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Seismic Fragility Analysis of Existing RC Residential Buildings: A Case Study on Tikathali, Lalitpur

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Abstract

The damage to the building during different earthquakes signifies the necessity of fragility curves and their evaluation for upcoming days. HAZUS methodology for estimation of potential losses on existing building stock has been used widely especially for urban areas. For the development of building capacity curves, we need nonlinear static analysis commonly known as pushover analysis which is used in this paper as well. For fragility curves, a procedure for selecting and calculating median spectral acceleration for different damage state is used and damage state of building is categorized as slight, moderate, extensive and complete with corresponding spectral acceleration and probability of damage. This paper present development of fragility curve of various damage states of RCC residential buildings of Tikathali, Lalitpur and study of the seismic performance of those buildings in different level of seismicity in terms of PGA. A representative fragility curve of Tikathali, Lalitpur is presented with random 14 sample of existing RC buildings.

Keywords

RC buildings, Fragility curves, Pushover curves, Seismic loss estimate, Existing Buildings, HAZUS, Damage states, Vulnerability

1. Introduction

Nepal is situated in active tectonic zone due to which many earthquakes have been experienced in past and a lot more expected in future as well. Due to presence of various fault lines as a result of subduction of Indian plate under Eurasian plate, larger earthquakes are expected and many of them have been faced. Major earthquakes were reported in 1255 AD, 1810 AD, 1866 AD, 1934 AD, 1980 AD and 1988 AD.[1]Recent 2015 Gorkha earthquake had less impact on the common residential structures in Kathmandu valley due to the lower frequency dominant ground motion [2] . Even though the topographical effects on the damage patterns were observed, Tikathali is one of the prominent locations for liquefaction potential [3] . Lalitpur municipality is one of the most important city of Nepal and Tikathali is an integral part of it. As per Nepal Census 2011, it consists of 10,136 populations. This area of Tikathali is 3.01 square kilometers with most of the low rise RC residential buildings. Many research has been done for different types of buildings like schools, historical important buildings, temples but seismic vulnerability of existing residential building stock has not been done till now. Although the buildings in this area are not dense like Kathmandu but the rate of building construction is increasing day by day, so the seismic vulnerability should be studied properly to be safe in future earthquakes and to be prepared for necessary actions in future. Seismic vulnerability assessment is a method used for quantification of risk involved due to expected earthquake in a region. The vulnerability is generally expressed in term of fragility curves. The seismic vulnerability of structures is commonly expressed through probabilistic fragility functions representing the conditional probability of reaching or exceeding a predefined damage state given the measure of earthquake shaking. Fragility curves are generally used for estimating probability of structural damage during an earthquake as a function of ground motion indices or other design parameters. The best method to do this is nonlinear time history analysis but it takes much time and the procedure is much complex to perform so an easy way is to perform Nonlinear static analysis for the development of fragility curves as per HAZUS manual. 14 RC residential low rise buildings are randomly sampled with different grids for the development of representative fragility curves. Etabs 2015 is used for modeling and pushover analysis of each building is done for the development of capacity curves. The result from pushover analysis is used for the development of fragility curves. Infill walls loads are considered during modeling and analysis of the buildings.

2. Literature Review

Many researchers have done research on building fragility and vulnerability in past days and have concluded with their observed level of risk of building damages during earthquakes. Silva et al [4] present paper studied the seismic behavior of existing RC buildings in Kathmandu Valley has been selected for analysis. The dynamic properties of the case study building models are analyzed and the corresponding interaction with seismic action is studied by means of non-linear analyses. The structural response measures such as capacity curve, inter-story drift and the effect of geometric non-linearity are evaluated for the two orthogonal directions. The effect of plan and vertical irregularity on the performance of the structures was studied by comparing the results of two engineered buildings. The nature of the capacity curve represents the strong impact of the P-delta effect, leading to a reduction of the global lateral stiffness and reducing the strength of the structure. The non-engineered structures experience inter-story drift demands higher than the engineered building models. Moreover, these buildings have very low lateral resistant, lesser the stiffness and limited ductility. Finally, a seismic safety assessment is performed based on the standard drift limits. Result indicates that most of the existing buildings in Nepal exhibit inadequate seismic resistance. Particularly for Lalitpur municipality observed distribution of total building damage for different earthquake scenario was indicated by a chart as follows.

