Influence of interface on the behavior of infilled frame subjected to lateral load using linear analysis

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Abstract. Two dimensional numerical investigations were carried out to study the influence of interface thickness and their pattern on the behavior of reinforced concrete frames subjected to in-plane lateral loads using commercial finite element tool SAP 2000. The linear elastic analysis was carried out on one and two bay structural systems as well as the influence of number of stories was studied by varying the number of stories as single, three and five. The cement mortar was used as interface material and their effect was studied by varying thicknesses as 6, 8, 10, 14 and 20 mm. The interface was recognized as one sided, two sided, three sided and four sided and their effect was studied by removing the interface material between the reinforced concrete frame and masonry infill. The effect of lateral loads on infill masonry wall was also studied by varying assumed loads as 10, 20, 30, 40, 50 and 60 kN. The behavior of infilled frames studied has revealed that there is a maximum influence of interface thickness and interface pattern corresponding to 10 mm thickness. In general, the lateral displacement of frame is increased linearly with increase in lateral loads.

Keywords: finite element method; interface thickness; interface pattern; in-plane lateral loads; maximum principal stress

1. Introduction

Recent earthquakes in Nepal (2015), Bhuj (2001), Turkey (Kocaeli 1999, Duzce1999, Bingol 2003) have demonstrated large seismic demands that were not accounted for in their design. Most of the weakest spot of the building are reinforced concrete frame element and infill masonry wall element which in spite of bonding layers of interface element. The post-earthquake reconnaissance surveys showed (Dogangun *et al.* 2008) the lack of lateral strength together with masonry infill, frame element and interface element for collapse in most cases. According to Erdik and Aydınoglu (2003), in urban areas, 30% buildings were reinforced concrete frame, 48% were brick masonry and 22% were adobe or rubble masonry. In rural areas, 82% of buildings were brick masonry while 18% were reinforced concrete frame. Therefore, the safety of the masonry building is very important in the moderate to severe seismic zones, as 90% of the world population lives and works in masonry buildings and these buildings should be protected during earthquakes.

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Girish and Achyutha (1996) performed experimental and analytical investigation on the response of reinforced cement concrete bare and non-integral brick masonry infilled frames under lateral reversed cyclic loads. They found that the infill-frame interaction is found to enhance the base shear capacity, improve the hysteretic behavior and alter the failure mode of the bare frame. Mehrabi and Singh (1997) have carried out experimental and analytical studies on masonry-infilled reinforced concrete frames under in-plane lateral loadings. A smeared-crack finite element model was used to model the behavior of concrete in the RC frames and masonry units. Authors concluded that the finite element models are able to simulate the failure mechanisms exhibited by infilled frames including the crushing and cracking of the concrete frames and masonry panels and the sliding and separation of the mortar joints. Ghosh and Amde (2002) formulated a non-associated interface models using the available test data on masonry joints to model the interface between the frame and the infill and the mortar joints surrounding the blocks of masonry. The results obtained by the finite element model showed that the numerical model not only is capable of predicting the load carrying capacities of infilled frames, but can also provide detailed information on the failure mode, ductility, and cracking, which can be of much value in evaluating the seismic resistance of in- filled frames. Anil and Altin (2006) conducted experimental investigations on partially infilled one-bay one-storey reinforced concrete frames under reversal cyclic load. The pushover analysis was also carried out using IDARC-2D to compare the ultimate strength of the infilled frame and resulted in slightly higher initial stiffnesses for the infilled specimens than the experimental values. Authors concluded that the monolithically infilled specimen showed 7 times more energy dissipation capacity than the bare frame. Asteris (2008) presented a simple method to simulate the complicated behavior of infilled frames under lateral loads. The proposed analytical method calculates the infill contact lengths as an integral part of the solution. Especially this technique calculates the infill/frame contact lengths for the case of unidirectional lateral loading and elastic response of the infill. The authors concluded that the proposed technique is easier and more practical to apply, and requires much less computational time than micro-modeling techniques based on discretizing the infill panel as a series of plane stress elements interconnected by a series of springs or contact elements. Mondal and Jain (2008) carried out finite element analysis on single-bay single-storey, single-bay two-storey, and single-bay three-storey infilled frames to examine the effect of central openings of different sizes on the initial lateral stiffness of infilled frames. Authors concluded that the effect of opening on the initial lateral stiffness of infilled frames should be neglected if the area of opening is less than 5% of the area of the infill panel, and the strut-width reduction factor should be set to one, i.e., the frame is to be analyzed as a solid infilled frame. The effect of infill on the initial lateral stiffness of infilled frame may be ignored if the area of opening exceeds 40% of the area of the infill panel, and the strut-width reduction factor should be set to zero, i.e., the frame is to be analyzed as a bare frame. Eshghi and Pourazin (2009) performed numerical investigation on full scale confined masonry wall with and without opening based on static nonlinear analysis under in plane loading using finite element tool DIANA. They found that the ultimate deformation capacity of the wall with opening is about 1/10 ultimate deformation capacity of the wall without opening. Okail *et al.* (2014) conducted experiments and numerical investigations on six full-scale confined masonry walls subjected to lateral loads. Authors found that the experimental results showed that the walls in general experienced a shear failure at the end of the lightly reinforced confining elements after the failure of the diagonal struts formed in the brick wall due to transversal diagonal tension. The numerical results showed acceptable correlation and were used to conduct a thorough parametric study on various design configurations. Abdel-Hafez *et al.* (2015) conducted experiments on single

storey bare frame, brick masonry infilled frames strengthened with glass fiber reinforced polymer (GFRP) sheets, steel rebar impeded in frame, plastering and ferrocement meshes studied under the in-plane lateral load. Authors found that the drift, toughness, ductility and failure load were improved by using such masonry wall due to like-shear wall effect which also increased frame capacity to resist lateral load. The ductility of infilled frame strengthened with Ferro cement was the best of all strengthened frames, while strengthening with GFRP increases its ultimate load carrying capacity but reduces its ductility. Khoshnoud and Marsono (2016) developed a simple method, called corner opening, by replacing the corner of infill walls with a very flexible material to enhance the structural behavior of walls. To evaluate the proposed method a series of experiments were conducted on masonry infill wall and reinforced concrete frames with and without corner openings. The experimental results revealed that the proposed method reduced the strength of infill wall specimens but considerably enhanced the ductility of infill wall specimens in the diagonal tension test. The authors have also found that the corner opening in infill walls prevented the sliding shear failure of the infill wall in RC frames with infill walls. In addition to that many studies found on masonry infilled reinforced concrete, non-ductile frames, different type of infill under seismic loadings, [Klingner and Bertero (1978), Buonopane and White (1999), Al-Chaar *et al.* (2002), Kaushik *et al.* (2006) and, Leite and Lourenco (2010)] and finite element modeling, [Ibrahimbegovic (1990), Ibrahimbegovic *et al.* (1990) and Ibrahimbegovic and Wilson (1991)].

