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Seismic Performance of Typical Low Storey RC frame Building with Consideration of Masonry Infill

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Abstract
Nepal National Building code (NBC) constitutes an essential form of resources for checks of buildings submitted to municipalities so as to ensure safer building construction. NBC 205 has been prevalent in most areas due to its ready to use guidelines. But National Building Code has been revised in 2020 but NBC 205 is still prevalent since its update has not been published. So, in this paper effort has been made so as to check a residential building submitted to municipality constructed with current prevalent building construction practice as per NBC 205 with column size of 300mm X 300mm. Moreover, effects of masonry infill is considered with separate model considering equivalent strut as per IS 1893:2016. The results displayed a substantial changes in time period of the building along with noticeable observation in eccentricity and drift ratios. Non-Linear Pushover analysis was performed on the building and overstrength and ductility factors were determined. For preparation of fragility curves, Hazus earthquake model was used to develop fragility curve for building. Damage state thresholds were used as proposed by barbat et al(2008). With the analysis it can be recommended that the current standard provisions as stated in NBC 205 cannot be fully entrusted to ensure full compliance as per NBC 105 and some additional checks and considerations needs to be done. The buildings were found to have increased strength but ductility of the building was reduced after consideration of masonry infill.

Keywords
Low Storey Buildings,Nepal National Building Code (NBC), Time Period, Linear analysis, Non Linear analysis

1. Introduction

Nepal Building Code (NBC) was introduced in 1993 and included four levels. NBC 000[1] states, building code is divided into four levels; International state of art (Part I), Professionally Engineered Structures (Part II), Mandatory Rules of Thumb (Part III) and Guidelines for Remote Rural Building (Part IV) infill.[1] Part III of NBC provided ready to use guidelines without design of buildings from engineers which prompted large communities to just copy the contents like column sizes, beam sizes and Slab thickness. Still most of the drawings submitted to the municipalities belong to part III of NBC. But lately, there has been revision of Nepal National Building Code in 2020 with publication of NBC 105:2020.[2]Mandatory rule of thumb code was incorporated in NBC 205 which was first published in 2003 and was updated in draft form in 2012. This code provided nominal size of column as 300mm x 300 mm and beam sizes of 230 mm x 350 mm. These buildings are considered as a bare frame models and practice of submitting designs with consideration of bare frame models is still prevalent in most municipalities. This statistics is also supported by Building code compliance survey conducted by National Society for Earthquake Technology, Nepal (NSET) in 46 municipalities from 2012 to 2018 . Figure 1 shows the trend of column sizes in buildings submitted to municipalities. This clearly shows more than 90% percentage of buildings constructed with column size of 12x12 inch in year 2018. This trend has continued over the years. [3]

After Gorkha Earthquake a survey was conducted where most of the buildings built in Nepal were found to be low storey with most buildings below 5 storey and are built with possibility of extension. These buildings comprise of 35-40% of the existing buildings. [4]

In municipalities of Nepal, building drawings submitted to the municipalities are modeled and designed as a bare frame models. After analysis of seismic demands of buildings with four different buildings, building with modified Nepal building code and well-designed structure were found to provide better performance with low-interstorey drifts. [5]

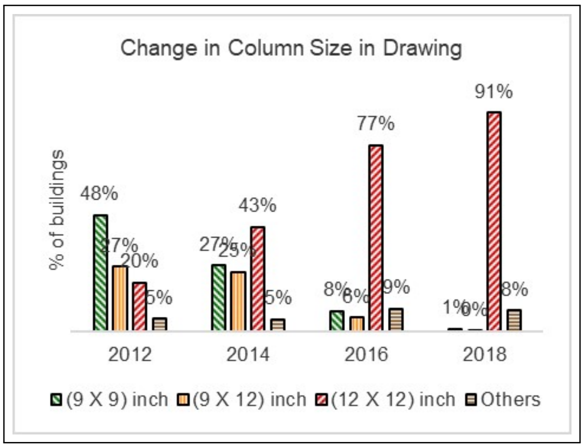

Figure 1: Column Sizes in drawings submitted to Municipalities(Source: NSET(2020)[3]

