Proceedings of IOE Graduate Conference, 2019-Summer
Peer Reviewed
Year: 2019 Month: May Volume: 6
ISSN: 2350-8914 (Online), 2350-8906 (Print)

Seismic Vulnerability Assessment of Steel Structures with Brick Masonry Infill Wall

Bishnu Chapagai [a], Siddharth Shankar [b]

[a] *Civil and Structural Engineer*
[b] *Department of Civil Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
Corresponding Email: [a] Bishnu2101@gmail.com, [b] Siddharth@ioe.edu.np

Abstract

Steel structural system provides a modern solution for building multi-story structures with more environment friendly features. In the last decades, steel structure has played an important role in construction Industry. It is necessary to design the steel structures to perform well under seismic loads. In Nepal, unreinforced masonry walls are highly used as infill walls in the steel frames after Gorkha earthquake. This system agrees for the combination of high strength and ductility of steel with the high stiffness of masonry infill walls however their real performance in higher seismic activity is still unknown. This article aims to examine the seismic vulnerability of these types of structures in area with high seismic hazard indices. Numerous steel frame buildings with various infill configurations are designed and evaluated in a parametric fashion. Method of analysis, design and evaluation data are presented in detail. Effect on the Structural capacity, roof displacement and inter story drifts, fundamental period, frequency of vibration and variation in performance point due to various parameters: The building height, configuration of infill, the thickness of infill masonry and the strength of infill masonry walls; are studied in detail.

Steel structures, three-bay, 3-,6- and 9-story height are designed and modelled with different infill configurations and parameters in SAP2000-V20 and the static pushover analysis is performed in the parametric study. It is clearly seen that the three-story buildings with infill masonry walls are safe but six story buildings and nine story buildings are vulnerable during the seismic actions. Six story buildings with all bays infilled with brick masonry walls are however found to perform well during the seismic actions. It is also observed that the buildings with 110mm infill wall thickness or 4.1 MPa infill wall strength are vulnerable during the seismic actions. Thus, the construction of steel framed building with 110 mm wall thickness or 4.1 MPa infill wall strength are not suggested.

Keywords

Steel Structures, Infill Masonry Walls, Cement Sand Mortar, Performance Point, Seismic Vulnerability

1. Introduction

Steel structural system provides a modern solution for building multi-story structures with more environment friendly features. Steel structures have numerous advantages over concrete structures. The construction process is faster with steel structures as they are easy to erect. This leads to the faster project completion time. Having a good scrap value also makes structural steel a better option than concrete which has practically no scrap value. Steel structures can be easily fabricated and mass produced. They are so versatile that they can be easily assembled, disassembled and replaced. Steel structures are eco-friendly option as they are easily recyclable. This means saving money in waste management. Steel is a highly durable metal. Steel can withstand a considerable amount of external pressure in comparison to the concrete. Steel structures are earthquake resistant whereas concrete structures are brittle and not as resistant as steel.

Steel is most useful material in construction and has played an important role in last few decades throughout the world. Steel framed building with masonry infill walls have become common these days in Nepal after Gorkha earthquake due to various advantages of steel frames over R.C frames and availability and economy of materials used for construction of infill masonry walls. There are many such structures constructed and under construction these days in Nepal. It is necessary to analyse and design these types of steel structures infilled with masonry walls to perform well under seismic loads. Initially masonry infill walls were considered nothing other than creating partition. But in reality, the overall strength and stiffness of infilled steel frames largely depend on the infill masonry walls. Moreover, in design practice for simplicity the masonry infills are ignored in steel frames. Unless and until the stiff masonry is considered, the real performance of the steel structures cannot be assessed. Thus, steel structures infilled with brick masonry walls need to be assessed for earthquake scenario.

2. Research Objectives

There is an urgent need to address the effects on the structural performance of steel structures infilled with brick masonry walls due to various building and infill wall parameters. Following are the objectives set to meet the needs:

1. Determination of seismic vulnerability of steel framed structures infilled with brick masonry walls in cement sand mortar
2. Computation of the effect on the structural capacity and drift due to various parameters: The building height, configuration of infill masonry walls, thickness of infill masonry walls and the strength of the infill masonry walls

3. Methodology

In order to predict the actual performance level and vulnerability of each structures, a static nonlinear (Pushover analysis) is performed. Different hinges are formed at both columns and beams as per their stress condition and deformation and at the equivalent diagonal struts the hinges are formed as per their axial compressive forces. When the maximum value of the compressive forces reaches the compressive strengths then the diagonal strut fails and takes no load.

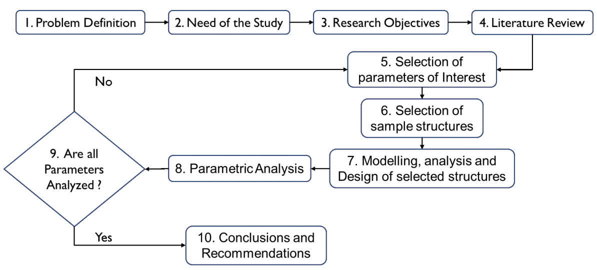


Figure 1: Flow chart showing the methodology adopted and organization of the article

The analysis is carried out using SAP 2000 V20 software. Further the methodology adopted and the organization of the research is shown in flow chart form in Figure 1.

To meet the objectives, Parameters are selected keeping in mind that they address the current scenario in construction industry. Table 1 shows the important parameters considered in the article.

