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Seismic Fragility Analysis of RC Residential Buildings

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Abstract

Nepal is located in one of the highly seismically active zone of the world. The construction of RC buildings is most prevalent in different towns of the country. In order to minimize the adverse effect of earthquake on such buildings, seismic performance should be performed. It is important to analyze the performance of the buildings with different geometry against seismic action. The present study is related with the investigation of the seismic performance of the RC residential buildings with different plan configurations. Three building models of rectangular, square and L-shaped plan configuration each having 2, 3, 4 and 5 stories are separately analyzed to obtain the seismic response of the buildings. For the seismic analysis, pushover analysis and non-linear time history analysis have been performed to evaluate demand and capacity respectively. Fragility curves were developed following the First Order Second Moment method for the four limit states: slight damage, moderate damage, extensive damage and complete damage to obtain the probability of failure damage due to various levels of strong ground motions. There is variation in probability of failure for different earthquake time history data even for same building due to the influence of ground motion parameters. The probability of failure varies with building configurations for RC residential buildings. The probability of complete failure of 3 story RC buildings of Kirtipur under 0.35g of 2015 Gorkha earthquake is approximately about 27% for square shaped, 30% for rectangular shaped and 48% for asymmetric type buildings.

Keywords

Fragility curves, Non Linear Static Analysis, Probability of failure, Time History Analysis

1. Introduction

Nepal lies in the boundary of Indian plate and Eurasian plate, which makes Nepal seismically very active. The past records of Earthquakes in Nepal show that Nepal is subjected to two large earthquakes of magnitude 7.5-8 Richter scale every forty years and one earthquake of 8+ Richter scale every eighty years. Nepal was struck by huge earthquake of magnitude 8.3 Richter in 1934 causing considerable damages to infrastructures and great loss of lives. As per the past reports, the casualties caused by this earthquake were highest for any recorded earthquake in history of Nepal till 1934. Almost 80 years after this earthquake, the disastrous earthquake of magnitude 7.8 Richter struck Nepal once again on 25 April, 2015 resulting huge loss of lives and properties forcing out many homeless. According to Post Disaster Needs Assessment (PDNA), a total of 498,852 houses were categorized as fully collapsed or damaged beyond repair and 256,697 houses were partly damaged. A major proportion of damage was in the housing sector as per estimation in PDNA. There is a need to identify the seismic vulnerability and risk of existing buildings to reduce the risk in future. The evaluation of seismic performance of RC residential buildings let us know about the failure of the buildings under earthquake. The necessity of seismic strengthening of structures by retrofitting can also be suggested. It can assist in management of earthquake risk reduction. Further it helps in loss estimation.

The fragility curves describe the probability of damage to the buildings. Building fragility curves are lognormal functions that describe the probability of reaching or exceeding damage states at given median estimates of spectral response. These curves take into account the variability and uncertainty associated with capacity spectrum characteristics, damage levels and ground shaking. [1] derived empirical fragility functions for Nepali residential buildings. Many researches have been carried out for seismic vulnerability assessment of reinforced concrete building [2] and [3] using nonlinear static analysis. The nonlinear dynamic time history analysis has been extensively used to evaluate the vulnerability of the different reinforced concrete buildings [4] and [5].

2. Objective

The main objective is to obtain the fragility curves for different geometrical configuration RC residential building due to earthquake. The next objective also include evaluation and determination of the seismic performance of RC residential buildings excited by various earthquake ground motion time histories.

3. Theoritical framework

[6] states that fragility curve as useful tools to estimate the probability of structural damage due to earthquakes as a function of ground motions indices or various design parameters. For the evaluation of seismic performance, the RC buildings are modeled and using non-linear static pushover analysis, the capacity of building is obtained. Also, the response of building is obtained by non-linear dynamic time history analysis. Further, the fragility analysis is performed which is the preliminary step to estimate the probability of failure of building. The proposed fragility analysis is done on RC building to obtain its probability of failure using First Order Second Moment (FOSM) method approach. The result of fragility analysis can be obtained in the form of fragility curves in terms of probability of failure and peak ground acceleration (PGA) with lognormal distribution.

