Effect of Various Interface Thicknesses on the Behaviour of Infilled frame Subjected to Lateral Load

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Abstract. Two dimensional numerical investigations were carried out to study the influence of interface thickness on the behaviour of reinforced concrete frames subjected to in-plane lateral loads using commercial finite element tool SAP 2000. The cement mortar, cork and foam was used as interface material and their effect was studied by varying thicknesses as 6, 8, 10, 14 and 20 mm. The effect of lateral loads on infill masonry wall was also studied by varying arbitrary loads as 10, 20, 40 and 60 kN. The resistance of the frame with cement mortar was found maximum with the interface thickness 10 mm therefore, it is concluded that the maximum influence of interface thickness of 10 mm was found effective. The resistance of integral infill frame with cork and foam interface was found maximum with the interface thickness 6 mm and it is concluded that 6 mm thick interface among the chosen thickness was found effective.

1. Introduction

Past earthquake has revealed that the lack of lateral strength from masonry infill, frame and interface has been the reason for collapse in most cases. It is noted that most of the weakest spots of the buildings are reinforced concrete frames and infill masonry walls, which in spite of bonding layers of interface element prove to be vulnerable. However, 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 they should be protected during earthquakes. Girish and Achyutha [1] carried out experimental and analytical investigations on the response of reinforced cement concrete bare frame and non-integral brick masonry infilled frames under lateral reversed cyclic loads. It was concluded that the infill-frame interaction is found to enhance the base shear capacity, improve the hysteretic behaviour and alter the failure mode of the bare frame. Mehrabi and Singh [2] have carried out experimental and analytical studies on masonry-infilled reinforced concrete frames under in-plane lateral loadings. Authors concluded that the finite element models are able to simulate the failure mechanisms exhibited by infilled frames including the crushing, cracking of the frames and masonry panels, also the sliding and separation of mortar joint. Anil and Altin [3] conducted experimental investigations on partially infilled one-bay one-storey reinforced cement concrete frames under static cyclic load. Authors concluded that the monolithically infilled reinforced cement concrete frame showed seven times more energy dissipation capacity than the bare frame. Ghosh and Amde [4] formulated a non-associated interface models using the available experimental data on masonry joints.
to model the interface between concrete frame, the infill and the mortar joints surrounding the blocks of masonry. Asteris [5] presented a conventional method to simulate the complicated behaviour of infilled frames under in-plane lateral loads. The authors concluded that the proposed technique is more-easier and more practical to apply. Also it requires much less computational time than micro-modelling techniques based on discretizing the infill panel as a series of plane stress elements connected by a series of springs and contact elements. Mondal and Jain [6] carried out finite element investigations on one-bay one-storey, one-bay two-storey and one-bay three-storey infilled frames to study 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 may be neglected if the area of opening is lesser than 5% of the area of infill panel, and the strut width reduction factor may also be set to one, i.e., the frame is to be analysed as a solid infilled frame. Abdel-Hafez et al. [7] conducted experiments on single storey bare frame, brick masonry infilled frames strengthened with glass fiber reinforced polymer (GFRP) sheets, steel reinforcing bar impeded in frame, plastering and ferrocement meshes studied under the in-plane lateral load. Authors found that the drift, toughness, ductility and failure loads were improved by using such a masonry wall due to like shear wall effect which also increase frame capacity to resist lateral load. Khoshnoud and Marsono [8] developed a simple method is called corner opening, by replacing the corner of infill walls with a very flexible material to enhance the structural behaviour of panels. The authors have also found that the corner opening in infill walls prevented the sliding shear failure of the infill wall in reinforced cement concrete frames with infill walls. In addition to that few studies found on the influence of interface materials on infill frame [9, 10] and comparative studies on bare frame [11-14] which describes the strength and stiffness.

The review of literature carried out has indicated that study on effect of interface of frame and different interface thickness is limited. An attempt is made in the present study to quantify the effect of interface patterning of infill wall on the behaviour of frames with respect to lateral displacement 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 reinforced concrete frame and infill is through the interface and any such variation or non-uniformity or absence can lead to ineffective infill frame action. Hence, it is significant to study the effect of such variation on the infill frame behaviour.

