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Seismic Performance Assessment of Masonry Infilled Steel Frame Structures

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ABSTRACT: Infilled steel frame structures are known to perform better as compared to infilled concrete frames under seismic loading. In comparison with masonry infilled reinforced concrete (RC) frame structures, very little research has been done on masonry infilled steel frames structures. Contribution of masonry infill in the positive performance of the infilled structures is widely recognized but no codes provide the clear and detailed guidelines on the design of infilled frame structures especially infilled steel frame structures due to the complex and unpredictable behaviour of masonry during an earthquake event. This study aims to provide a detailed insight into the composite behaviour of steel frame structures with unreinforced masonry infill under seismic loading. Time history analyses have been performed on masonry infilled steel moment resisting frame structures and structural performance has been evaluated in terms of global structural performance parameters of fundamental time period, maximum roof displacement and base shear and local parameters of interstorey drift ratios, structural member forces and infill stresses. The effect of masonry infill on the performance of infilled steel moment resisting frames has been investigated by varying the number of bays, number of storeys, percentage opening in the infill wall, location of the opening, type of openings, number of openings, infill strength, outer frame strength and infill thickness. The results of this research will help to understand the complex behaviour of masonry infilled steel frames for different variations mentioned above.

KEYWORDS: Masonry infill, Infilled steel frame structures, Time history analysis, Opening in the infill, Performance parameters, Seismic Performance Assessment, SAP2000, FEM.

1 INTRODUCTION

Construction of masonry infilled frame structures is common practice in many countries. Infills contribute to the performance of structures which is generally neglected in analysis and design by considering it as non-structural element. However the infill panels have significant in-plane stiffness that contribute to the frame stiffness and as a result, presence of the infills significantly increases the lateral strength and stiffness and frequency of the frame structures.

Contribution of masonry infill in the positive performance of the infilled structures is widely recognized but no codes provide the clear guidelines on the design of infilled frame structures especially infilled steel frame structures due to the complex and unpredictable behaviour of masonry during an earthquake event. A very little research has been done on masonry infilled steel frames. In this research seismic performance assessment has been conducted for detailed evaluation of seismic behaviour of masonry infilled frames, which is concerned with the evaluation of local and global parameters of a structure when it is subjected to seismic loads.

2 PREVIOUS RESEARCH

Analytical and experimental studies on seismic response of infilled frames started from mid-1950. Various research studies have shown that infill improves lateral strength and the stiffness of bare frame significantly and also greatly improves the energy dissipation capability of the structure.

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Benjamin and Williams (1958) [1] investigated three models including a masonry wall, masonry wall encased with the reinforced concrete frame and the masonry wall with steel frames. All these models were tested under an in-plane load. The test revealed the importance of aspect ratio which influences the ultimate capacity of the infilled frames. It was also reported that masonry has significant role in contributing lateral strength to the frame, however the size of masonry element did not affected the result.

Smith (1962) [2] conducted a study on a infilled structure experimentally on a small scale specimen. The specimen had steel frame and concrete mortar as infill. The in plane load was applied at the top corner of the infilled specimen. A compression region within the infill panel was observed which made the frame stiff and thus the concept of Diagonal strut method was evolved. It was also reported that longer is the contact length between the infill panel and the frame, wider the width of strut is.

Carydis et al (1992) [3] performed shake table tests on steel frames infilled with brick walls in which the gap between the frame and infill walls was filled with a non-shrinkable grout. The experiment revealed that frames good behavior was mainly due to grout filled gap.

Moghaddam (2004) [4] investigated lateral load behavior of masonry infilled steel frames with repair and retrofit. Experimental and analytical investigations on repaired and strengthened brick infilled steel frames were done. Two main repair techniques were examined in which the corner material was replaced with concrete or a concrete cover is placed on the panel. Efficiency and adequacy of these techniques were confirmed both experimentally and analytically.

Menari and Aliaari (2005) [5] developed an isolation system called SIWIS system. This system prevents the failure of column or infill walls by introducing a sub system which is breakable after reaching the full strength and stiffness of the infill wall. However, such system is not recommended in any of the codes yet as it would be expensive solution.

Arthur de Rooij (2005) [6] conducted an experimental and numerical research on steel frames with precast reinforced concrete infill panels. It was found that the behaviour of the panel-frame connections has a very large influence on the behaviour of the total structure. It was reported that the load-displacement behaviour of the steel frame with precast reinforced concrete infill panel can be represented by four stages: a linear elastic stage, a linear plastic stage and a non-linear plastic stage. The stresses in the concrete infill panel showed a compression and a tension diagonal.

Moghaddam et al. (2006) [7] performed experimental and analytical investigation to evaluate the shear strength and cracking pattern of infill panels in masonry and concrete infilled steel frames. It was reported that unlike masonry infills, corner crushing was dominant mode of failure in concrete infills.

Amin Mohebkhah (2008) [8] studied a two-dimensional numerical model using the specialized discrete element method (DEM) software UDEC, developed for the nonlinear static analysis of masonry-infilled steel frames with openings subjected to in-plane monotonic loading. It was found that the model can be used confidently to predict collapse load, joint cracking patterns and explore the possible failure modes of masonry-infilled steel frames with a given location for openings and relative area.

Tasnimi et al. (2011) [9] described an experimental program to investigate the behavior of brick-masonry infilled steel frames with 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. It was reported that that infilled frames with openings are not always more ductile than the ones with solid infill and the ductility of such frames depends on the failure mode of infill piers. This experimental investigation showed that infilled frames with openings experienced pier diagonal tension or toe crushing failure and had smaller ductility factors than those frames with solid infill.

3 METHODOLOGY

All selected structures have been designed in SAP2000 under gravity loads only. Micro modeling has been used to model the infill. Three acceleration time histories were used and dominant earthquake was selected for further research. Seismic performance assessment involves investigation of response of structure in terms of structural performance evaluation parameters by varying selected variation parameters under seismic loading. It gives insight of structural behaviour during an earthquake. A step by step procedure of seismic performance assessment is shown in figure 1 in the form of flow chart.

