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Effect of Location of Opening on the Infilled Reinforced Concrete Frame

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Abstract
To study the Effect of location of opening on the infilled frame structures with variable wall opening, 2-D computer models of a wall panel of 3 storey typical buildings consisting of 2 bays in Y-direction with variable openings ratios of 25%, 29.5% and 34% and variable opening positions were made in ETABS. The infill was modeled as Shell Element. Prior to modeling the 2-D infill wall as Shell Element validation of models using diagonal strut and were made for buildings having (a) single storey single bay in each directions with centrally located opening and without opening and (b) five storey three bays in each directions without opening. For the strut model, the wall with opening was modeled using diagonal strut of reduced width. For the shell element model the wall was modeled as is with gap element at the interface between the frames and the wall. The shell element model was then used to create 2-D models of the wall panel in YZ plane with the wall openings. Nonlinear Push over analysis was performed on the 2-D models. The results obtained for different openings percentages were compared in terms of Base shear, Displacement, Ductility ratio and Effective time period at performance point for different opening location and the best location for opening was determined.

Keywords
Location of opening – infilled frame – wall with opening – shell element

1. Introduction

In common practice of civil engineering the infill walls are often neglected in the evaluation of the structural seismic behaviour. However, the damages observed in past earthquakes around the world, have shown as the presence of infills significantly influence the seismic performance of Reinforced Concrete (RC) resisting frames. Wall panels though made up of masonry, a relatively weaker material in comparison to concrete, offer substantial lateral resistance to lateral loads by virtue of its larger sectional area. Infill walls act as a compressed diagonal strut if frames are subjected to lateral loads. The significant contribution of infill walls to the lateral stiffness and strength of the surrounding frame structures has been widely acknowledged. Accordingly, formulas for the strut width of solid infill wall and infill wall with openings were adopted [1]. Presence of opening, however, is inevitable part of the wall for functional purposes. Though it seems logical to overlook the walls with large openings, recent studies showed that despite the opening, the infill wall still contributes to the lateral stiffness of the frame. Therefore, both walls and openings should be considered in structural modeling to obtain more accurate responses and hence, better design for structures subjected to earthquake loads. The topic becomes interesting for many reasons. First, because earthquakes may happens at any time, at any magnitude and result in many casualties. The Nepal (Gorkha) earthquake on the 25th of April, 2015 occurred after 81 years without strong tremors and resulted in casualties of more than 9000 killed, twice as many injured, and many ancient structures made of unreinforced masonry were flattened [2]. Second, the infilled frame type of structure constitutes a great percentage of building systems used for low to medium rise building in developing countries, including in regions with high seismicity. Third, the highly non-linear nature of the infill materials and the interface between the walls and the frames make the analytical solutions problematic and make the answers to these questions are still evolving. In this paper emphasis is given to the effect of location of opening on the infilled 2-D RC structures for typical wall panel consisting of 2 bay in Y direction. The walls consist of varying window opening with practical RC columns and beams around the openings. In this study, a shell element model is used and applied to 2-D structures. At present there is no proper code for modelling the infill wall as shell element. Thus to ensure the accuracy of the shell element model, validation 3-D models are made for two types of simple buildings each for Equivalent diagonal strut model and Shell element model consisting of (a) single storey single bay with central opening (b) 5-storey 3 bays without opening. A model of bare frame was also included for comparison.

2. Validation of Shell Element Model

In this paper, computer models using ETABS software version 15 [3] were made for validation.