Table 1: Parameters of Interest

Parameters	Range of options
Structure Height	3-story, 6-story and 9-story
Infill configuration	0–1–0, 1–0–1 and 1–1–1
Infill Thickness	110mm, 230mm and 350mm
Infill Strength	4.1MPa, 6.6MPa and 7.5MPa

4. Literature Review

4.1 Modelling of infill masonry wall

Macro modelling approach is adopted for the modeling of infill masonry walls. The masonry is treated as homogeneous continuum and there is no distinction between masonry units and joints. Approach of simulating the masonry action by an equivalent diagonal compression strut is the basic concept of macro-modelling. This approach has its origins in early research of (Polyakov,1956) who recognized ”truss-like” action of the infilled frames, this led to the equivalent diagonal strut models in which the infills are replaced by single diagonal strut along the loaded diagonal. [1] The way of modelling has been substantially improved during the last few decades by many other researchers. [2, 3, 4, 5, 6]

The restriction of the single strut model is its incapability to realistically present distribution of bending moments and shear forces in the frame elements. Accordingly, very important phenomena like short column effect or large localized shear dorefmations of column web near the frame joints cannot be shielded by this model. The main constraint of this method is inability to give vision into local interaction process taking place in areas next to the frame corners. Thus, the next logical step was to encompass those interaction effects into analytical modelling, resulting in models with multiple struts placed at and nearby the frame corners as shown in Figure 2. Also, the mentioned facts can be, up to a certain extent, involved into macro-models by the

”nonlinear hinge”. The nonlinear-hinge enables introduction of discrete nonlinearity defined by the lateral force-deformation or stress-strain relationship that simulates the behavior of the masonry infill. The advantage of this approach is that different modes of infill’s failure can be represented, but the inability of taking into interpretation the effects of interaction still remains. There are many various ideas how to calculate characteristics and place those struts inside the frames.

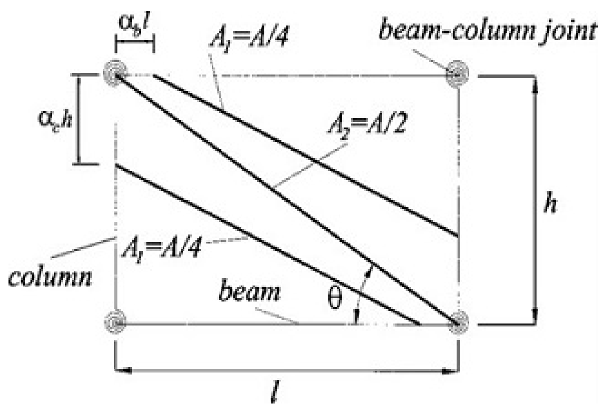


Figure 2: Equivalent three diagonal strut model for masonry infilled frames.

4.2 Modelling and analysis of steel frames

Plastic hinge hypothesis is generally used to capture the nonlinear behaviour according to which plastic deformations are lumped on plastic hinges and rest of the system shows linear elastic behaviour. For the beam default hinge is given in SAP2000 V20 that yields based upon the flexure (M3) as per ASCE 41-13, Table 9-6 And for the column assign default hinge that yields based upon the interaction of the axial force and bending moment (P-M2-M3) as per ASCE 41-13, Table 9-6. After modelling the steel frame members.[7] The seismic performance of a multi-story steel frame structure is analysed according to the provision of current Indian code (IS800-2007), seismic data and seismic factor from Indian code (IS1893-2002). The models were analysed as per Indian standard codes and FEMA356 and ATC 40 guidelines which are compiled in ASCE 41-13. Different performance levels such as Immediate Occupancy, Life Safety, Collapse prevention and collapse are defined. The pushover analysis is carried out using SAP2000 v20, a product of computer and structure international.

5. Sample Structures for Modelling

5.1 Building descriptions

Three-story, Six-story, and Nine-story buildings are considered representing low-rise, mid-rise, and high-rise structures, respectively as shown in Figure 3. The shaded area in the figure represents the frame infilled with the unreinforced masonry wall. These buildings are regular both in plan and elevation. For all buildings, the bay widths considered are 4 m for all bays and story height of 3 m for all as shown in figure 4.

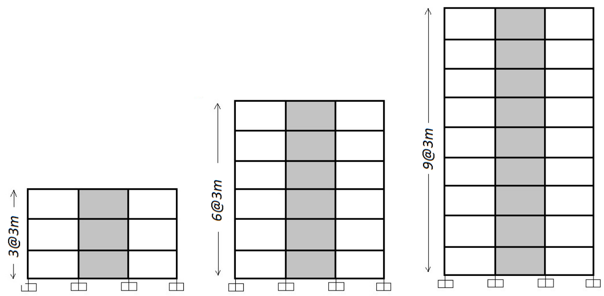


Figure 3: Low-rise, mid-rise, and high-rise building with mid bay infilled (0-1-0)

Effect of infill masonry walls on the building height is studied by taking wall thickness and wall strengths as constant and just varying the building heights and infill configuration. The wall thickness is fixed to 230 mm thickness and wall strength is fixed to 6.6MPa.