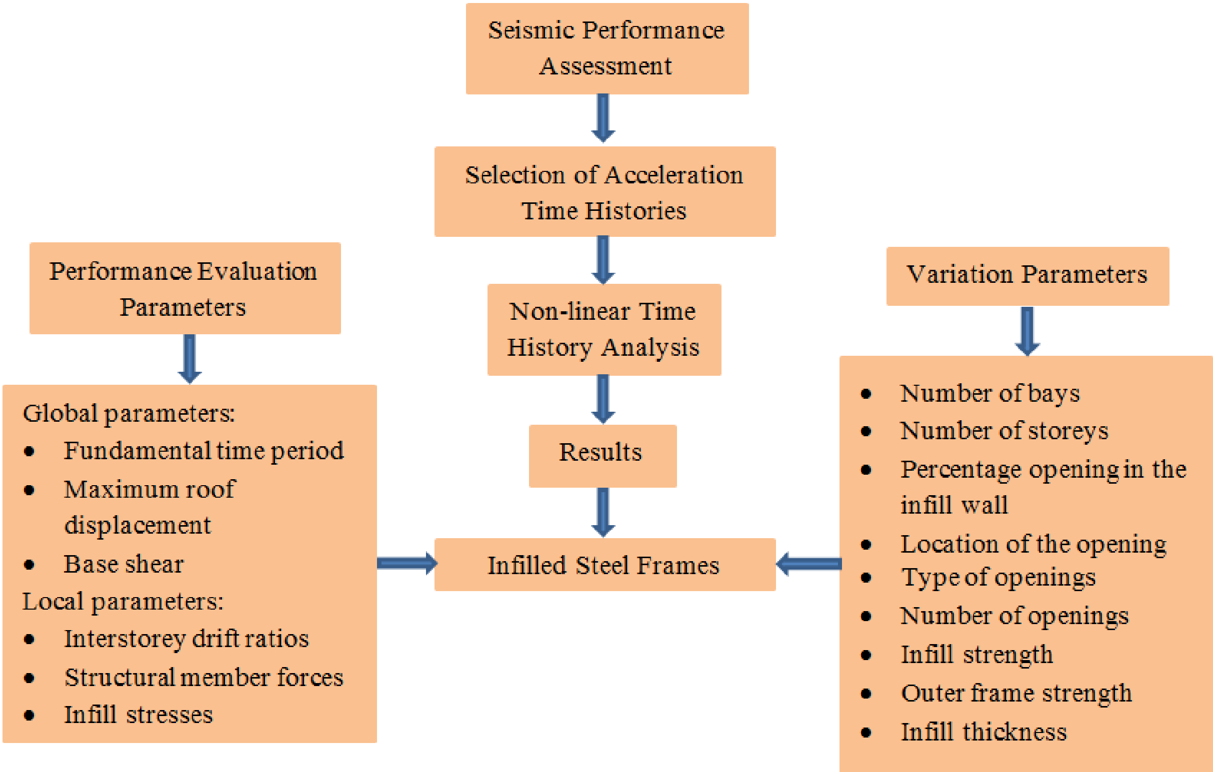


Figure 1: Seismic Performance Assessment (Flow Chart)

4 DESIGN OF PROPOSED BUILDINGS

Two groups of structures have been considered for this research. First group includes three storeys frame structures with varying number of bays from one to four and the other includes three bays structures with varying number of storeys as three, five, seven and nine. All structures are hypothetical regular and symmetrical moment resisting frame structures. Soil Structure Interaction is ignored and a raft foundation is considered representing fix supports at the base of structure in models.

Table-1: Geometric parameters of models

Bay Size	20 ft.
First Storey Height	13 ft.
Typical Storey Height	12 ft.
Roof Slab Thickness	5 inch.
Typical floor Slab Thickness	6 inch.

All the buildings are considered as office buildings and are designed in SAP2000 under gravity loading, with live loads being taken from UBC-97 [10]. Steel frames have been designed according to AISC LRFD99 [11]. ASTM A-36 steel (FY= 36 Ksi and FU=58 Ksi, AISC LRFD99 Table-2) has been used for all structural members.

5 MODELING OF MASONRY INFILL PANEL

Infill has been modeled in SAP2000 by using micro modeling i.e. Finite Element Modeling, FEM). Before modeling of all structures a detailed study on a single bay three storey models was conducted to investigate the effect of different area elements available in SAP2000, meshing and interface elements on behaviour of structure and was compared with the results of previous researches to optimize the modeling. Gap element (Figure 2.a) was used as interface element at contact surface of frame and infill to transfer the forces between infill and frame. It was found that if meshing is very fine, the increased numbers of contact points due to very fine meshing are sufficient enough to transfer the forces between infill panel and frame elements and the results of models with fine meshing were similar to those models with Gap elements. So for all models Gap elements were neglected due to the conformance of results. The results of time history analysis using El Centro acceleration time history data on single bay three storey model in terms of base shear and roof displacement are given in Table-2.

Finite element modeling (FEM) of infill has been done using plain stress elements in SAP2000. Very fine meshing (9”x9”) has been used to transfer forces from outer frame to infill by assuming semi integral infilled frame.

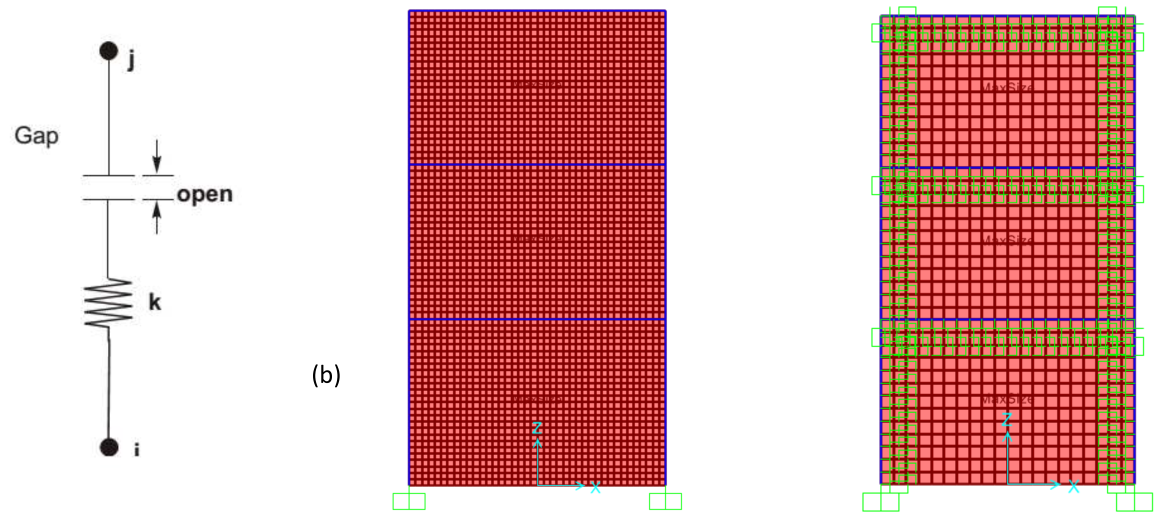


Figure 2: (a) Gap element (CSI Reference Manual SAP2000) (b) FEM Model with very fine meshing (c) FEM Model with Gap elements

Table-2: Results of time history analysis on initial investigation models

Model Type	Parameters	
	Base Shear (Kips)	Roof Displacement (ft)
Model with Gap element	85	0.004917
Model without Gap element	85	0.004917

The properties like compressive strength and unit weight of infill were taken as actual as found by experimental testing (Table-3). Modulus of Elasticity for bricks masonry was calculated by using an empirical relation E=750f_m (Pauley, 1992) [12] where f_m is compressive strength of masonry. Thickness of the infill for general models was used as 9”, equal to the standard length of Pakistani brick.

Table-3: Compressive strength of brick masonry prisms

Sr. No.	Crushing Load (Kips)	Compressive Strength (Ksi)
1	23.16	0.61
2	28.78	0.77
3	25.85	0.70
Average	25.93	0.69

6 Analysis, Results and Discussion

Three earthquake records of Kobe, Loma Preita and El Centro were selected initially and dominant earthquake was determined on the basis of structural response in terms of maximum roof displacement, base shear and interstorey drift ratio. For all structures considered, El Centro was found to be dominant earthquake due to longer ground motion duration and matching frequency. So this earthquake has been used in further research. Mass source for earthquake forces has been taken as recommended by UBC97 [10] i.e. Dead Load (DL) + 0.25 Live Load (LL). Results of analysis have been described below.

6.1 Effect of Variation of Number of Bays

In this analysis four three storey structures with varying number of bays from 1 to 4 have been considered. Fundamental time period, maximum roof displacement and interstorey drift ratios decrease with the increase in number of bays due to the increased lateral stiffness and infill stresses and base shear follow the opposite trend and increase with the increase in number of bays. The results have been shown in figure 3. Figure 3 (a) shows that percentage difference of time period between one bay and two bay structures is found to be 11.7%, between two bay and three bay structures is 10.3% and between three bay and four bay structures is about 2%. So the percentage difference of the time period between structures decreases as the number of bays decreases. From figure 3(d), it can be seen that the infill stresses are less than compressive strength of the brick masonry which means material is able to resist the lateral loads without being crushed.