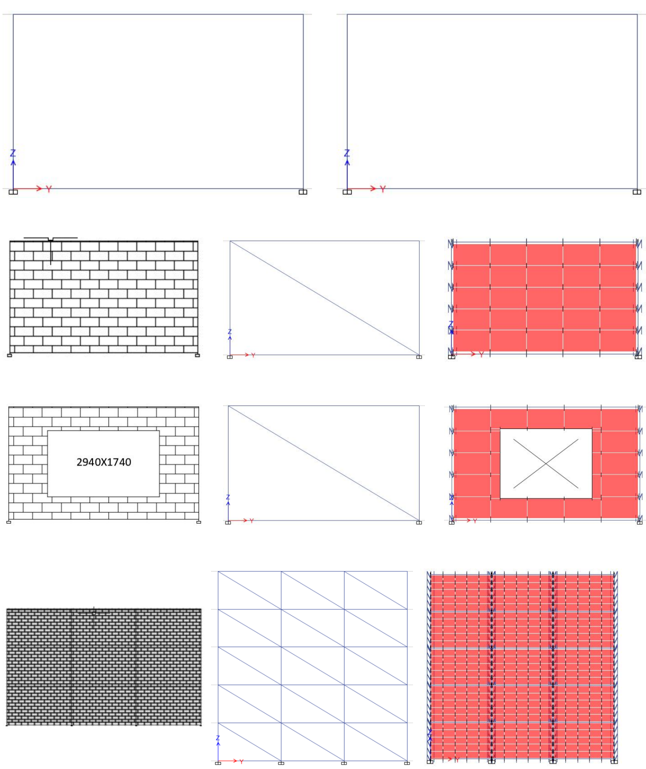

Figure 1: Geometry of modeled frames (first column) and their corresponding models using strut and shell element (second and third column)

Fig. 1 shows the computer models. The first columns shows the geometry of frames. Corresponding models using strut and shell elements are shown in the second and third column. The bare frame and two single storey single bay frame with infill wall without opening and two single storey single bay frame with infill wall having central opening with opening ratio of 34% each for strut model and shell model and two 5-storey 3 bays frame with infill wall without opening each for strut model and shell model were modeled to compare the responses of Equivalent diagonal strut model and Shell element model. The strut model used single diagonal strut and for the shell element model, gap element was used at interface between frame and wall. Material properties for infill are those obtained from the research of Hemant B. Kaushik, et.al [4]. The compressive strength of concrete fc is 20 MPa and the infill compressive strength fm is 7.13 MPa. The initial elastic modulus of masonry Em is calculated based on FEMA recommended value of 550fm [1]. For fm of 7.13 MPa, Em becomes 3918.75 MPa.

The strut model for infilled without opening uses frame element for frame members and the diagonal strut, in which both ends of the strut were released against rotations. The width of the strut is that specified by Holmes as follow:

$$W = dz/3 \quad (1)$$

where, dz = Diagonal length of infill panel Development of strut model for infill with central opening follows the modified diagonal strut model, in which the width of the strut for solid infill is reduced by factor using equation proposed by Goutam Mondal, et.al [5].

$$\rho_w = 1\text{-}2.6\ \alpha_{co} \quad (2)$$

where, α_{co}=ratio of the area of opening to the area of the infill Models using shell element were also created in which the infill wall was modeled as is without any modification or reduction using thick shell with the thickness of infill wall. The interface between RC frame and infill wall was model as gap element. The results obtained from the Equivalent diagonal strut model and Shell element model were compared in terms of Base reaction, Maximum joint displacement and Mode Time period.

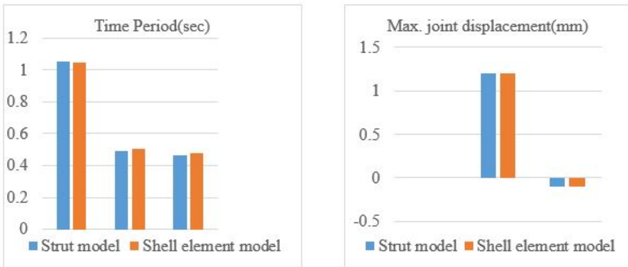

Figure 2: Comparison of Time period and maximum Joint displacement for single storey strut and shell element model without opening

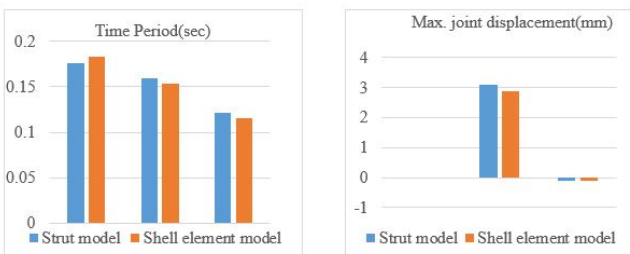

Figure 3: Comparison of Time period and maximum Joint displacement for single storey strut and shell element model with central opening

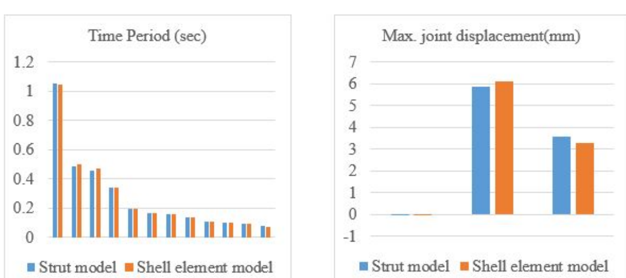

Figure 4: Comparison of Time period and maximum Joint displacement for 5-storey strut and shell element model without opening