3.1 Static pushover analysis

Pushover analysis is carried out to get capacity curves for both push X and push Y direction. For this, plastic hinges are defined in columns and beams. In this study, the default hinge properties was assigned to a frame element at 5% distances from each ends. The built-in default hinge properties for concrete members are based on ATC-40 and FEMA-273. Degree of freedom for columns is P-M2-M3 directions and thus the hinge type is selected from table 10-8 (concrete column) of ASCE 41-13 and degree of freedom for beam is M3 direction, and thus the hinge type is selected from table 10-7(Concrete Beams- Flexure) items 1 of ASCE 41-13 which is provided by default in ETABS V 16.2.0. Displacement control approach of pushover analysis was adopted for nonlinear static analysis of structure in both directions. Different damage states are pointed out based on a solution proposed by [7].

Table 1: Damage states by (FEMA, HAZUS Technical Manual, 2003: Phadnis, 2018)

Damage State	Median spectral displacement (Sd,ds)
Slight	Sd,S = Sd,y (First yield)
Moderate	Sd,M = 1.5Sd,y
Extensive	Sd,E = 0.5(Sd,M + Sd,C)
Complete	Sd,C = Average median value from capacity spectrum of building near collapse state

3.2 Time history analysis

Time history analysis of each building is carried out to get the demand of structure. The ground motions are selected from previous recorded earthquake from ¡strongmotioncenter.org¿ with various magnitude, mechanism and PGA value.

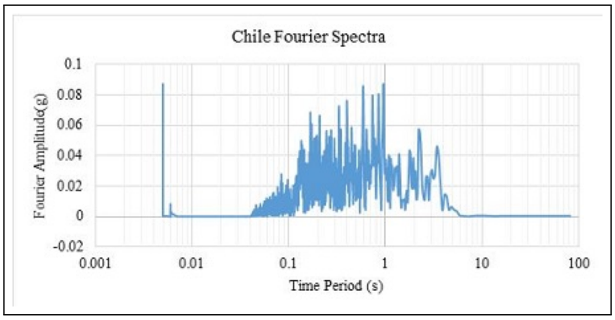

Figure 1: Fourier amplitude spectra of Chile earthquake

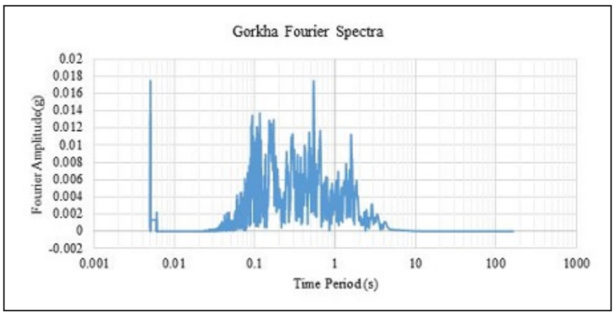

Figure 2: Fourier amplitude spectra of Gorkha earthquake

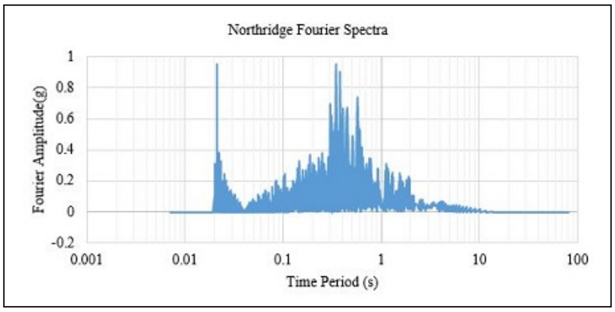

Figure 3: Fourier amplitude spectra of Northridge earthquake

The earthquake ground motion time histories of Northridge earthquake (6.7 Mw and 1.92g PGA), Chile earthquake (8.8 Mw and 0.135g PGA) and Gorkha earthquake (7.8 Mw and 0.18g upward PGA) are chosen based on the high amplitude content of earthquake in the range of time period corresponding to the fundamental time period of considered buildings. Each of these time histories are matched with IS 1893:2002 in time domain based on [8] and synthesized by scaling up or down at step of 0.15g so that fragility curves can be generated using first order second moment method approach.