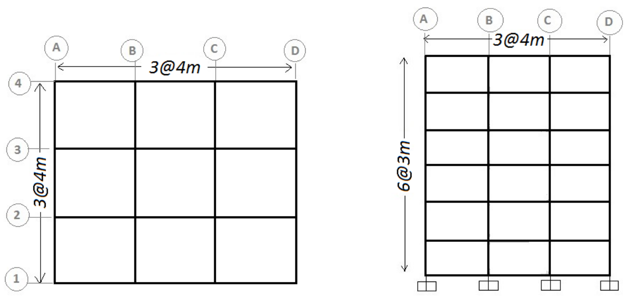


Figure 4: Plan and elevation of mid-rise building

For a parametric study of wall thickness and strength, six story buildings of different infill configurations is chosen, for different infill configuration the thickness and strengths of the unreinforced masonry is varied. The different wall thickness taken for the study are 110mm, 230mm and 350mm (Corresponding to typical 4.5-inch, 9-inch and 14-inch wall thickness). For varying wall thickness, the walls are simplified to a crushing strength of 6.6MPa. Similarly, for varying wall strengths the walls are simplified to a thickness of 230mm. The different wall prism strengths taken are 4.1MPa, 6.6MPa and 7.5MPa (4.1MPa correspond to infill prism strength for low strength mortar (1:0:6) similarly 6.6MPa for intermediate strength mortar (1:0.5:4.5) and 7.5MPa for high strength mortar (1:0:3)[8]). For each wall thickness and strengths, the six-story building is analysed with bare frame, mid bay infilled, outer bays infilled and all bays infilled as shown in Figure 5.

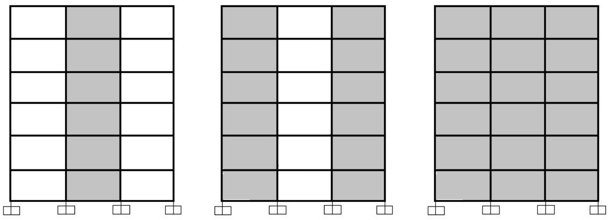


Figure 5: Six story building with 0-1-0, 1-0-1 and 1-1-1 infill wall configurations

5.2 Design and earthquake parameters

The steel structures are analysed and designed for Indian seismic zone V with medium soil conditions and importance factor of 1.0 is assumed. Dead and live loads are as per IS 875. Seismic loads are in accordance with IS 1893 (2002) and the frames are designed as per IS 800:2007 In the present study, the grade of steel used is Fe 250. The live load is taken as $3.5KN/m^2$ for floors and $1.5KN/m^2$ for roof. Floor finish is taken as $1KN/m^2$ and the roof treatment as $1KN/m^2$. Composite slab is used in the floors and roofs, in the filled type deck slab the grade of the concrete is M25. The grade of all the steel is taken as Fe 250. The overall thickness of the slab is 110 mm. The density of the masonry wall is taken as $18KN/m^3$ with a Poisson's ratio of 0.1 and the density of the reinforced concrete is $25KN/m^3$. Plastic hinge hypothesis is used to capture the nonlinear behaviour according to which plastic deformations are lumped on plastic hinges and rest of the system shows linear elastic behaviour. Beams are generally assigned flexure (M3) hinges and the columns are generally assigned with the axial force and bending moment interaction (P-M2-M3) hinges.

5.3 Various models for Parametric study

There are basically twelve different models. Considering thickness and strengths of infilled walls to be constant i.e. 230 mm and 6.6 MPa respectively the twelve models are:

Model 1: Three-story bare steel frame;
Model 2: Three-story steel frame with mid bay infilled;
Model 3: Three-story steel frame with two bays infilled;
Model 4: Three-story steel frame with all three bays infilled;
Model 5: Six-story bare steel frame;
Model 6: Six-story steel frame with mid bay infilled;
Model 7: Six-story steel frame with two bays infilled;
Model 8: Six-story steel frame with all three bays infilled;
Model 9: Nine-story bare steel frame;
Model 10: Nine-story steel frame with mid bay infilled;
Model 11: Nine-story steel frame with two bays infilled;
Model 12: Nine-story steel frame with all three bays infilled

For varying thickness and for varying strengths of the infilled masonry walls four models of six story buildings are chosen for the parametric study. Thus, there are sixteen other added models four different models for each 110 mm thickness, 350 mm thickness, 4.1 MPa strength and 7.5 MPa strength of infilled masonry walls.

6. Modelling and Analysis of the Structures

6.1 Modelling of infill masonry wall

Infill Wall Geometrical Model

The analytical model with three equivalent diagonal struts (El-Dakhakhni et.al.,2003) is chosen as representative for multiple struts models for infilled masonry walls.[9] The contact areas between the frame and the infill masonry panels are of particular concern in this model, and in the case of steel frames infilled with masonry infill walls the contact lengths are located at distances given by following contact distance from the beam-column connections,

$$\alpha_c.h_c = \sqrt{\frac{2.(M_{pj}+0.2.M_{pc})}{f'_{m-0}.t_w}} <= 0.4.h_c$$

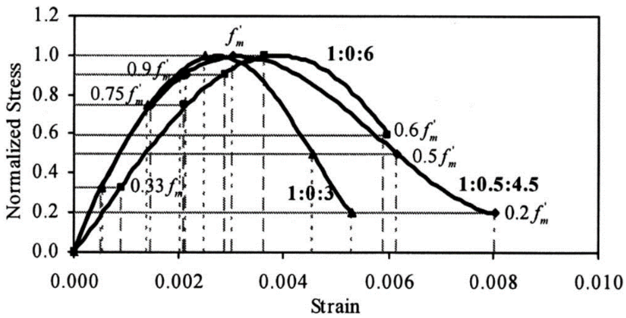
$$\alpha_b.l_b = \sqrt{\frac{2.(M_{pj}+0.2.M_{pb})}{f'_{m-90}.t_w}} <= 0.4.l_b$$