Since introduction of NBC 105:2020, the buildings built with provisions stated in NBC 205 might not meet the new demands set in by revised standards. So, an effort has been made to understand the behavior of these buildings. Moreover, since these buildings are built with masonry infills, properties of the buildings with masonry infill needs to be studied. After 2001 Bhuj Earthquake in the Kach region of Gujrat in India, it was found that the presence of masonry throughout the height of the buildings prevented the collapse of many buildings.[6] There was also a separate study on analysis of real bare frame RC building existent in Nepal. It suggested that with increase in ductility of infill, structure can deform for a larger time period without collapse which benefit alternative strengthening technique.[7]

2. Modeling of Building

The model was modeled in standard finite element package ETABS 19.1.0. Beam and column were modeled as line element and slab as area element.

2.1 Description of the building

Since this drawing was submitted to the municipality, material properties was as per details of the drawing and Table 1 mentions information of the building. Figure 2 provides building plan and computer model of the building.

Table 1: Building Parameters and Material Properties

Number of storey	2 + staircase roof with corrugated sheet
Concrete grade	M20 (1:1.5:3)
Rebar grade	HYSD 415
Column Size	300 mm x 300 mm
Beam Size	230 mm x 350 mm
Slab Depth	100 mm
Storey Height	3048 mm
Unit Weight of Concrete	25 KN/m^3
Unit Weight of Masonry	20 KN/m^3
Young's Modulus of Elasticity for masonry wall	2703.2 N/mm^2
Poisson's ratio of masonry wall	0.32

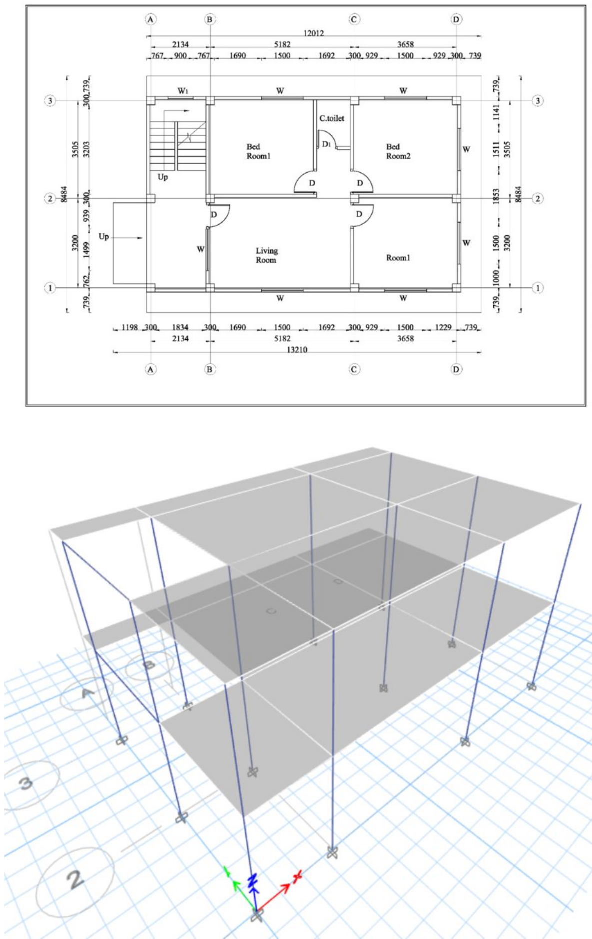

Figure 2: Building Plan and Computer model of the building

NBC 105:2020 has stated provision for effective stiffness of cracked sections. Effective stiffness of different components are as shown in Table 2.

Table 2: Building Parameters and Material Properties

S.No.	Component	Flexural Stiffness	Shear Stiffness
1	Beam	0.35 E_cI_g	0.4 E_cA_w
2	Column	0.7 E_cI_g	0.4 E_cA_w

2.2 Seismic Load Calculation

NBC 105:2020 has provided equations for calculations based on linear static analysis. Design base shear is calculated using time period (T)as per NBC 105:2020.

$$T = 0.075H^{3/4} \tag{1}$$

Where, H is Height of the building above ground level.

Approximate fundamental time period calculated using empirical equations shall be increased by factor of 1.25.