The review of literature carried out has indicated that study on effect of interface of frame and infill as well as influence of interface pattern and different interface thickness is limited. An attempt is made in this study to quantify the effect of interface patterning of infill wall on the behavior of frames with respect to lateral stiffness and maximum infill stress. One of the construction difficulties is to ensure uniform thickness of the mortar joints. In some cases the frame to infill joining is so ineffective that one may consider that it is totally absent. The interaction between frame and infill is through the interface and any such variation or non-uniformity or absence can lead to ineffective infilled frame action. Hence, it is significant to study the effect of such variation on the infilled frame behavior. Also an attempt is made in this study to quantify the effect of lateral stiffness on the behavior of one storey, three storey and five storey as well as single bay and two bay frames.

2. Analytical investigation

Analytical models that have been developed to quantify the effect of interface thickness and effect of interface pattern on the frames are proposed to carry out an analytical investigation as outlined in this Section. In the investigation linear elastic analysis is carried out and the geometric details of the frame are shown in Table 1. According to Indian Standard 13920:1993, the minimum dimension of the member shall not be less than 200 mm. However, in frames which have beams with Centre to Centre span exceeding 5 m or columns of unsupported length exceeding 4 m, the shortest dimension of the column shall not be less than 300 mm. In addition to that, most of the residential buildings have room sizes and height approximately 3 m and lateral dimensions are 0.23 - 0.30 m. Therefore, the length and height of the frame was 3.0 m while cross section of the beam and column was 0.3 x 0.3 m considered in the present study. The interaction between the frame and the infill due to applied load plays important role in the behavior of the infilled frames. In most applications, the infill is connected to the frame by mortar, see Fig. 1. Since the connection

of link elements and masonry infill, interface elements are enabled to take tension and shear forces, the interaction between the frame and the infill through this mortar joint is modeled by an interface element capable of transferring normal and shear forces in the elastic and inelastic ranges of loading. The interface as well as infill elements are modeled as a shell elements considered as a plane stress type. In the finite element modeling of the infilled frame, the modeling of the interface between the infill and the frame has been given the prime emphasis.

Finite element modeling of bare frame and infilled frame has been shown in Figs. 2(a) and 2(b) respectively, using SAP 2000 Version 15. In the parametric study, five parameters, i.e., interface thickness, interface pattern, lateral loads, number of storeys and number of bays are considered. For this purpose, the interface element thicknesses were assigned as 6 mm, 8 mm, 10 mm, 14 mm and 20mm. The cement mortar was used as interface material and their effect was studied by varying thicknesses as 6, 8, 10, 14 and 20 mm. The interface was recognized as one sided, two sided, three sided and four sided and their effect was studied by removing the interface material between the reinforced concrete frame and masonry infill. For instance, the side 2, side 3 and side 4 was removed, marked as "None", see Fig. 2(b) and side 1 was showing "Interface" since it was modeled as one sided interface and vice versa. The cement mortar and masonry infill are clearly shown in Fig. 2(c).

Table 1 Geometric details of reinforced concrete systems

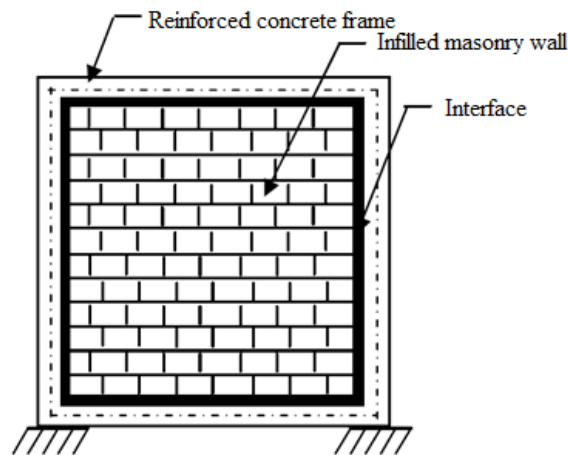| Particulars	Details, mm
Bay width	3000
Ground floor and typical floor height	3000
Beam dimension	300×300
Column dimension	300×300
Infill panel thickness	300

Fig. 1 Conventional masonry infilled reinforced concrete frame with interface

The four interface sides left, top, right and bottom side of the frame are illustrated by side 1, side 2, side 3 and side 4. The fully interface infilled frame labeled as four sided interface. The lateral load on infill frame was varied as 10, 20, 30, 40, 50 and 60 kN and the effect was studied. The lateral load considered in the present study was arbitrary. Six sets of reinforced concrete infilled frames, namely single-bay single-storey, single-bay three-storey, and single-bay five-storey, two-bay single-storey, two-bay three-storey, and two-bay five-storey were analyzed and their lateral displacement and infill stress was predicted by linear elastic analysis. Thus a total of 435 models were analyzed in the parametric study. The critical cases are decided on the basis of highest percentage of variation influenced due to the interface pattern and interface thicknesses are presented here. In the present study, authors are concerned that the knowledge of the elastic response of composite structure is very critical for a thorough understanding of its response under monotonic/cyclic loading. For this reason, the research paper concentrates on the elastic domain of the analysis.

The linkage elements were used to connect the weak interface elements and the surrounding concrete frame, see Fig. 2(b). **A** link element was used to connect two joints, separated by thickness *or width of interface*, such that specialized structural behavior was modeled. The linear properties were assigned to link elements such that directional properties of U1, U3 and R2 are restrained. Based on the developed forces in these linkage elements, separation between infill and frame was assumed to occur.
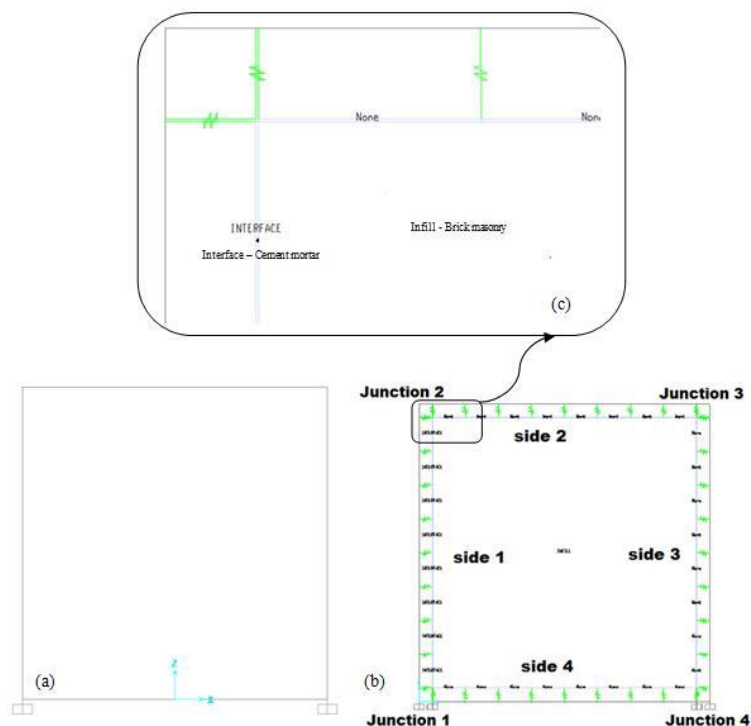

