Proceedings of 12th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2022 Month: October Volume: 12

Effect of Masonry Infill on Seismic Performance, Ductility Factor and Overstrength Factor for Regular Steel Framed Structures

Sushagya Dhonju [a], Hari Darshan Shrestha [b]

[a, b] *Department of Civil Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
[a] 076msste019.sushagya@pcampus.edu.np, [b] harishrestha@pcampus.edu.np

Abstract
Steel has been the preference of construction material in industry today. It is widely used in construction of low-rise residential buildings to high-rise towers. Masonry walls are commonly used as infill panel between the frames which is not taken into account in common practice of structural analysis. However, the consideration of infill walls have shown considerable influence in the dynamic characteristics of the building. Bare frame steel buildings and steel buildings with masonry infill of three story to eight story has been considered for the study. The brick masonry infill walls has been modelled using the equivalent compressive strut width recommended by FEMA 273 with the coefficient for reduction for openings in infill recommended by Ghassan Al-Chaar. Steel frames were analyzed using Equivalent Static Method as per NBC 105: 2020. Non-linear static pushover analysis has been performed based on literatures and provisions on FEMA356. The effects of masonry infill on the seismic performance, ductility factor and overstrength factor of the steel framed buildings was analyzed. It was seen that the masonry infill increased the initial stiffness and overstrength factor of the steel framed structure but it significantly decreased the ductility of the structure.

Keywords
Steel Buildings, Masonry Infill, Bare Frame, Seismic Performance, Ductility Factor, Overstrength Factor

1. Introduction

Steel structures is widely used in construction industry for almost every type of structure including building, equipment support system, bridge, tower, airport terminal, heavy industrial plant, etc. Steel structures provides numerous advantages in construction – cost saving, quick erection, flexibility, durability, low maintenance costs and possess a good scrap value. The versatility in working with steel in easy assembly, fabrication and disassembly, and being an eco-friendly material with easier recycling, the use of steel structures is growing at a rapid rate in the market.

Masonry infill are widely used as infill panels in steel framed structures. In common practice, stiffness and strength of a brick infill wall is not taken into account while modeling framed structures, but past studies have shown that the infill walls in framed structures alters the failure mode of frames and affects the seismic performance of the structure [1]. The incorporation of stiffness of brick masonry infill in the structures also affects the dynamic characteristics of the building. such as stiffness, strength and ductility of the entire structure and response to earthquakes [1],[2]. Infill can also completely change the distribution of damage throughout the structure [3]. The location of the plastic hinges in the structural elements may change dramatically by varying the arrangement of the infill walls [4]. Depending upon several factors, the effect of masonry infill walls on overall seismic performance can be both positive and negative. So, neglecting the effects of the infill walls in steel framed structure may lead to noticeable misunderstanding of the seismic performance of the structure and should be considered in the design of the frame structures in order to profit from its positive contribution to the strength of the structure and to avoid the possible harmful effects [2].

The main aim of the study is to analyze the effect of brick masonry infill on the seismic performance, ductility factor and overstrength factor of the steel framed structures. A regular steel building has been taken for case study varying the story of the building ranging from three story to eight story.

2. Objectives

The objectives of the study are as follows:

1. To determine the seismic performance of the bare frame steel buildings and steel building with brick masonry infill.
2. To evaluate the effect on ductility factor and overstrength for steel frames with incorporation of masonry infill.

3. Materials and Methods

3.1 Description of Case Study Building

For the study purpose, regular steel framed buildings of three story to eight story are considered for study purpose having three bays in both X-direction and Y-direction with center-to-center grid spacing of 5m as shown in Figure 1. Square hollow sections has been assigned for the steel columns and the steel frame sections from IS800 [5] has been adopted for steel beams, and the mechanical properties of the masonry has been adopted from the experimental work carried out by Phaiju and Pradhan [6] with the description and details of the study building shown in Table 1.

