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Seismic Vulnerability of RC Frame Buildings non complying with MRT based on Slenderness Ratio and Plan Aspect Ratio

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Abstract

Rapid development and urbanization has resulted in construction of lot of residential buildings recently in Nepal. But due to poor law enforcement of National Building Code by the government has resulted in haphazard construction of residential buildings. Government has implied Mandatory rule of thumb for the construction of ordinary residential buildings upto three storey. But lack of seriousness from both state and houseowners has resulted very unique structures. One of the important limitation given by Nepal national building code for pre-engineered buildings was of slenderness ratio and plan aspect ratio. But, we can find many residential building exceeding the limitation of these ratios as prescribed by Mandatory Rule of Thumb (MRT) of Nepal National building code. This research intends to find the seismic vulnerability of such structure and also determines how the damage grade will vary while varying slenderness ratio and plan aspect ratio.

Keywords

Slenderness ratio – Plan aspect ratio – Seismic vulnerability – Fragility curve

1. Introduction

Rapid population growth and urbanization has enhanced in the last few decades. People like to build houses in the city areas. This has caused very limited space in the city areas. Since our government hasn't been strict enough in implying the National Building Code, people have constructed various residential buildings in limited space according to their own will and design. This has resulted some unique structures in the country. It's very common to find very tall structures or very long structures in the city areas.

The ratio of total height of the building to the width of the building is referred as slenderness ratio of the building and ratio of total length to width of the building in referred as plan aspect ratio. Both ratios shouldn't exceed 3 according to clause 4.2 of National Building Code 205:1994.[1] Exceeding this ratio is not allowed according to rule but we can see this rule being violated by different house owners according to their own will. Although Gorkha Earthquake was disastrous and devastating, but it has certainly been good in one way i.e government being strict in complying Nepal National Building Code. Recent Earthquake has made all of us realize about it's importance. Common people are being conscious in building construction and government is also taking this matter seriously.

But the question mark remains for those building not complying with Mandatory rule of thumb and still standing tall even after earthquake. Are those safe enough for next Earthquake? This is really a question to address in today's perspective. Only properly designed and well-constructed RC building are earthquake resistant. But we have plenty of non-engineered buildings in Nepal. Non-engineered buildings and poorly constructed buildings are not only vulnerable themselves but will tend to increase the vulnerability of additional structures as well.

Lang provided various method for vulnerability analysis such as observed vulnerability, vulnerability based on expert opinions, simple analytical models, score assignment and detailed analysis procedures.[2] By any of the above methods, probability of failure of the building can be evaluated by developing fragility curves. The elements of the seismic response of building can be obtained either analytically (analytical fragility curves) or obtained through empirical data collection and evaluation spotting sizes i.e empirical fragility curves.[3] This research intends to find the effect of slenderness ratio and plan aspect ratio in seismic vulnerability of Reinforced concrete frame buildings. Parametric study is done in two different models and its vulnerability is analyzed.

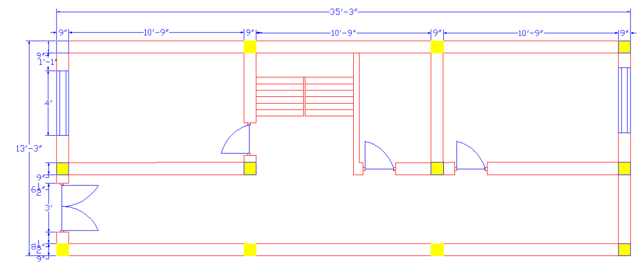

Figure 1: Plan of Model 1

2. Case buildings

Two different models namely, Model 1; exceeding the limitation of slenderness ratio and, Model 2; exceeding the criteria of plan aspect ratio are selected. However all other details are in according to Mandatory Rule of Thumb of Nepal National Building Code. Both of these models are real models situated in Madhyapur Thimi municipality of Kathmandu valley. Live load on slab is taken as 3KN/m2 according to IS 875 part 2.[4] Floor finish has been taken as 1 KN/m2. Size of the columns and beams were 9”*9” and 9”*13” respectively which was according to NBC 205:1994. Concrete grade used was M15 in slab, beam and columns. Four TOR bars of 16 mm diameter was used in beam as well as columns.