2. Numerical 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 discussed here. According to Indian Standard 13920:1993 [15], the minimum dimensions of the member should not be less than 200 mm. However, in frames members which have beams with centre to centre span exceeding 5 m or columns of unsupported length greater than 4 m, the shortest dimension of the column should 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 - 0.3 m. Therefore, the length and height of the frame was 3 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 concrete frame and infill due to applied load plays an important role in the behaviour of the infilled frames. In most applications of construction practices, the infill is connected to the frame by cement mortar. Since the connection of link elements and masonry infill, interface elements are enabled to take compression, tension and shear forces, the interaction between the frame and the infill through the cement mortar joint has been modelled by an interface element capable of transferring bending and shear forces in the elastic and plastic series of loading. The interface as well as infill elements are modelled as a shell elements
considered as a plane stress type. In the finite element modelling of the present study, the modelling of the interface between the infill and the reinforced concrete frame has been given the prime emphasis. Finite element modelling of infill frame has been shown in Fig. 1 using SAP 2000 Version 16 and their lateral displacement and infill stress was predicted by linear elastic analysis. 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 and cyclic loading. For this reason, the manuscript concentrates on the elastic province of the analysis. In the parametric study, three parameters, i.e., interface thickness, interface material and lateral load are considered. The interface element thicknesses were assigned as 6, 8, 10, 14 and 20 mm. The cement mortar, cork and foam was used as interface material and their effect was studied by varying thicknesses as 6, 8, 10, 14 and 20 mm. The lateral load on infill frame was varied as 10, 20, 30, 40, 50 and 60 kN and the lateral load considered in the present study was arbitrary.

**Figure 1.** Finite element modelling of infill frame.

The frame elements were modelled as beam and column elements, while the infill and interface elements were modelled 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 such as cement mortar, cork and foam were modelled as 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 [16, 17] roughly equal to 5 MPa was considered for the analysis and the concrete having a compressive strength of 20 MPa was used and the properties are shown in Table 1. For concrete, the modulus of elasticity is taken as that recommended by IS 456:2000 [18], that is $5700\sqrt{f_{ck}}$ MPa where $f_{ck}$ characteristic compressive strength of 20 MPa. Poisson’s ratio of concrete and cement mortar interface was taken as 0.15 commonly adopted for the design. For cement mortar, the elastic modulus and Poisson’s ratio are taken as 10000 MPa and 0.15, respectively, Chung-Chia, et al. [19]. For masonry, the elastic modulus and Poisson’s ratio are taken as 6300 MPa and 0.15, respectively, Dhanasekhar and Page [20]. Therefore, the modulus of elasticity and Poisson’s ratio second class brick masonry are approximately taken as 5000 MPa and 0.15, respectively considered in the present study. All the simulations were carried out by applying lateral load in combination of body forces (Gravitational loads). The frames were loaded at storey level at the top left corner with 10 kN lateral forces as point load and discussed in Senthil and Satyanarayanan [21]. The elastic properties of interface materials such as cork and foam has also been studied through three point bending test and discussed in Muthukumar et al. [22].

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 is available in SAP were represented by individual lines connected by nodes and considered as structural elements (beam
and column). The size of mesh used in beam and column elements is 0.375 m. A node element model is technically called as finite-element model in which a single line element represents as structural element, SAP 2000 [23]. Node based element modelling follows the direct stiffness method (displacement method/equilibrium method), whereas finite element modelling 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 body. The number of elements are $20 \times 20$ and $2 \times 2$ used as infill and interface elements, respectively. The linkage elements were used to connect the interface elements and the surrounding concrete frame. A link element was used to connect two joints, separated by thickness or width of interface, such that specialized structural behaviour was modelled. The linear properties were assigned to link elements such that directional properties of $U_1$, $U_3$ and $R_2$ are restrained. Based on the developed forces in these linkage elements, separation between infill and frame was assumed to occur.

Table 1. Material properties of structural elements.

| Description               | Reinforcement | Interface material | Infill element |
|---------------------------|---------------|--------------------|----------------|
|                           | Frame         | Cement mortar      | Cork           | Foam          | Brick masonry |
| Density kg/m$^3$           | 7849          | 2500               | 1733           | 170           | 24            | 1835          |
| Modulus of Elasticity N/mm$^2$ | 200000       | 20000              | 10000          | 12.6          | 2             | 5000          |
| Poisson’s ratio            | 0.33          | 0.15               | 0.15           | 0.40          | 0.49          | 0.15          |
| Shear Modulus N/mm$^2$     | 76903         | 8695               | 4347           | 4.5           | 0.6711        | 2173          |

3. Results and Discussions
The scheme of numerical work is aimed at quantifying the difference in the behaviour of frames with varying interface thicknesses and their influence. In order to evaluate the behaviour of infill frame the following behavioural parameters are used such as interface thickness, interface material 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 on varying Interface Material
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 integral infill frame with interface are presented in Table 2-4. From the analysis the lateral deflection, bending moment, shear force and axial force of the infill frame has been compared with the conventional reinforced concrete bare frames. All the above parameters have been predicted at the joint where lateral load is applied.