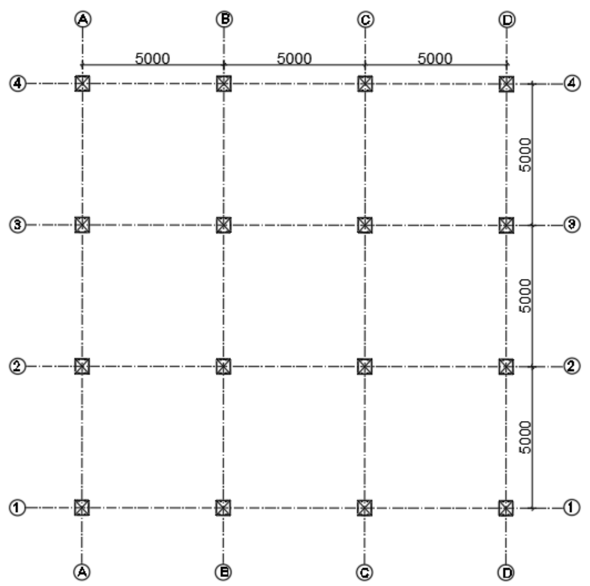

Figure 1: Grid spacing of study model (Plan)

Table 1: Description of the model building

Description	Details
Grids in X-direction	4 Grids at 5m c/c
Grids in Y-direction	4 Grids at 5m c/c
No of stories	3 story - 8 story
Floor Height	3m
Steel Column	SHS 300 X 300 X 10
Steel Beams	ISMB 300
Thickness of Deck Slab	75mm
Grade of Steel	Fe250
Grade of Concrete (for slab)	20 MPa
Unit weight of brick masonry	19.2 N/mm^2
Modulus of Elasticity of brick masonry	2703.2 N/mm^2
Compressive Strength of brick masonry	2.5 N/mm^2
Poisson's Ratio	0.32
Live Load at Slab	2 kN/m^2
Floor Finish Load at Slab	1 kN/m^2
External Wall Load	9.54 kN/m
Internal Wall Load	5.1 kN/m

3.2 Infill Panel Modelling

For the evaluation of seismic response of a structure infilled with masonry, two modelling approaches are usually adopted: micro-modelling and macro-modelling. Micro-models allows the analysts to account the local effects, crack patterns and collapse mechanisms, whereas macro-models allows to evaluate the global behavior of the masonry panels and their influence in the structure [7]. The equivalent diagonal strut model was initially based on the observation that the compressive path in the masonry panel, due to horizontal loads, develops mainly along its diagonal. Therefore, a way to represent the stiffening and strengthening effect of the masonry infill is replacing the panel with an equivalent no-tension strut acting along the compressive path [8].

For the modelling of equivalent strut for masonry infill, past studies have shown that found that the single strut model does not account with accuracy the local interaction between frames and infill, and distribution in shear and moment demand in the surrounding frames. However, the single strut model well predicts the global behavior of the masonry infilled frames [9]. For this research, we aim to study the global behavior of the structures so we intend to use the single strut model with equivalent diagonal compression strut width (a) defined in Equation 1 as recommended by FEMA 273 [10] for modeling the masonry infill in the structures as shown in Figure 2.

$$a = 0.175(\lambda h_{col})^{0.4} r_{inf} \tag{1}$$

where, a = width of equivalent strut
h_{col}= column height between centerlines of beams

r_{inf} = diagonal length of infill panel

$$\lambda = \sqrt[4]{\frac{E_{wv} t_w sin(2\theta)}{4 E_c I_c h_w}} \quad (2)$$

where, E_{wv} = elastic modulus of masonry panel in the diagonal direction
t_w = thickness of the infill panel
$E_c I_c$ = flexural stiffness of the columns of the surrounding frame
h_w = panel's height, and
$\theta = \tan^{-1}(\frac{h_w}{l_w})$

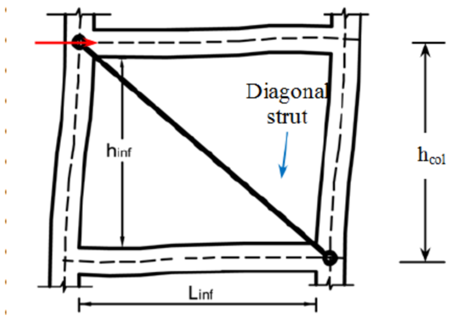

Figure 2: Equivalent diagonal compressive strut for masonry infill

From the comprehensive review of literatures, it was found that the openings in the masonry can have significant effect on the performance of the structures [11, 12]. Different researchers have proposed different formulas for the reduction coefficient to be used for the consideration of openings in the infill. For our study, we aim to use the reduction coefficient for stiffness and strength of masonry wall with openings suggested by Ghassan Al-Chaar [13] defined in Equation 3. According to Al-Chaar [13], the infill walls can be neglected for area of opening greater than 60%.

