IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X
PP 24-29
www.iosrjournals.org

Equivalent Diagonal Strut for Infilled Frames with Openings using Finite Element Method

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ABSTRACT : *Reinforced concrete frames are infilled by brick or concrete-block masonry walls. The presence of infill in reinforced concrete structures can decisively alter the behavior of the structure under lateral loading. The increase in overall stiffness and strength is the positive effect of the presence of the infill. The analytical models for masonry infill are the macro modeling based on a physical understanding of the behavior of each infill panel as a whole, represented by a single structural member termed as equivalent diagonal strut and the micro models, where each infill panel is represented with a fine mesh of finite elements.. The presence of infill is studied by several authors and developed various models to understand the behavior and proposed diagonal strut model to incorporate the effect of Solid infill. Opening in the infill to accommodate the windows and doors for functional reasons are the inevitable part of infill. The presence of opening in the infill reduces the lateral stiffness of the infill frames. The primary objective of this paper is to investigate the reduction in initial lateral stiffness of the infilled frames with openings over that of solid infilled frames and propose a reduction factor for the diagonal strut for the infill with openings.*
Keywords *– Diagonal Strut, Infilled frames, Openings, Micro models, Strut width*

I INTRODUCTION

A large number of buildings in India are constructed with Reinforced concrete frames with un – reinforced masonry infill panels for architectural and functional requirements. The infill panels are classified as non-structural elements and the structures are analyzed and designed by considering them as dead load and neglecting any kind of structural interaction of infill panels because the bond between masonry infill and bounding RC frames is negligible at sides and top surface of the infill as the masonry infills are invariably constructed after the basic frameworks of beams, columns and slabs have gained sufficient strength. This assumption of neglecting the effect of masonry infill is reasonable and justifiable for the structure under gravity loading as infill panels remains almost inactive due to their construction methods. However the same is not true for the structures with masonry infill when subjected to lateral loads. The presence of infill under lateral loads has a significant structural contribution by improving the lateral stiffness, strength and energy dissipation capacity. The presence of infill also increases damping of the structures due to the propagation of cracks with increasing lateral drift. Presence of openings in the infill for functional requirements decreases stiffness and strength of infilled frames. Extensive researches have been carried out worldwide in the last five decades. Many researchers have proposed a single strut element, very simple to implement in general purpose finite element commercial software to capture the global behavior of the effect of the solid infill panels.

In the present paper, a finite element analysis has been carried using SAP2000 on single story, single bay infilled frames with openings of different configuration to cover the entire range of openings to evaluate the stiffness reduction factor for reinforced concrete frames with infill having different percentage of opening. Based on the results it is proposed a suitable strut width reduction factor for different percentage of opening

II MODELING OF INFILLED FRAMES

In order to fully understand the behaviour of infill panel and its mode of failure, several analytical models have been proposed by researchers around the world. These models can be classified into two main groups, namely micro-models and macro-models.

1.1 Micro Models

Micro models are represented by using Finite Element Method (FEM). The finite element method is the most popular analysis tool for complex structural engineering problems. Since the pioneer work of Mallick and Severn [1], several difficulties were evident from the simulations, namely the issues of modeling the separation between frame and panel, the bond strength and friction of the connection between frame and panel, and of the mechanical constitutive behavior of masonry itself. Riddington and Stafford-Smith [2] found that the critical stresses for the masonry panel are located in the center and are mostly associated with tensile and shear failure. In this case, the frame-panel interaction was modeled by using double nodes and normal springs at the interfaces, with contact/separation modeled in a simplified way. King and Pandey [3] further extended the numerical representation by adding interface elements capable of taking into account contact and friction for the frame-panel interaction. This work was further extended with non-linear behavior of the panel and frame, by Liauw and Kwan [4] and Dhanasekar and Page [5] in the framework of continuum modeling, and by Mehrabi and Shing [6] in the framework of discontinuous modeling. Asteris [7] used frame –infill separation as a criteria to model the complicated behavior of infilled frames under lateral loading. The major physical boundary condition between infill and frame is that the infill panel cannot get into the surrounding frame. The benefit of using finite element approach is to study in detail all possible modes of failure but its use is limited due to the greater computational effort and time required in analysis & modeling.