Fig. 2 Schematics of (a) bare frame (b) infilled frame with interface at only one side (one sided) (c) cement mortar
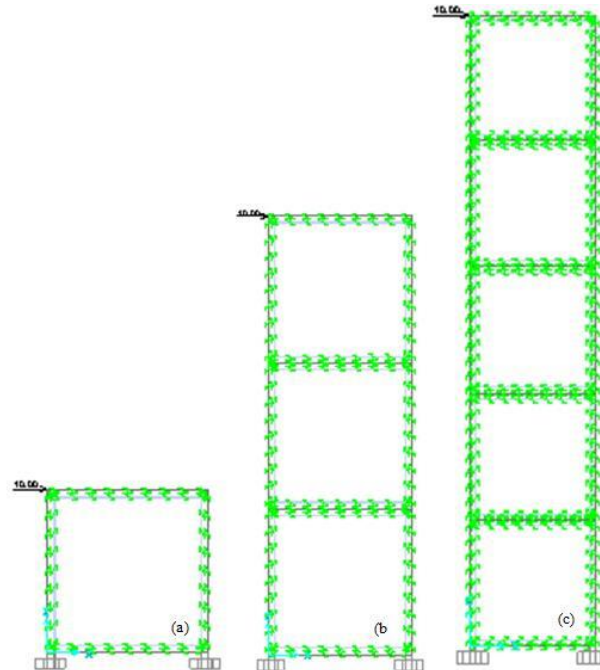
Fig. 3 Typical load application on (a) single (b) three and (c) five storey

The frame elements were modeled as beam and column elements, while the infill and interface elements were modeled as shell elements with plane sections. In the frame element such as beam and columns elements, auto meshing at intermediate points was specified by default. The infill and interface elements (Cement Mortar) were shell elements and discretized as area mesh through auto meshing. The boundary conditions were assigned as a fixed joint and zero displacement was specified for fixed degree of freedom at restraint support locations. The compressive strength of brick masonry at 28 days is 4.6 MPa [Rai 2005 and New Zealand Concrete Masonry Manual (2011)] roughly equal to 5 MPa was considered for the analysis and concrete having a characteristic compressive strength of 20 MPa was used and the properties are shown in Table 2. For concrete, the modulus of elasticity is taken as that recommended by IS 456:2000, that is $5700\sqrt{f_{ck}}$ MPa where f_{ck} characteristic compressive strength of 20 MPa is. Poisson's ratio of interface and concrete was taken as 0.15 commonly adopted for the design. For cement mortar, the modulus of elasticity and Poisson's ratio are taken as 10000 MPa and 0.15, respectively, Yang *et al*. (1996). For masonry, the modulus of elasticity and Poisson's ratio are taken as 6300 MPa and 0.15, respectively, Dhanasekhar and Page (1986). Therefore, the modulus of elasticity and Poisson's ratio are approximately taken as 5000 MPa and 0.15, respectively considered in the present study. All the models were analyzed by applying lateral load in combination with gravity load. The frames were loaded at storey level at the top left corner with 10 kN lateral forces as point load, see Fig. 3.

In the present study, node element model has been used to discretize the beam and column element whereas finite element model is used for infill and interface. Node element model in

structural elements are represented by individual lines connected by nodes. The size of mesh used in beam and column elements is 0.375 m. A node element model is technically a finite-element model in which a single line element represents the structural element, (SAP 2000). Node element modeling, however, follows the direct stiffness method, whereas finite element modeling follows the finite element method. Finite element model with a meshing procedure creates a network of line elements connected by nodes within a material continuum. The number of elements are 20 × 20 and 2 × 2 used as infill and interface elements, respectively.

3. Results and discussions

The scheme of numerical work is aimed at quantifying the difference in the behavior of frames with varying interface thicknesses and pattern. In order to evaluate the behavior of infilled frames the following behavioral parameters are used such as interface thickness, pattern, and number of storey, number of bay and lateral load. The following sections bring out the comparison of the frames studied with respect to the above parameters.

3.1 Effect of interface thickness

The effect of interface thickness was studied by varying the thickness as 6, 8, 10, 14 and 20 mm against lateral loading of 10 kN. The lateral deflection of the bare frame and infilled frames are presented in Table 3. From the analysis the lateral stiffness, bending moment, shear force and axial force of the infilled frame has been compared with the conventional reinforced concrete bare frames. All the above parameters have been obtained at the joint where lateral load is applied.

In general, the behavior of infilled frame with respect to lateral deflection, bending moment and axial force has been found to decrease as compare to bare frame while shear force has been found increased. Hence the presence of infill improves the overall behavior of RC frame subjected to lateral loads. The ratio of lateral deflection of infilled frame to bare frame indicates: There is 75% increase in the lateral deflection value of bare frame when compared to that of infilled frame, see Fig. 4(a). The lateral deflection of infilled frame was found to decrease linearly with increase in the thickness of interface.