where, α_c is the ratio of the column contact length to the height of the column h_c, which should be taken equal to or less than $0.4.h_c$, α_b is the ratio of the beam contact length to span of the beam l_b; which should be taken equal to or less than $0.4.l_b$, M_{pj} is the minimum of the column, beam or connection's plastic moment capacity; M_{pc} and M_{pb} are the column and beam's plastic moment capacities, respectively; f_{m-0} and f_{m-90} are the compressive strength of the masonry panel parallel and normal to the bed joint, respectively, and t_w is the infill thickness. It is worth noting that the influence of actual steel joint behavior can also be taken into account by use of the above expressions. In this approach the single strut model is improved by addition of two other equivalent struts on each side of the central diagonal strut. The total diagonal struts area is calculated by following expression:

$$A = \frac{(1-a_c).a_c.h_c.t_w}{\cos\theta}$$

where θ is an angle defining inclination of the central strut, t_w is the infill masonry wall thickness as shown in Figure 2. The total area should be divided in such a way that the central strut has half of the total area and each of the other two struts has one quarter of the total area.

Infill Wall Material Model



Stress in terms of f_m'	Strain in prism for mortar grades		
	1:0:6	1:0:3	1:0.5:4.5
0.00	0.0000	0.0000	0.0000
0.33	0.0009	0.0005	0.0005
0.75	0.0021	0.0014	0.0015
0.90	0.0029	0.0021	0.0021
1.00	0.0036	0.0025	0.0030
0.60	0.0059	-	-
0.50	-	0.0045	0.0062
0.20	-	0.0053	0.0080

Figure 6: Stress-strain curves for masonry prisms for different grades of mortar; stress is normalized with respect to prism compressive strength for each curve

The material model for masonry walls developed by HB. Kaushik et.al.(2007) is used for material model of the infill masonry walls.[8] Based on the results and observations of experimental study, nonlinear stress-strain curves were obtained for bricks, mortars and masonry and six control points were identified on the stress strain curve as shown in Figure 6. The model needs only the compressive strength of bricks and mortar as input data , which can be easily obtained experimentally and are generally available in codes. Simple relationships were identified for obtaining the modusus of elasticity of bricks, mortars and masonry from their respective compressive strengths.

Table 2 and Table 3 shows the properties of masonry infill walls and properties of steel frame members respectively used for the design and analysis of the sample models.

Table 2: Properties of masonry infill walls

Parameters	Properties
Unit Weight	$18KN/m^3$
Poisson's ratio	0.1
Modulus of elasticity	$550.f_m'$
Width of diagonal struts	Thickness of the wall
Depth of diagonal struts	A/Thickness of the wall

Table 3: Properties of steel frame members

Parameters	Properties
Unit Weight	$7850Kg/m^3$
Poisson's ratio	0.3
Grade of steel	Fe 250
Modulus of elasticity	210000 Mpa
Column sections	HE360A, HE400A, HE450A
Beam sections	IPE 220, IPE 240

7. Results and Discussions

7.1 Results of pushover analysis

The Pushover curves (base shear vs. roof displacement curves) indicated that the structures with infill masonry walls are better than structures without infill masonry walls given that the deformation compatibility is taken in consideration. Figure 7 shows various pushover curves for buildings with different parameters. It is seen that the capacity curve become more linear for structures with infill masonry walls. No matter whatever is the building height, infill wall thickness or the infill wall strength, if more numbers of bays are infilled with masonry walls, it increases the building strength capacity and decreases the displacement capacity.