6.2 Effect of Variation of Number of Storeys

In this analysis four three bay structures with varying number of storeys as 3, 5, 7 and 9 have been considered. All parameters including structural period, maximum roof displacement, Interstorey drift ratio, Base shear and infill stresses increase with the increase in number of storeys.

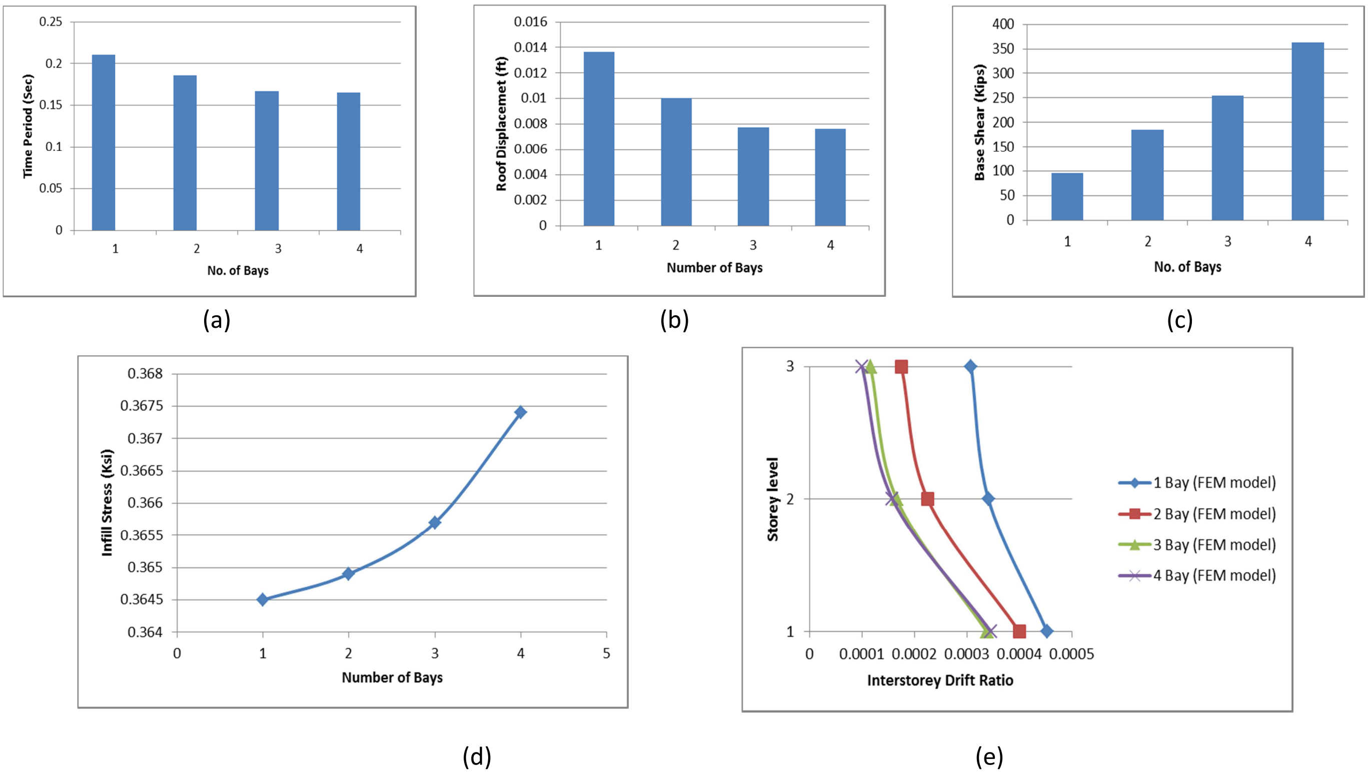


Figure 3: Effect of variation of number of bays on (a) Structural Period (b) Maximum roof displacement (c) Base shear (d) Infill stresses (e) Interstorey drift ratios

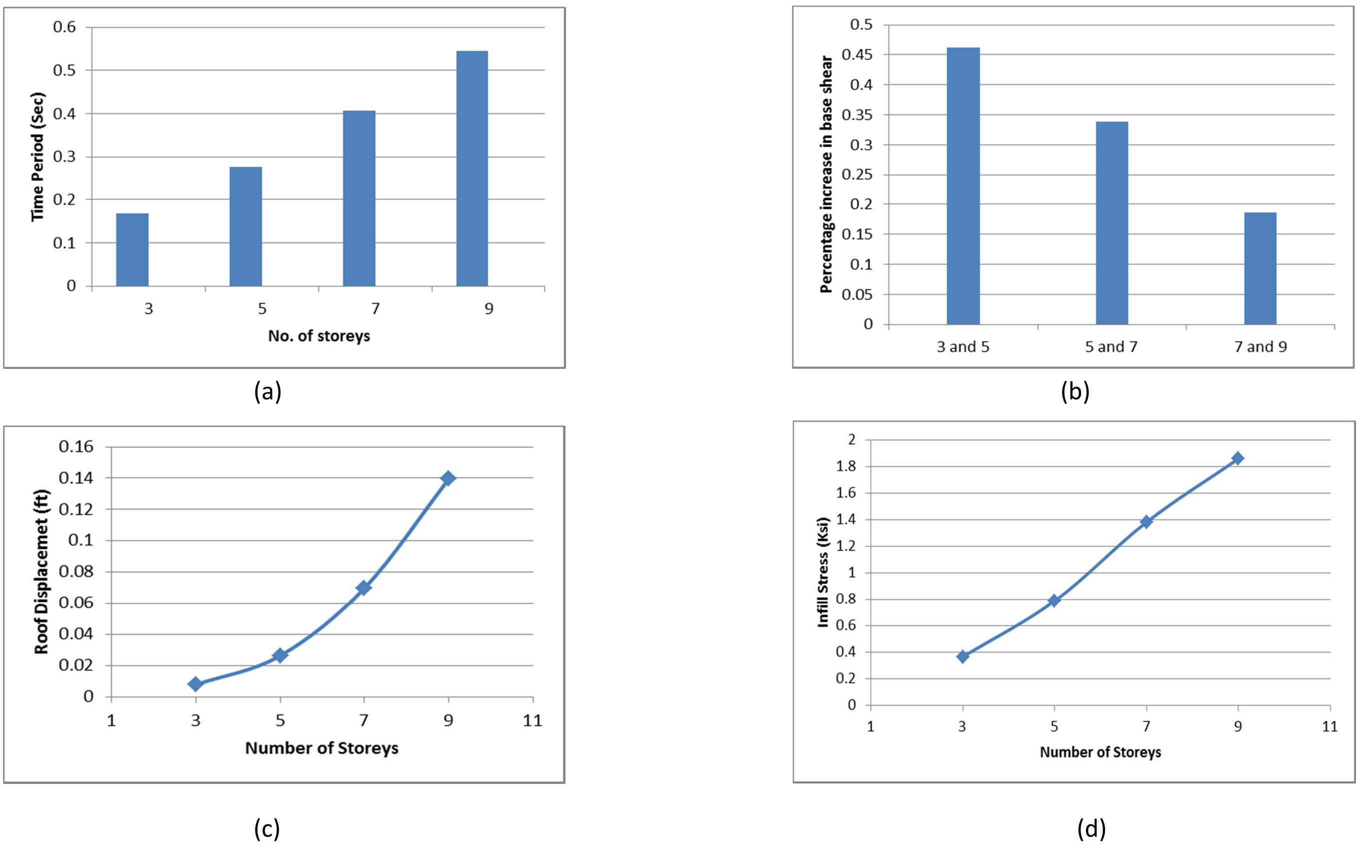
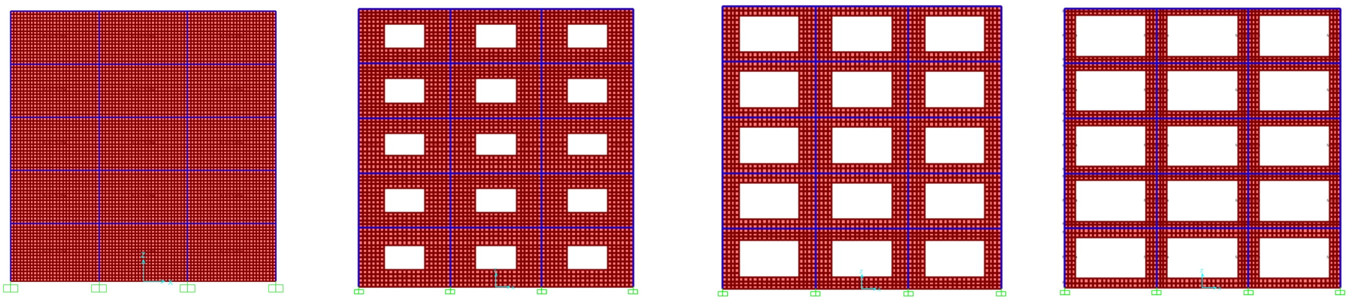


