FEMA 2010) program can be used to estimate potential losses at a regional scale due to various hazards including floods, earthquakes, and hurricanes. The HAZUS methodology provides estimates of losses due to structural and nonstructural damage in terms of repair costs, expressed as a percentage of building replacement costs. The repair costs are provided by building occupancy class and model building type.[16]

According to the seismicity and the records of the previous considerably high magnitude earthquakes, Yangon Region can be regarded as the low to medium seismicity region. Moreover, tectonically the region is surrounded by the subduction zone between the Indian Plate and Burma Plate to the west and the right lateral Sagaing fault to the east. Some of the large earthquakes that caused the considerable damages to some buildings and some casualties in and around Yangon Region can be recognized in the past records.[15]. Most of the low-rise to mid-rise residential reinforced concrete buildings are designed for gravity loads only. Therefore, it is necessary to assess the seismic vulnerability of gravity only design buildings due to future seismic events. Expected Annual Loss (EAL) can be used to express the quantitative measure of seismic losses and it is also helpful for the identification of effective design and retrofit measures that consider seismic performance over a range of intensity levels.

In this study, a five- story RC residential building is chosen as a case study in order to compare the seismic performance of gravity only design and seismic design buildings. For both designs, nonlinear static pushover analysis is performed using SAP2000 software to generate the capacity curve of the building models. Then, Fragility curves are derived based on HAZUS methodology for two different seismic hazard levels i.e. design basic earthquake (DBE) level and maximum considered earthquake (MCE) level. Discrete probabilities for different damage states under two hazard levels are calculated for both designs. Damage probability matrices (DPM) are formed depending on the performance point corresponding to each hazard level and the damage states are compared. Probabilistic seismic hazard analysis is performed in order to derive hazard curve with annual frequencies of exceedance per peak ground acceleration. Then expected annual loss values are calculated for both design models and the results are compared.

II. Case Study

In this study, a five storey residential RC building which is a two-unit apartment located in Latha Township, which is a congested downtown area of Yangon region is considered. Fig. 1 shows photo of buildings in Latha Township. Fig. 2 shows the case study building.

Figure 1. Buildings in Latha Townships

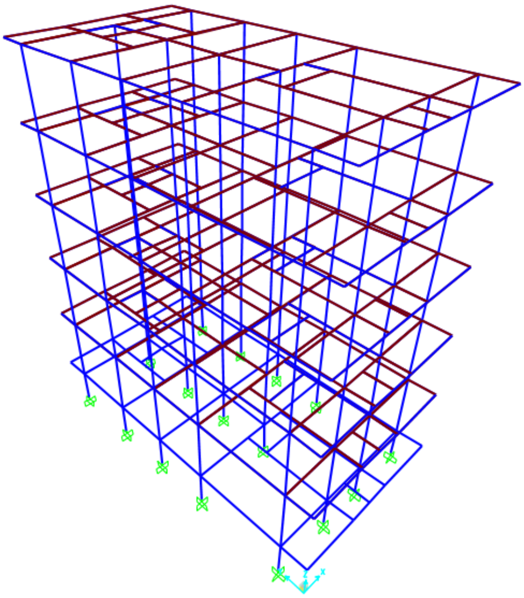

Figure 2. 3-D Model of Case Study Building

The building is designed as per IBC 2006 and ASCE 7-05 for both gravity design and seismic design. The storey height of the building is 10 feet. The plan dimensions are 25ft x 49 ft. For gravity design model, the compressive strength of concrete f'c is 2500 psi and yield strength of reinforcing bars fy is 40000 psi. On the other hand, the compressive strength f'c and yield strength of reinforcing bars fy for seismic design model are 4000 psi and 50000 psi respectively. The material properties values for case study building are considered to be consistent with the practice in the construction industry for this type of building in Yangon.

For gravity design, only gravity loads are considered. However, detailing for structural members are provided as per requirements of intermediate moment resisting frame according to information from Yangon City Development Committee, YCDC.