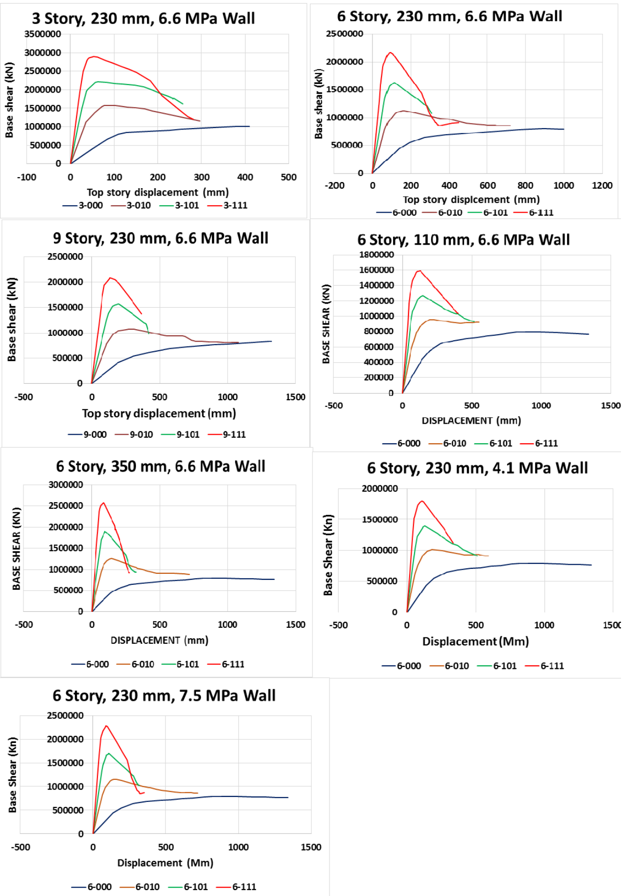


Figure 7: Pushover curves of different buildings for parametric analysis

7.1.1 Ultimate strength compared to the number of bays infilled

The ultimate strength and stiffness relationship to the number of infilled bays is shown more clearly in Figure 8 for different height of the buildings for different thickness and strength of infill masonry walls. Here it is seen that when all frame bays are infilled, the increase in ultimate strength of the system increases in a similar pattern for all parameters. Compared to the bare steel frame, Infill configuration shows 27%-55%, 75%-118% and 125%-185% increase in strength with the addition of, respectively, single, double and all three infilled bays with different parameters.The increase in ultimate strength is in linear pattern with the number of bays infilled with masonry walls.It is seen that the increase in strength goes in the same way for all story heights, for all thickness and strength of the infill walls.

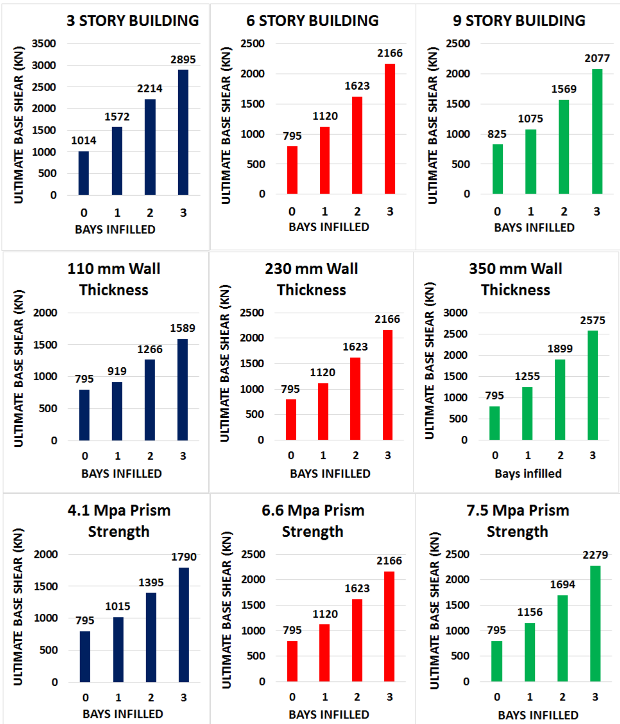


Figure 8: Ultimate strength for different parameters compared to the number of bays infilled

7.1.2 Total story displacements and inter story drifts

The total story displacement and inter story drifts of the steel framed buildings abruptly reduced to about 20% of initial displacement and drift capacities for single bay infill for all height of the buildings, for all strengths of the infill wall and for 230mm and 350mm wall thicknesses as shown in Figure 9, Figure 10 and Figure 11, and with further increase in the width of masonry walls the total story displacement and inter story drifts reduces gradually in about linear manner.

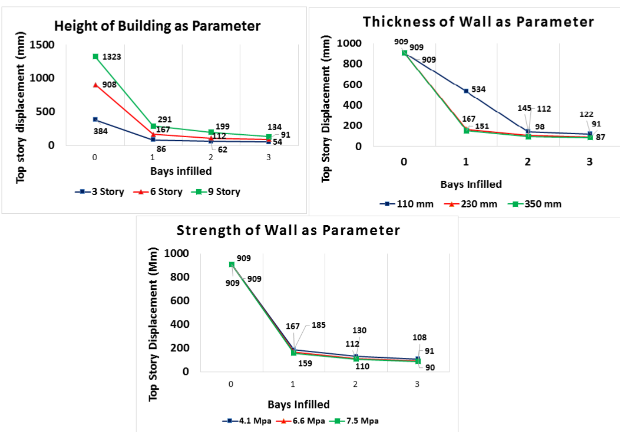


Figure 9: Top story displacement vs number of bays infilled for different parameters

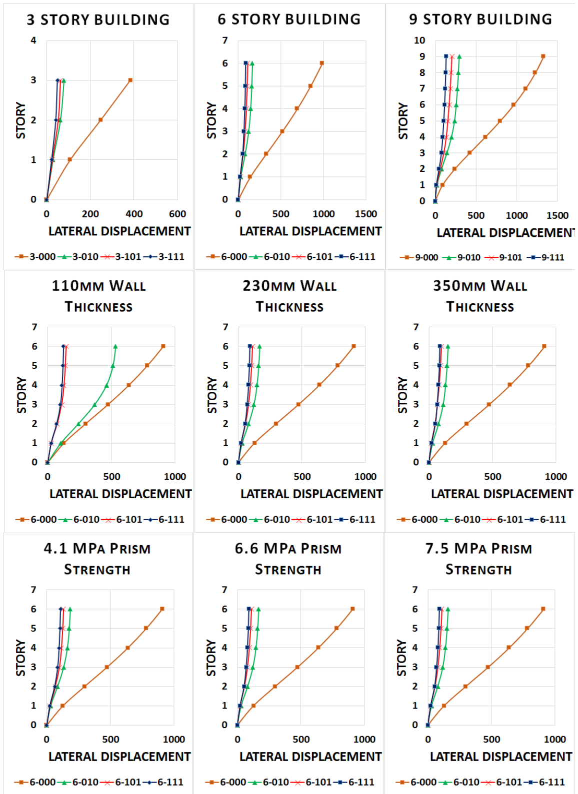


Figure 10: Total displacement at each story for different parameters with different infill configurations