3.3 Development of Fragility curves

First order second moment (FOSM) is one of analytical method of development of fragility curves. This method uses basic random variables which are usually described only by their first and second moments (mean and standard deviation). Fragility curve is described by the following lognormal probability density function [5].

$$P(\frac{ds}{Sd}) = \frac{\phi * log(\frac{Sd}{Sd,ds})}{\beta ds} \tag{1}$$

where,Sd,ds is the threshold spectral displacement
βds is the standard deviation of the natural logarithm of this spectral displacement.
ϕ is the standard normal cumulative distribution function.
Sd is the spectral displacement of the structure.

After calculating the mean and standard deviation of natural logarithmic of spectral displacement, the standard normal distribution for the probability function is calculated for each variable and fragility curve is plotted between probability of failure as vertical axis and intensity measure as horizontal axis.

4. Case Study

4.1 Data collection

The data of 5649 residential buildings registered and uploaded in the in the website of Kirtipur municipality shows that 73% buildings are RC frame buildings while the remaining are either tahara or load bearing structures. Also, it is found that 2 story, 3 story, 4 story and 5 story buildings consists of 27.5%, 41.98%, 16.58% and 5.80% respectively of RC frame buildings.

4.2 Building description

Three building models of rectangular, square and L-shaped plan configuration each having 2, 3, 4 and 5 stories are in finite element software ETABS 2016. The building model R1 is long rectangular type, building model S1 is of square plan selected to represent the symmetrical and regular buildings and the building model P1 is P shaped representing the P/L shaped eccentric plan. Each building model R1, S1 and P1 is modelled and analyzed separately into 2 storey, 3 storey, 4 storey and 5 storey building models. All the models used in this study are RC residential buildings with infill walls loads. Three of the total twelve building models considered are as follows:

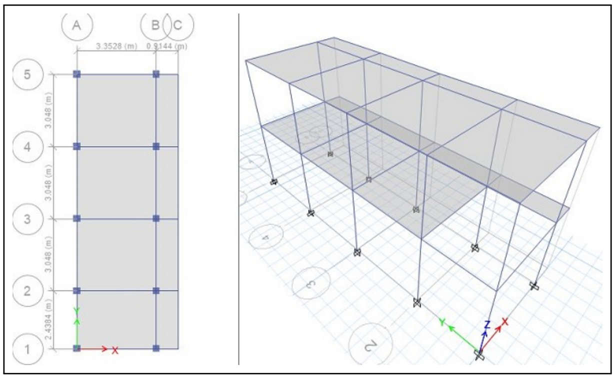

Figure 4: Plan and 3D of building R1

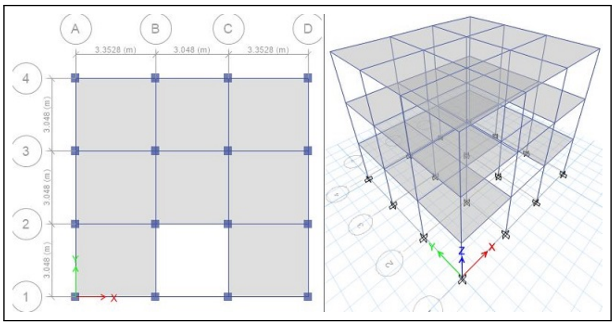

Figure 5: Plan and 3D of building S2

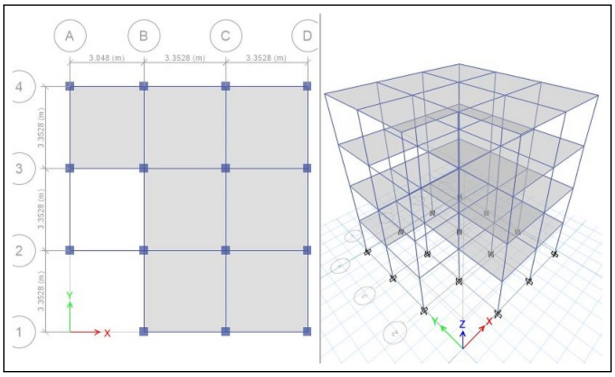

Figure 6: Plan and 3D of building P3

Other data adopted during analysis are given below. Concrete grade of M20 and re-bar as Fe 415 is used for all building models during modeling in ETABs 2016. The density of brick masonry and concrete used is 19kN/m^3 and 25kN/m^3 respectively.