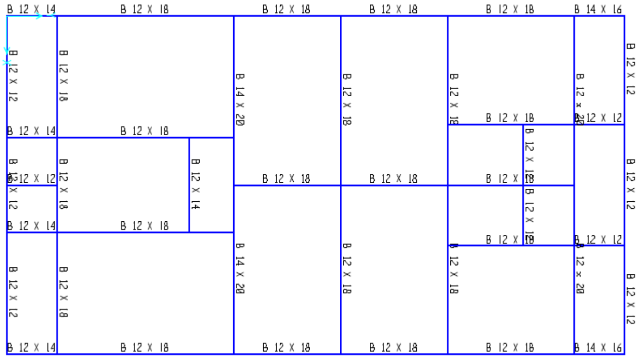

Figure 3. Typical Beam Plan of Seismic Design Model

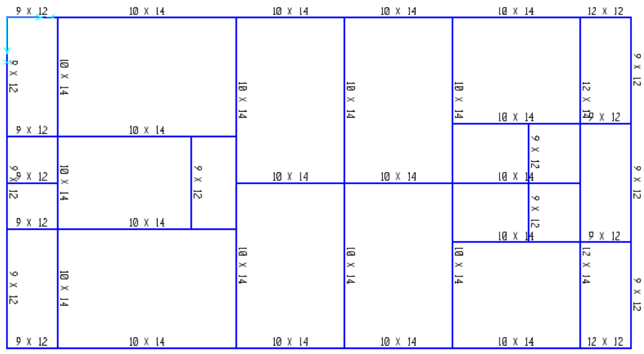

Figure 4. Typical Beam Plan of Gravity Design Model

TABLE I. SIZES OF COLUMNS FOR SEISMIC DESIGN AND GRAVITY DESIGN MODEL

Sizes of Columns			
Seismic Design		*Gravity Design*	
Size (inx in)	*Floor Level*	*Size (inx in)*	*Floor Level*
20 x 20	Base to 2nd Floor	14 x 16	Base to 1st Floor
18 x 18	2nd Floor to 4th Floor	14 x 14	1st Floor to 3rd Floor
16 x 16	4th Floor to Roof	12 x 12	3rd Floor to Roof

Seismic design of the building is designed as a special moment resisting frame. Soil profile type is taken as S_D, stiff soil condition. Wind load is also considered for seismic design model with a wind speed of 100 mile per hour for Yangon Region according to Myanmar National Building Code MNBC. [5]

Typical beam plan for seismic design and gravity design are described in Fig. 2 and Fig. 3 respectively. Sizes of columns for seismic design model and gravity design model are shown in Table I.

III. Methodology

A. Nonlinear Pushover Analysis

In this study, nonlinear static pushover analysis is performed considering both material and geometric nonlinearities. The material nonlinearity is considered by assigning plastic hinges at the end of beam and column elements. P-M2-M3 hinge considering the interaction of axial force and bending moments are used for columns and flexural M3 hinges are used for beams. The hinge properties according to FEMA-356 are used in this study. Geometric nonlinearity is modelled by considering P-Δ effects. [4]

B. Capacity Curve

Building capacity curves, used with capacity spectrum method provide simple and reasonably accurate means of predicting inelastic building displacement response for damage estimation purposes. Building response is characterized by building capacity curves. A building capacity curve is a plot of a building's lateral load resistance as a function of a characteristic lateral displacement. It is derived from a plot of static-equivalent base shear versus building roof displacement, pushover curve. [1]

C. Fragility Curves

For the development of fragility curves, guidelines given by HAZUS technical manual have been used. HAZUS methodology was developed for FEMA by National Institute of Building Science (NIBS). Building fragility curves are lognormal functions that describe the probability of reaching, or exceeding, structural and non-structural damage states, given median estimates of spectral response, for example spectral displacement. These curves take into account the variability and uncertainty associated with capacity curve properties, damage states and ground shaking. For a given damage state, a fragility curve is described by the lognormal probability density function as in equation (1). [3]

$$P\left[ds / S_d\right] = \phi\left[\frac{1}{\beta_{ds}} \ln\left(\frac{S_d}{\bar{S}_{d,ds}}\right)\right] \quad (1)$$

Where,

S_d = spectral displacement

$S_{d,ds}$ = the median value of spectral displacement at which the building reaches the damage state threshold, ds

β_{ds} = the standard deviation of the natural logarithm of spectral displacement for damage state, ds

Φ = the standard normal cumulative distribution function

The standard deviation of the natural logarithm of spectral displacement for each damage state, β_{ds} are obtained from HAUS MH-MR 4. According to the description for model building types of HAZUS methodology, the case study building is a mid-rise concrete moment frame, C1M. Seismic design level for seismic design model is taken as moderate code because the building is located in seismic zone 2B. For gravity design model, the seismic design level is taken as precode level as seismic loads are not considered in the design. [3]

IV. Damage Assessment

A. Damage State Thresholds

Barbat et al. have proposed damage state thresholds for four damage states as slight, moderate, severe and complete damage states based on yield and ultimate spectral displacement of the buildings. Those damage state thresholds values are shown in Table II. and Fig. 4.