Plan of Model 1 and Model 2 are presented in figure 1 and figure 2. Linear time history analysis for four different accelerograms i.e Elcentro, Chamauli, Lalitpura and Gorkha Earthquake is done in ETABS version 2016 to calculate the seismic demand. For determining the capacity pushover analysis is done.

The model drawn in ETABS is shown in Figure 3 and Figure 4.

Slenderness ratio for Model 1 is 4.0 and plan aspect ratio for Model 2 is 3.5. For parametric study, both slenderness ratio and plan aspect ratio are varied from 3.0 to 5.0 with 0.5 interval. While varying the slenderness ratio and plan aspect ratio, height of storey is kept between 9’ to 11’ and length between the bays is kept between 9’ to 12’. The important thing to note is while making slenderness ratio and plan aspect ratio as 3.0; models automatically comply to the rules of Nepal National Building Code since other all aspects are already in according to norms.

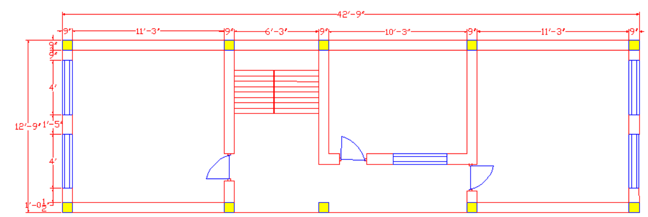

Figure 2: Plan of Model 2

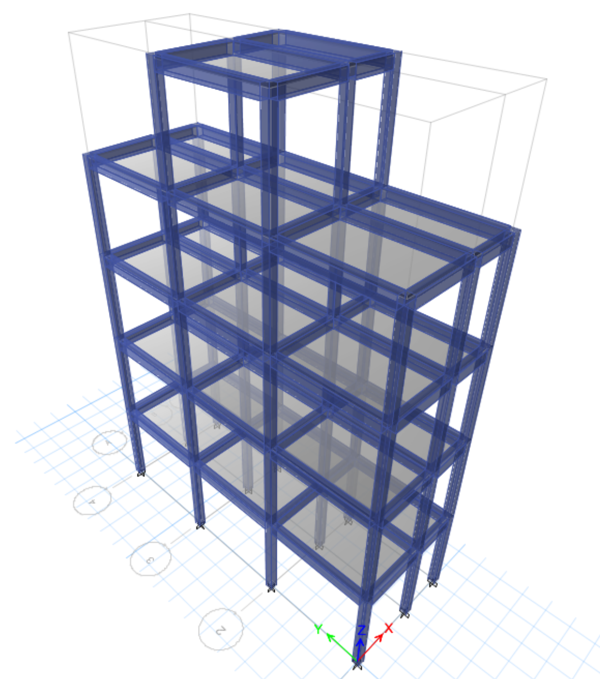

Figure 3: Model 1 in ETABS

3. Analysis

Pushover analysis and linear time history analysis are done for all parametric models to determine the capacity and demand of the structure respectively. Four different