Figure 4: Effect of variation of number of storeys on (a) Structural Period (b) Base shear (c) Maximum roof displacement (d) Infill stresses

Results show that the percentage increase in maximum roof displacement decreases as we move to structures with greater number of storeys. The percentage difference between the maximum roof displacement of three storey and five storey structures is 70% and between seven storey and nine storey structures is 50%. This is due to the reason that the effect of increase in the mass of the structure becomes dominant over the increase in the lateral stiffness for structures with higher number of storey. The percentage increase in the base shear also decreases from 3 storey structures to 9 storey structures as shown in the results (figure 4-b). Results also show that the infill stresses are less than compressive strength of the brick masonry for low rise structures and it exceeds the compressive strength value for medium to high rise structures. So infills effectiveness decreases with the increase in height of structure and infill with higher compressive strength is required. Average percentage increase in the infill for every additional two storeys is 40.7% (figure 4-d).

6.3 EFFECT OF VARIATION OF PERCENTAGE OPENING IN INFILL WALL

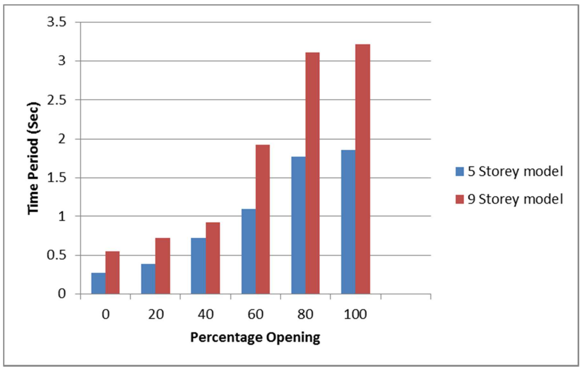
Openings are essentials in almost every type of buildings. Openings have significant effect on the performance of infilled frame so it is necessary to assess the response of the infilled structures by considering the effects of the openings. For this research a central opening has been considered and size of the opening is expressed in terms of percentage of infill wall area. Percentage opening has been varied from 0% (fully infilled) to 100% (bare frame).



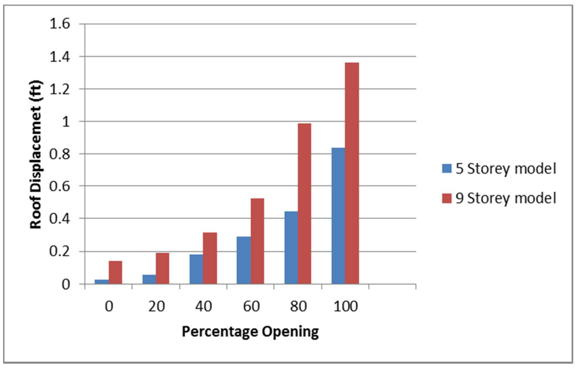
(a) (b) (c) (d)

Figure 5: 5 Storey model with different percentages of openings in the infill (a) Fully infilled (0% Opening) (b) 20% Opening(c) 40% Opening (d) 60% Opening

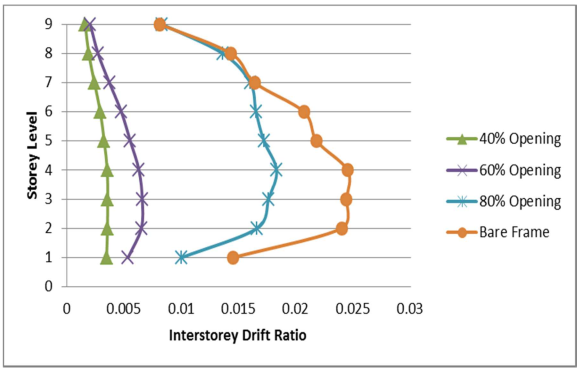
Fundamental time period, maximum roof displacement, interstorey drifts ratio and structural member forces increase with the increase in percentage opening in infill wall. This is due to reason that with increase in opening size the lateral stiffness provided by infill decreases. On other hand base shear and infill stresses decrease with the increase in opening size which shows less resistance by the structure to lateral loads. The percentage difference in the fundamental time period of the fully infilled nine storey model and the nine storey models having percentage opening of 20%, 40%, 60%, 80% and 100% is 23.9, 41.1, 71.2, 82.4 and 83.01 respectively. Maximum value of roof displacement is 1.36' for a nine storey structure with 100% opening (bare frame) and minimum is 0.14' for a nine storey structure with no opening (fully infilled). The percentage difference of maximum roof displacement between the fully infilled model and the models with 20%, 40%, 60%, 80% and 100% is 26.9, 56.05, 73.5, 85.8 and 89.8 respectively for nine storey infilled steel frame structures. The percentage difference of the base shear between the fully infilled frame and frames having 20%, 40%, 60%, 80% and 100% openings in infill panel is 29.6, 48.5, 57.9, 62.5 and 65.7 respectively for nine storey structures and for five storey structures the percentage difference is 13.6, 26, 48.6, 50.2 and 55.3 respectively. There is no specific trend for interstorey drift at different storey levels for the same structures however the maximum interstorey drift occurs at one third of structure height form base as found by the researchers. As the percentage in the opening increases, the interstorey drift ratio at a particular storey level also increases and approaches to that of bare steel frame. As already described that stresses in the infill were found to be decreased with the increase in the percentage opening in the infill due to decrease in lateral load resisting capacity. As the percentage opening increases the lateral load resisting capacity of the infill decreases because infill can absorb or resist less stresses due to reduced amount of infill in the structural system. Infill stresses variation for a 9 storey steel infilled structure is shown in the figure 6-d. Average decrease in infill stresses for a nine storey model is 29.5% for every 20% increase in the infill opening. Structural member forces are also affected by opening in the infill wall. The column moments (Mc) were found to increase by 36.3% on average and beam moments (Mb) were found to increase by 45.2% on average for every 20% increase in the opening size. Similarly, the shear forces in the beam (Vb) and column (Vc) were found to increase by 43.4% and 34.3% on average respectively for every 20% increase in the opening size. The increase in the member forces by increasing percentage opening is due to decrease in the lateral stiffness of the structure.