$$r_p = 0.6(\frac{A_o}{A_p})^2 - 1.6(\frac{A_o}{A_p}) + 1 \quad (3)$$

where, A_o = Area of openings
A_p = Area of masonry panel

Diagonal struts were considered for exterior 230mm walls and interior 115mm walls with 15% openings for doors in 115mm internal infill walls and 20% openings for windows in 230mm external infill walls. The strength and stiffness of the masonry infill beyond the elastic range were determined following the constitutive relation proposed by Kaushik et al. [14] to address their nonlinear behavior as mentioned in the literature by Bose and Rai [15]. The control points for the nonlinear curve for masonry infill wall was adopted from the literature of Bose and Rai [15] characterized by a multilinear curve as shown in Figure 3.

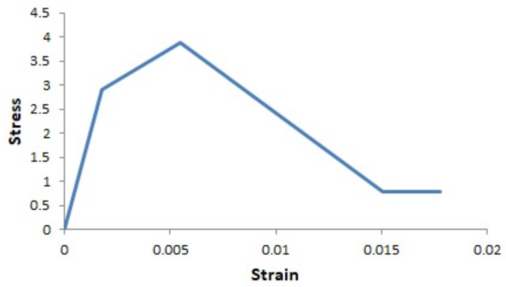

Figure 3: Stress-strain curves for brick masonry infill with control points

3.3 Finite Element Modelling

The building was numerically modeled using a 3D finite element model in SAP2000 v24. Columns and beams were modeled using line element with appropriate steel sections. Semi-rigid diaphragms were assigned and the structure was restrained in all direction at the base of the columns. A 3D bare frame steel building model and elevation view of steel building with masonry infill using compressive strut are presented in Figure 4 and Figure 5 respectively. For our study, we consider 12 different models – bare frame steel buildings and steel building with masonry infill using compressive strut of 3 story to 8 story,

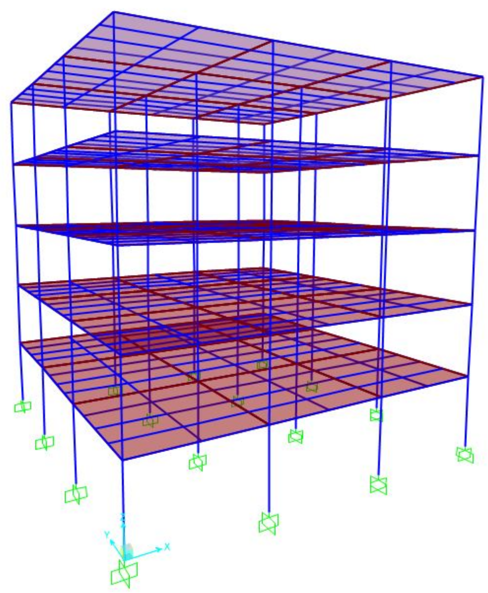

Figure 4: 3D model of five story bare frame steel building

with 15% opening in infill in 115mm interior walls and 20% openings in 230mm exterior walls.

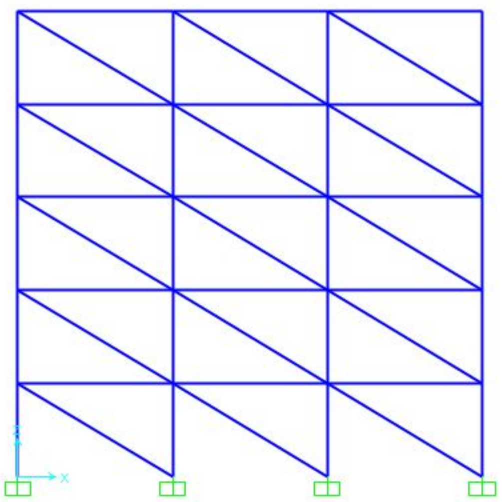

Figure 5: 3D model of five story steel building with equivalent strut

Equivalent static method using NBC 105:2020 [16] for ultimate limit state was used for analyzing the seismic performance of the structures. Base shear, modal period and top story displacement were observed for the bare frame steel buildings and steel buildings with equivalent strut.