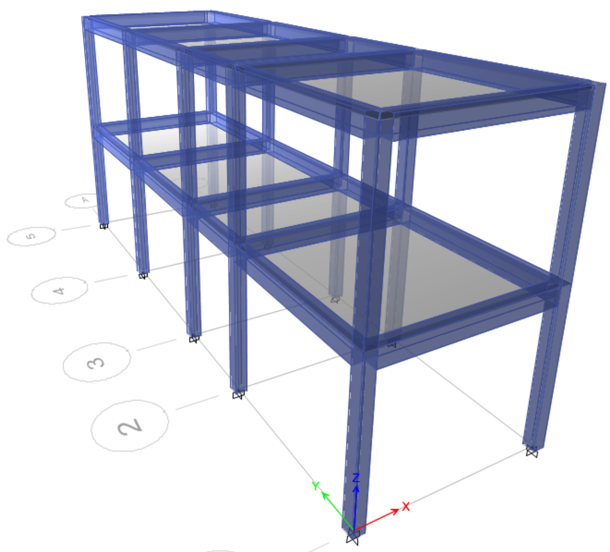

Figure 4: Model 2 in ETABS

real accelerograms i.e Elcentro(N-S component, Chamauli, Lalitpura and Gorkha (N-S component) are taken for linear time history analysis. Seismic vulnerability of structure is determine by drawing fragility curves. In this study, fragility curves are constructed to correlate the cumulative probability of failure(Pf), with increasing value of demand displacement (Sd) based on obtaining the best fitted log-normal distribution function of equation which is defined by the median and standard deviation parameters i.e Sc and β respectively.[5]

$$P(f) = \phi[\{ln(Sd/Sc)\}/\beta]$$

where, $\phi()$ is cumulative log normal distribution function β is log standard deviation that represents total uncertainty. It is an estimate that accounts for other unknown factors that affect the accuracy of the functions and that has an impact on the determination of the median PGA in the process of deriving the fragility curves. It is simply the square root sum of the squares combination of individual variability terms which is equivalent to 0.64. Fragility curves are derived at four Damage States as specified by HAZUS- MH-MR3.[6]

1. Slight damage , capacity = 0.7dy
2. Moderate Damage, capacity = 1.5dy
3. Extensive Damage, capacity= 0.5 (dy + du)
4. Complete Damage, capacity = du

where, 'dy' is yield displacement and 'du' is ultimate displacement.

4. Result

Guoxin et all has given the peak ground acceleration at bed rock level of Kathmandu valley. [7] The seismic hazard map given by Guoxin et al with 10 percent probability of exceedence in 50 years is given in figure 5.

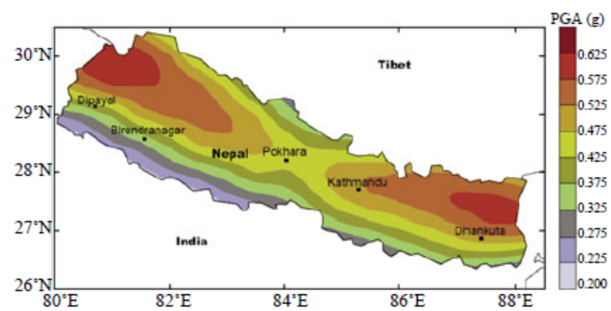

Figure 5: Seismic hazard map of Nepal

It can be clearly seen the peak ground acceleration of Kathmandu valley with 10 percentage probability of exceedance in 50 years lies in the range of 0.475g to 0.525g. Hence, 0.5g is selected for the sake of comparison of the probability of failure obtained from fragility curve. The results are shown graphically from figure 6 to figure 13.

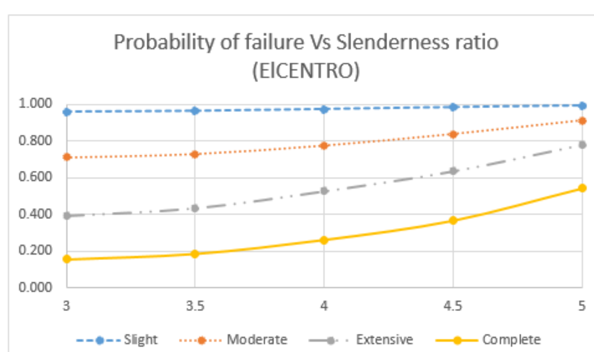

Figure 6: Probability of failure Vs Slenderness ratio(ELCENTRO)