Table 2 Material properties of structural system

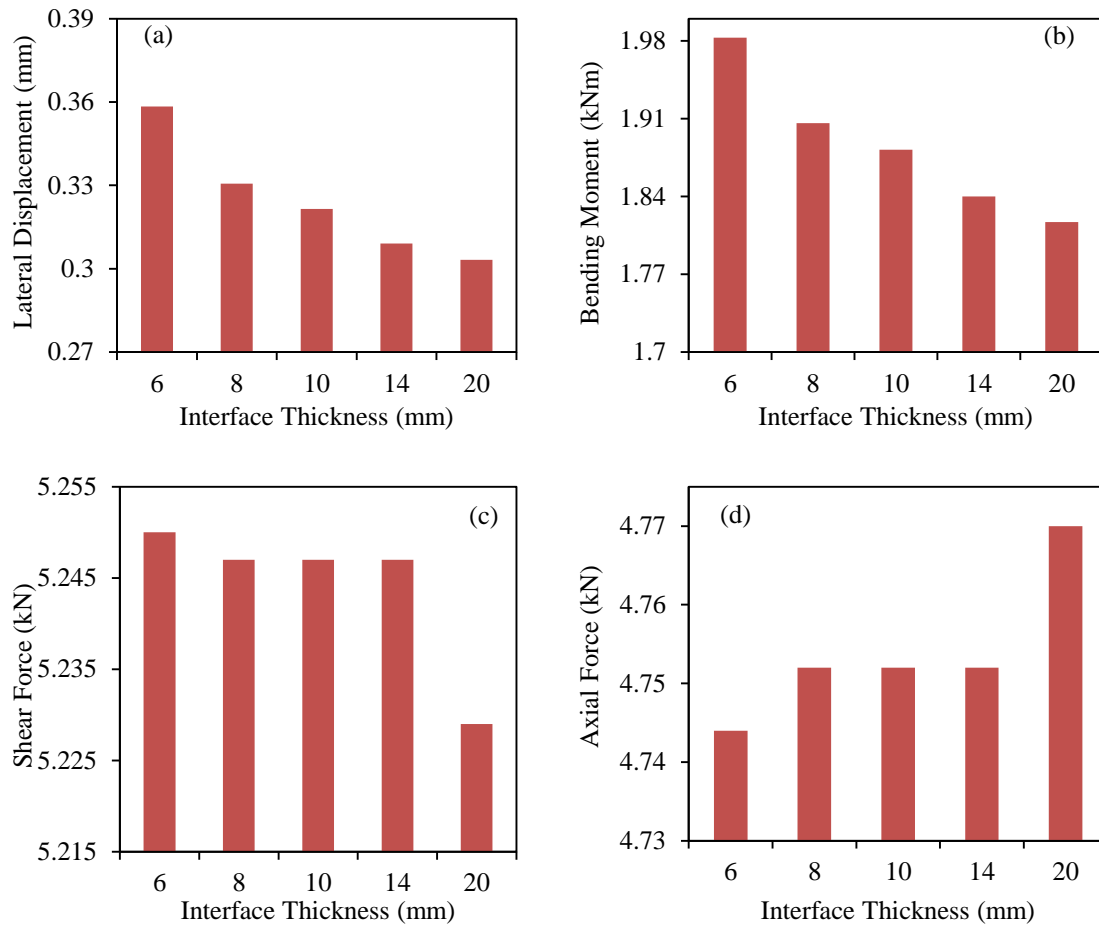| Material name	Reinforcement	Frame element	Interface element	Infill element
		RCC (Beam & column)	Cement mortar	Brick masonry
Density, kg/m^3	7849	2500	1733	1835
Modulus of Elasticity, N/mm^2	200000	20000	10000	5000
Poisson's ratio	0.33	0.15	0.15	0.15
Shear Modulus, N/mm^2	76903	8695	4347	2173

Fig. 4 Influence on (a) Lateral deflection (b) bending moment (c) shear force and (d) axial force with respect to interface thickness

Table 3 Comparison of parameters of bare frame and infilled frame

Particulars	Bare frame	Infilled frame with varying interface thickness (mm)				
		6	8	10	14	20
Lateral Deflection	1.381	0.3584	0.3306	0.3215	0.3091	0.3032
Bending Moment	6.31	1.983	1.906	1.882	1.84	1.817
Shear Force	5.02	5.250	5.247	5.247	5.247	5.229
Axial Force	4.975	4.744	4.752	4.752	4.752	4.770

The lateral displacement of infilled frame with 6, 8, 10, 14 mm interface was found increased by 18, 9, 6 and 2% as compare to 20 mm interface thickness. Similarly, the bending moment of infilled frame with 6, 8, 10, 14 mm interface was found increased by 9, 5, 3.5 and 1.2% as compare to 20 mm interface thickness. The bending moment of bare frame to infilled frame is decreased by 70%, see Fig. 4(b) whereas the influence on shear and axial force was found same for interface thickness 14 mm.

For interface thickness 20 mm, the shear force was found dropped and axial force was found jumped, see Fig. 4(c) and 4(d). The shear force drop was found very nominal, 5.247 to 5.229 MPa. It may be due to the friction at interface, affecting the behavior of infilled frame. Also the axial force increased because of shear, the reason may be the same. The shear force on the bare frame obtained from the simulation was taken as 5.02 kN by left side column and 4.98 kN by right side column. When the infilled frame is subjected to horizontal load, the infill and the frame separate over the region where tension occurs and remain in contact where compression occurs. The effect of this interaction reduces the lateral displacement of the frame and improves its lateral strength and it reduces the bending moment. Hence the design becomes economical though the axial force is increased, see Fig. 4(d).

The maximum principal stress at interface and masonry infill was shown in Fig. 5. The maximum principal stress decreased as 1.05, 0.91, 0.77, 0.63 and 0.49 N/mm^2 corresponding to interface thickness varied as 6, 8, 10, 14 and 20 mm. The highest maximum principal stress was observed at top left and bottom right corners. The maximum principal stress observed at cement mortar interface is not visible because the thickness of interface is very small as compared to width of masonry infill. The decrement in the interface stress on 8, 10, 14 and 20 mm as compared to the stress on 6 mm interface thickness was found as 13.3, 26.6, 40 and 53%.