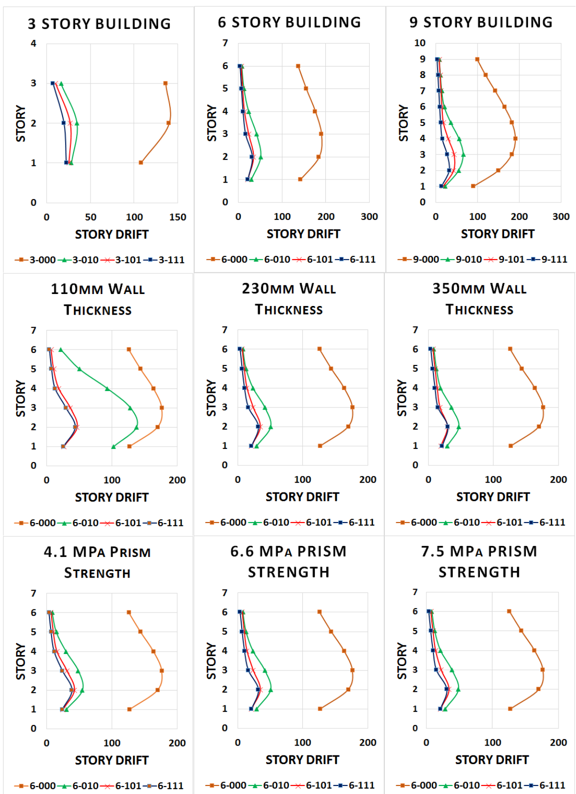


Figure 11: : Inter story drifts compared to different parameters with different infill configurations

However, this behaviour is obtained different for 110 mm wall thickness. The roof displacement reduced to 59% of the bare frame when only single bay is infilled. This high deformation may give rise to furthermore damage in infill walls thus the buildings with 110mm wall thickness are more vulnerable during seismic actions.

7.1.3 First mode time period and frequency

Modal period for first mode of masonry infilled steel frames is comparatively less than that of bare frames for all parameters as shown in Figure 12. Time periods reduced to 57%-64%, 48%-54% and 41%-47% of bare frame with the addition of, respectively, single, double and all three infilled bays.For the first bay infill the reduction is abrupt and with increase in infill walls, the reduction of modal period is almost in linear pattern.The increase in the frequency with infill masonry walls goes in the similar way, Figure 12.

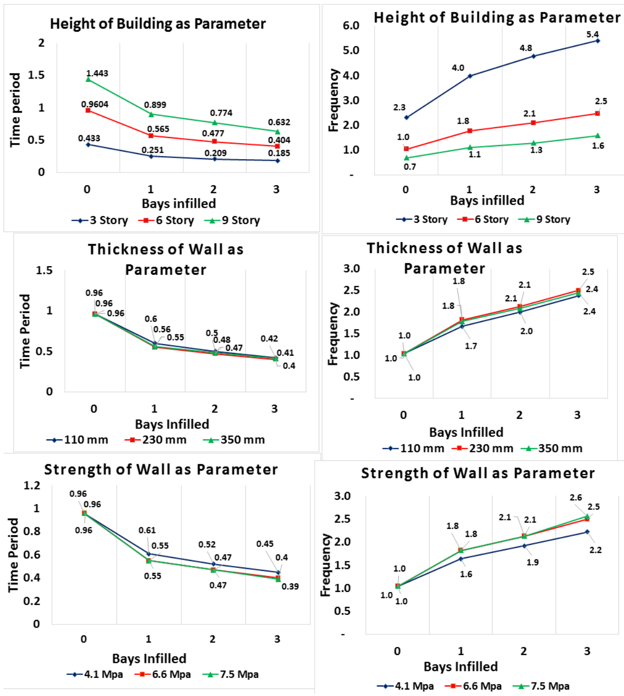


Figure 12: First mode time periods and frequencies for different parameters with different infill configurations

7.1.4 Performance points compared to the number of bays infilled

Intersection point of capacity spectrum (building capacity) and demand spectrum (earthquake ground motion) is known as Performance Point. Capacity curve is calculated using the spectral acceleration vs spectral displacement and the demand curve is calculated from ground acceleration and period of the structure. Building with infilled masonry walls have higher performance point than bare frames as shown in Figure 13.

Table 4 shows the states of plastic hinges formed in infill masonry walls at performance points it is clearly seen that the three-story buildings are safe during the seismic actions but six story buildings and nine story buildings are not safe in seismic actions. Six story buildings with all bays infilled with brick masonry walls are however found to perform well during the seismic actions. It is clearly seen that the buildings with 110mm infill wall thickness and 4.1 MPa infill wall strength are not safe during the seismic action. Thus, the construction of steel framed building with 110 mm wall thickness and 4.1 MPa infill wall strength are not suggested. For mid-rise buildings partially infilled frames are found more vulnerable than the fully infilled steel frames.

