Effect of Infill on Performance of Steel Frame Buildings

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Abstract: In India steel buildings are less common, though steel buildings may be economical in many instances. The study of the performance of steel buildings needs to be carried out to understand the seismic behaviour of steel buildings. One such study involves the effect of infill on the steel building performance. The Infill has significant influence on the response and performance of the buildings. In general it increases the stiffness of the system. However, it may shift the action from the column to beam. In the present study, the infill effect has been modeled by equivalent strut as per FEMA 356. SAP2000 version 14 has been used to evaluate the performance of the buildings. The study highlights the effect of infill on steel buildings including that on time period and nonlinear performance.

Keywords: Steel buildings; building performance, time period, design drift; performance level.

Introduction

Introduction of infill in steel structures will change the properties of steel structures. It is supposed to perform positively under seismic loading. Thought it has so many advantages, very less investigation were done under this topic. Infill in steel structures are supposed to increase the lateral stiffness, strength, fire resistance, wind resistance, weather resistance etc. Seismic force acting on the structures shall be carried by infill walls and frames, so that stiffness of the structure with infill will be much higher than stiffness of structure without infill.

Seismic performances of reinforced concrete structures with infill were analyzed before. It is used to give better performance than the structure without infill under seismic loading, so many researches have been done under that topic. Steel structures with and without infill has been analyzed by this work. In this research, a detail evaluation for seismic performance of infill steel frames has conducted by software SAP2000. Infill effect is modeled by equivalent struts. Performances of both the types of buildings are done by linear and non linear dynamic analysis (time history analysis) and non linear static analysis (push over analysis).

Past Works

Analytical and experimental researches on RC buildings and Steel buildings are started before. A very little research has been done on steel buildings comparing to RC buildings. Various research studies have shown that buildings with infill perform better than buildings without infill and stiffness increased after the infill introduction.

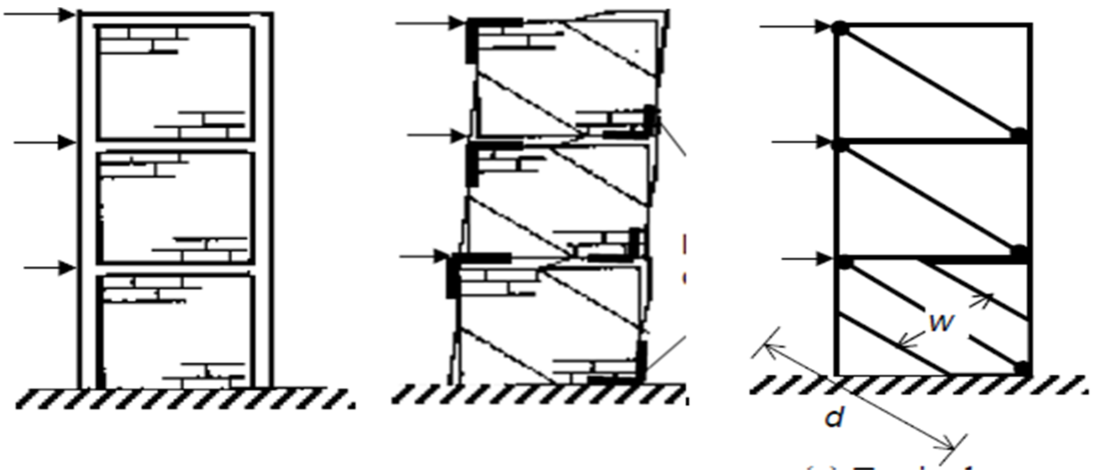
Davis R (2004) conducted seismic performance of masonry infill RC frames. For those he choosed two typical buildings located in moderate seismic zones of India. For knowing performance response spectrum analysis and non linear push over analysis done over these buildings. After these analyses he concluded that the presence of infill increases the stiffness of building it modifies the structural force distribution, also bending moments in the ground floor column increases and the mode failure by soft storey mechanism.

The typical behavior of an infilled frame subjected to lateral load as shown in figure 1.