3.2 Effect on interface pattern

As discussed in Section 2, the interface pattern are classified as one sided, two sided, three sided and four sided and it is designated by removing the interface material between the reinforced concrete frame and masonry infill. The lateral load on infill frame was also varied as 10, 20, 30, 40, 50 and 60 kN. The lateral displacement of infilled frame with 6 mm interface thickness on four sided, three sided, two sided and one sided against 10 kN is shown in Fig. 6. The lateral displacement of three sided, two sided and one sided interface infilled frame was found increased to 8, 15 and 22% as compared to fully infilled frame. Hence, the composite in-plane action of the wall and the frame renders the structure very stiff and strong; however the ductility of frame is lowered during failure. The stiffness of an infilled frame is dependent on the separate stiffness of the frame and infill panel and on the way which they interact at the interface of the two. The displacements on 6, 8, 10, 14 and 20 mm thick one sided interface frame have been found as 0.4356, 0.4257   0.4206, 0.4236 and 0.5109 mm respectively. The resistance of the frame was found maximum with the interface thickness 10 mm and corresponding lateral displacement was 0.4206 mm. Therefore, it is concluded that the maximum influence of interface thickness and maximum influence of interface pattern corresponding to 10 mm thickness of interface was found effective. Also the displacement on bare frame and infilled frame with 10 mm thick one sided interface was found 1.381 and 0.42 mm, respectively.
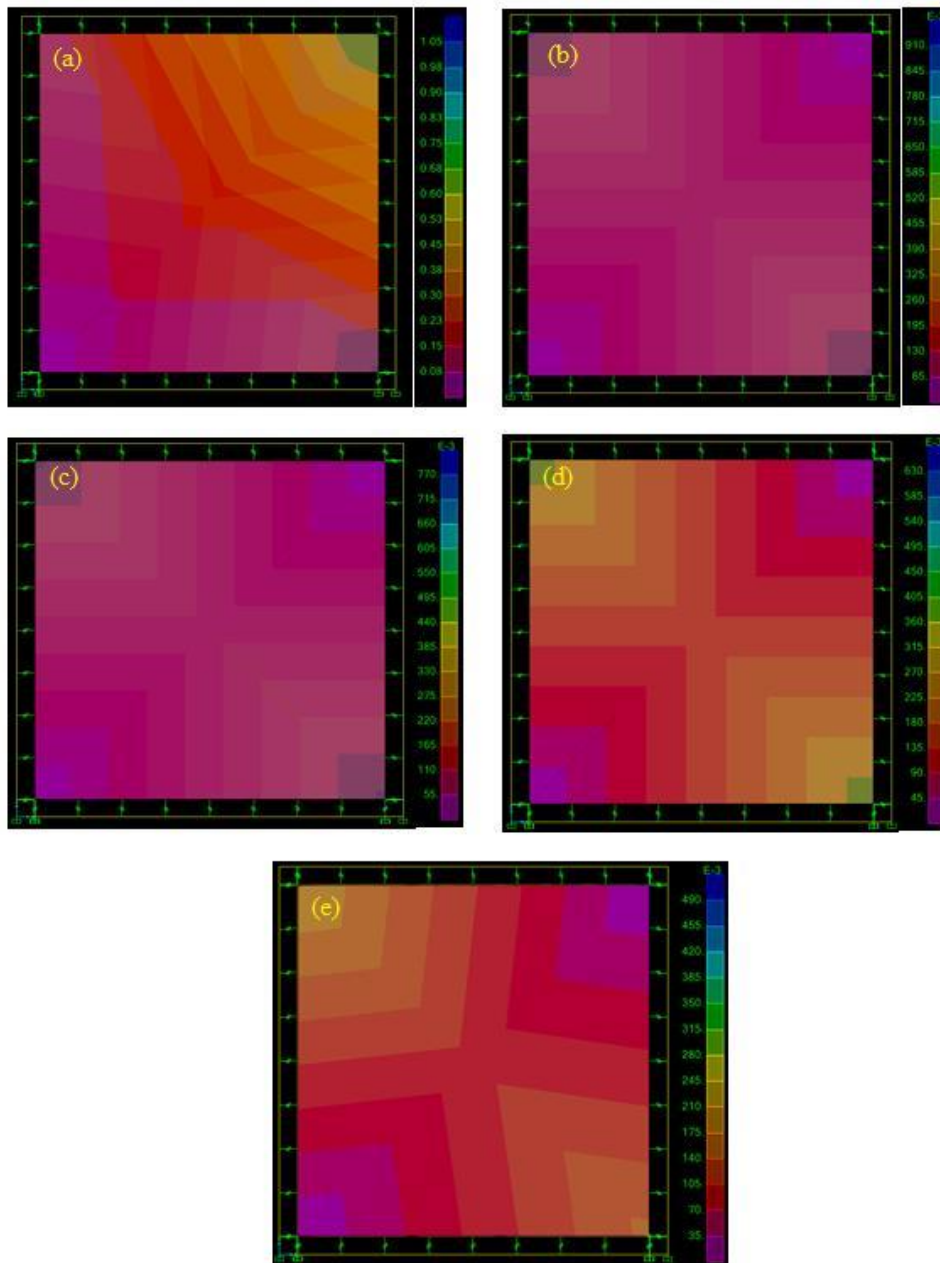
Fig. 5 Maximum principal stresses (N/mm^2) on interface and masonry infill against (a) 6 mm, (b) 8 mm, (c) 10 mm, (d) 14 mm and (e) 20 mm thick interface thickness
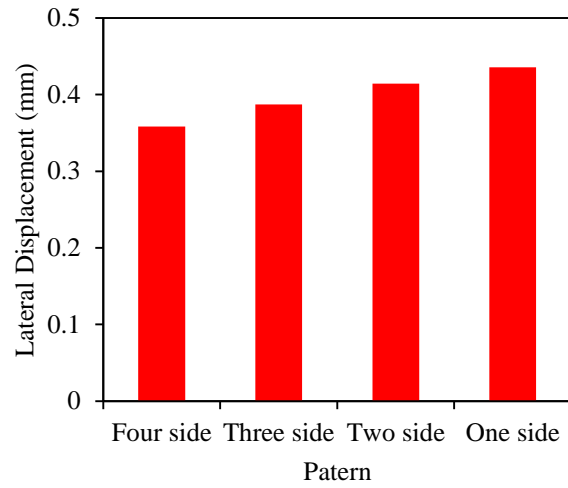
Fig. 6 Lateral deflection of infilled frame with 6 mm thick interface corresponding interface pattern
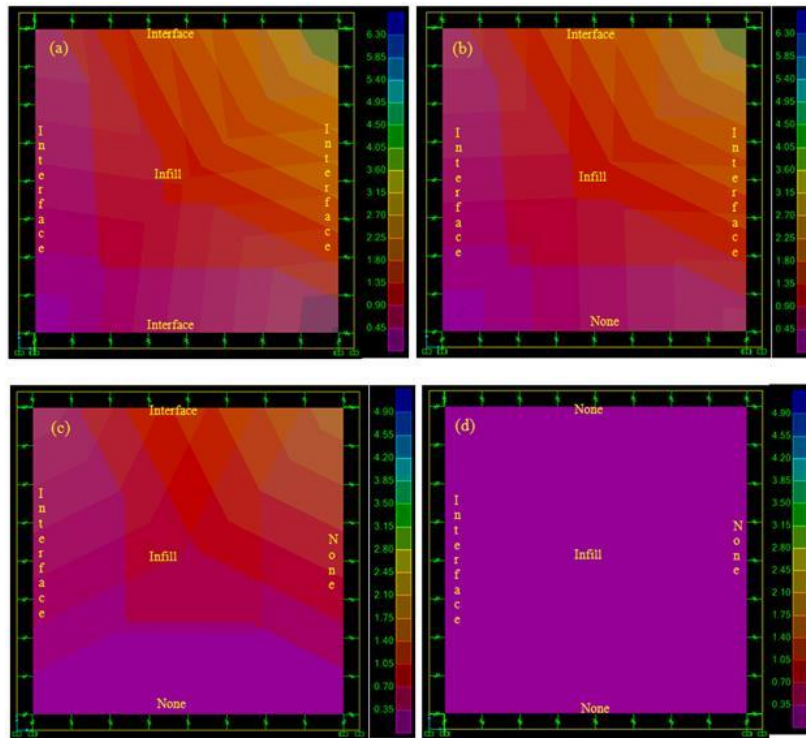

Fig. 7 Maximum principal stresses (N/mm²) on interfaces and infill against (a) four sided, (b) three sided, (c) two sided and (d) one sided interface subjected to 60 kN loading
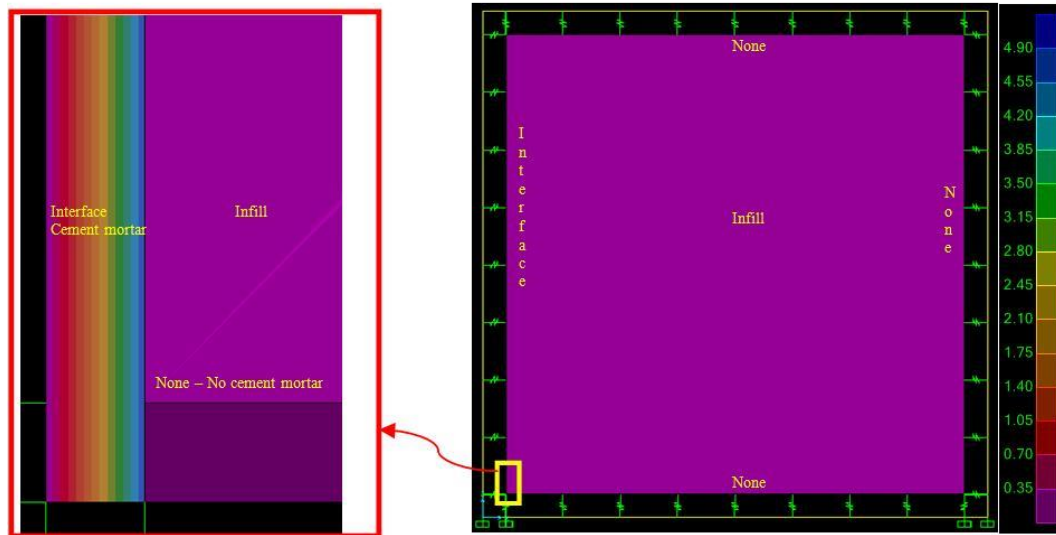
Fig. 8 Maximum principal stresses (N/mm2) on interfaces occurred due to one side interface