Table 1: Distribution of total building damage in Lalitpur Sub-Metropolitan City

Damage state	EQ1		EQ2		EQ3		EQ4	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
No damage	46,329	3773	44,666	5200	38,034	6334	13,732	6865
Moderate damage	6398	2680	7540	3663	10,097	4159	22,986	4679
Extensive damage	1328	1281	1774	1977	4447	3046	11,229	4134
Collapse	523	816	599	1112	2002	2615	6632	6212

Gautam et. Al [5] ; derived the fragility functions for residential building using more than a million damage data from the 1934 Bihar-Nepal earthquake (Mw 8.4) up to 2015 Gorkha seismic sequence (Mw 7.8). This study also proposed the new damage classification system fragility function and stone masonry building classes are derived.

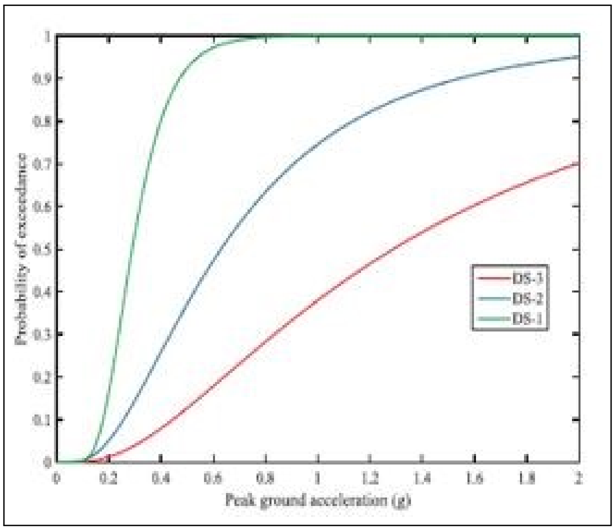

Figure 1: Fragility Curves with different state of Damage as a function of Peak ground acceleration(g)

Duan and Pappin [6] presents a practical and easy stepwise procedure for establishing building fragility curves for earthquake loss estimate of existing building stock in a region based on nonlinear static pushover analysis. It provides basic procedure for estimating median spectral displacement for different damage states of buildings which is one of the most difficult problem during fragility function development for loss estimate. This process uses pushover analysis capacity curve and demand curve to generate fragility curve of building stocks. Vazurkar and Chaudhary [7] developed the fragility curves for RC buildings considering three different RC building models. Fragility curves were developed for each of the buildings using HAZUS methodology and nonlinear static pushover analysis with SAP2000 v14. Infill walls were not included during analysis of building. This paper concludes with the idea to predict the damage level of building corresponding to particular value of spectral displacement They concluded with different fragility curves for different models of buildings.

3. Construction Practices in Tikathali, Lalitpur

After 2015 Gorkha Earthquake, all stakeholders including house owners are aware and sensitive about the process of building earthquake resistant buildings in Tikathali area but still due to some lack of competency the construction practices are not good enough to meet the seismic demand during earthquake shaking. Mostly lack of knowledge as well as ignorance is the main key for bad practice in building construction. Although there are several provisions and earthquake analysis required on paper work during building permit process, implementation of designed process in real construction process is overlooked. Ductile detailing is the key part of earthquake resistant building construction but the people are still taking the process of ductile detailing lightly and buildings are being built improperly which will ultimately lead to process of developing vulnerable structures for future earthquakes

4. System development

The process of fragility curve development of Tikathali by selecting random 14 RC residential buildings were done by three step procedures.

4.1 Building model detail

14 random sample of low rise existing residential building is taken with average of 3 storey. Almost all of the buildings have same column size of 12” *12” with most of the reinforcement as 4-12mm dia rebar and 4-16mm dia rebar (8mm dia stirrups). Concrete grade of M20 and rebar as FE 415 is used for all building models during modeling in Etabs 2015. Out of fourteen building models, only five of them was designed with structural analysis.