Design lateral force or design seismic base shear along any principal direction was determined by the following expression.

$$V = C_d W \tag{2}$$

where C_d is horizontal base shear coefficient and W is seismic weight of the building. Design horizontal seismic coefficient C_d is determined by

$$C_d = \frac{C_t}{R_\mu \Omega\mu} \tag{3}$$

Where, R_μ is Ductility factor and $\Omega\mu$ is Overstrength factor

2.3 Modeling of Masonry Infill

IS 1893:2016 part 1 has also provided the equation for the equivalent strut. Diagonal struts ends are considered to be pin-jointed to RC frame. Thickness of the equivalent diagonal strut was taken as thickness t of original unreinforced masonry infill wall, where h/t should be less than 12 and l/t should be less 12, where h is clear height of unreinforced masonry infill wall between the top beam and bottom floor slab, and l clear length of the URM infill wall between the vertical RC elements (columns, walls or a combination thereof) between which it spans.[8] Width of equivalent strut is given by

$$w_{ds} = 0.175\alpha^{-0.4} L_{ds} \tag{4}$$

Where,

$$\alpha_h = h\left(\sqrt[4]{\frac{E_m t \sin 2\theta}{4E_f I_c h}}\right) \tag{5}$$

Where E_m and E_f are the moduli of elasticity of the materials of the Unreinforced masonry infill and Reinforced Concrete Moment Resisting Frame, I_c the moment of inertia of the adjoining column, t the thickness of the infill wall, and θ the angle of the diagonal strut with the horizontal Al-Chaar provided equations of reduction factor for openings (R_f) of infill wall as:[9]

$$R_f = 0.6\left(\frac{A_o}{A_p}\right)^2 - 1.6\left(\frac{A_o}{A_p}\right) + 1 \tag{6}$$

Where, A_o is area of opening and A_p is area of full infill panel. Equation for equivalent strut require modulus of elasticity and poisson's ratio is required in modeling of strut in finite element packages. An experimental study was done to find the modulus of rigidity and other properties for masonry walls generally used in Kathmandu Nepal. It devises the Young's modulus of 2703.2 N/mm^2, shear modulus of 915.1N/mm^2 and Poisson's ratio of 0.32.[10]

3. Results and Discussions

3.1 Modal Analysis

Time period of the building was calculated using equations provided by Rayleigh. .

$$T_1 = 2\pi\sqrt{\frac{\sum_{i=1}^{n}(W_i d_i^2)}{g\sum_{i=1}^{n}(F_i d_i)}} \tag{7}$$

Where, d_i is elastic horizontal displacement of center of mass at level i, ignoring the effects of torsion. F_i is lateral force acting at level i, g is acceleration due to gravity, i is level under consideration, n is number of levels in the structure and W_i is seismic weight at level i.

Table 3: Time Period of the Building

Cases	Time Period
Empirical Formula (NBC 105)	0.363s
Bare Frame Model(Rayleigh)	$T_x = 0.488s$ $T_y = 0.505s$
Infill Wall Model(Rayleigh)	$T_x = 0.224s$ $T_y = 0.260s$

NBC 105:2020 clause 3.4 has provided with effective stiffness for beam and column components in flexural stiffness and shear stiffness. In the analysis of above model, this values are used with property modifier. So, previous building code would have suggested lower time period but due to this major change time period for bare frame model has resulted in value of 0.505s. Empirical formula as suggested by the NBC 105:2020 results a time period of 0.363 s. Modelling of infill masonry, done as per the codal provisions stated in IS 1893:2016 provides a time period of building as 0.260 second.

NBC 105:2020, clause 7.3 has stated for inclusion of sufficient number of modes so as to include at least 90% of the total seismic mass in the considered direction. In the above buildings, 85% of modal mass fall in first mode in bare frame model, while this proportion has decreased with infill models. First mode mass proportion is close to 90% but codal provision do suggest the need to consider multiple modes in analysis of structure.