In general, the behaviour of infill frame with respect to lateral deflection, bending moment and axial force has been found to decrease as compared to bare frame while shear force has been found to increase, see Table 2. Hence the presence of infill improves the overall behaviour of RC frame subjected to lateral loads. The ratio of lateral deflection of infill frame to bare frame indicates: There is 75% increase in the lateral deflection value of bare frame when compared to that of infill frame, the lateral deflection of infill frame was found to decrease linearly with increase in the thickness of interface. The lateral displacement of infill frame with 6, 8, 10, 14 mm interface was found to increase by 18, 9, 6 and 2% as compare to 20 mm interface thickness. Similarly, the bending moment of infill frame with 6, 8, 10, 14 mm interface was found to increase by 9, 5, 3.5 and 1.2% as compared to 20 mm interface thickness. The bending moment of bare frame to infill frame is decreased by 70%, whereas the influence on shear and axial force was found same for interface thicknesses of 8, 10 and
14 mm. For interface thickness 20 mm, the shear force was found to drop and axial force was found to jump. 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 behaviour of infill frame. Also the axial force increased because of shear, the reason may be the same.

**Table 2. Response of infill frame with cement mortar as interface material.**

| Particulars                  | Bare frame | Infill 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 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 infill 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. The maximum principal stress at cement mortar interface and brick masonry infill against 60 kN was shown in Fig. 2. The maximum principal stress decreased as 1.05, 0.91, 0.77, 0.63 and 0.49 N/mm² corresponding to interface thickness varied as 6, 8, 10, 14 and 20 mm, [21]. 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 panel. Therefore, enlarged view of interface and infill for all four corners has been shown in Fig. 2 since the maximum stress was observed on interface. 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%.

**Figure 2. Maximum principal stresses (N/mm²) on interface and masonry infill against 20 mm thick cement mortar interface.**

In case of infill frame with cork as interface material, the behaviour of infill frame with respect to shear force has been found to be decreased as compared to infill frame with cement mortar whereas deflection and bending moment has been found increased, see Table 3. However the axial force in both the frame was found same. The influence of thickness of cork on the infill frame was found almost same however minor variations was observed. The lateral displacement of infill frame with 6,
8, 10, 14 mm interface was found increased by 0.17, 0.17, 0.13 and 0.09% as compare to 20 mm interface thickness. Similarly, the bending moment shear force and axial force of infill frame with 6, 8, 10, 14 mm thick cork interface was found insignificant as compare to 20 mm interface thickness. It was observed that the resistance of frame with 6 mm thick cork interface was found increased in terms of bending moment, shear force and axial force whereas the displacement was found almost same. Therefore, it is concluded that the 6 mm thick cork interface material was found effective among the chosen interface thickness. The maximum principal stress at 20 mm thick cork interface and brick masonry infill against 60 kN was shown in Fig. 3. The highest maximum principal stress was observed at top and left side of the frame. The maximum principal stress observed at cork interface is also not visible because the thickness of interface is very small as compared to width of masonry infill panel. Therefore, enlarged view of interface and infill for all four corners has been shown in Fig. 3 since the maximum stress was observed on interface.

Table 3. Response of infill frame with cork as interface material.

| Particulars         | Infill frame with varying interface thickness (mm) |
|---------------------|-----------------------------------------------|
|                     | 6     | 8     | 10    | 14    | 20    |
| Lateral deflection  | 0.4543| 0.4543| 0.4541| 0.4539| 0.4535|
| Bending moment      | 2.314 | 2.377 | 2.386 | 2.397 | 2.392 |
| Shear force         | 4.807 | 4.814 | 4.814 | 4.813 | 4.813 |
| Axial force         | 4.764 | 4.838 | 4.841 | 4.841 | 4.850 |

Figure 3. Maximum principal stresses (N/mm²) on interface and masonry infill against 20 mm thick cork interface.

Table 4. Response of infill frame with foam as interface material.

| Particulars         | Infill frame with varying interface thickness (mm) |
|---------------------|-----------------------------------------------|
|                     | 6     | 8     | 10    | 14    | 20    |
| Lateral deflection  | 0.4547| 0.4547| 0.4547| 0.4546| 0.4546|
| Bending moment      | 2.394 | 2.384 | 2.374 | 2.360 | 2.395 |
| Shear force         | 4.810 | 4.810 | 4.810 | 4.810 | 4.810 |
| Axial force         | 4.811 | 4.855 | 4.856 | 4.856 | 4.857 |