This figure illustrates how equivalent struts are providing. The results of the study have shown that after adding infill the stiffness of the building increasing with respect to increase in storey shear. Time period of the building got decreased by the addition of infill.

Tasnimi A A (2011) described an experimental program to investigate the in-plane seismic behavior of steel frames with brick masonry infills having openings. Test specimens included masonry infills having a central opening, strong pier-weak spandrel, weak pier-strong spandrel and a door opening. All infills were unreinforced and all lateral deformations were imposed in the plane of the frames. He concluded that the ductility of infilled frames with openings depends on the failure mode of infill piers, and by experimentally found that diagonal tension failure in their piers and do not exhibit more ductility than solid infilled frames.

Raza S (2014) conducted a detailed evaluation of masonry infilled steel structures under seismic performance, which is concerned with the evaluation of local and global parameters of a structure when it is subjected to seismic loads. By that he concluded that For infilled steel frame structures the fundamental time period, roof displacement and interstorey drift ratios



(a) Infilled frame (b) Deformed shape (c) Equivalent strut

Figure 1. Behavior of infilled frames. (Robin Davis, 2004)

decrease with the increase in number of bays due to increase in the lateral stiffness, and the parameters increase with the increase in number of stories due to increase in the mass of the structure and larger height to base width ratio.

Methodology

Building Discription

The building Nomenclature for 4 steel buildings used in the present study is as shown below. Roman number indicates plan number and the last numerical figure indicates the number of stories.

Table 1. Building Nomenclature

Sl No	Building Name	No.of Stories	Description
1	**PI-4**	4	Plan I having 4 stories
2	**PII-5**	5	Plan II having 5 stories
3	**PI-4 INF**	4	Plan I having 4 stories and with infill
4	**PII-5 INF**	5	Plan II having 5 stories and with infill

Methodology

In this study, steel frame buildings with and without infill has been designed as per IS 800:1998 and IS 1893:2002. Also it has been conducted detail evaluation for seismic performance of infill steel frames by software SAP2000 version 14. Infill effect modeled by equivalent struts. Perform the analysis over time history and non linear analysis and find out the results like base shear distribution, response spectra, interstorey drift, performance level(push over analysis), roof displacement function, floor spectra, hinge pattern, push over curve. It gives an idea about overall structural behavior during an earthquake.

In nonlinear seismic analysis the ground motions has to be represented through time histories. Five Spectrum Compatible Ground Motions (SCGMs) has been generated with the following name with refers to the design spectrum at IS 1893: 2002 (Part 1) for zone 5. The SCGMs has been developed by software named Kumar (2004).

Table 2. SCGMs

Sl. No	**Name of SCGM**	**Background earthquake**	**Duration(sec)**
1	**GM1**	Petrolia-Cape Mendocino(1992)	60
2	**GM2**	Lome Prieta-Santa cruz mtns(1989)	40
3	**GM3**	Kerncounty-California(1952)	55
4	**GM4**	Elcentro-Imperial valley(1940)	54
5	**GM5**	Coalinga(1983)	65