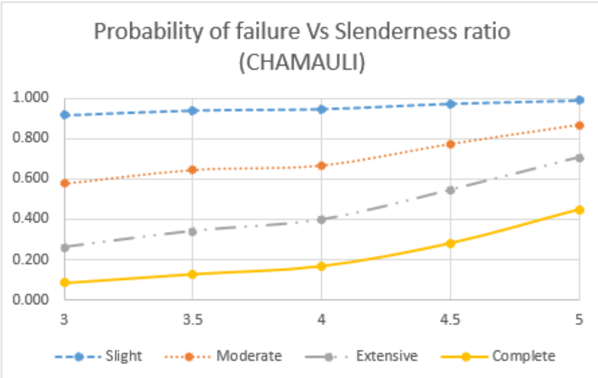

Figure 7: Probability of failure Vs Slenderness ratio (CHAMAULI)

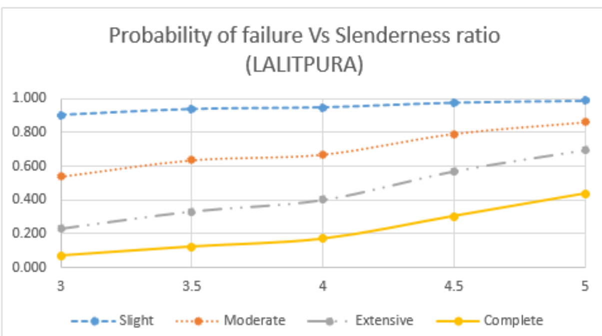

Figure 8: Probability of failure Vs Slenderness ratio(LALITPURA)

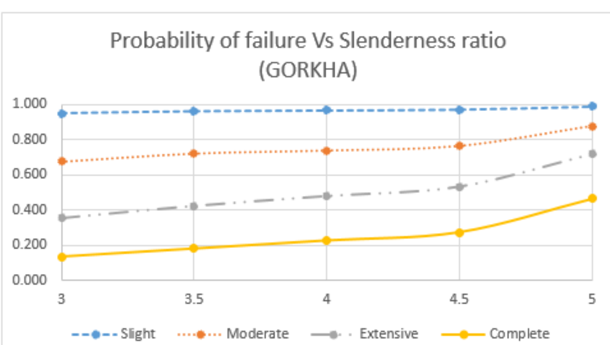

Figure 9: Probability of failure Vs Slenderness ratio (GORKHA)

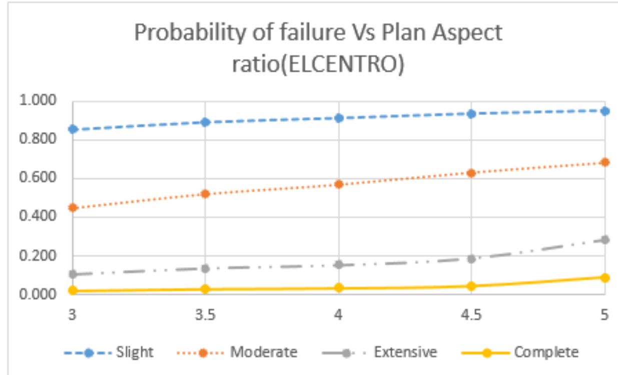

Figure 10: Probability of failure Vs Plan Aspect ratio(ELCENTRO)

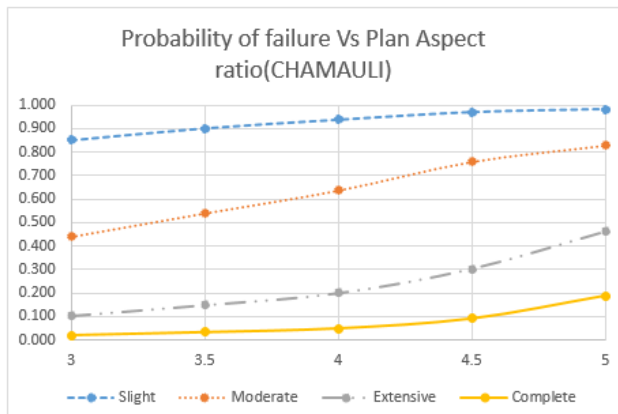

Figure 11: Probability of failure Vs Plan Aspect ratio(CHAMAULI)