Inter-story Height of Building :2.895m

Column Size:

- 300mm x 300mm for 2 and 3 storey buildings
- 350mm x 350mm for 4 storey buildings
- 400mm x 400mm for 5 storey buildings

Beam Size:230mm x 350mm

Depth of Slab:127mm

Plinth area of considered buildings:

- R1 type: 531.727 sq.ft for 2, 3 and 4 storey buildings and 671.656 sq.ft for 5 storey building
- S1 type: 959.508 sq.ft for all buildings
- P1/L1 type: 701.908 sq.ft for 2, 3 and 4 storey buildings and 945.515 sq.ft for 5 storey building

Table 2: Dead and Live load

Load	Intensity
Floor live load	3 kN/m^2
Roof live	1.5 kN/m^2
Floor Finish	1 kN/m^2

Table 3: Design Parameters (IS 1893:2002)

Factor name	Value
Zone V with zone factor	0.36
Importance Factor	1
Response reduction factor	1.5
Soil type	II (MEDIUM)

5. Result and Discussions

5.1 Identification of damage points:

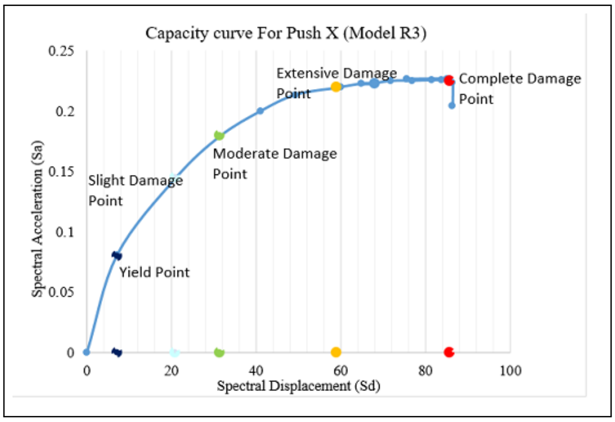

Figure 7: Capacity curve for pushover in X-direction of modal R3

Above figure shows the capacity curve of three story rectangular building. Also, different damage state points: slight to collapse including the first yield point are highlighted in the capacity curve. Different damage states are pointed out based on the solution proposed by Duan and Pappin (2008) in 14th World Conference in Earthquake Engineering which is based on recommendation of HAZUS.

5.2 Comparison of damage states of different plan configurations of 3 story buildings:

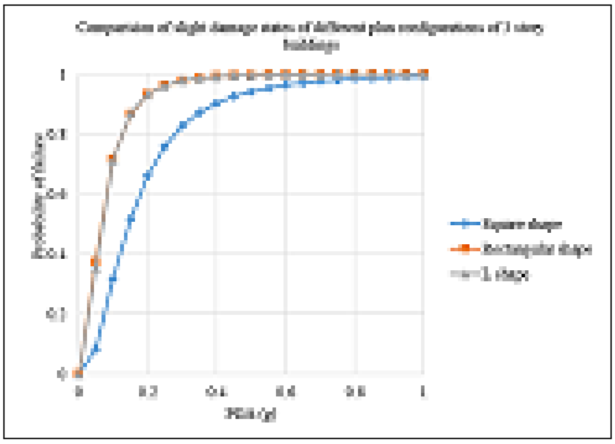

Figure 8: Comparison of slight damage state of different plan configurations of 3 story buildings

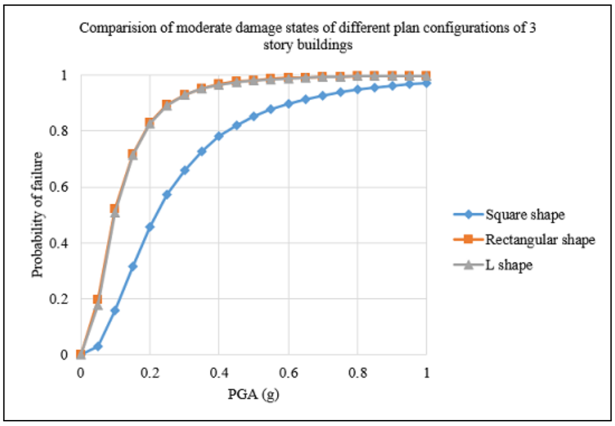

Figure 9: Comparison of moderate damage state of different plan configurations of 3 story buildings