Flow Chart of present study

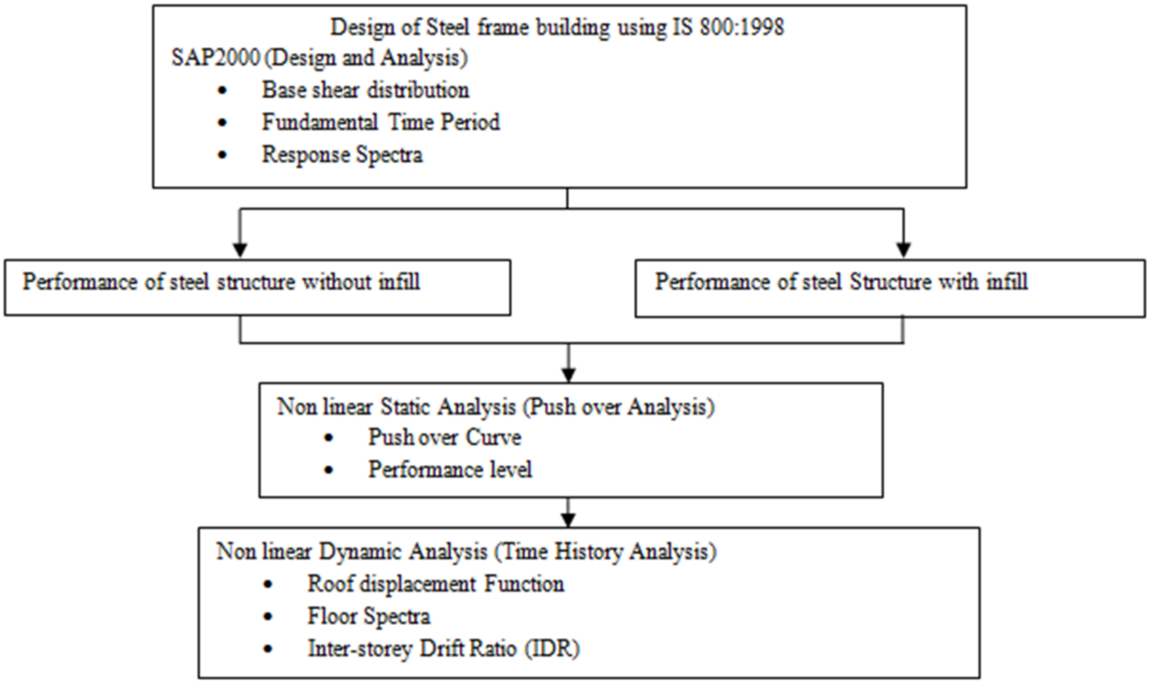


Figure 2. Flow chart of present study

Introduction of infill in Steel buildings

FEMA 356 is used for the introduction of infill in steel buildings. The elastic in-plane stiffness of a solid unreinforced masonry infill panel prior to cracking shall be illustrated with an equivalent diagonal compression strut of width, *a*, given by Equation. The equivalent strut shall have the same thickness and modulus of elasticity as the infill panel it represents,

$$a = 0.175(\lambda_1 h_{col})^{-0.4} r_{inf}$$

Where, $\lambda_1=[(E_{me}\, t_{inf} \sin 2\Theta)/(4E_{fe}\, I_{col}\, h_{inf})]^{1/4}$, and h_{col} = Column height between centerlines of beams (in), h_{inf} = Height of infill panel (in), E_{fe} = Expected modulus of elasticity of frame material (ksi), E_{me} = Expected modulus of elasticity of infill material (ksi), I_{col} = Moment of inertia of column (in^4), L_{inf} = Length of infill panel (in), r_{inf} = Diagonal length of infill panel (in), t_{inf} = Thickness of infill panel and equivalent strut (in), Θ = Angle whose tangent is the infill height-to length aspect ratio (radians), λ_1= Coefficient used to determine equivalent width of infill strut.

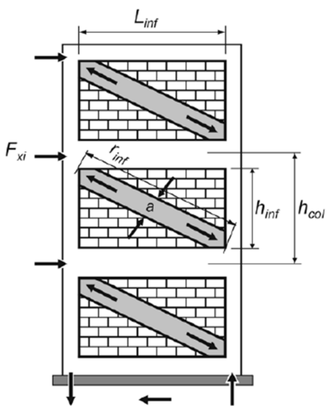
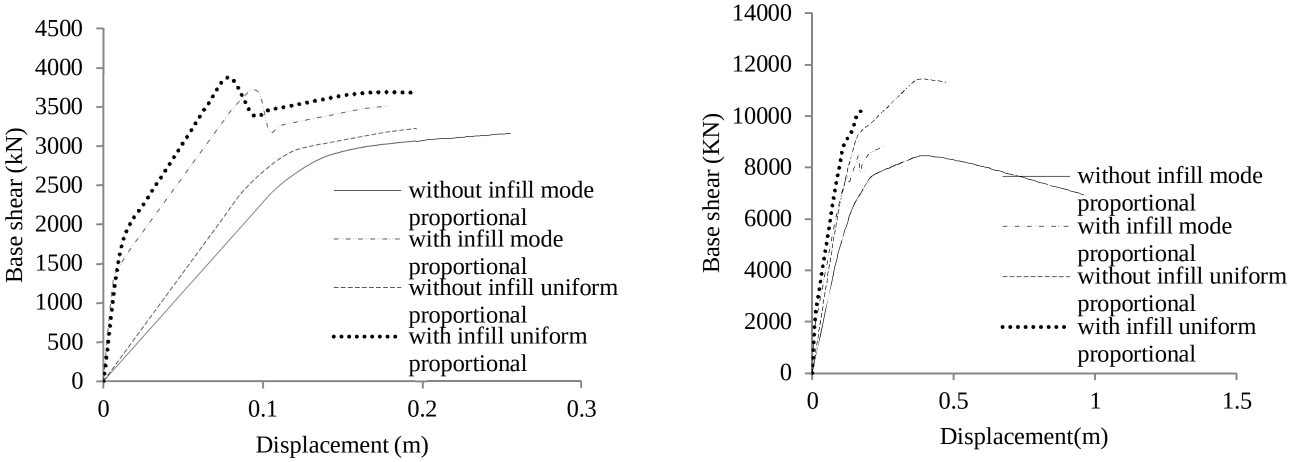