In case of infill frame with foam as interface material, the behaviour of infill frame with respect to the chosen parameters has been found almost same as compare to infill frame with cork, see Table 4. The
influence of thickness of foam on the infill frame was found almost same however minor variations was observed an axial force. The lateral displacement, bending moment and shear force of infill frame with 6, 8, 10, 14 mm thick cork interface was found insignificant as compare to 20 mm interface thickness. The axial force of infill frame with 6, 8, 10, 14 mm interface was found decreased by 0.95, 0.04, 0.02 and 0.02% as compare to 20 mm interface thickness. It was observed that the resistance of frame with 6, 8, 10, 12, 16 and 20 mm thick cork interface was found almost same. Therefore, it is concluded that the 6 mm thick cork interface material was found effective among the chosen interface thickness. The maximum principal stress at 20 mm thick foam interface and brick masonry infill against 60 kN was shown in Fig. 4. The highest maximum principal stress was observed at top and left side of the frame and distributed along the length and height of the frame. The maximum principal stress was observed only at masonry infill and it seems foam interface is not experiencing much of stress as compared to masonry infill, see Fig. 4 and it is confirmed through the experiments [22].

Figure 4. Maximum principal stresses (N/mm²) on interface and masonry infill against 20 mm thick foam interface.

Table 5. Lateral drift of infill frame against varying lateral load.

| Particulars   | Load kN | Infill frame with varying interface thickness (mm) |
|---------------|---------|---------------------------------------------------|
|               |         | 6       | 8       | 10      | 14      | 20      |
| Cement mortar | 10      | 0.3584  | 0.3306  | 0.3215  | 0.3091  | 0.3032  |
| Cork          |         | 0.4543  | 0.4542  | 0.4541  | 0.4539  | 0.4535  |
| Foam          |         | 0.4547  | 0.4547  | 0.4547  | 0.4546  | 0.4546  |
| Cement mortar | 20      | 0.7167  | 0.6612  | 0.6431  | 0.6180  | 0.6063  |
| Cork          |         | 0.9087  | 0.9086  | 0.9083  | 0.9078  | 0.9070  |
| Foam          |         | 0.9094  | 0.9094  | 0.9094  | 0.9093  | 0.9092  |
| Cement mortar | 40      | 1.4330  | 1.3220  | 1.2860  | 1.2360  | 1.2120  |
| Cork          |         | 1.8170  | 1.8170  | 1.8160  | 1.8150  | 1.8140  |
| Foam          |         | 1.8180  | 1.8180  | 1.8180  | 1.8180  | 1.8180  |
| Cement mortar | 60      | 2.1500  | 1.9830  | 1.9290  | 1.8540  | 1.8180  |
| Cork          |         | 2.7260  | 2.7250  | 2.7240  | 2.7230  | 2.7210  |
| Foam          |         | 2.7280  | 2.7280  | 2.7280  | 2.7270  | 2.7270  |
3.2. Effect of varying Lateral Load
The effect of varying interface material and thickness on infill frame was also studied against varying in-plane lateral loading. The lateral load on infill frame was varied as 10, 20, 40 and 60 kN. The lateral displacement of infill frame with cement mortar, cork and foam against varying lateral load is shown in Table 5, was found increased linearly with increase in lateral loads. The lateral displacement of infill frame with 6, 8, 10, 14 mm thick cement mortar interface against 10 kN was found increased by 18, 9, 6 and 2% as compare to 20 mm interface thickness however, the same trend was observed for 20, 40 and 60 kN. The variation in lateral displacement of infill frame with chosen thickness of cork as well as foam interface against 10 kN was found insignificant and the same trend was observed for 20, 40 and 60 kN. It was observed that the influence of interface thickness on the behaviour of infill frame against lateral load was found insignificant. Therefore, it is concluded that for both cork and foam interface, the minimum thickness of 6 mm was found effective and sufficient to resist lateral load.

4. Conclusions
The present numerical investigation describes the behaviour of integral infill frame subjected to in-plane lateral load. The influence of the interface thickness (6, 8, 10, 14 and 20 mm), interface material (cement mortar, cork and foam) and lateral load was studied. The results thus obtained through finite element investigations led to the following conclusions:

The resistance of the frame with cement mortar was found maximum with the interface thickness 10 mm therefore, it is concluded that the maximum influence of interface thickness corresponding to 10 mm thickness of interface was found effective. Similarly, the resistance of integral infill frame with cork and foam interface was found maximum with the interface thickness 6 mm and it is concluded that 6 mm thick interface among the chosen thickness 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. It is concluded that the infill wall in the integral frame significantly enhances both the stiffness and strength of the frame. The lateral displacement of infill frame with 6, 8, 10, 14 mm thick cement mortar interface against 10 kN was found increased by 18, 9, 6 and 2% as compare to 20 mm interface thickness however, the same trend was observed for 20, 40 and 60 kN. The variation in lateral displacement of infill frame with chosen thickness of cork as well as foam interface against 10 kN was found insignificant and the same trend was observed for 20, 40 and 60 kN. It was observed that the influence of interface thickness on the behaviour of infill frame against lateral load was found to be insignificant.

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