TABLE II. DAMAGE STATE THRESHOLDS

Damage States	Spectral Displacement (cm) (Sd,ds)
Slight	0.7Dy
Moderate	Dy
Severe	Dy + 0.25(Du – Dy)
Complete	Du

The yield spectral displacement (D_y) and ultimate spectral displacement (D_u), are obtained analytically from the capacity curve. Yield capacity point represents the true lateral strength of the building considering redundancies in design, conservatism in code requirements and true strength of materials. Ultimate capacity point represents the maximum strength of the building when the global structural system has reached a fully plastic state. [2]

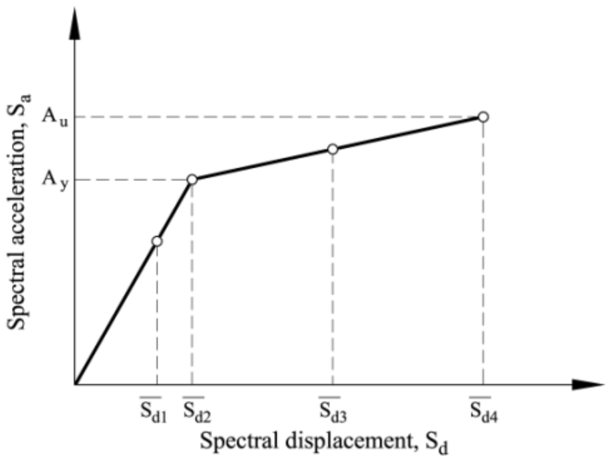

Figure 5. Damage State Thresholds from Capacity Spectrum

B. Demand Spectrum

For the demand spectrums, MCE spectral response acceleration at short period S_s value of 0.77g, MCE spectral response acceleration at 1 sec period S_1 value of 0.31g and long-period transition period T_L value of 6 sec is taken for Yangon Region according to Myanmar National Building Code (MNBC). [5]

C. Damage Probability Matrix

A mean damage index or weighted average damage index, DS_m is close to the most likely damage state of the structure and can be calculated as in equation (2). DS_m can be applied to estimate the most likely damage state of the structure.

$$DS_m = \sum_{i=1}^{4} ds_i P\left[ds_i\right] \quad (2)$$

Where, the values of ds_i are 1, 2, 3 and 4 for the damage states i considered in the analysis and $P[ds_i]$ are the corresponding occurrence probabilities. Table III. shows the most probable damage grade as a function of the mean damage index. [2]

For each seismic hazard level, damage probability matrices (DPM) mainly depend on the spectral displacement of the performance point and the capacity of the building.

TABLE III. DAMAGE STATE AND MEAN DAMAGE INDEX VALUES

Mean damage index intervals	More probable damage state
0-0.5	No damage
0.5-1.5	Slight damage
1.5-2.5	Moderate damage
2.5-3.5	Severe damage
3.5-4.0	Complete damage

D. Results for Seismic Design Model

After performing the pushover analysis, capacity curve for both designs are obtained by capacity spectrum method of ATC 40. [1]

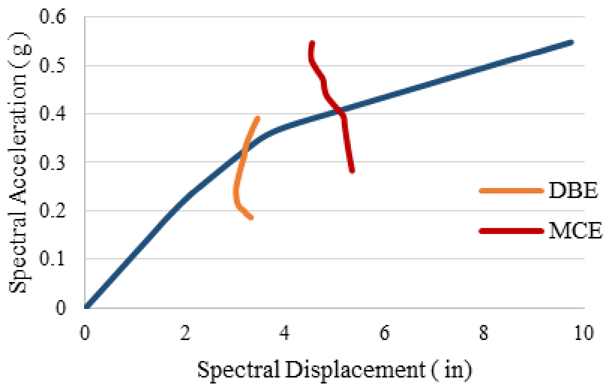

Figure 6. Capacity Curve with Demand Curves of Seismic Design Model

The capacity curve and demand curve of seismic design model for DBE and MCE hazard levels are shown in Fig. 5.

For seismic design model, yield spectral displacement Dy is 3.62 in and ultimate spectral displacement Du is 9.74 in. Performance point is the intersection of the capacity spectrum with the corresponding demand spectrum in the capacity spectrum method and the associated damage state for the structure can be evaluated by using this point. The spectral displacement at the performance points are 3.19 in for DBE level and 4.84 in for MCE level respectively.