Figure 3. Compression Strut Analogy (FEMA 356)

Non linear static and non linear dynamic analyses are done as per FEMA 356 using SAP 2000. Results have been given in following chapter.

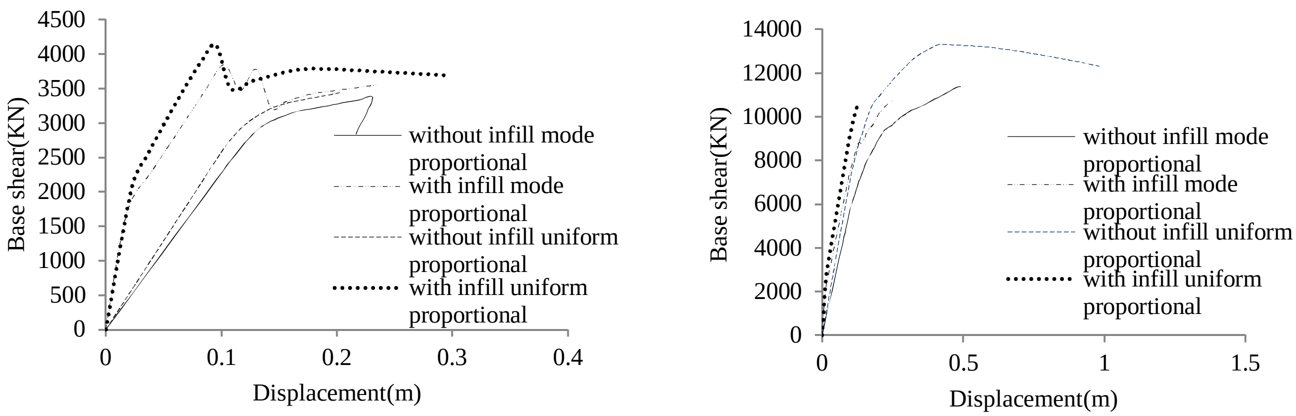
Results and Discussions

Both the buildings were analyzed using non linear static, non linear dynamic analysis and response spectrum method using IS 1893:2002 (part 1). The analyses were done by software SAP2000. The fundamental time period of the buildings were obtained from software. Steel buildings are rigid than the concrete buildings. According to this it will perform better than concrete buildings. When infill is considered, the fundamental time period of the building reduces and the building attracts more base shear. It is performing far better than the reinforced concrete buildings and bare steel frame buildings. Figure 1 and 2 shows the building changes after and before adding infill in terms of base shear vs. displacement.