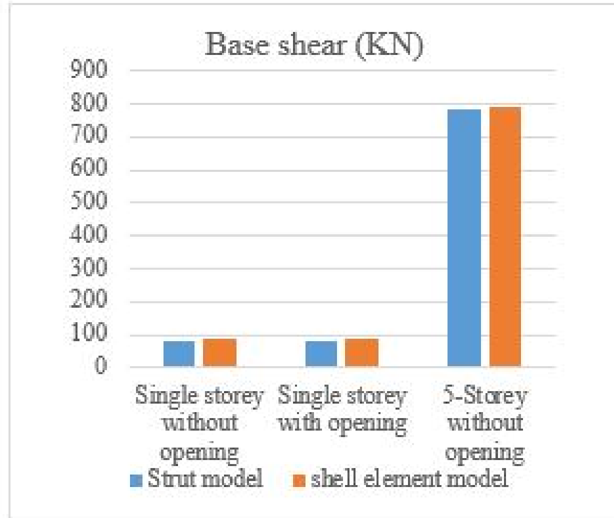

Figure 5: Comparison of Base shear for strut and shell element model

3. Structural Model Development And Analysis

The 2-D frame used model consists of six 3-storey 3-bay frames each of 3.9624 meter in YZ plane each frame have opening position at (i) Opening at two third height of both infill panel (ii) Opening at centre of both infill panel (iii) Opening in contact with beam of both infill panel (iv) Opening at left of both infill panel (v) First opening at left of first infill panel and second opening at right of second infill panel (vi) First opening at right of first infill panel and second opening at left of second infill panel. Infill wall consist of three different sizes openings with opening ratios 25%, 29.5% and 34% of the infill area. A shell element model with gap element was used to model the 230 mm infill wall. Fig. 4 shows the different locations of opening used for each percentage of openings. The same main beam of 228.6/355.6 was used for all models together with 127 mm thick floor and roof slab. Dimension of columns are 304.8/304.8 mm. A total of eighteen 2-D models were created consisting of 6 models for each percentage of openings. All models were loaded according to according to IS code and non-linear static push over analysis was performed. The concrete compressive strength fc of 20 MPa and infill compressive strength fm of 7.13 MPa were used with elastic modulus Em of 3918.75 MPa. The corresponding stiffness of gap element is 108 KN/m.

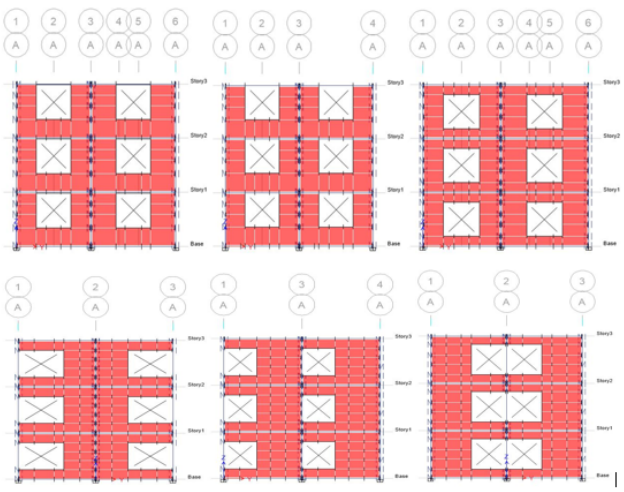

Figure 6: Different locations of opening

4. Results And Discussions

The comparison charts were presented in terms of Base Shear, Displacement, Ductility Ratio and Effective Time Period for different location and percentage of openings in Fig. 7 and Fig. 8. From graph it is clear that the performance point of structure is more when the opening is in contact with beam as compared to when opening is at centre. In between upper beam and centre of infill there is a place where the performance point of structure is better as compared to when opening is in contact with beam and when opening is at centre. And that position is when the opening is at 2/3rd height of the infill panel. This result is same for all percentage of openings. So it can easily be concluded that the best position for opening is when the opening is centrally located and the centroid of the opening is at two third height of both the infill panel. The percentage of opening doesn't affect this result. For each percentage of opening the performance point, Ductility ratio and effective time period is more when the opening is centrally located and the centroid of the opening is at two third height of both the infill panel. As the opening percentage increases the capacity of the structures decreases. The performance point of infilled frame decreases when the opening percentage increases. This is because of the fact that the presence of opening in infill decreases the lateral stiffness of the infilled frame. When the opening percentage increases the base shear at the performance point decreases but at the same time the displacement at the performance point increases. Also the ductility ratio and effective time period goes on increasing as the opening percentage increases. By taking the consideration of storey drift limit this shows that presence of opening make the structure more ductile. As the opening percentage increases the structure becomes more ductile. But up to what percentage of opening this result is valid this will be a topic for further research