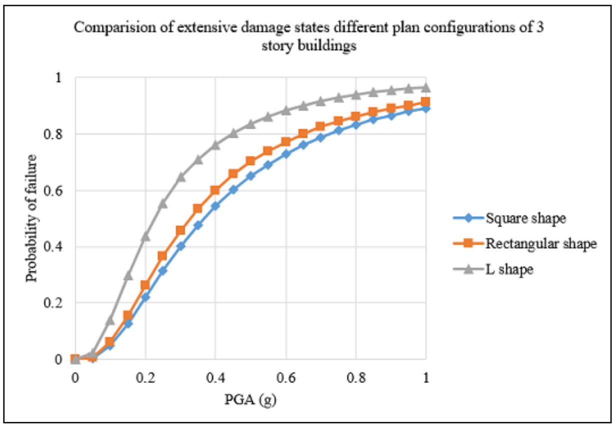

Figure 10: Comparison of extensive damage state of different plan configurations of 3 story buildings

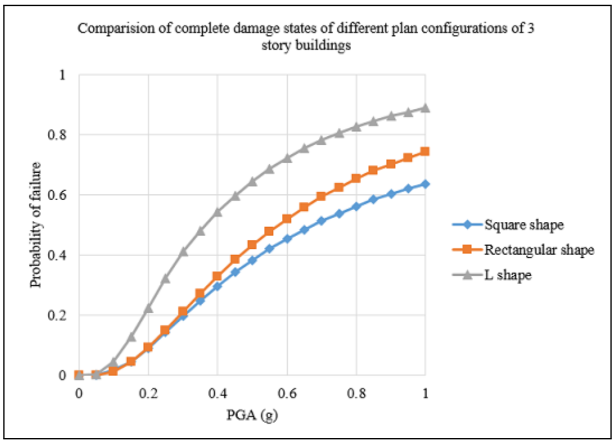

Figure 11: Comparison of complete damage state of different plan configurations of 3 story buildings

From figures 8 to 11, it is found that for the buildings of same story configurations the probability of failure at same damage state differs with respect to the plan configurations of buildings. Asymmetric buildings are more vulnerable than rectangular and square buildings. Similarly, rectangular slender buildings are seen to have higher probability of damage than square symmetric buildings. Asymmetric buildings have irregularity in mass and stiffness and produces torsion in the building. As a result, higher stress is generated in the structural member.

5.3 Comparison of different damage states for different story configurations of asymmetric buildings:

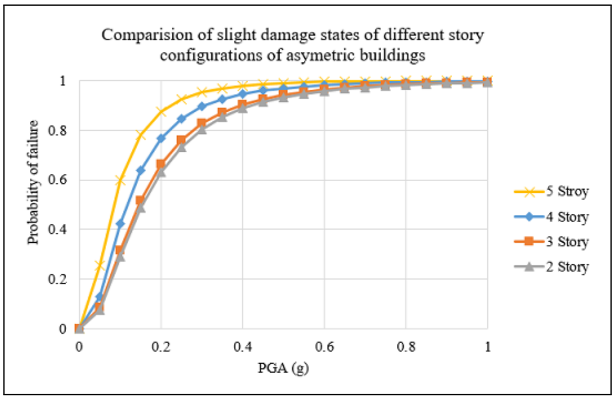

Figure 12: Comparison of slight damage states for different story configurations of asymmetric buildings

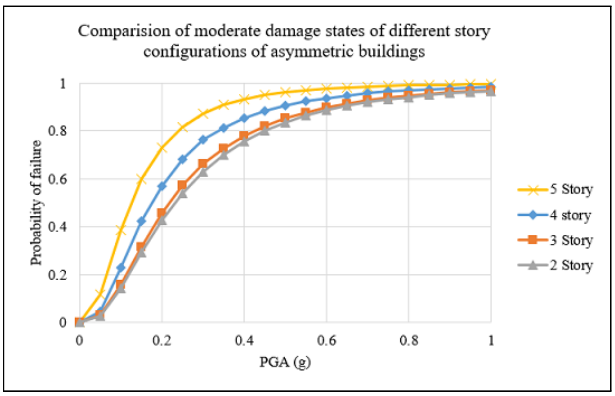

Figure 13: Comparison of moderate damage states for different story configurations of asymmetric buildings