For consideration of non-linearity in the structure, non-linear hinges as per ASCE 41-13 [17] were assigned to the beam and column elements at a distance of 10% of the length of the member from the joint. For the beam, the uncoupled moment M3 hinges that yields upon flexure were assigned to beams and the P-M2-M3 hinges were assigned to columns because of its coupled axial and biaxial bending behavior. For the equivalent diagonal compressive strut, axial P hinge was defined at 50% of length of the strut for which the stress-strain control points were defined as mentioned in the literature by Bose and Rai [15].

For the non-linear static analysis, a non-linear gravity load case was applied as a force controlled load which comprised of total dead load plus 30% of live load. The non-linear static pushover load case was carried out under displacement controlled incremental acceleration loading including P-delta effect which was continued at the end of the gravity load case. For the displacement controlled pushover analysis, target displacement was set as 4% of the height of the building. The capacity curve obtained from the pushover analysis was converted into ideal bilinear curve based on the concept of equal area method following the guidelines of FEMA 356 [18] as shown in Figure 6. The ductility factor and overstrength factor was calculated from the parameters obtained from the ideal bilinear pushover capacity curve - yield base shear (Vy), yield displacement (dy), ultimate base shear (Vu) and ultimate displacement (du).

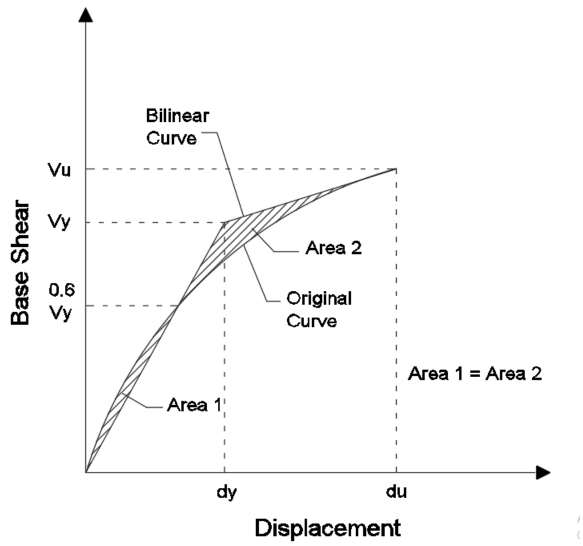

Figure 6: Bilinear idealization of pushover curve

3.4 Ductility Factor

The ductility reduction factor (Rμ) can be defined as the ratio of maximum lateral force, (Ve) which would develop in a structure if it were to remain entirely linear elastic (μ = 1) under the specified ground motion to the idealized yield strength (Vy) of the structure. For the ductility factor calculation, the equation proposed by Miranda [19] assuming 5% critical damping through regression analysis has been used. Three different equations were proposed depending upon the soil sites. The buildings are assumed to be on alluvium soil sites in this research. So, we use Equation 4 and Equation 5 for the calculation of ductility factor.

$$R_\mu = \frac{\mu - 1}{\phi} + 1 \geq 1 \tag{4}$$

For alluvium soil sites,

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

where, ϕ = function necessary to compute approximate strength reduction factor
T = period of vibration

3.5 Overstrength Factor

The structures are able to resist larger earthquake without considerable damage for which they were designed for due to the reserved strength of the structure present beyond the design strength. Overstrength factor is denoted by Ω and is the ratio of yield base shear (Vy) to design lateral strength (Vd) as shown in Equation 6.

$$\Omega = \frac{Vy}{Vd} \tag{6}$$

4. Results and Discussions

4.1 Base Shear

The base shear of the structure increased with increase in height of the structure as base shear is proportional to the seismic weight of the structure. The base shear also increased significantly for the same story buildings with the incorporation of masonry infill. The base shear increased by an average of 11.79% for the models considered when equivalent compressive struts were modeled for masonry infill in the structure. Thus, the consideration of masonry infill in steel structure increased the stiffness of the steel framed buildings.

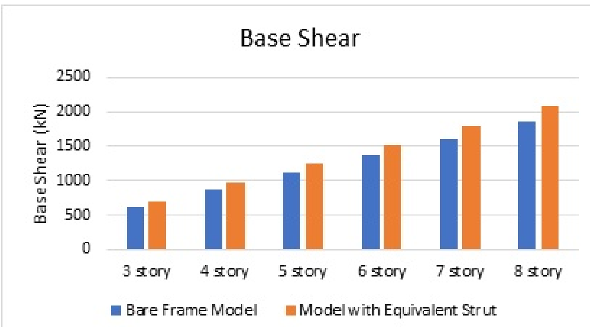

Figure 7: Base Shear

The natural period of the first three modes for the models were analyzed. The time period of the steel frames increased with the increase in building height. The time period decreased significantly by an average of 45.15% with the incorporation of masonry infill for buildings of same story height. Thus, the stiffness of the steel framed buildings increased with the incorporation of masonry infill.