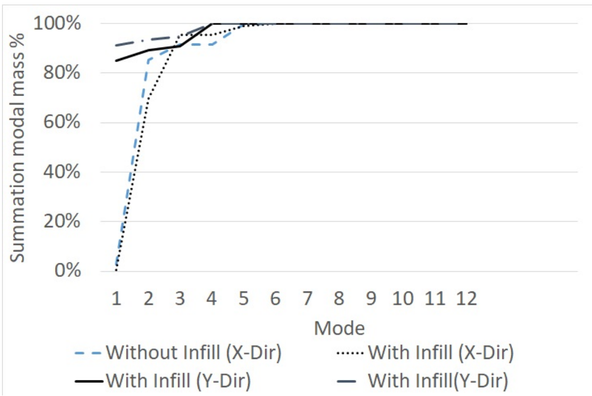

Figure 3: Modal mass Participation Factor in X and Y direction

As per IS 1893:2016, first three modes shall contribute at least 65 percent mass participation factor in each of the principal plan direction. It was observed more than 65% so the building above do not have lateral storey irregularity.

3.2 Deflection and Drift Ratio

Deflection of the building was calculated based on linear static analysis procedure. Maximum deflection calculated at each storey levels are as provided in figure 4.

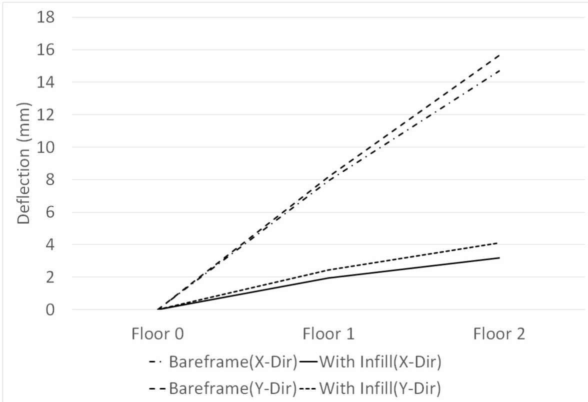

Figure 4: Maximum deflection of the Building in X and Y direction

There has been big reduction in displacement in building. In an average 75-80% reduction in displacement in both X and Y direction is observed. This is due to the stiffness provided by the masonry infill wall.

Similarly, Drift ratio was calculated at each direction of the building. Results are as shown in figure 5.

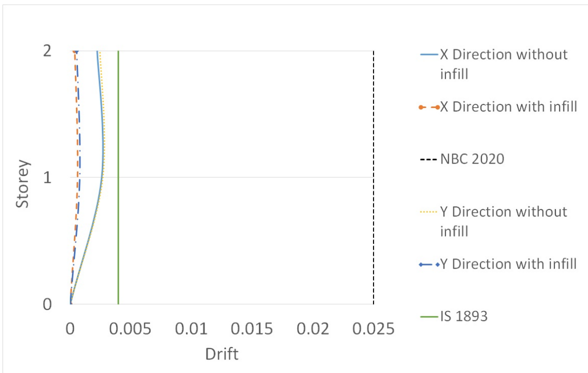

Figure 5: Maximum deflection of the Building in X and Y direction

There has been reduction in drift ratio of the building with consideration of masonry infill but drift ratio has remained within the NBC 105:2020 restricted value of 0.025. Drift ratio for buildings were also found to be within restriction of 0.004 as stated in IS 1893:2016.

3.3 Torsion

According to NBC 105:2020 clause 5.5.2.1, torsion irregularity existent in the building where the maximum horizontal displacement at any floor in the direction of the lateral force (applied at the center of mass) at one end is more than 1.5 times it's minimum horizontal displacement at the far end. Similarly, accidental eccentricity is set as $\pm 0.1b$. Torsion of the building were checked with calculation of center of stiffness and center of mass of the building.

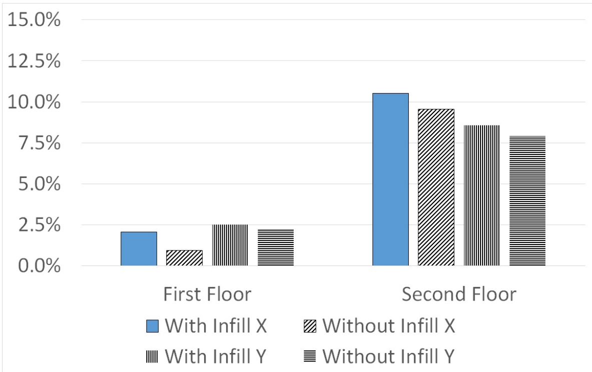

Figure 6: Torsion of the Building in X and Y direction

There has been increase in eccentricity in building with consideration of masonry infill as given in figure 6. Masonry infill are of 115 mm size but they are not uniformly distributed. There has been a rise in eccentricity from 9% in bare frame model to more than 10% for infill model in X direction of 2nd floor. This value of eccentricity obtained is larger than the 10% accidental eccentricity suggested in NBC 105.