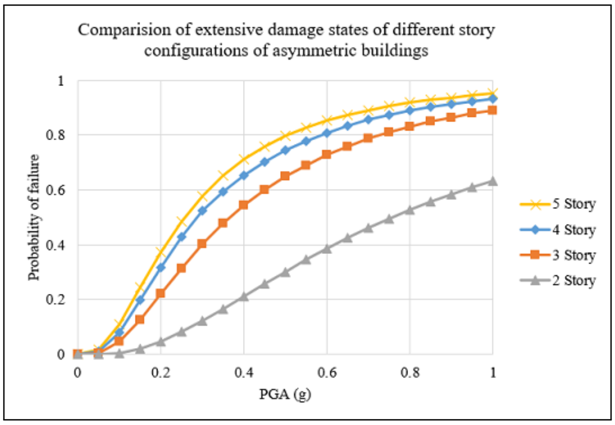

Figure 14: Comparison of extensive damage states for different story configurations of asymmetric buildings

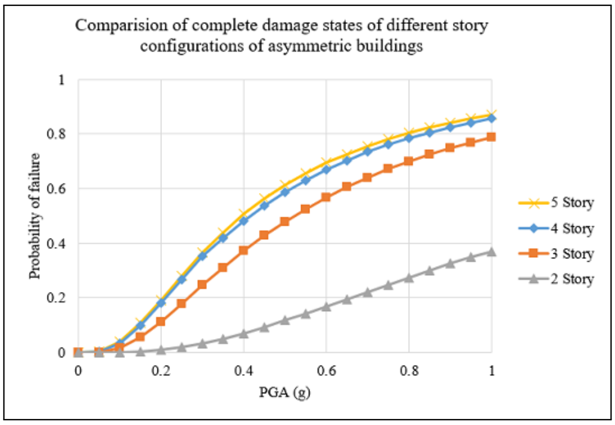

Figure 15: Comparison of complete damage states for different story configurations of asymmetric buildings

The variation on different damage states on variation of story height for Gorkha earthquake is illustrated in above figures 12 to 15. It is found that probability of failure of building increases with the increase in story height of building. This is because the seismic weight of building increases as the number of stories are added to the building. But in some cases when the time period of the earthquake ground motion time history matches with the natural time period of the building heavy damage can be found in lower story buildings compared to higher story buildings.

5.4 Comparison of moderate damage states for different earthquakes on different story configurations of square buildings:

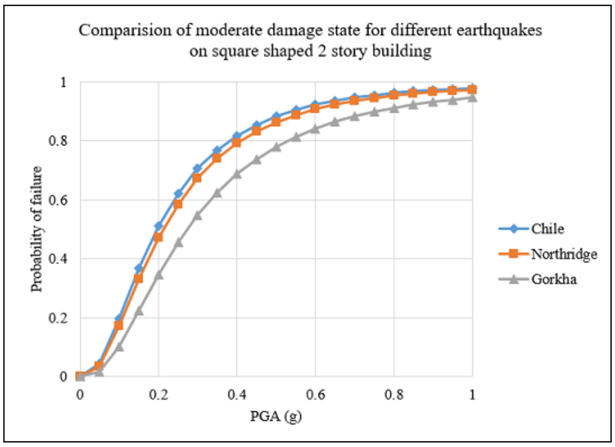

Figure 16: Comparison of moderate damage states for different earthquakes on 2 story building

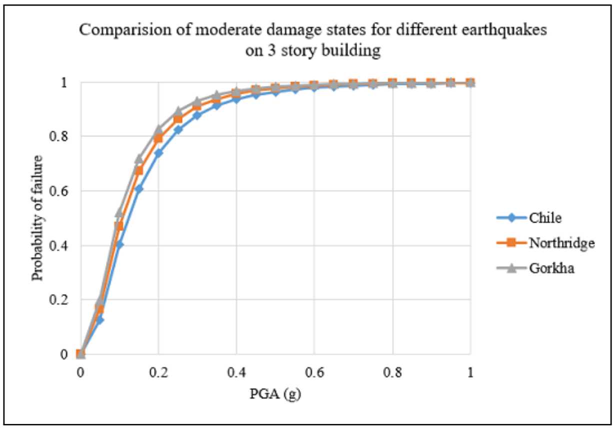

Figure 17: Comparison of moderate damage states for different earthquakes on 3 story building