4.2 Modal Period

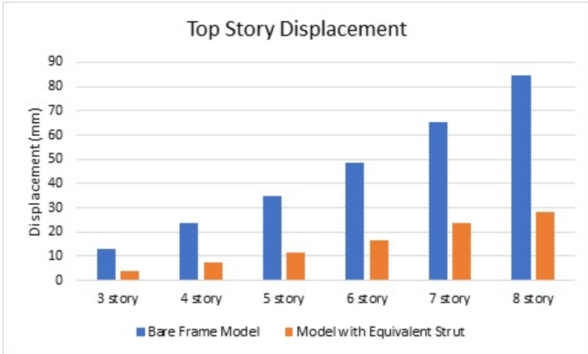

Figure 8: Modal period of first three modes

The top displacement of the steel structure decreased when the buildings are modelled with masonry infill. The top story displacement decreased by an average of 67.06% when the masonry infill was incorporated in the steel framed buildings. Thus, the structure becomes stiffer with consideration of masonry infill as the story displacement decreased significantly with modelling of equivalent strut in steel buildings.

4.3 Top Story Displacement

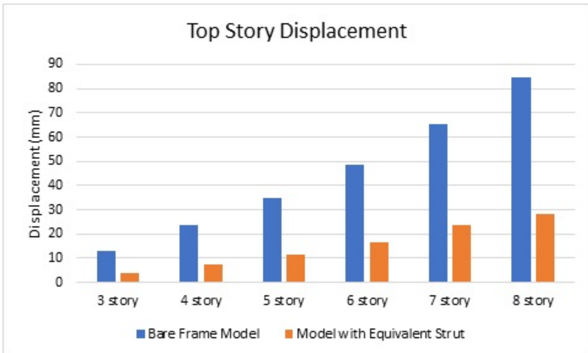

Figure 9: Top story displacement

4.4 Ductility Factor

The masonry infill significantly decreased the ductility factor of the steel buildings. The ductility factor decreased by an average of 50.99% for the models considered when masonry infill was incorporated in the steel buildings.

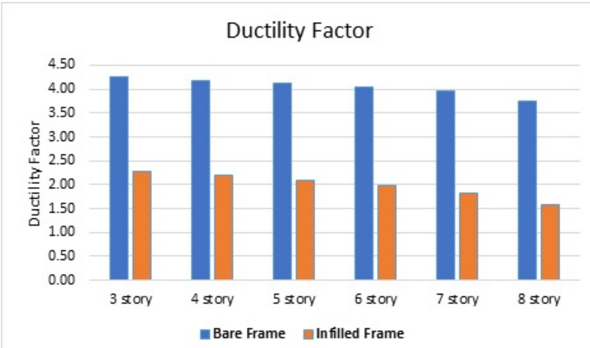

Figure 10: Ductility factor

The masonry infill significantly increased the overstrength factor of the steel buildings. The overstrength factor increased by an average of 36.01% for the models considered when masonry infill was incorporated in the steel buildings.

4.5 Overstrength Factor

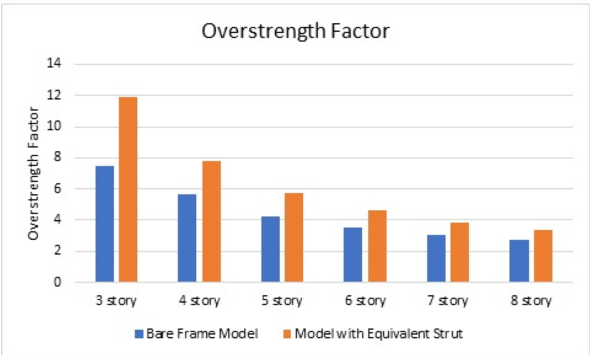

Figure 11: Overstrength factor

5. Conclusion

Following conclusions have been made on the basis of results obtained after the study on effects of masonry infill on the steel framed buildings.