a) Long direction b) Short direction

Figure 4: Push over curve for PI-4 and PI-4 INF

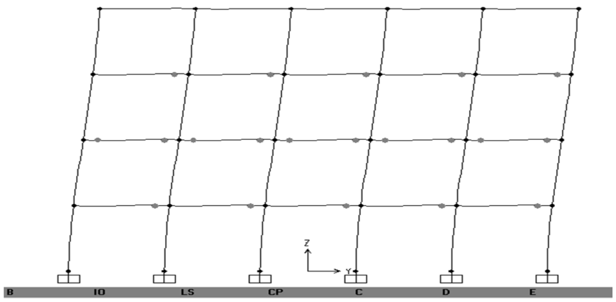


a) Long direction b) Short direction

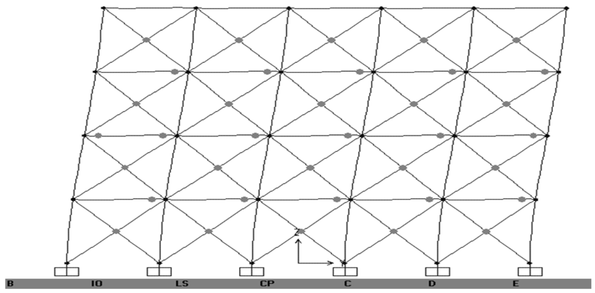
Figure 5: Push over curve for PII-5 and PII-5 INF

From these two figures it is clear that the infill increases the stiffness of building with respect to increase in base shear. Here nonlinear static results for both mode proportional and uniform proportional are given. Mode proportional push over curve means here it is taking vertical loads (gravity loads) acting on the building. Uniform proportional means it is taking only horizontal loads coming to buildings.

Figure 5 shows the hinge pattern for the plan I 4 storey building. It is clear that after adding infill hinge is changing from LS (life safety) to IO (immediate occupancy). Immediate Occupancy, is defined as the post-earthquake damage state that remains safe to occupy, it retains the pre-earthquake design strength and stiffness of the structure. Life Safety, means the post-earthquake damage state in which significant damage to the structure has occurred, but some margin against either partial or total structural collapse remains.