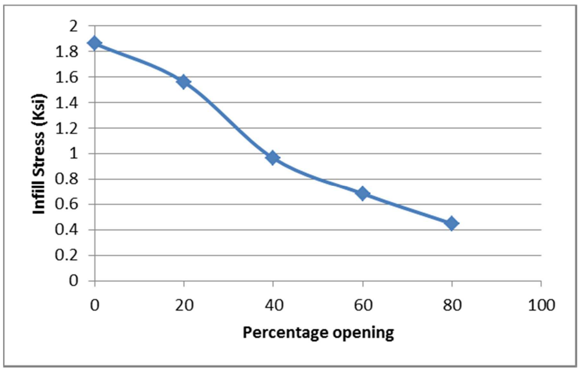
(a)



(b)



(c)



(d)

Figure 6: Effect of variation of Percentage Opening on (a) Structural Period (b) Maximum roof displacement (c) Interstorey drift ratio (d) Infill stresses

For models with openings in the infill, maximum infill stresses are found at corners unlike to fully infilled models where maximum stresses are found at the compressive corners of the masonry infill panel. Figure 7 shows compression stress path in infill with an opening which is according to FEMA 356 [13] compression strut analogy for perforated infill panels.

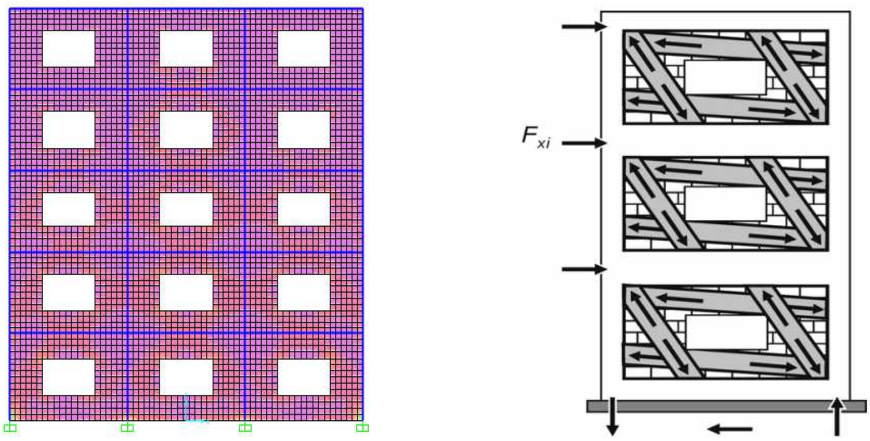
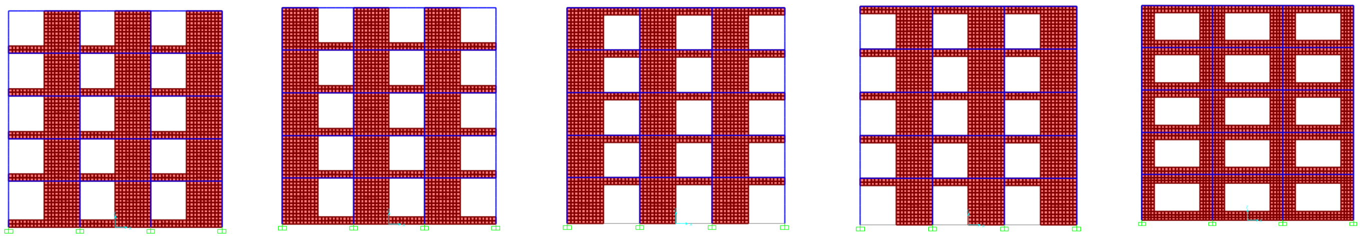


Figure 7: Compression stress path around an opening in comparison with FEMA 356

6.4 Effect of Different Opening Locations

Opening can be present at different locations in any building like at center, at right side, at left side in the infill wall etc. For this research five types of variations in the opening location are considered as at center, bottom left corner, bottom right corner, top left corner and top right corner to represent the possible opening locations in buildings. 40% opening was selected as a representation of typical openings sizes in infill walls in Pakistan.



(a) Top Left (b) Top Right (c) Bottom Right (d) Bottom Left (e) Central

Figure 8: Different locations of 40% openings considered in the study

Time period, interstorey drift ratio and maximum roof displacement for structures having opening at bottom are maximum and minimum for the structures with central opening. All parameters of a regular and symmetrical structure doesn't depend on whether the top or bottom opening is at right or left corner. Stresses in the infill were found to be maximum for central opening and minimum for bottom left corner opening. This is due to the presence of infill at corners of the structure to resist the lateral forces. Also infill stresses for right openings were found to be larger than left openings for both top and bottom locations. Another result obtained from this study is infill stresses were found higher in 5 storey models than in 9 storey models although stresses were found to be increased with number of storeys. Reason is influence of infill in high rise structures is reduced with increase in the openings size in the infill because increase in mass predominate the increase in stiffness due to infill. A similar trend is found for base shear i.e. base shear is maximum for central opening and minimum for bottom opening.