1. The base shear of the steel buildings increased by an average of 11.79% when the masonry infill struts were considered. Thus, the incorporation of masonry infill increased the stiffness of the steel framed structure. With the increase in story height of the steel framed buildings, its overall stiffness decreased.

2. The time period of the steel building with masonry infill decreased significantly with an average of 45.15% compared to the bare frame steel building Thus, the masonry infill added significant stiffness to the steel structure.

3. Top displacement decreased significantly with an average of 67.06% with the inclusion of masonry infill in the steel framed buildings. Thus, the masonry panel added significant stiffness to the steel framed buildings.

4. Although the masonry infill enhanced the initial stiffness and strength of the steel frames, it significantly reduced the ductility of the structure. The ductility of the steel framed structure decreased by an average of 50.99% when the masonry infills were incorporated in between the frames.

5. The masonry significantly increased the overstrength of the structure. The overstrength factor increased by an average of 36.01% when the masonry infills were incorporated in between the frames.

Modelling only the bare frame may significantly overestimate the seismic demands of steel framed structures, since the increased stiffness and strength due to masonry infill is neglected, and the ductility factor and actual strength of the structure may also vary significantly when the masonry infills are not considered. So, the masonry infill should be considered in the analysis of steel framed structures in order to gain its positive contribution to the strength of the structure and avoid the possible harmful effects that may occur in the structure.

References

[1] S. Li S. Shan and S. Wang. Effect of infill walls on mechanisms of steel frames against progressive collapse. *Journal of Constructional Steel Research*, 2019.

[2] T. Elouali. Effect of infill masonry panels on the seismic response of frame buildings. *IIT Kanpur*.

[3] M. Dolesk and P. Fajfar. The effect of masonry infills on the seismic response of a four-storey reinforced concrete frame — a deterministic assessment. *Engineering Structures*, 2008.

[4] M. S. Razzaghi and M. Javidnia. Evaluation of the effect of infill walls on seismic performance of rc dual frames. *International Journal of Advanced Structural Engineering (IJASE)*, 2015.

[5] Is 800 : 2007 general construction in steel - code of practice. *Bureau of Indian Standards*, 2007.

[6] S. Phaiju and P. M. Pradhan. Experimental work for mechanical properties of brick and masonry panel. *Journal of Science and Engineering*, 2018.

[7] E. Brunesi G. Mucedero, D. Perrone and R. Monteiro. Numerical modelling and validation of the response of masonry infilled rc frames using experimental testing results. *Buildings*, 2020.

[8] R. Mainstone. Supplementary note on the stiffness and strength of infilled frame. *Building Research Establishment*, 1974.

[9] F. J. Crisafulli. Seismic behaviour of reinforced concrete structures with masonry infills. *Ph.D. Thesis, University of Canterbury, Christchurch, New Zealand*, 1997.

[10] Fema 273 - nehrp guidelines for the seismic rehabilitation of buildings. *Federal Emergency Management Agency*, 1997.

[11] H. Medriosa M. J. Tanjung and Y. Hayati. Effects of single and multi openings in brick infills on the seismic response of infilled rc frames. *MATEC Web of Conferences*, 2018.

[12] N. Lahbari A. Rahem, D. Yahiaoui and B. Tayeb. Effect of masonry infill walls with openings on nonlinear response of steel frames. *Civil Engineering Journal*, 2021.

[13] G. Al-Chaar. Evaluating strength and stiffness of unreinforced masonry infill structures. *Engineer Research and Development Center*, 2002.

[14] D. C. Rai H. B. Kaushik and S. K. Jain. Stress-strain characteristics of clay brick masonry under uniaxial compression. *ASCE Journal of Materials Engineering*, 2007.

[15] S. Bose and D. C. Rai. Behavior of aac infilled rc frame under lateral loading. *Tenth U.S. National Conference on Earthquake Engineering, Frontiers of Earthquake Engineering, Anchorage, Alaska*, 2014.

[16] Nbc 105:2020, nepal national building code - seismic design of buildings in nepal. 2020.

[17] Asce 41-13 seismic evaluation and retrofit of existing buildings. *American Society of Civil Engineers*, 2014.

[18] Fema 356 - prestandard and commentary for the seismic rehabilitation of buildings. *Federal Emergency Management Agency*, 2000.

[19] E. Miranda. Site-dependent strength-reduction factors. *Journal of Structural Engineering - ASCE*, 1993.