3.4 Non Linear Static Analysis

Pushover analysis is carried out to obtain capacity curves for two orthogonal direction X and 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 10% distances from each ends. The built-in default hinge properties for concrete members are defined based on ATC-40 and FEMA-273. Degree of freedom for columns is P-M2-M3 directions (concrete column) of ASCE 41-13 and degree of freedom for beam is M3 direction (Concrete Beams- Flexure) of ASCE 41- 13 which is provided by default in ETABS V 19. Pushover Curves were obtained for the buildings with and without consideration of masonry infill. These are obtained for both x and y direction.

Hinge properties for masonry infill walls were defined as per the constitutive relation proposed by Dolsek and Fajfar (2008).[11] Openings in masonry infill is considered in the constitutive relationship. The nonlinear behavior of masonry infill is characterized by a multilinear envelope curve. Non linear properties is given by the figure 7.

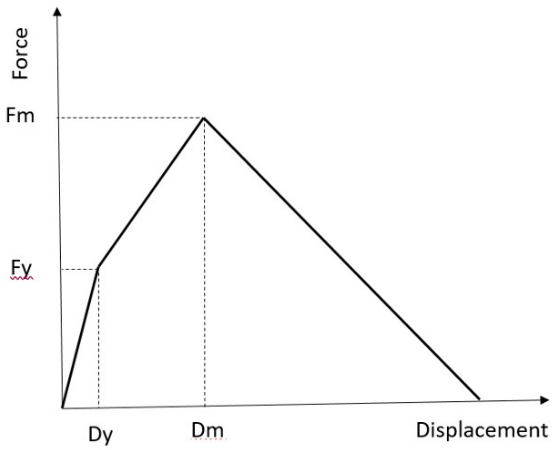

Figure 7: Force Displacement Relationship for Masonry infill (Dolsek and Fajfar(2008)

Where, F_y is yielding force, F_m is maximum force in diagonal strut, D_y is Displacement at yield force, D_m is Displacement at maximum force. With all the Non linear properties pushover curve was prepared and figure 8 provides pushover curve for both bare frame model and masonry infill model in X and Y direction.

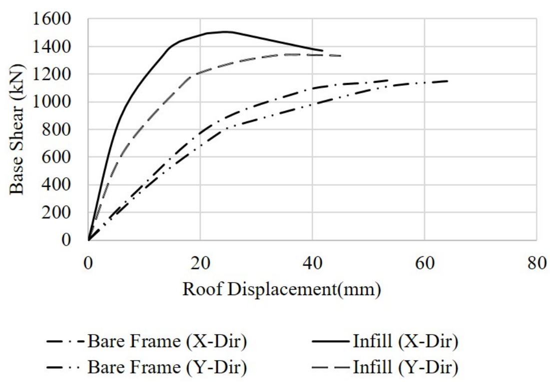

Figure 8: Pushover Curve of Buildings with and without infill in X and Y direction

Steep rise in pushover curve can be observed due to the effect of masonry infill. Displacement of the building has reduced with consideration of masonry infill. Higher yield strength is observed in X direction than in y direction is observed. This is due to the orientation of masonry walls in the building. Above curve is bilinearized and overstrength and ductility factor was obtained. Overstrength factor (Ω_{μ}) is the ratio of maximum base shear at the yield level V_u to the design base shear V_d.

$$\Omega_{\mu} = \frac{V_u}{V_d} \tag{8}$$

Miranda proposed equations based on different soil conditions which depend upon displacement ductility ratio and period of vibration (T).[12] Ductility factor is given as

$$R_{\mu} = \frac{\mu - 1}{\phi} + 1 \geq 1 \tag{9}$$

Where μ is displacement ductility factor

$$\mu = \frac{d_u}{d_y} \tag{10}$$

d_u is ultimate displacement and d_y is yield displacement and ϕ is given as per equation 11.