1.2 Macro Models

In order to overcome the complexity and computational requirement using micro-models, research has been done to simplify the modelling of infill panel with a single element. The main idea has been to study the global effects of infill panel on structures under lateral loads.Since first attempts from Polyakov[8], analytical and experimental test have shown that a diagonal strut with appropriate mechanical properties can provide a solution to the problem. Several authors have modified the characterisitics of single strut model with multi strut configaration to better understand the infill-frame interaction. Holmes[9] suggested that the infill panel can be replaced by an equivalent pin jointed diagonal strut of width equal to on third of the diagonal length. From the experimental results, Stafford [10] relates the width of the strut to the contact length between the frame and the infill. Paul and Priestley[11] noticed that a high value of diagonal strut will results in a stiffer structure and they proposed the width of diagonal strut as one fourth of diagonal length. Based on the experimental and analytical data, Mainstone [12] proposed an empirical equation for the calculation of strut width. Durrani and Luo [13] also proposed a semiempirical equation for calculating the equivalent strut.

III METHODOLOGY

In the present study, the reinforced concrete members and masonry infill members are modelled using SAP2000. It is a powerful finite element software developed by Computers & Structures Inc, which can greatly enhance a designer's analysis & design capabilities for structures.

The frame members of the RC frame are modelled with three dimensional elements having three degree of freedom at each node. A masonry infill panel is represented by two dimensional four node rectangular plane stress elements having two degree of freedom at each node. The contact between infill and corresponding bounding frame is represented by short and very stiff three dimensional elements known as link elements., but the node connecting the infill is made a structural hinge so that no moment is transferred from the link element to the infill. The nodes connecting the link elements to the frame elements will have three degree of freedom and the nodes connecting link elements to the infill elements is made to posses two degree of freedom so that no moment is transferred to the infill from the link element. After running the analysis, the axial forces in the link elements are checked and link elements that are in tension are identified and removed. This iteration process is continued till no link elements are in tension. The final stiffness of the frame is calculated for the frame with no tension link elements. Fig 1 shows the finite element discretization of solid infilled frame.

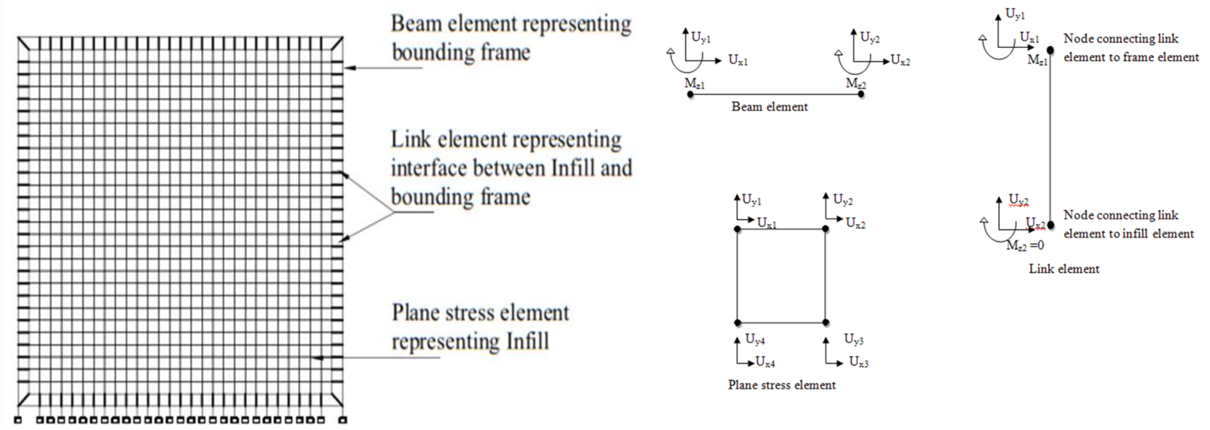


Fig 1: finite element discretization of solid infilled frames

Experiments are very important to observe the behavior of complex structures. Many a times, analytical models have been developed on the basis of experimental results, and sometimes, experimental studies have been carried out to verify the analytically developed model. The proposed analytical model is initially compared with the experimental results of Chiou, Y. J., et al., [14]. They have conducted a full scale test to study the behaviour of one bay, one story framed masonry walls. The infill panel size of the specimen tested is 2.4m x 2.3m. The cross sections of the beam and column elements are 0.35m x 0.40m and 0.3m x 0.35m respectively. The thickness of the masonry wall is 0.2m and the elastic modulus of concrete & masonry are 2.4247 x 10^7 kN/m2 and 2.087 x 10^7 kN/m2 respectively. The main output of the experimental investigation was a load versus displacement curve for solid frame. The results from the experimental investigation are used to compare the results of finite element model. Fig.2 presents lateral force and the corresponding lateral displacement at the top of the leeward column for the two models, namely experimental and finite element models. A good agreement is observed especially at lower loads. Considering this fact, a finite element method is chosen for the present work in order to understand the behavior of infilled frames.