3.3 Effect on number of storey

Three sets of reinforced concrete infilled frames, namely single-bay single-storey, single-bay three-storey, and single-bay five-storey were analyzed. The lateral displacement and infill stress of infilled frame with four sided interface (fully infilled frame) was predicted by linear elastic analysis. The lateral deflection of one, three and five storey was 0.3584, 1.4164 and 3.272 mm respectively against 10 kN loading. The maximum principal stresses on interfaces and masonry infill of three and five storey frame against 10 kN loading have been shown in Fig. 9(i). Similarly, the maximum principal stresses on three and five storey frame against 60 kN loading have been shown in Fig. 9(ii). The bounding frame acts as tie and strut member and the infill acts like an inclined diagonal strut member, see Fig. 9(b) at second and fifth floor.

Ghosh and Amde (2002) conducted the finite element analysis on infilled frame with different relative frame-infill strength have been compared with the experiments performed by Riddington (1984). Riddington (1984) carried out experiments on flexible frame (column and beam) was made 152 x 152 x 30 mm wide flange section with 2710 x 2710 mm infill. The frames were formed from Grade 43 rolled steel sections welded together at the frame corners. The compressive strength of infill was 7 N/mm^2 made by masonry cement and sand mortar. The Modulus of elasticity and the Poisson's ratio of the masonry infill were 15400 N/mm^2 and 0.15, respectively. The finite element model by Ghosh and Amde (2002) includes interface elements in between frame and masonry infill. The interaction between the frame and the infill through this mortar joint is modeled by an interface element capable of transferring normal and shear forces in the elastic and inelastic ranges of loading. The thickness of interface element was set to an infinitesimally small value. They predicted the failure mode and the minimum principal stress on infill flexible frame against 216 kN lateral load, which is shown in Fig. 10(a) and these plots show that the infill stress is very high

at the corners, 11,600 kN/m^2 and similar results were predicted in the present study as shown in Fig. 10(b) and the stress at the corners is 1500 kN/m^2 corresponding to lateral load of 60 kN.
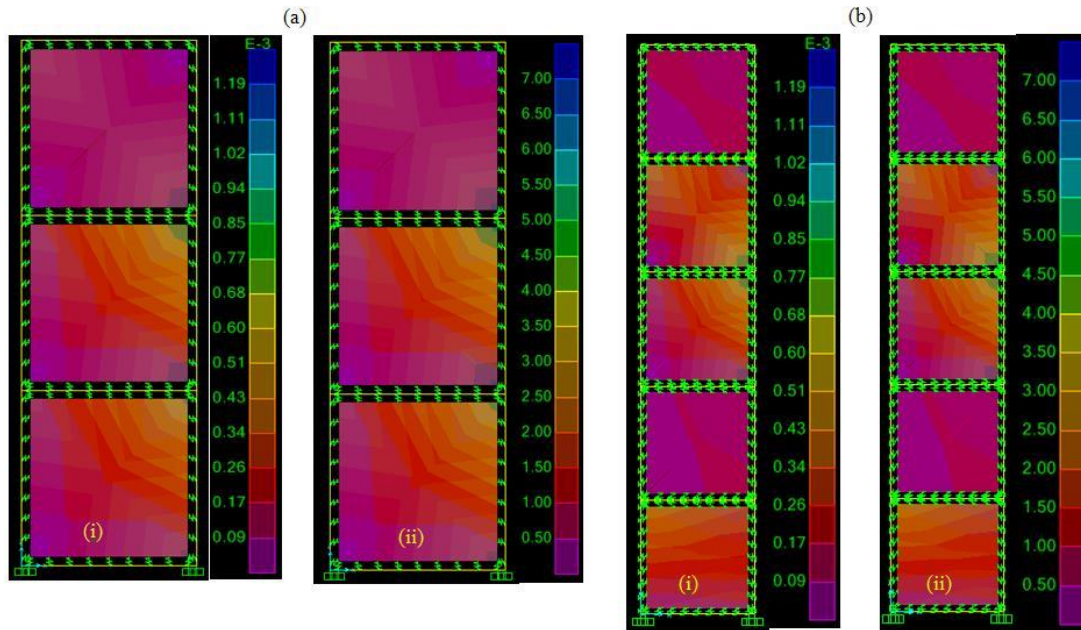

Fig. 9 Maximum principal stresses (N/mm^2) on interfaces and masonry infill of (a) three and (b) five storey frame against (i) 10 kN and (ii) 60 kN loading
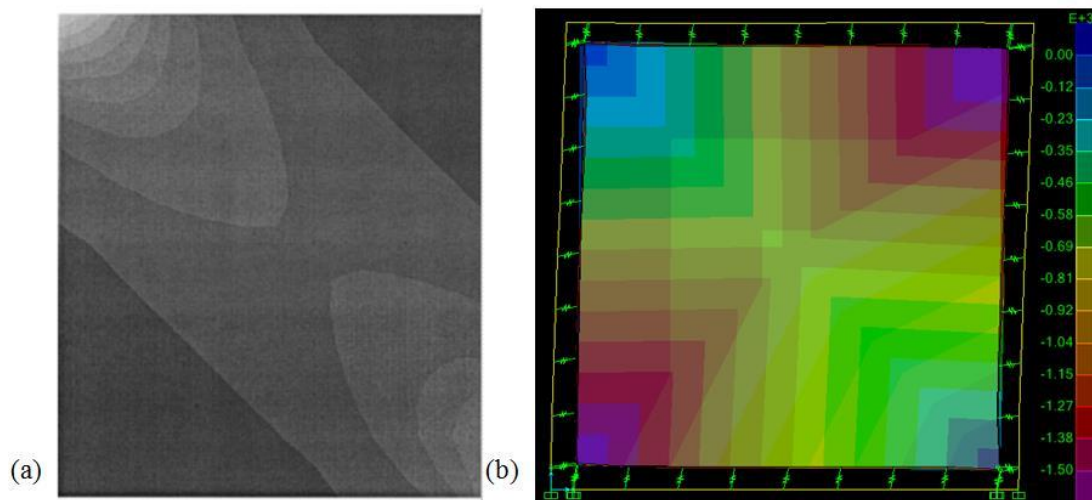