The median spectral displacement for slight, moderate, extensive, complete damage states of the seismic design model which obtained from damage states thresholds are shown in Table IV.

TABLE IV. MEAN SPECTRAL DISPLACEMENT FOR EACH DAMAGE STATE OF SEISMIC DESIGN MODEL

Median spectral displacement $\bar{S}$ d (cm)			
Slight (DS1)	Moderate (DS2)	Severe (DS3)	Complete (DS4)
2.53	3.62	5.15	9.74

The fragility curves for four damage states are derived for seismic design model and are shown in Fig. 6.

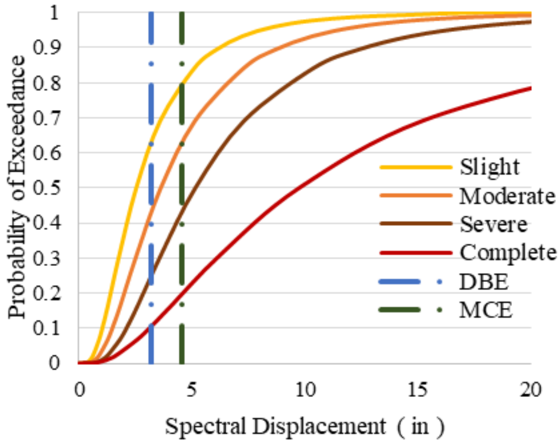

Figure. 7 Fragility Curve for Seismic Design Model

TABLE V. DAMAGE PROBABILITY MATRICES AND MORE PROBABLE DAMAGE STATES FOR SEISMIC DESIGN MODEL

Hazard Level	Damage state probabilities				Weighted Mean Damage Index (DS_m)	More Probable Damage State
	DS1	DS2	DS3	DS4		
DBE	0.19	0.15	0.16	0.13	1.47	Slight damage
MCE	0.17	0.18	0.23	0.24	2.17	Moderate damage

Figure 6. shows that for DBE hazard level of 3.19 in spectral displacement S_d, the expected probability for the slight damage is about 63%, moderate damage 44%, severe damage 28% and complete damage 13% respectively. Similarly, for MCE hazard level of 4.84 in spectral displacement S_d, the damage is increased to expected probability for the slight damage of 81%, moderate damage of 65% severe damage of 47% and complete damage of 24%.

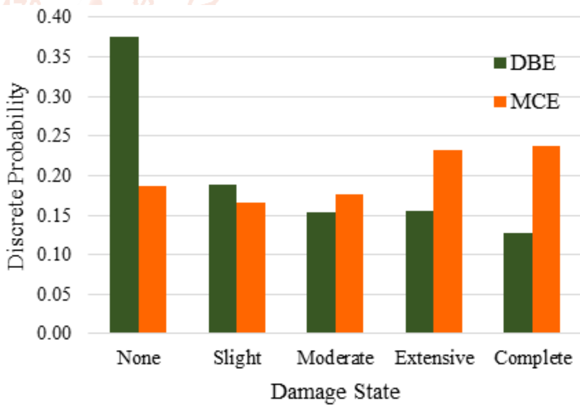

Figure 8. Discrete probabilities of Different Damage States for Seismic Design Model

According the mean damage index values from Table V, it has been observed that the seismic design model is expected to be in slight damage state for DBE level and in moderate damage state MCE level. Fig.7 shows the discrete probabilities of different damage states of two hazard levels for seismic design model.

E. Results for Gravity Design Model

The capacity curve and demand curve of gravity design model for DBE and MCE hazard levels are shown in Fig.8.

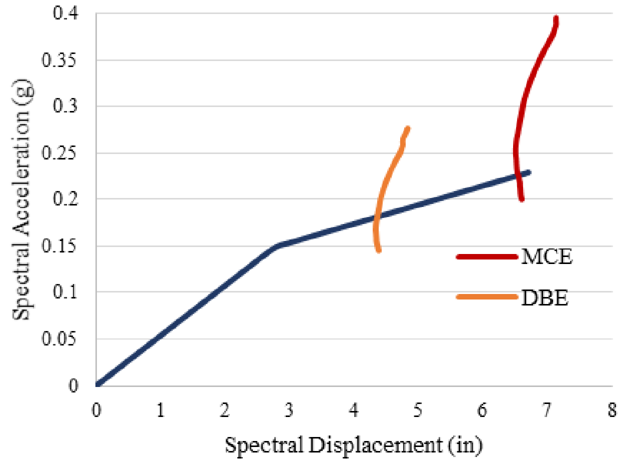

Figure 9. Capacity Curve with Demand Curves of Gravity Design Model

For gravity design model, yield spectral displacement Dy is 2.62 in and ultimate spectral displacement Du is 6.70 in. The spectral displacement values at the performance points are 4.37 in for DBE level and 6.56 in for MCE level respectively. The median spectral displacement for slight, moderate, extensive, complete damage states of the gravity design model which obtained from damage states thresholds are shown in Table VI.