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$$\phi = 1 + \frac{1}{12T + \mu T} - \frac{2}{5T} exp[-2(lnT - \frac{1}{5})^2] \tag{11}$$

Where, T is time period of the building

Table 4: Overstrength and Ductility Factor

Factors	For Bare Frame Model	For Masonry Infill
Overstrength Factor (x,y)	3.22, 2.91	4.875, 4.124
Ductility Factor (x,y)	2.24 ,2.745	2.021, 2.280

Results from table 4 provides clear explanation of action of masonry infill. Rise in overstrength factor can be observed in building with consideration of masonry infill. These values for both bare frame model and masonry infill are greater than overstrength factor 1.5 as provided in NBC 105:2020. While ductility factor of the building has reduced with consideration of masonry infill. But these values are less than ductility factor of 4 for reinforced concrete buildings with moment resisting frames.

3.5 Fragility Analysis

Fragility curves were generated using the guidelines provided by hazus technical manual [13]. Median values for fragility curves are obtained from damage state thresholds provided by barbat et.al [14].The values for four different damage levels are provided in table 5.

Table 5: Damage State Thresholds

Sd1= 0.7 D_y	Slight
Sd2 = D_y	Moderate
Sd3 = D_y+0.25($D_u - D_y$)	Severe
Sd4 = D_u	Complete

Fragility curve is defined by the following log-normal probability density function. It is also defined as in equation 12.

$$P[ds/S_d] = \phi[\frac{1}{\beta_{ds}} ln(\frac{S_d}{S_{d,ds}})] \tag{12}$$

Table 6 provides earthquake time history data taken to perform non linear time history analysis on the model building. These are selected so as to include time history with different fault mechanism and total earthquake duration.

Table 6: Earthquake Time history data

Event(years)	M_w
Kobe, Japan(1995)	6.9
Lome prieta (1989)	6.93
Northridge-01(1994)	6.69
Chi-chi Taiwan(1999)	7.62
San Fernando(1971)	6.61
Cheutsu-oki Japan (2007)	6.8
Gorkha(2015)	7.8

These earthquake data were matched with NBC 105:2020 response spectra. Matched time history data were applied at both direction and maximum displacement obtained are taken for each 0.1 g increment in scaling factor.

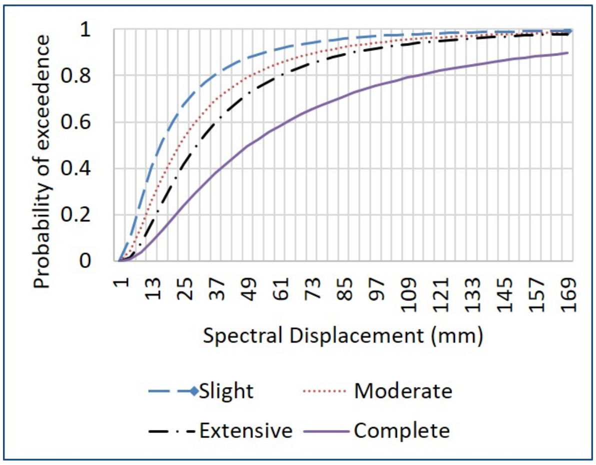

Figure 9: Fragility curves for building without masonry infill

Figure 9 provides fragility curve for building in terms of spectral displacament with consideration as bare frame. It indicates that at spectral displacement of 50 mm probability of failure was 0.85 for slight, 0.75 for moderate, 0.67 for severe and 0.45 for complete failure.

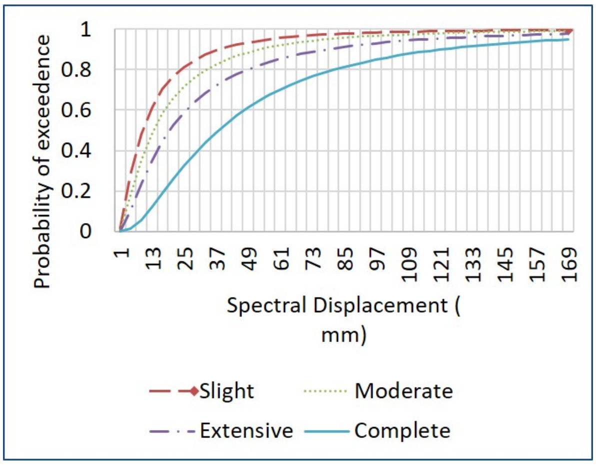

Figure 10: Fragility curves for building with masonry infill

Figure 10 provides fragility curve for building consideration with masonry infill. It indicates that at spectral displacement of 50 mm probability of failure was 0.92 for slight, 0.89 for moderate, 0.78 for severe and 0.53 for complete failure. From the above two analysis, it is observed that probability of failure for two different models are comparable for a certain spectral displacement.