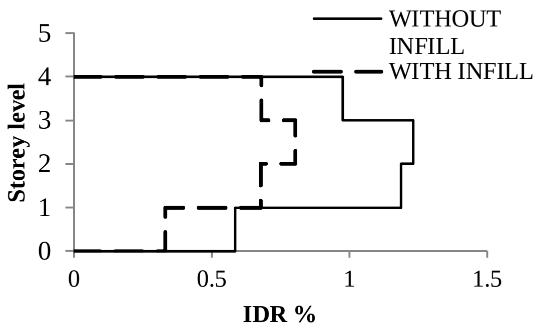


(a) Hinge pattern for PI-4 without infill

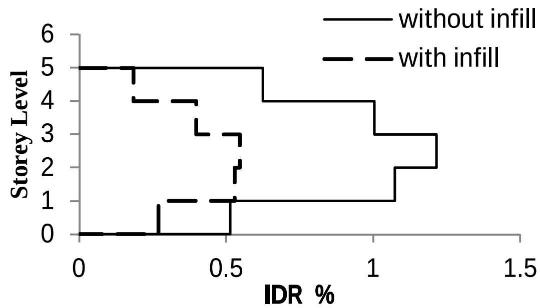


(b) Hinge pattern for PI-4 INF with infill

Figure 6. Hinge pattern for PI-4 with and without infill



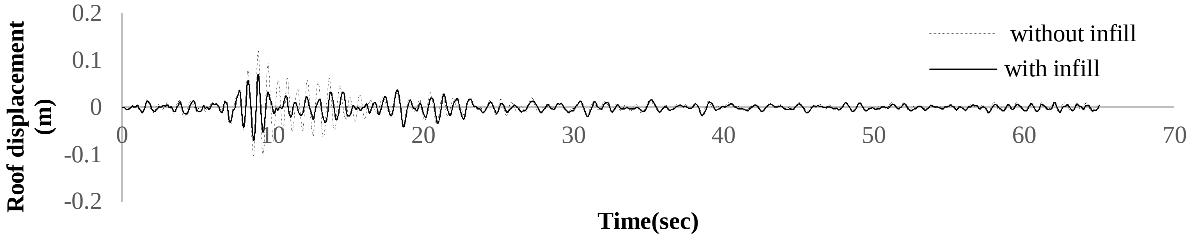
a) IDR for PI-4 and PI-4 INF



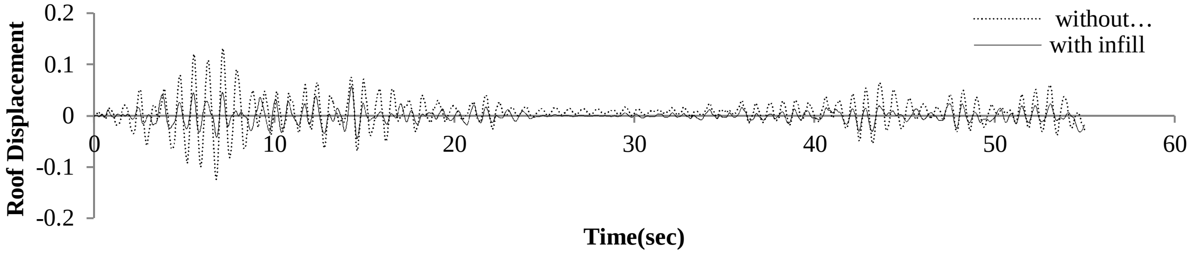
b) IDR for PII-5 and PII-5 INF

Figure 7: Storey level vs. IDR%

Figure 6 shows the maximum IDR obtained for the buildings after nonlinear dynamic analysis (time history analysis). Figure 6 shows the roof displacement with respect to time period. From figure 6 and 7 it is clear that introduction of infill reduces the drift of the building. Infill gives strength and stiffness to the building.

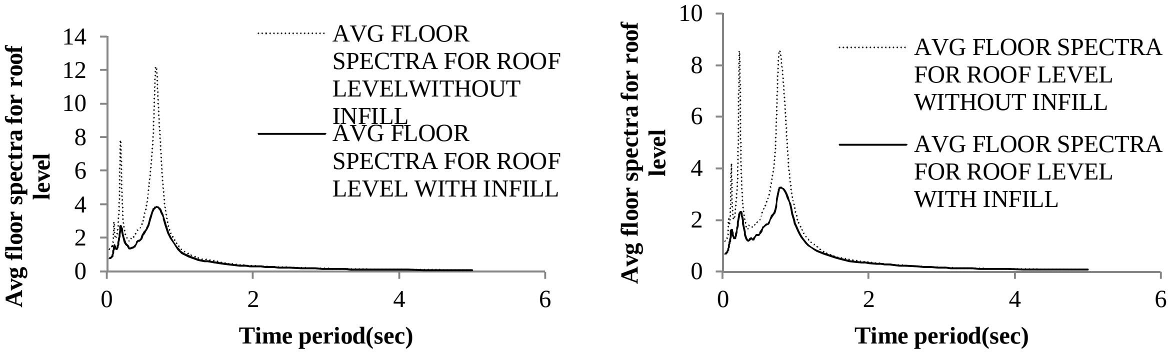


a) Roof Displacement for PI-4 and PI-4 INF



a) Roof displacement for PII-5 and PII-5 INF

Figure 8: Roof displacement vs. Time period for both buildings



a) Average floor spectra for PI-4 b) Average floor spectra for PII-5

Figure 9. Average floor spectra for PI-4 and PII-5

Floor spectra are the measure of maximum response characteristic of floor motion. Figure 8 indicates the average floor spectra for roof level of both the buildings. From figure it is shown that after infill addition the floor response also getting decreased. That figures out building is gaining more stiffness with infill.

Conclusion

The performances of steel building with and without infill are carried out by static non-linear pushover analysis and non-linear dynamic time history analysis. It is concluded that steel buildings with infill performed much better than steel buildings without infill. The stiffness of the building is increasing with decreasing time period. While time period is decreasing spectral acceleration of the building is increasing. Base shear and spectral acceleration have direct proportional relation and the base shear behavior with displacement obtained from push over analysis. From that it concluded that building stiffness increased with infill. After non linear dynamic analysis, ie., time history analysis it found that interstorey drift ratio of infilled frame building got decreased. Drift is indirectly proportional to stiffness. Roof displacement and floor spectra for roof level also gave the clear idea about building behavior.

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