Fig. 10 Minimum principal stresses (kN/m^2) on infill from (a) results by Ghosh and Amde (2002) and (b) present study

When the infilled frame is subjected to horizontal load, the infill and the frame separate over the region where tension occurs and remain in contact where compression occurs, see Fig. 11(a). The maximum principal stress at infill of junction 2 and 4 was found maximum, 1500 kN/m^2, see Fig. 11(b). The maximum principal stress on interface seems to be zero stress at junction 1 and 3 due to the infill and RC frame separated over the region where the tension influenced by the lateral load, see Fig. 11(c). The principal stress on interface seems to be maximum (1500 kN/m^2) stress at junction 2 and 4 due to the infill and RC frame slip occurs over the region where the compression influenced by the lateral load, see Fig. 11(c). In the present study, proper separation or slip could not be predicted through simulations.
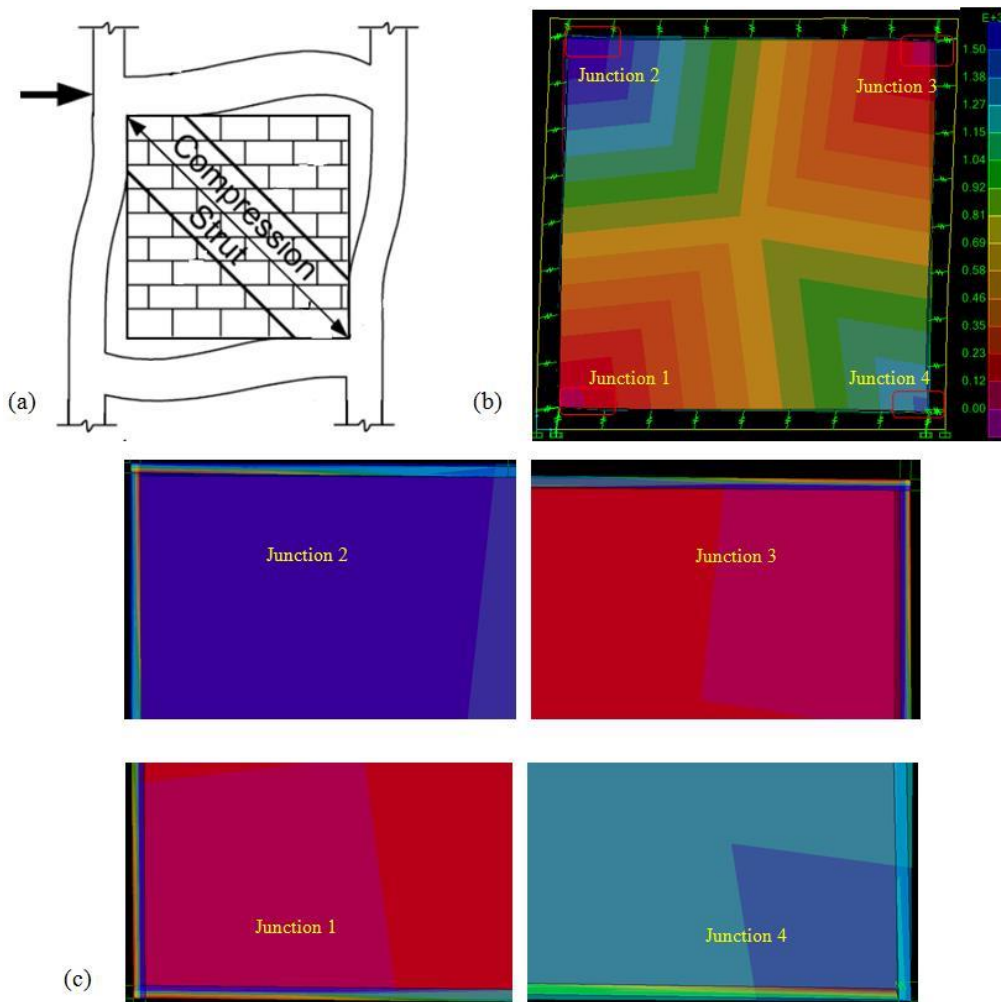

Fig. 11 Strut action of (a) schematic, (b) maximum principal stress (kN/m^2) on infill and (c) maximum principal stress (kN/m^2) on interface
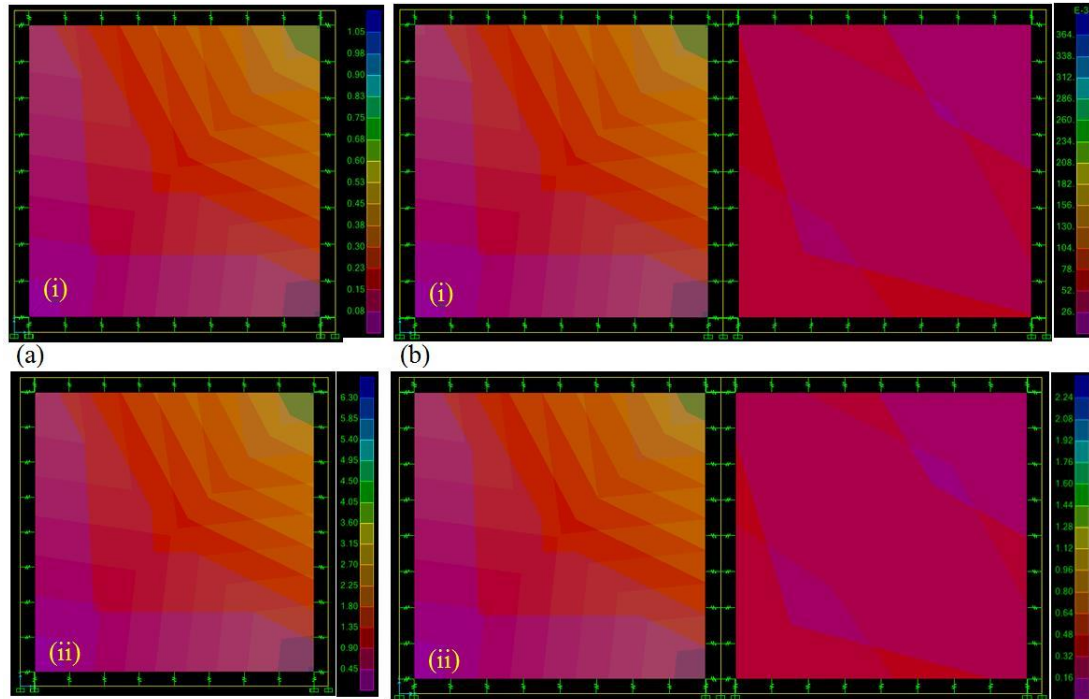
Fig. 12 Maximum principal stresses (N/mm^2) on interfaces and masonry infill of (a) one bay and (b) two bay frame against (i) 10 kN and (ii) 60 kN loading

3.4 Effect on number of bay

The finite element analysis has been carried out on single bay-single storey and two bay- single storey against in-plane lateral loading, see Figs. 12(a) and12(b). The resistance of the infilled frame was obtained by varying lateral load as 10 kN and 60 kN. Lateral deflection of single bay-single storey and two bay-single storey infilled frame is 0.3584 and 0.189 mm, respectively. The maximum principal stresses 1.05 and 0.36 N/mm^{2}on interfaces and masonry infill of single and two bay frame respectively against 10 kN loading has been shown in Fig. 12(i). Similarly, the maximum principal stresses 6.3 and 2.24 N/mm^{2}on single and two bay frame respectively against 60 kN loading have been shown in Fig. 12(ii). Therefore it is concluded that two bay square frames with equal areas of infill exhibit more lateral stiffness and reduces the stress in the infill almost 70%.