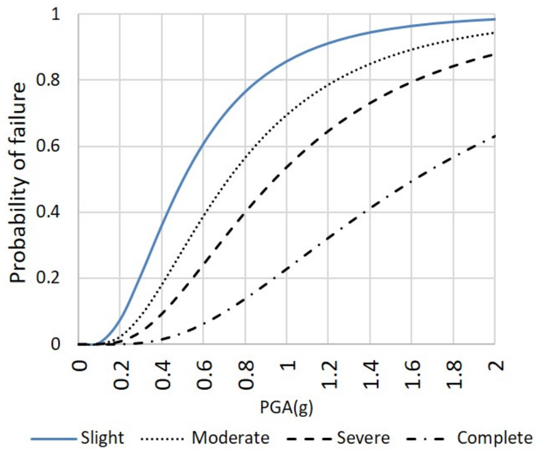

Figure 11: Fragility curves for building in terms of PGA without masonry infill

Figure 11 provides fragility curve for building consideration as bare frame. It indicates that at peak ground acceleration of 0.8g probability of failure was 0.17 for slight, 0.41 for moderate, 0.59 for severe and 0.77 for complete failure.

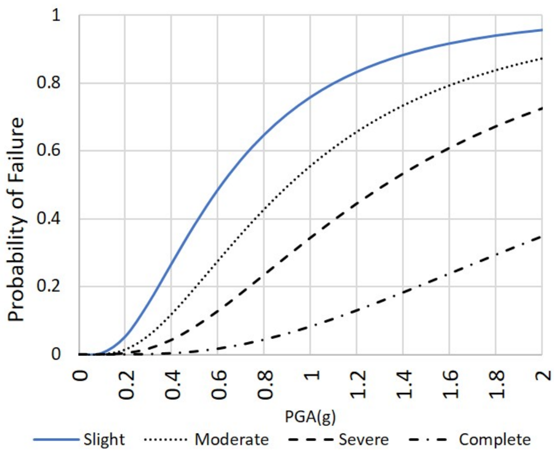

Figure 12: Fragility curves for building in terms of PGA with masonry infill

Figure 12 provides fragility curve for building consideration as bare frame. It indicates that at peak ground acceleration of 0.8g probability of failure was 0.08 for slight, 0.23 for moderate, 0.41 for severe and 0.63 for complete failure. From the above two fragility curves, it is observed that probability of failure has improved with application of masonry infill in the building.

4. Conclusion

Use of 300mm x 300mm are still popular in most of the urban municipalities in Nepal. After publication of NBC 205:2012 (draft), public have attracted towards use of these ready to use guidelines and thus avoiding design from professionals. NBC 105:2020 has now threw in new criterion's for checks and with revised NBC 205 still to be published, it has created a gap with building code implementation.

From results we can append that time period of the building have now changed from previous calculations. While there was reduction of around 45% to 55% in time period with consideration of masonry infill. Consideration of the modified time period can help devise revised base shear coefficient and thus calculate revised forces.

Consideration of masonry infill in buildings has displayed a 70-80% reduction in deflection of the building. These are directly as a result of extra stiffness provided by the masonry infill. One critical observation is made in eccentricity of the building. It is shown that there is difference in eccentricity values with consideration of masonry infill. Despite the wall size being 115 mm, change in eccentricity is noticeable. So, it is important to consider masonry infill in check for eccentricity of buildings.

Non linear analysis further justifies the fact that masonry infill has provided additional strength to the building. But there has been reduction in ductility properties of the buildings. Fragility curves were developed to provide probability of damage at different spectral displacement and it has shown similar probabilities of failure at certain spectral displacement. Similarly, in terms of spectral acceleration only a slight improvement is observed with consideration of masonry infill.

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