TABLE VI. MEAN SPECTRAL DISPLACEMENT FOR EACH DAMAGE STATE OF GRAVITY DESIGN MODEL

Median spectral displacement S̄ d (cm)			
Slight (DS1)	Moderate (DS2)	Severe (DS3)	Complete (DS4)
1.83	2.62	3.64	6.70

The fragility curves for four damage states are derived for gravity design model and are shown in Fig. 9.

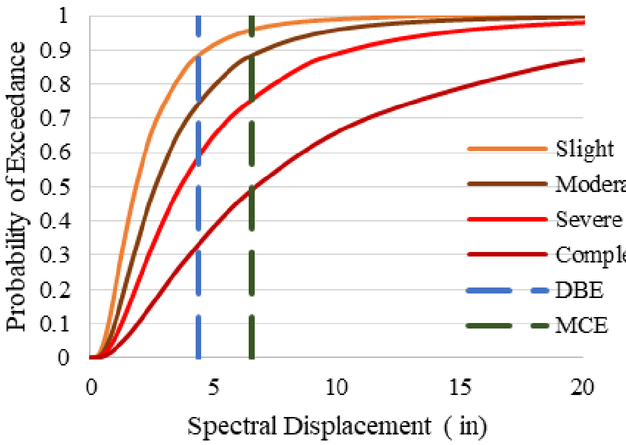

Figure 10. Fragility Curve for Gravity Design Model

According to Figure. 9, it can be seen that for DBE hazard level of 4.37 in spectral displacement S_d, the expected probability for the slight damage is nearly 88%, moderate damage 75%, severe damage 59% and complete damage 33% respectively. Similarly, for MCE hazard level of 6.56 in spectral displacement S_d, the damage is increased to expected probability for the slight damage of 96%, moderate damage of 88% severe damage of 76% and complete damage of 49%.

TABLE VII. DAMAGE PROBABILITY MATRICES AND MORE PROBABLE DAMAGE STATES FOR GRAVITY DESIGN MODEL

Hazard Level	Damage state probabilities				Weighted Mean Damage Index (DS_m)	More Probable Damage State
	DS1	DS2	DS3	DS4		
DBE	0.14	0.16	0.26	0.33	2.50	Moderate damage
MCE	0.08	0.12	0.27	0.49	3.09	Severe damage

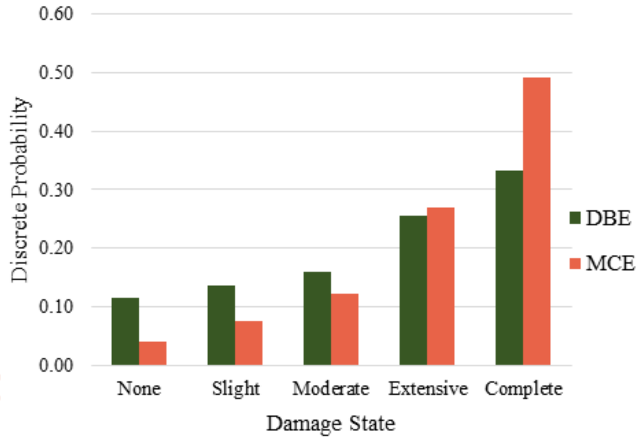

Figure 11. Discrete probabilities of Different Damage States for Gravity Design Model

Table VII. shows the mean damage index values for gravity design model. It has been observed that the gravity design model is expected to be in moderate damage state for DBE level and severe damage state for MCE level. Fig.10 shows the discrete probability of different damage states of two hazard levels for gravity design model.

F. Comparison of Results and Discussions

The discrete probabilities belonging to different damage states of the gravity design and seismic design for DBE and MCE seismic design levels are compared and shown in Fig. 11 and Fig. 12.