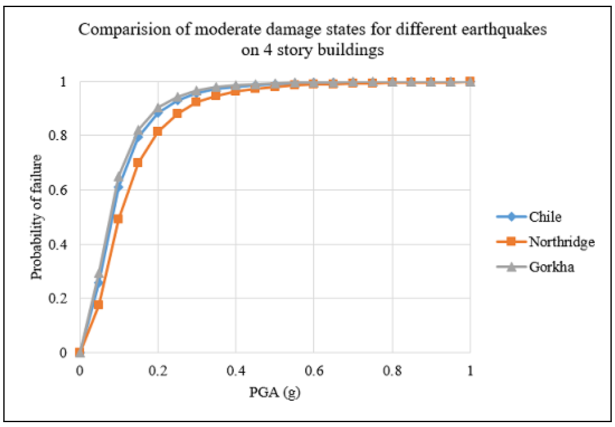

Figure 18: Comparison of moderate damage states for different earthquakes on 4 story building

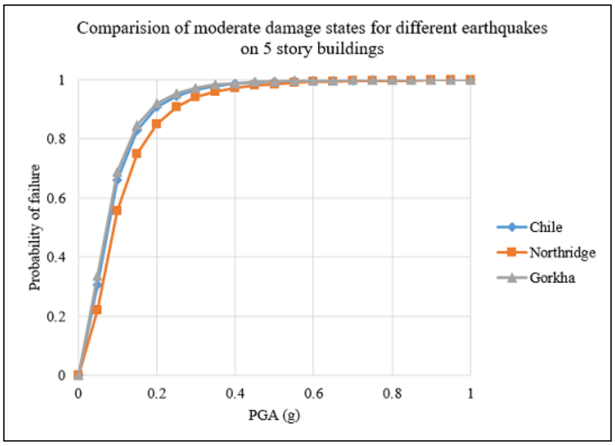

Figure 19: Comparison of moderate damage states for different earthquakes on 5 story building

The variation of moderate damage state for different earthquakes on story variation of square symmetric buildings is shown in above figures 16 to 19. It is found that the moderate damage probability due to different earthquakes varies slightly with the variation of earthquake ground motion time histories. It is found that lower height buildings are slightly more vulnerable to Chile earthquake but the vulnerability to Gorkha earthquake is found to be increasing as the number of story increases. This is because of high amplitude content in the time period range of respective earthquakes corresponding to fundamental time period of buildings.

5.5 Comparison of different damage states for various configurations at PGA of 0.35g of Gorkha earthquake:

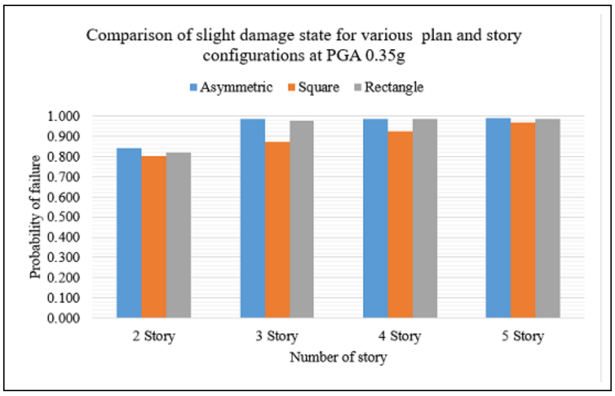

Figure 20: Comparison of slight damage states for various geometric configurations at PGA of 0.35g

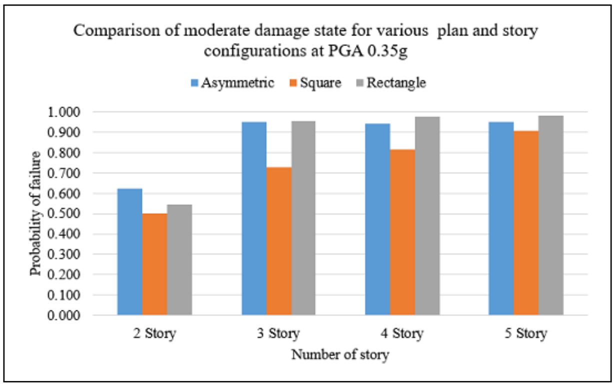

Figure 21: Comparison of moderate damage states for various geometric configurations at PGA of 0.35g