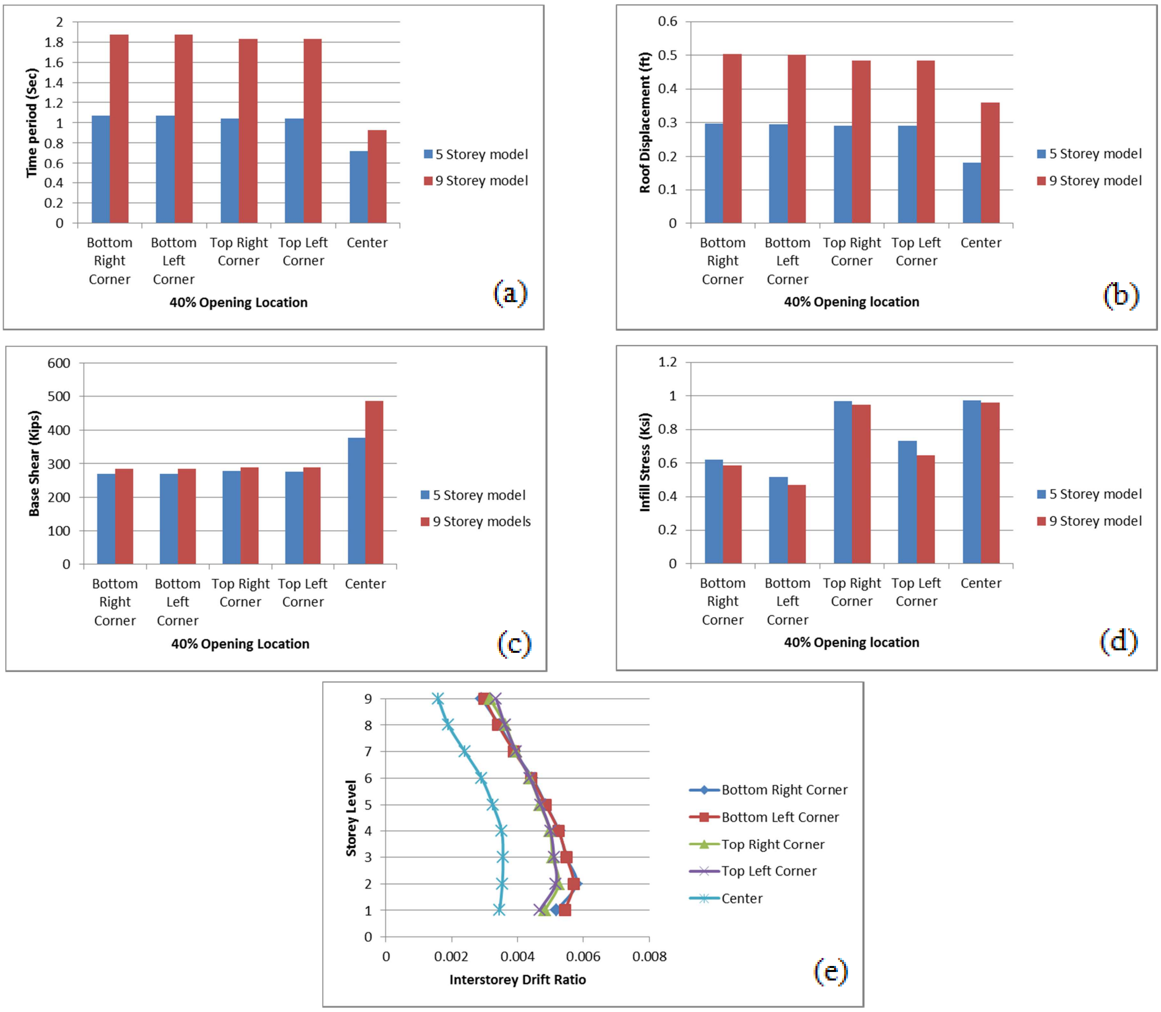


Figure 9: Effect of Different opening locations on (a) Structural Period (b) Maximum roof displacement (c) Base shear (d) Infill stresses (e) Interstorey drift ratios

6.5 Effect of Different Types of Opening

This section has been introduced to study the phenomenon like partially infilled frames, frame with no infill at bottom storey (Soft storey phenomenon) or any storey at intermediate level (Weak storey or soft storey at intermediate height level).

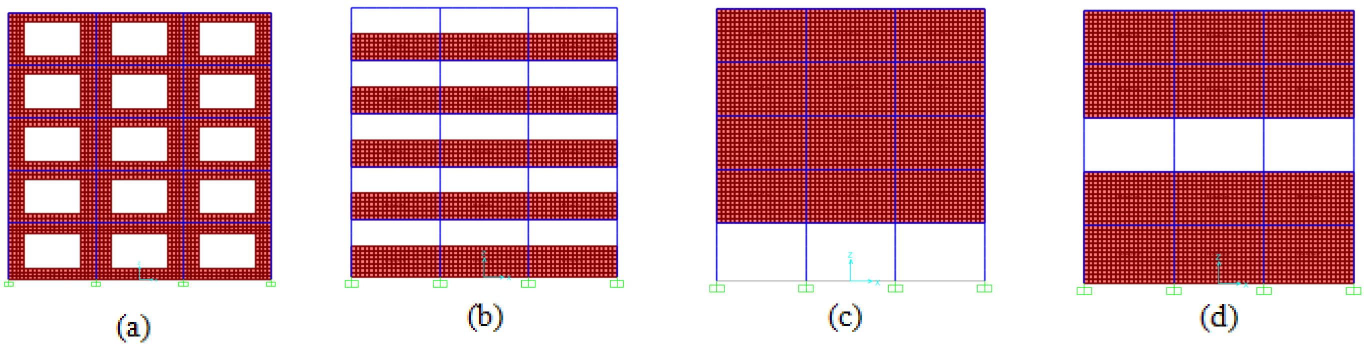


Figure 10: Different types openings considered in the study

Fundamental time period, maximum roof displacement and interstorey drift ratio were found maximum for partially infilled frame even more than the bare frames. This is because of the localized failure of the main frame structural members (columns). So instead of providing stiffness, it concentrates the forces at the level to which frame is partially infilled and infill just increases the mass only. Also the base shear and infill stresses were found least for partially infilled frames than other options. Even the infill stresses are negligible showing no role of infill in lateral stiffness. Base shear for the partially infilled steel structures are less than the bare steel frames by 19.94% and 37.8% for 9 storey and 5 storey structures respectively. Performance of structures with soft storey at middle level is better than those having soft storey at base due to the presence of infill at the base to resist the lateral loads. Percentage difference of the structural period between the soft storey (at base) and weak storey (at mid-height) is 2.23% and 15.3% for nine and five storey infilled steel frame models. Also the roof displacement for the soft storey is greater than weak storey by 3% and 25% for nine storey and five storey steel infilled frame structures respectively. Interstorey drift ratios were found to be maximum at first storey and middle storey for soft storey and weak storey structures respectively. This is due to the uneven distribution of damage in all storeys. Partially infilled frames are the worst case and must be avoided in every case.

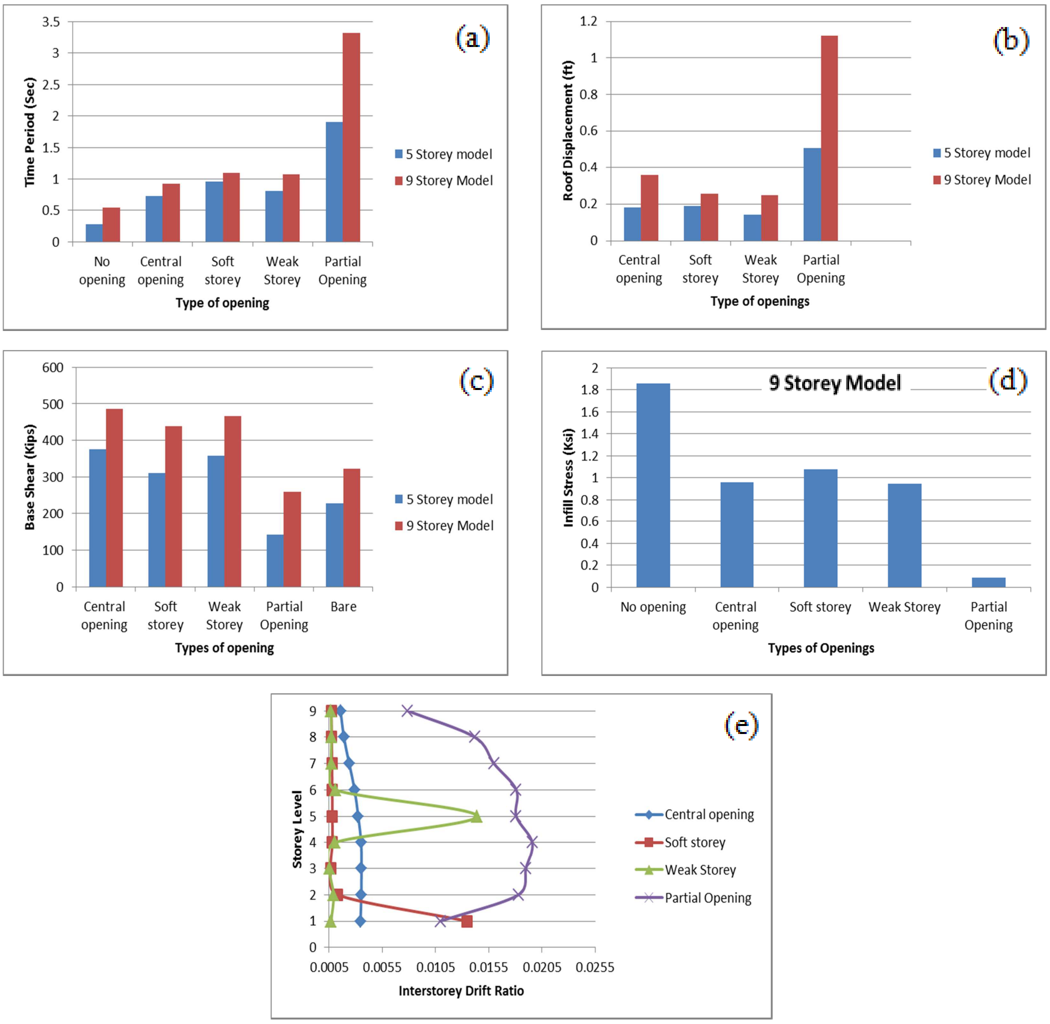


Figure 11: Effect of Different types of opening on (a) Structural Period (b) Maximum roof displacement (c) Base shear (d) Infill stresses (e) Interstorey drift ratios

6.6 Effect of Number of Openings

This parameter has been considered to evaluate the performance of the structure if a specific percentage of the opening is provided either as single opening or as dual opening. This will help us to understand whether an infilled structure with a single opening in the center is safer or structure having two openings. The results for 20% and 40% opening in the infill wall for 5 storey and 9 storey structures are presented below.