3.5 Effect of lateral load

The effect of interface pattern, number of storey and number of bays was studied against varying in-plane lateral loading, see Figs. 13(a)-13(c). The lateral load on infilled frame was assumed as 10, 20, 30, 40, 50 and 60 kN. The lateral displacement of one, two, three and four sided interface pattern frame against varying load is shown in Fig. 13(a), increased linearly with increase in lateral loads. The lateral displacement of fully infilled frame, described by red solid

circle is lesser as compared to three, two and one sided interface of 6 mm thickness. Further, when the lateral load was increased as 10, 20, 30, 40, 50 and 60 kN, the significant deviation was observed between fully infilled frame and one sided infilled frame. The lateral deflection of fully infilled frame and one sided interface frame due to 10 kN lateral load was found almost same as 0.35 and 0.43 mm, respectively while the lateral load was increased to 60 kN, 2.15 and 2.6 mm, respectively. Therefore, the deviation between the fully infilled frame and one sided infilled frame was found to be 0.08 and 0.45 mm with respect to 10 and 60 kN. The stiffness of the fully infilled frame increased to 25% when compared to the one sided infilled frame against 60 kN. Therefore, it is concluded that the interface pattern significantly affects the structural system when the lateral load increased.

   The lateral displacement of one, three and five storey infilled frame against varying load is shown in Fig. 13(b), increased linearly with increase in lateral loads. The lateral deflection of frame varied in the range of 2 – 20 mm as the number of storey varied upto five. The increment in the lateral displacement was found steep on five storey frame as compared to three and single storey frame.   Similarly, the resistance of single bay and two bay frames was also studied against varying load is shown in Fig. 13(c). The stiffness of two bay frame increased significantly and the lateral deflection is reduced to 50% compared to single bay frame.
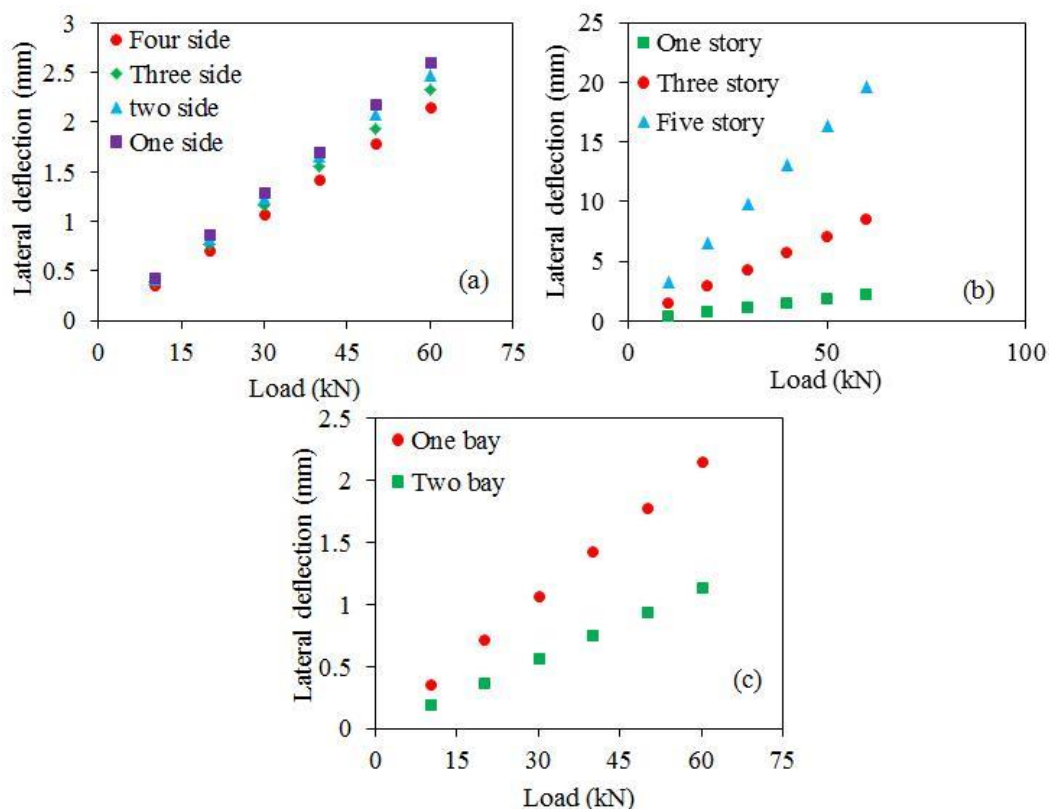

Fig. 13 Effect of (a) interface pattern, (b) number of storey and (c) number of bay by varying the lateral load

4. Conclusions

The present numerical study describes the behavior of infilled frame subjected to lateral in-plane load. The influence of the interface thickness, interface pattern, number of stories, number of bays and lateral load was studied. The results thus obtained through finite element investigations led to the following conclusions;

The resistance of the frame was found maximum with the interface thickness 10 mm therefore, it is concluded that the maximum influence of interface thickness and maximum influence of interface pattern corresponding to 10 mm thickness of interface was found effective. Also the displacement on bare frame and infilled frame with 10 mm thick one sided interface was found 1.381 and 0.42 mm, respectively.

The lateral displacement of three sided, two sided and one sided interface to infill was increased to 8, 15 and 22% as compared to fully infilled frame, respectively. The lateral deflection of one, three and five storey has been obtained as 0.3584, 1.4164 and 3.272 mm respectively and the infill acts like an inclined diagonal strut member as observed at second and fifth floor.

The lateral deflection of single bay-single storey and two bay- single storey infilled frame is 0.3584 and 0.189 mm respectively, while the maximum principal stresses reduced significantly to1.05 and 0.36 N/mm^2.

Also, it is concluded that two bay square frames with equal areas of infill exhibit more lateral stiffness and reduce the stress in the infill by almost 70%. The stiffness of the fully infilled frame increased to 25% when compared to the one sided infilled frame against 60 kN. Therefore, it is concluded that the interface pattern significantly affects the structural system when the lateral load increased.

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