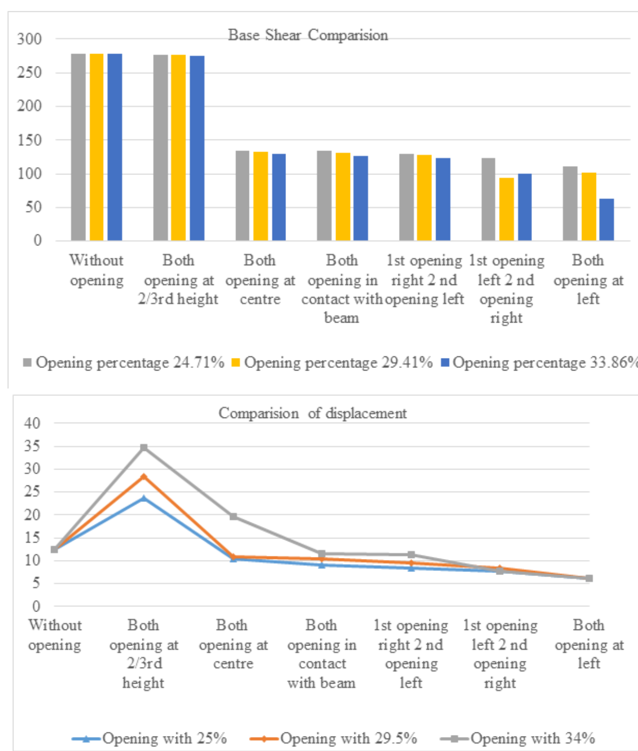

Figure 7: Comparison of Base shear and displacement for different percentage of opening

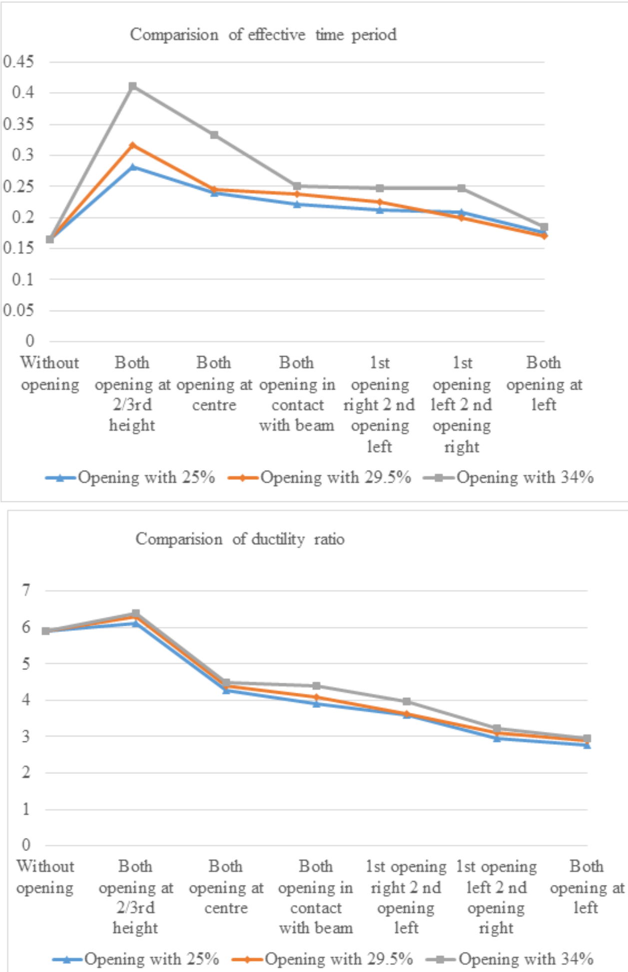

Figure 8: Comparison of Base shear and displacement for different percentage of opening

5. Conclusion

This research includes the validation of shell element model, finding the best location of opening in the infill frame with different percentage of openings. In this study the parameters Base Shear, Displacement, Ductility Ratio and Effective time period at performance point for different percentage of openings were studied. After this research work following conclusions are drawn:

1) The best position for opening is when the opening is centrally located and the centroid of the opening is at two third height of the infill panel.
2) As the opening percentage increases the performance point of the structure decreases.
3) Increase in opening makes the structure more flexible.

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