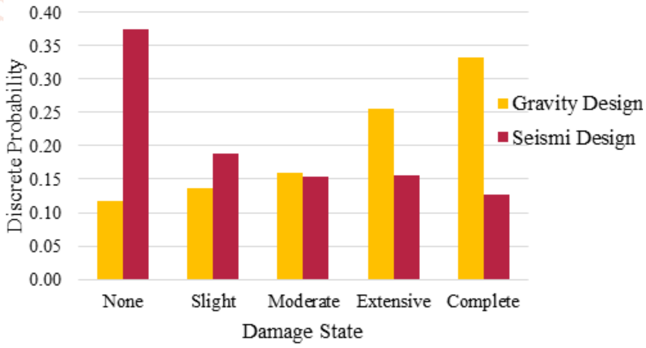

Figure 12. Discrete Probabilities of Different Damage States for Gravity Design and Seismic Design at DBE Hazard level

From the figures, it can be seen that the probabilities of complete damage for gravity design model are more than double of those values for the gravity design model for both DBE and MCE hazard levels. The probabilities of extensive damage are also higher for gravity design model. On the other hand, it is observed that the probabilities of none and slight damage for seismic design model are significantly higher than those corresponding values for the gravity design model.

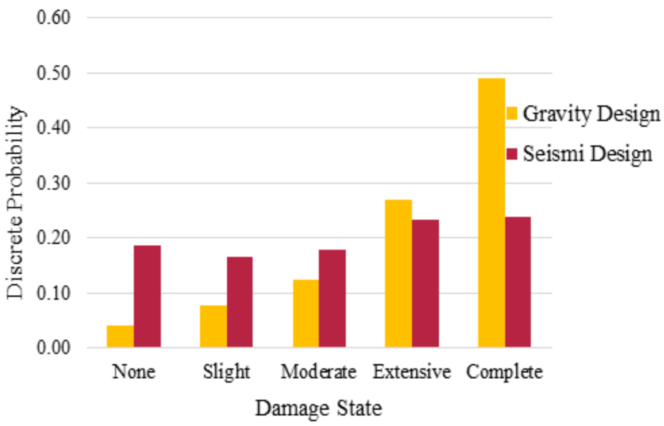

Figure 13. Discrete Probabilities of Different Damage States for Gravity Design and Seismic Design at MCE Hazard level

Therefore, it is clear that gravity design model is more vulnerable and may undergo severe damage condition and encounter losses under high seismic loading.

TABLE VIII. MORE PROBABLE DAMAGE STATES FOR SEISMIC DESIGN AND GRAVITY DESIGN

Hazard Level	More Probable Damage State	
	Seismic Design	Gravity Design
DBE	(1.47) Slight	(2.50) Moderate
MCE	(2.17) Moderate	(3.09) Severe

Table VIII. shows the comparison of probable damage states for seismic design and gravity design for DBE and MCE hazard levels. The probable damage state of the seismic design model is slight for DBE hazard level and moderate for MCE hazard level. For gravity design, it has been observed that probable damage state for DBE and MCE hazard levels are moderate and severe damage states respectively. Therefore, under the higher seismic hazard level, the gravity design model is more likely to experience severe damage and losses.

V. Expected Annual Loss Calculation

A. Fragility Curves in terms of PGA

Conversion of spectral displacement S_d to peak groung acceleration PGA (g) are carried out using formulations and tables based on the method stated in the SYNER-G (2011). [14]