Building Model Summary
Building Type: Low Rise RC Building
Avg No. of Story: 3
Concrete Grade: M20
Rebar: Fe 415
Column Size: 12” x 12”
Beam Size: 9” x 14”
No. of Building Sample: 14
Infill Wall: Considered

Development of Fragility curves

In this paper, a solution proposed by (Pappin, The 14th World Conference in Earthquake Engineering) 2008 in 14th World Conference in Earthquake Engineering is used to develop fragility curves for Tikathali area following steps as follows.

- First of all, identifying the spectral displacement on the capacity curve (spectrum) at which yielding occurs. This is the median point of yielding capacity
- Then identify the spectral displacement value at which the first component reaches the complete damage state on the generalized nonlinear component force – component deformation relationship curve. According to recommendation of HAZUS, this point is the median spectral displacement for the Slight Damage state.
- After that the median spectral displacement value for the Moderate Damage state may be established by multiplying the median spectral displacement for the Slight Damage state by a factor of 1.5, as recommended by HAZUS. The spectral displacement corresponding to the near collapse point on the capacity curve is identified.
- Relate this spectral displacement to a much lower probability value on the fragility curve, between 1% to 10%, say 5% probability for instance, rather than the median value (50%), to establish the median spectral displacement for the Complete Damage state.
- The median spectral displacement for the Extensive Damage state can be determined by locating it to be midway between the median points for the Complete Damage state and the Moderate Damage state on a log scale.

PSHA for Lalitpur

PSHA is done to get peak ground acceleration (PGA) of the study area i.e. Lalitpur to estimate and discuss about the fragility and vulnerability of existing RC building of Lalitpur. For PSHA 11 attenuation relationship are taken and line source are taken into consideration. 5 active shallow crustal and 6 subduction interface having different weightage are taken. PSHA is carried out by GEM openquake. After PSHA, PGA for Lalitpur was found to be 0.424g.

5. Result and Discussions

To obtain the fragility curve for different damage states for low rise RCC residential buildings, the structure was modelled in ETABS 2015 and capacity curve were developed for both Push X and Push Y direction. After obtaining capacity curves for each building as a function of spectral acceleration and spectral displacement, fragility curves were developed by choosing proper median displacement and corresponding spectral acceleration were used for plotting the fragility curve as a function of probability of damage. Both direction i.e. Push X and Push Y case were taken into account and separate fragility curves are developed.

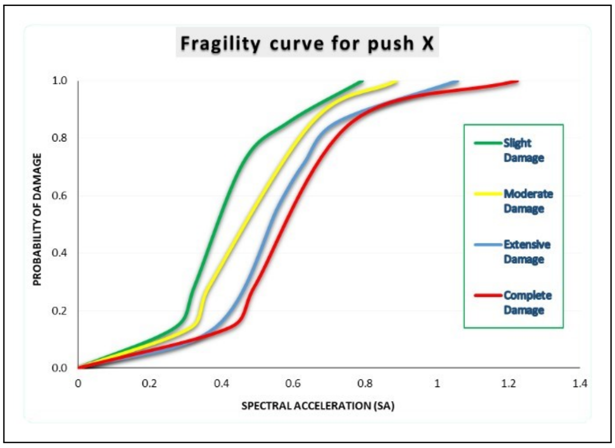

Figure 2: Fragility curves for RC residential buildings of Tikathali Lalitpur (Push X)

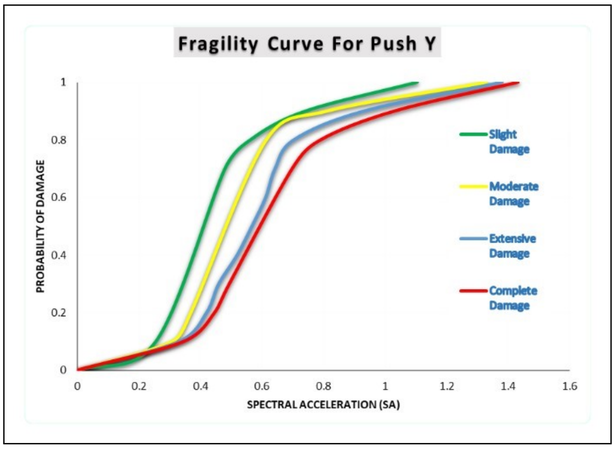

Figure 3: Fragility curves for RC residential buildings of Tikathali Lalitpur (Push Y)

These fragility curves represent seismic fragility of existing RC residential buildings of Tikathali, Lalitpur which will help to estimate seismic loss of the area in certain level of seismicity. Finally, by the help of PSHA, PGA of study area is found to be 0.424g considering bed rock shear wave velocity of 760m/s.