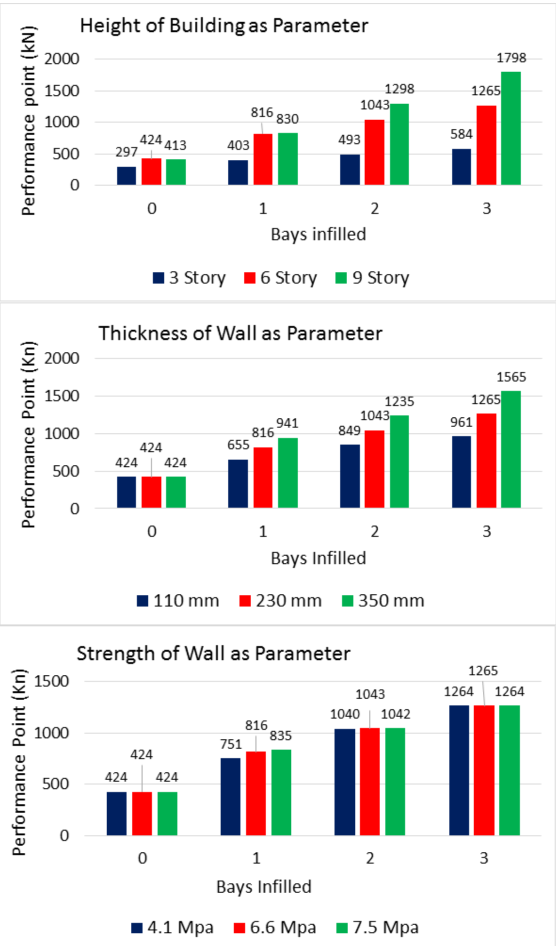


Figure 13: Performance points for buildings with different parameters

Table 4: State of hinges formed in brick masonry infill walls at performance points

Building Model	Performance Point (KN)	Step	State of Plastic Hinges at Performance Point of infill walls				Remarks
			OP-IO	IO-LS	LS-CP	Beyond CP	
3-000	297	1 to 2	All				Safe
3-010	403	0 to 1	6	3			Safe
3-101	493	0 to 1	10	8			Safe
3-111	584	0 to 1	10	16	1		Safe
6-000	424	1 to 2	All				Safe
6-010	816	2 to 3	6	3	1	8	Not Safe
6-101	1043	1 to 2	14	12	9	1	Not Safe
6-111	1263	0 to 1	30	23	1		Safe
9-000	413	2 to 3	All				Safe
9-010	830	3 to 4	9	3	5	10	Not Safe
9-101	1298	2 to 3	22	11	8	13	Not Safe
9-111	1798	2 to 3	34	19	10	18	Not Safe
Building Model	Performance Point (KN)	Step	State of Plastic Hinges at Performance Point of infill walls				Remarks
			OP-IO	IO-LS	LS-CP	Beyond CP	
110mm, 6-000	424	1 to 2	All				Safe
110mm, 6-010	655	2 to 3	3	3	2	10	Not Safe
110mm, 6-101	849	1 to 2	12	15	7	2	Not Safe
110mm, 6-111	961	1 to 2	22	18	13	1	Not Safe
230mm, 6-000	424	1 to 2	All				Safe
230mm, 6-010	816	2 to 3	6	3	1	8	Not Safe
230mm, 6-101	1043	1 to 2	14	12	9	1	Not Safe
230mm, 6-111	1263	0 to 1	30	23	1		Safe
350mm, 6-000	424	1 to 2	All				Safe
350mm, 6-010	941	1 to 2	6	7	4	1	Not Safe
350mm, 6-101	1235	1 to 2	18	7	9	1	Not Safe
350mm, 6-111	1565	0 to 1	34	19	1		Safe
Building Model	Performance Point (KN)	Step	State of Plastic Hinges at Performance Point of infill walls				Remarks
			OP-IO	IO-LS	LS-CP	Beyond CP	
4.1 MPa, 6-000	424	1 to 2	All				Safe
4.1 MPa, 6-010	751	2 to 3	6	3	1	8	Not Safe
4.1 MPa, 6-101	1040	2 to 3	12	6	3	15	Not Safe
4.1 MPa, 6-111	1264	1 to 2	25	16	12	1	Not Safe
6.6 MPa, 6-000	424	1 to 2	All				Safe
6.6 MPa, 6-010	816	2 to 3	6	3	1	8	Not Safe
6.6 MPa, 6-101	1043	1 to 2	14	12	9	1	Not Safe
6.6 MPa, 6-111	1263	0 to 1	30	23	1		Safe
7.5 MPa, 6-000	424	1 to 2	All				Safe
7.5 MPa, 6-010	835	2 to 3	6	6	5	1	Not Safe
7.5 MPa, 6-101	1042	1 to 2	14	12	9	1	Not Safe
7.5 MPa, 6-111	1264	0 to 1	31	22	1		Safe

7.2 Hinge results

Study of hinges formed during pushover analysis showed that higher percentage of frame hinges reached more vulnerable damage states in case of structures without infill masonry walls,Table 5. For masonry infilled buildings of different height and for all thickness and strength of the infill masonry walls, most of the hinges of the steel frame members are in Immediate occupancy states,Table 5. Whereas, the severe and collapsed state of damage is observed more in structures without infill walls. Thus, it can be concluded that the steel framed buildings with infill masonry walls are less vulnerable to the overall collapse of building during the seismic actions.