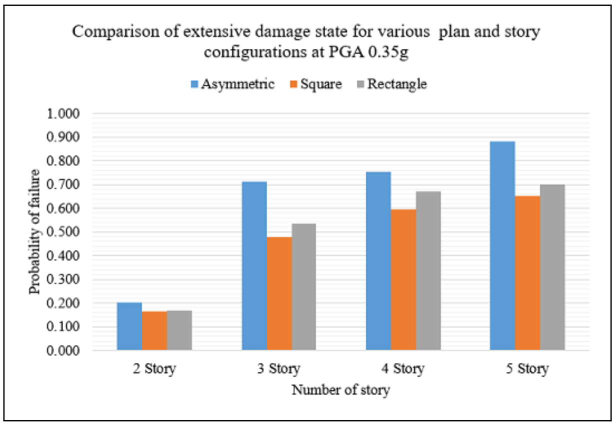

Figure 22: Comparison of extensive damage states for various geometric configurations at PGA of 0.35g

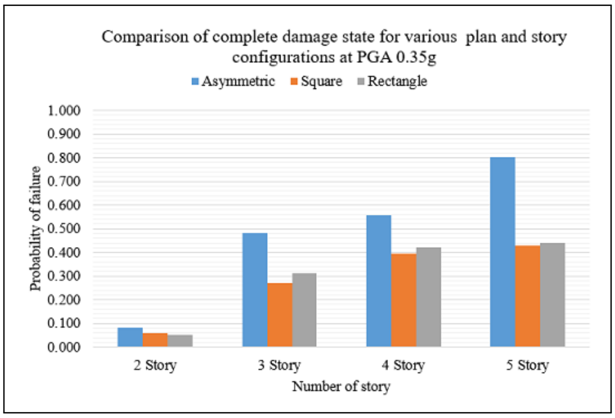

Figure 23: Comparison of complete damage states for various geometric configurations at PGA of 0.35g

The comparison of all four damage states for PGA of 0.35g of Gorkha earthquake for various plan and story configurations are shown in bar diagrams from figure 20 to 23 It can be said that the square or symmetric buildings are comparatively less fragile than irregular and slender buildings. Also, figures 8 to 11 showed the better performance of symmetric buildings. Irregularity in mass and stiffness is the main cause for asymmetric buildings to be more fragile. With reference to 4.1 it can be concluded that three story buildings have the probability of failure for complete damage state at PGA of 0.35g of 2015 Gorkha earthquake is 27% for square buildings, 30% for rectangular buildings and 48% for asymmetric buildings.

6. Conclusion and Recommendation

6.1 Conclusions:

Different story and plan configuration RC framed residential buildings were taken to determine the probability of failure with various earthquake ground motions histories with varied peak ground acceleration. The building was modelled in ETABS 2016 and seismic performance was evaluated following non-linear procedure of analysis. Using the response and capacity of building, fragility curves were developed following First Order Second Moment method approach. The displacement parameter is taken in this study to create fragility curve for the buildings. These fragility curves can be used in determining the probability of failure of buildings at different PGA for different earthquakes. Following major conclusions were drawn from this research:

1. Seismic fragility curve of all the building models are constructed with four damage states (slight, moderate, extensive and complete).
2. The seismic fragility analysis of reinforced concrete frame residential buildings shows that the asymmetric buildings are more vulnerable.
3. There is variation in probability of failure for different earthquake time history data even for same building. Also probability of failure varies with building configurations for RC residential buildings.
4. The probability of complete failure of 3 story RC buildings of Kirtipur under 0.35g of 2015 Gorkha earthquake is approximately about 27% for square shaped, 30% for rectangular shaped and 48% for asymmetric type buildings.

6.2 Recommendation:

The scope of the study can be increased with the following recommendations:

1. Nonlinear Direct Integration Method can be performed because it gives accurate nonlinear analysis result incorporating more nonlinear properties of structure.
2. Auto hinges are defined for nonlinear modelling of structures which is based on codal basis modal. User defined hinges can be better.
3. The nonlinear analysis can be performed for numbers of earthquake ground motion time histories.
4. Fragility analysis is done so that structure losses estimation can be performed.

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