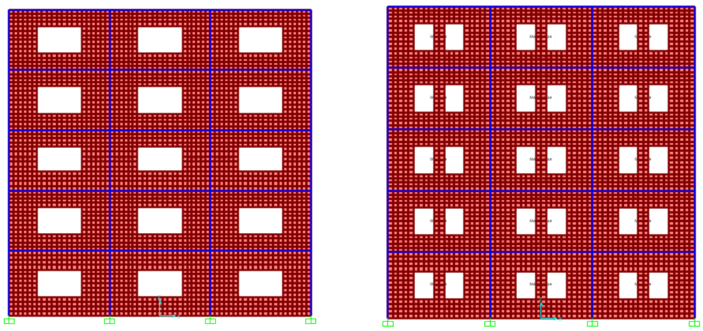


Figure 12: 20% single and dual opening for 5 storey steel infilled frame

The time period, roof displacements and interstorey drift ratio were found to be decreased with the increase in number of openings. Base shear was found to be increased with the increase of opening number. For 40% opening, the percentage increase in base shear between single and double opening is 14.3 and 21.9 for 9 storey and 5 storey infilled steel structures respectively. This is because of dividing the specific percentage of opening at two locations distributes the single major structural discontinuity in the form of opening in the infill wall and prevents the concentration of stresses and forces around a single central opening. Infill stresses were found to have a different pattern for this variation parameter. Infill stresses were found to be increased with increase in number of openings for 20% opening but as the percentage opening is increased the infill stresses were found to decrease which may be due to the reason that with the higher percentages of openings, by increasing the number of openings from one to two causes two major discontinuities as the opening is larger and causes concentration of stresses at corners.

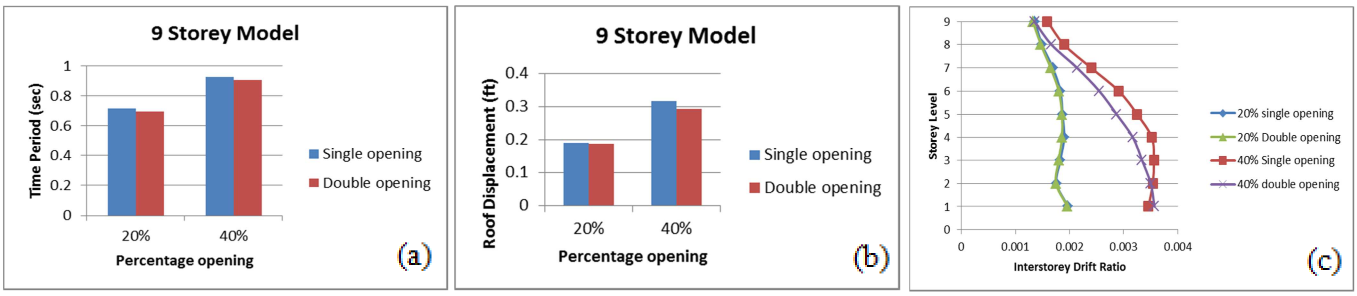


Figure 13: Effect of number of openings on (a) Structural Period (b) Maximum roof (c) Interstorey drift ratios

6.7 EFFECT OF VARIATION OF INFILL STRENGTH

This parameter has been selected to evaluate the variation in the strength of the infill. Strength of infill may vary due to availability of different types of infills in the market like bricks, concrete hollow and solid blocks, stone infills and glass infills etc. Even strength may vary for one type of materials like concrete blocks of different strengths are available. For this analysis infill materials with strengths of 600 Psi, 800 Psi, 1000 Psi, 1200 Psi, 1400 Psi, 1600 Psi and 1800 Psi were used. Time period, roof displacements, interstorey drift ratio and member forces were found to be decreased with the increase in the infill strength. Base shear and infill stresses were found to be increased with the increase in the infill material strength for infilled steel structures. The percentage decrease in the time period and roof displacement decreases with increase in the infill strength. The difference of time period between the infill of 600psi and 800psi is 8.11% and between 1600 and 1800 psi is 3.62% for nine storey steel structure and for five storey structure the difference of time period between 600psi and 800psi infill is 9.96% and between 1600psi and 1800psi is 4.25%. Similarly, the percentage difference of maximum roof displacement between 600psi and 800psi is 15.6 and 22.3 for nine storey and five storey structures respectively and the percentage difference between 1600psi and 1800psi is 8.3 and 9.69 for nine storey and five storey structures respectively. Percentage increase in the base shear is less significant. For a nine storey structure the increase in base shear is about 4% between 600 psi and 800 psi and percentage increase is about 1% between 1600 psi and 1800 psi. Average percentage increase in infill stresses is 2.82 and 6.5 for 5 and 9 storey structures respectively for every 200 psi increase in the infill strength. The percentage decrease in the member forces is decreased with the increase in infill strength. On average the column shear (Vc) decreases by 15.65% and beam shear (Vb) decreases by 16.65% on average for every 200 psi increase in the infill strength. Similarly the percentage decrease in beam and column moments was found to be 16.54 and 15.1 respectively for every 200 psi increase in the infill strength.

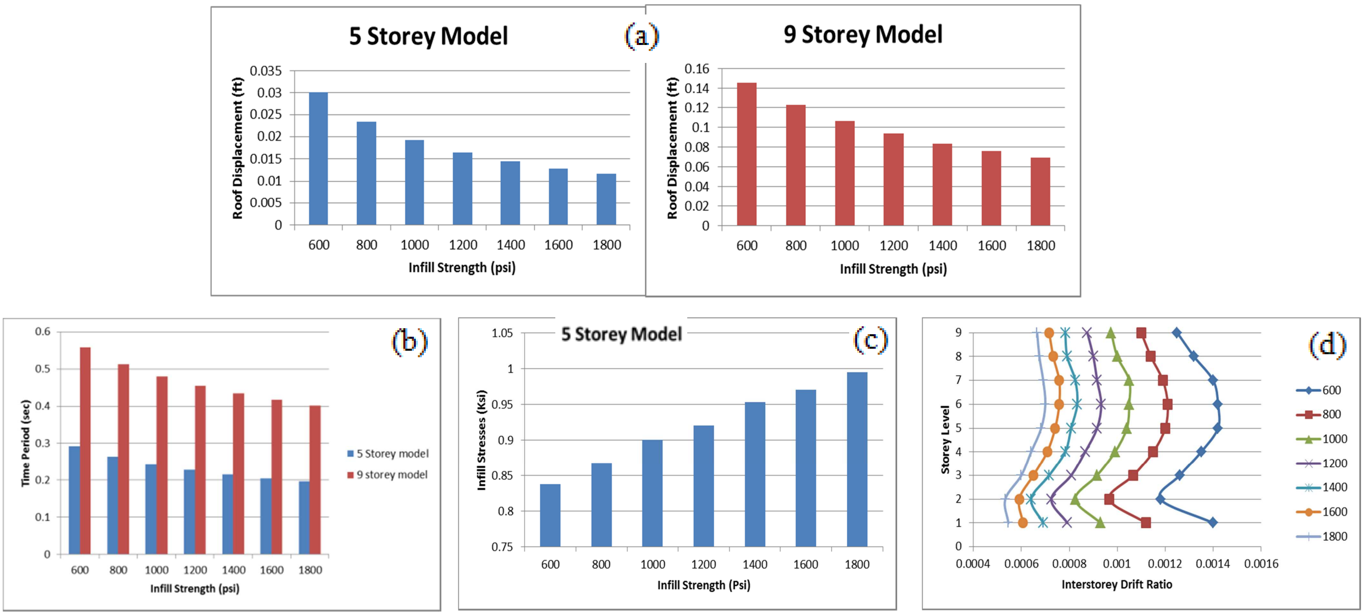


Figure 14: Effect of Variation of Infill Strength on (a) Maximum roof displacement (b) Structural Period (c) Infill stresses (d) Interstorey drift ratios