Table 5: Hinge results at ultimate strength for low rise, mid rise and high rise buildings

Hinge Result Table for 3 Story Building								
Infill Configuration	**Step**	**A to B**	**B to IO**	**IO to LS**	**LS to CP**	**C to D**	**Beyond E**	**Total**
3-000	18	26	0	12	6	4	0	48
	Steel Frame	26	0	12	6	4	0	48
	Infill Wall	0	0	0	0	0	0	0
3-010	8	38	10	0	0	0	9	57
	Steel Frame	38	10	0	0	0	0	48
	Infill Wall	0	0	0	0	0	9	9
3-101	6	42	7	5	0	0	12	66
	Steel Frame	41	7	0	0	0	0	48
	Infill Wall	1	0	5	0	0	12	18
3-111	9	53	4	0	0	0	18	75
	Steel Frame	44	4	0	0	0	0	48
	Infill Wall	9	0	0	0	0	18	27
Hinge Result Table for 6 Story Building								
Infill Configuration	**Step**	**A to B**	**B to IO**	**IO to LS**	**LS to CP**	**C to D**	**Beyond E**	**Total**
6-000	15	50	0	12	13	15	0	90
	Steel Frame	50	0	12	13	15	0	90
	Infill Wall	0	0	0	0	0	0	0
6-010	9	73	20	3	0	0	12	108
	Steel Frame	70	20	0	0	0	0	90
	Infill Wall	3	0	3	0	0	12	18
6-101	7	91	11	6	0	0	18	126
	Steel Frame	79	11	0	0	0	0	90
	Infill Wall	12	0	6	0	0	18	36
6-111	8	101	7	9	0	0	27	144
	Steel Frame	83	7	0	0	0	0	90
	Infill Wall	18	0	9	0	0	27	54
Hinge Result Table for 9 Story Building								
Infill Configuration	**Step**	**A to B**	**B to IO**	**IO to LS**	**LS to CP**	**C to D**	**Beyond E**	**Total**
9-000	13	70	4	18	18	22	0	132
	Steel Frame	70	4	18	18	22	0	132
	Infill Wall	0	0	0	0	0	0	0
9-010	9	111	28	2	1	0	17	159
	Steel Frame	104	28	0	0	0	0	132
	Infill Wall	7	0	2	1	0	17	27
9-101	8	134	16	6	6	0	24	186
	Steel Frame	116	16	0	0	0	0	132
	Infill Wall	18	0	6	6	0	24	54
9-111	7	155	7	15	2	0	34	213
	Steel Frame	125	7	0	0	0	0	132
	Infill Wall	30	0	15	2	0	34	81

8. Conclusions

1. Capacity curves become more linear for structure with infill walls. The strength of the structure increases linearly with the increase in infilled bays. No matter whatever is the building height, infill wall thickness or the infill wall strength, if more numbers of bays are infilled with masonry walls, it increases the building strength capacity and decreases the displacement capacity.
2. The story displacement and inter story drifts reduces abruptly to 20% of initial for mid bay infill, and reduces gradually in a linear manner with further increase in number of infilled bays. This behaviour is obtained different for 110 mm wall thickness. The roof displacement reduced to 59% of the bare frame when only single bay is infilled with 110 mm walls.
3. The modal period reduces abruptly to 60% of initial for mid bay infill, with increase in number of infilled bays modal periods reduces gradually in linear manner. The increase in the frequency with masonry walls goes in the similar way.
4. Three-story buildings with infill masonry walls are safe during the seismic actions but six story buildings and nine story buildings are not safe in seismic actions. However, Six story buildings with all bays infilled with brick masonry walls perform well during the seismic actions. Buildings with 110mm infill wall thickness and 4.1 MPa infill wall strength are not safe. Thus, the construction of steel framed building with 110 mm wall thickness and 4.1 MPa infill wall strength are not suggested.
5. Hinges formed during pushover analysis showed that higher percentage of steel frame hinges reaches more vulnerable damage states in structures without infill masonry walls.

References

[1] SV Polyakov. Masonry in framed buildings, gosudalstvennoe'stvo literature po straitel'stuv i arkitecture, moskva. *Trans. GL Cairns, Building Research Station, Watfor, Herts*, 1956.

[2] M Holmes. Steel frames with brickwork and concrete infilling. *Proceedings of the Institution of Civil Engineers*, 19(4):473–478, 1961.

[3] Bryan Stafford Smith and C Carter. A method of analysis for infilled frames. *Proceedings of the institution of civil engineers*, 44(1):31–48, 1969.

[4] Rowland J Mainstone. Summary of paper 7360. on the stiffness and strengths of infilled frames. *Proceedings of the Institution of Civil Engineers*, 49(2):230, 1971.

[5] MJN Priestley and Tom Paulay. Seismic design of reinforced concrete and masonry buildings. *New York: John Wiley & Sons, Inc*, 1992.

[6] SG Buonopane and RN White. Pseudodynamic testing of masonry infilled reinforced concrete frame. *Journal of structural engineering*, 125(6):578–589, 1999.

[7] American Society of Civil Engineers, editor. *ASCE standard ASCE/SEI 41-13: American Society of Civil Engineers: seismic evaluation and retrofit of existing buildings*. Number 41-13 in Standard. American Society of Civil Engineers, Reston, Virginia, 2014.

[8] Hemant B. Kaushik, Durgesh C. Rai, and Sudhir K. Jain. Stress-Strain Characteristics of Clay Brick Masonry under Uniaxial Compression. *Journal of Materials in Civil Engineering*, 19(9):728–739, September 2007.

[9] Wael W. El-Dakhakhni, Mohamed Elgaaly, and Ahmad A. Hamid. Three-Strut Model for Concrete Masonry-Infilled Steel Frames. *Journal of Structural Engineering*, 129(2):177–185, February 2003.