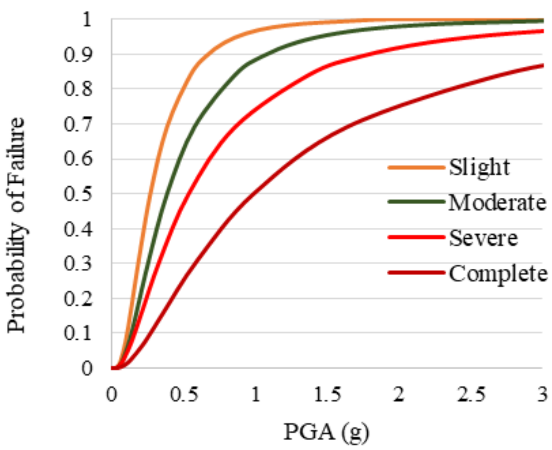

Figure 14. Fragility Curve for Gravity Design Model

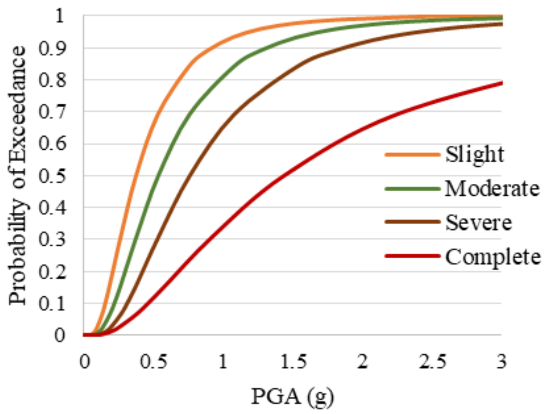

Figure 15. Fragility Curve for Seismic Design Model

Using the corresponding building period and the amplification factor for site class D, the peak ground acceleration PGA (g) are calculated and fragility curves are derived for both design in terms of PGA (g) and are shown in Figure 13 and 14.

B. Probabilistic Seismic Hazard Analysis

Probabilistic seismic hazard analysis is performed to calculate surface ground motion and to derive hazard curve for the study area, Latha Township. In this study, the estimated seismic hazard levels and Gutenberg-Richter relationship of Sagaing fault are based on the seismic hazard assessment for Myanmar developed by Myo Thant et al (2012). [9]

The annual rate of exceedance curve for Sagaing fault is developed as a function of corresponding moment magnitudes and is shown in Fig. 15.

Peak ground acceleration (PGA) at the bed rock is estimated for the southern segment of Sagaing fault, SGSMS_03, a right lateral strike-slip fault, by applying the attenuation relationship proposed by Boore, et al. (1997).

$$\ln Y = b_1 + b_2(M-6) + b_3(M-6)^2 + b_5 \ln r + b_v \ln \frac{V_s}{V_A} \quad (3)$$

$$r = \sqrt{r_{jb}^2 + h^2}$$

$b_1 = b_{1SS}$ for strike-slip earthquakes
Y = peak horizontal acceleration or pseudo acceleration response (g)
M = moment magnitude
r_{jb} = closest horizontal distance to the surface projection of the rupture plane (km)
V_s = average shear wave velocity to 30m (m/sec)

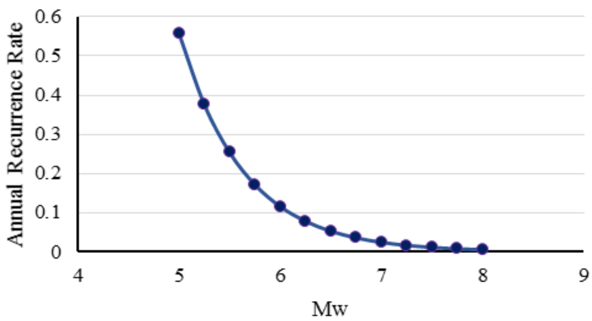

Fig. 16 Annual Rate of Exceedance of Certain Earthquake Magnitude for the Sagaing Fault