6.8 Effect of Variation of Outer Frame Strength

Frame strength variation may happen due to the availability of different grades of steels for frames. In this study AISC grade A992 (represented by A50 for this study) and grade 36 steels have been used to assess this parameter. Effect of the outer frame strength is negligible for infilled steel frame structures due to same modulus of elasticity for both grades of steel. This is because the stiffness is function of modulus of elasticity (E) and moment of inertia (I). Maximum roof displacement, time period and interstorey drift ratio are found to be decreased with the increase in the outer frame strength and base shear and infill stresses are found to be increased with the increase in infill strength however variation is negligibly small. The increase in the base shear for 9 storeys and 5 storeys structure is only 0.1% and 1% respectively. Similarly percentage decrease in roof displacement is 0.5% for nine and 0.87% for five storey structures and increase in infill stress is 0.11% for 9 story model and 0.51% for 5 storey model.

6.9 Effect of Variation of Infill Thickness

In Pakistan, burnt clay bricks are most commonly used infill material. Thickness of brick infills is generally 9” for external walls and 4.5” for the internal or partition walls. Also the trend for concrete solid and hollow blocks is also increasing to be used as infill materials, which have thickness varying as 6” and 8”. So these four values were used as infill thickness variation. Time period, roof displacement, interstorey drift ratio and member forces were found to be decreased with the increase in the infill thickness. The percentage decrease in the fundamental time period gradually decreases with the increase in the infill thickness as the difference of time period between 4.5in and 6in thick infill is 7.5% and 8in and 9in thick infill is 2.7% for nine storeys structure. On average the beam (Vb) and column (Vc) shear (kips) decreased by 13.6% and 12.4% by varying thickness from 4.5” to 9” at above stated intervals. Also the percentage decrease in beam (Mb) and column (Mc) moments (kip-ft) was found to be 13.6 and 11.97 respectively by varying thickness from 4.5” to 9” at above stated intervals.

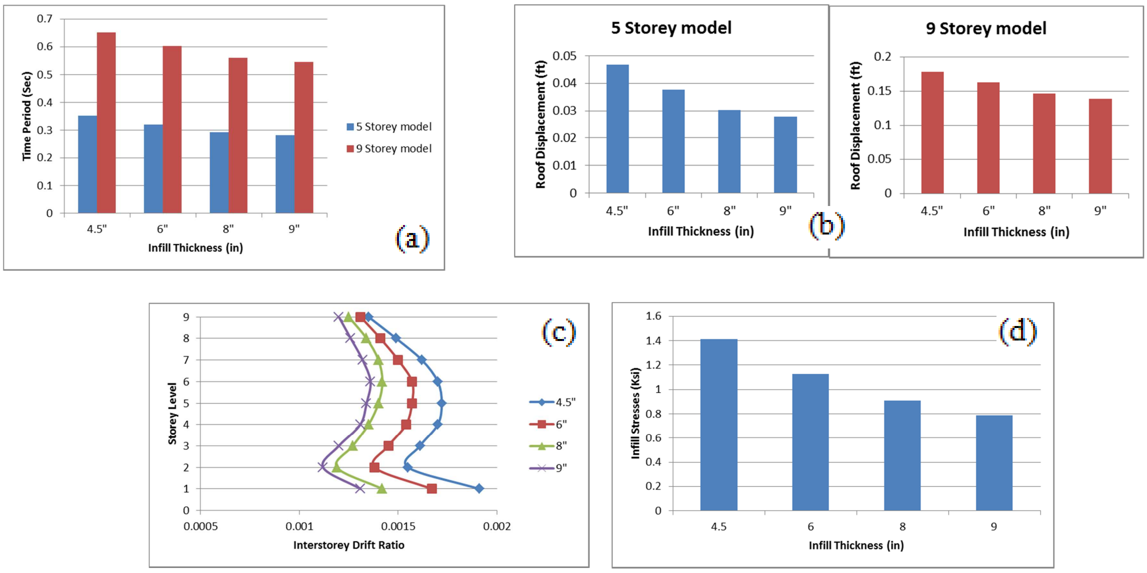


Figure 15: Effect of Variation of Infill thickness on (a) Structural Period (b) Maximum roof displacement (c) Interstorey drift ratios (d) Infill stresses

Base shear was found to be increased with the increase of infill thickness. However percentage increase in base shear does not follow any specific trend. Stresses in the infill were found to be decreased with the increase in the infill thickness. Average percentage decrease in infill stresses by varying the thickness of the infill between the values of 4.5”, 6”, 8” and 9” is 7.98 and 17.6 for 9 storey and 5 storey infilled steel structures respectively.

7 CONCLUSIONS

Following conclusions can be drawn from this research:

- Performance of the infilled frames is dependent on the material and geometric properties of the infill and frame and on how well they perform in integrity with each other.
- For infilled steel frame structures the fundamental time period, roof displacement and interstorey drift ratios decrease with the increase in number of bays due to increase in the lateral stiffness. However percentage decrease in these parameters decreases as the number of bays increases. Base shear and infill stresses increase with the increase in number of bays representing higher resistance to the lateral loading at the base and attracting more forces respectively.
- The fundamental time period, roof displacement, infill stresses, base shear and interstorey drift ratios increase with the increase in number of storeys due to increase in the mass of the structure and larger height to base width ratio (aspect ratio of the structure).
- With the increase in the opening sizes the time period, roof displacement, member forces and interstorey drift ratio increases due to decrease in the lateral stiffness of the structure and infill stresses and base shear decrease showing less resistance to the lateral forces.
- Influence of the infill in positive performance of the structures decreases from low rise to high rise buildings because the increase in the stiffness provided by the infill is dominated by the increase in mass due to the presence of the infill.
- For infilled structures having openings, maximum infill stresses were found at the corners of the openings unlike to the fully infilled structures where the maximum infill stresses were found at the compression corners of the panel.
- Time period, roof displacement and interstorey drift ratios are maximum for the partially infilled frames even greater than the bare frames due to the localized failure of the structural members (columns) at the level to which infill is provided. The infill provided is just addition to the mass of the structure.
- Interstorey drifts were significantly higher at soft storey level and weak storey level as compared to the other levels for structures with soft storey and weak storey respectively.

- Roof displacement, time period, interstorey drift ratio and member forces were decreased with the increase in the strength of the infill due to increase in the lateral stiffness. Base shear and infill stresses increase with the increase in the infill strength.
- Time period, interstorey drift ratio and roof displacement decrease and base shear increases if a specific percentage of the opening in the infill is provided at more than one location due to the distribution of irregularity at different locations. And the percentage variation increases with the increase in the opening percentage.
- Infill stresses decreases with the increase of infill thickness probably due to the more load bearing area as the contact surface between frame and infill wall increases with the increase in the infill thickness.

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