5.1 Discussion

1. From Fragility curve obtained by analyzing sample of 14 RCC residential buildings both direction X and Y, moderate fragility can be seen. For push X case and PGA of 0.424g, 14% complete damage,18% extensive damage,29% moderate damage and 42% slight damage can be found from fragility curve. For push Y case and PGA of 0.424g, 18% complete damage,30% extensive damage,36% moderate damage and 41% slight damage can be found from fragility curve.
2. As residential buildings are taken for modelling, most of the buildings with irregular grid and with improper load path are more vulnerable than those with regular grids in both x and y direction.
3. Some of the buildings seems to reach collapse damage state in low spectral displacement as well as acceleration due irregular grids, and presence of large and irregular cantilever projections.
4. Overall fragility curve denotes that the existing RCC residential buildings in Tikathali, Lalitpur are moderately fragile for upcoming earthquakes which can still be improved so that each and every building will be safe and operational in designed earthquakes.

The probability of damage of RC residential buildings in Tikathali, Lalitpur according to fragility curve obtained with different level of PGA in term of spectral acceleration in both X and Y direction is shown in the form of column chart as follows.

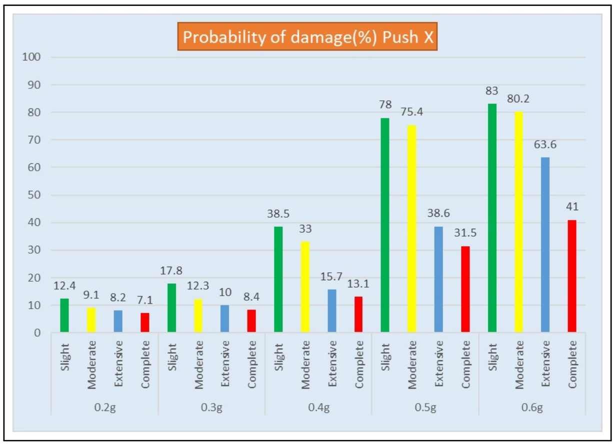

Figure 4: Probability of Damage (Push X)

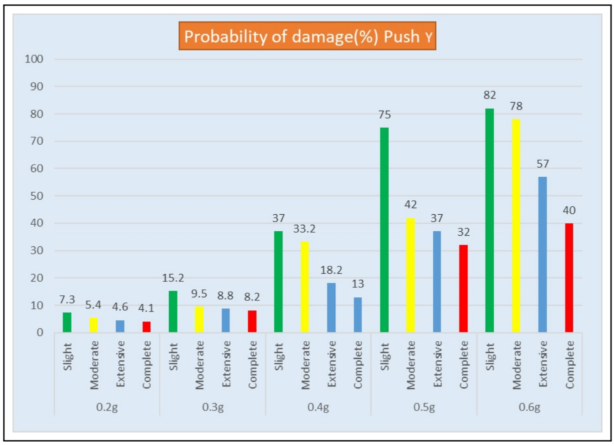

Figure 5: Probability if Damage (Push Y)

6. Summary and Conclusion

1. From seismic evaluation, it was found that the predicted responses of the existing building were not satisfactory and seems moderately fragile so they need to be analyzed properly to be safe in future earthquakes.
2. Buildings with irregular grids are more vulnerable and reach collapse point in low spectral displacement as well as spectral acceleration.
3. Overall seismic fragility analysis of existing RCC residential buildings in Tikathali, Lalitpur shows that the buildings are vulnerable and have low capacity in reference to failure states obtained from fragility curves.
4. Strengthening of the existing RCC buildings need to be done and need to analysed properly for future safety in earthquakes.

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