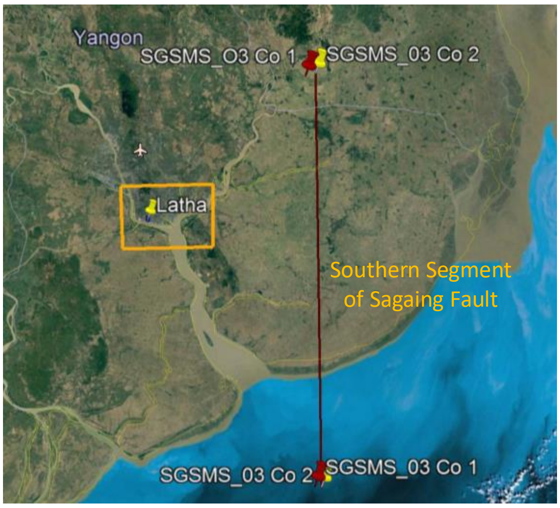

Fig. 17 Location map of case study area and the Sagaing Fault

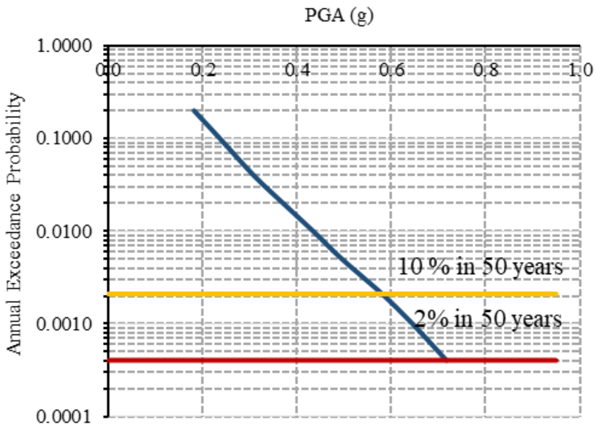

Fig. 18 Seismic Hazard Curve

In this study, the epicentral distance from the Sagaing fault to the study area, Latha Township is taken as 36.2 km. Peak ground acceleration value are calculated for the return periods of 5, 10, 25, 50, 100, 200, 475, 1000 and 2475 years respectively.

Peak ground acceleration values on the surface are calculated by multiplying the bed rock PGA with amplification factor value of 2.1 which is obtained from the soil amplification factor map for Yangon city area developed by Chit Su San [11]. The location map of the case study area and the Sagaing fault is showed in Figure 16 and the seismic hazard curve of the study area is shown in Fig. 17.

C. Expected Annual Loss

Mean damage ratio for each limit states are adopted based on HAZUS methodology. Mean damage ratio (MDR) values expressed in terms of percent of the replacement cost of the building are described in Table IX.

TABLE IX. MEAN DAMAGE RATIO

Limit States	Mean Damage Ratio (MDR)
Slight	(0.05) 5 % of the replacement cost
Moderate	(0.15) 15 % of the replacement cost
Severe	(0.50) 50 % of the replacement cost
Complete	(1.0) 100 % of the replacement cost

Estimation of the expected annual loss has been evaluated by integrating hazard, fragility and the exposed value. Seismic hazard has been computed in terms of the annual rate of exceeding a given PGA and denoted by λ(PGA). The probability of expected annual loss l is estimated using hazard curve and fragility curve as follow:

$$l = \int P(LS|PGA)|d\lambda(PGA)| \qquad (4)$$

Fragility curves composed of n limit states for each building model has been computed in terms of probability of exceeding a given limit state LS given the PGA value and denoted by P(LS|PGA). The expected annual loss EAL per each building can be calculated according to the following equation:

$$EAL = \sum_{LS=1}^{n} MDR \int [P(LS|PGA) - P(LS+1|PGA)]|d\lambda(PGA)| \qquad (5)$$

Where for the last limit state, P(n + 1|PGA) = 0 and n value is 4 as there are four limit states for this study. For each limit state, mean damage ratio (MDR) value has been defined according to the Table IX.

D. Results and Discussions

Table X shows the comparison of expected annual loss (EAL) values for both designs. It has been observed that expected annual loss (EAL) values of seismic design and gravity design model for 2475 years period are 0.015 and 0.023 percent respectively and the probable seismic loss for gravity design model is a bit more than 50% higher than the seismic design model.

TABLE X COMPARISON OF EXPECTED ANNUAL LOSS FOR TWO BUILDING MODELS

Model	EAL(%) for 475 years Period	EAL(%) for 2475 years Period
Gravity Design	0.102	0.023
Seismic Design	0.061	0.015

For the case of 475 years period, EAL values are 0.061 percent for seismic design and 0.102 percent for gravity design. Therefore, EAL value of gravity design model is about 67% higher than seismic design model.

VI. Conclusion

In this study, seismic performance assessment of gravity design and seismic design model of a six-storey residential reinforced concrete frame building has been evaluated with static nonlinear pushover analysis. Analytical fragility curves have been developed for four limit states. Probabilistic seismic hazard analysis is performed and seismic hazard curve has been derived for the study area.

The discrete probabilities of the each damage state are calculated and the damage probability matrices are developed to identify the probable damage state for both design models. The fragility curves indicate higher damage probability for gravity design model at both DBE and MCE level. By means of damage probability matrices and mean damage index intervals, it has been observed that the gravity design model may experience moderate damage during DBE hazard level but may undergo the severe damage state under MCE hazard level.

The expected annual loss values are calculated for each design model and results are compared. The results shows that the expected annual loss (EAL) value for the gravity design model is apparently higher than those value for seismic design model. Therefore, it can be seen that the earthquake insurance premium value for gravity design may be apparently higher than the seismic design model if the expected annual loss value is considered as the pure premium value for this building. To sum up, as the damage state conditions and expected annual loss value of seismic design model is considerably lower than those value of gravity design model, it can be concluded that seismic design model may undergo less damage and losses and will provide safer environment condition for residents.

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