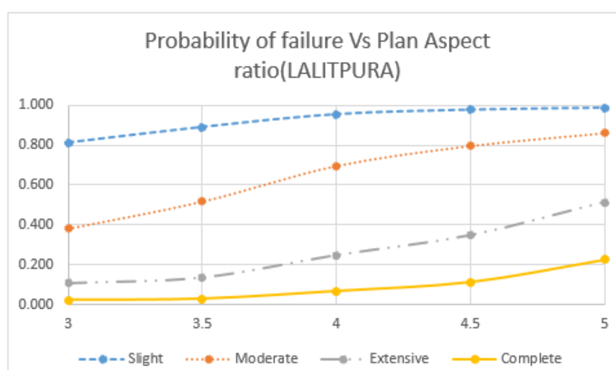

Figure 12: Probability of failure Vs Plan Aspect ratio(LALITPURA)

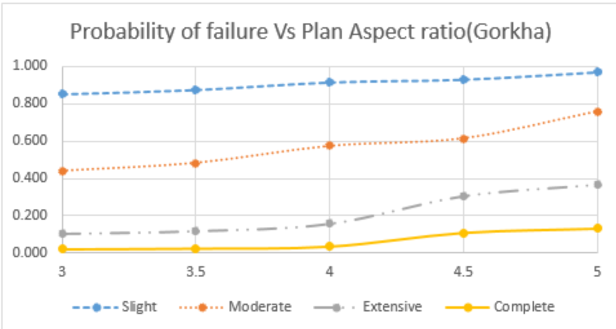

Figure 13: Probability of failure Vs Plan Aspect ratio (Gorkha)

5. Conclusions

From above figures, we can conclude from all four different earthquake; the building is likely to have moderate damage if it's slenderness ratio exceeds 3.0. Extensive failure is expected beyond ratio 4.0 for Elcentro earthquake while it is expected beyond 4.5 for Chamauli, Lalitpura and Gorkha Earthquake. Complete failure is expected only for Elcentro Earthquake in slenderness ratio 5.0. From this analysis it can be observed that for these slender type buildings; Elcentro earthquake has been more critical. The probable reason behind this is because of the resonance of the structural frequency and earthquake dominant frequency. The dominant frequency of Elcentro earthquake is 1.062 Hz and the natural frequency of model with slenderness ratio 5.0 is 1.065 Hz. The dominant frequency of Chamauli, Lalitpura and Gorkha Earthquake are 1.965 Hz, 2.173 Hz and 0.23 Hz respectively [8] [9] [10]

Similarly, for second parametric models; moderate failure is expected beyond ratio 3.5 for Elcentro, Chamauli and Lalitpura Earthquake while it is expected beyond 4.0 for Gorkha Earthquake. Extensive failure is only expected in Lalitpura Earthquake after plan aspect ratio 5.0. Here, Lalitpura earthquake is found to be more critical. Model with plan aspect ratio 5.0 has natural frequency as 2.33 Hz which is nearly equal to the dominant frequency of Lalitpura.

As we know that maximum limit for slenderness ratio and plan aspect ratio is 3.0 prescribed by Mandatory Rule of Thumb; we can compare the results with it. It is found that building following even upper limit of plan aspect ratio of mandatory rule of thumb will not undergo moderate failure as we can observe only slight failure for model with plan aspect ratio of 3.0 for all four earthquake. However, Moderate failure was observed for all the parametric models of slenderness ratio including the building following Mandatory rule of thumb as well i.e even with slenderness ratio 3.0.

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