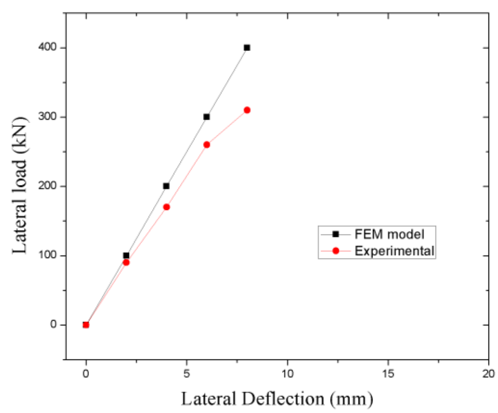


Fig 2: comparison of lateral deflection of FEM model and experimental model for solid infill

IV STRUT WIDTH REDUCTION FACTOR

To study the effect of opening in an infilled frames, a single story, single bay infilled frame of aspect ratio 1.0 is considered for analysis as shown in Fig 3 with different opening configuration covering the entire range of opening where, w_o = width of opening, w = width of infill, h_o = height of opening and h = height of infill. The value of $w_{o/}$ w is varied for a range where, $w_{o/}$ w=0.1,0.2,0.24,0.36,0.48,0.6,0.8 and 1.0 for each value of h_o /h which varies in the range of h_o /h=0.17.0.33,0.5,0.67 and 1.0. Totally 39 infilled models for different opening percentage, one bare frame model and one solid infilled frame model is analysed totalling 41 models for analysis. For different configuration of opening, lateral stiffness of the frame is calculated and a graph is generated as shown in Fig 4.

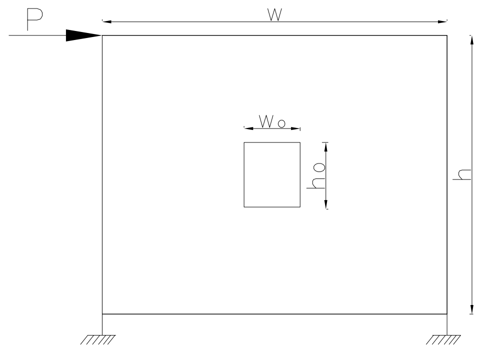


Fig 3: single bay, single story infilled frame with central opening

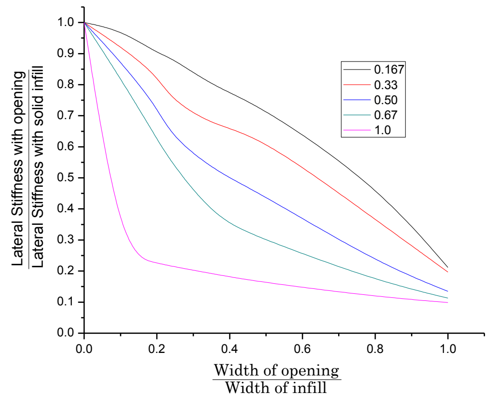
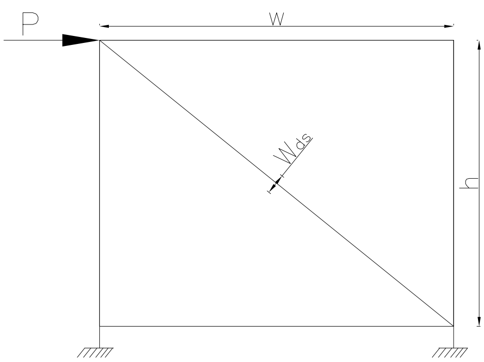


Fig 4: variation of lateral stiffness ratio for different percentage openings.

For the same model, Infill panel which is represented by fine mesh of finite elements is replaced with single diagonal strut having same material properties of the infill as shown in Fig 5. Analysis is carried out by replacing the infill with single diagonal strut by varying the width of diagonal strut(W_{ds}) for a range where W_{ds} = 0.01d, 0.025d, 0.05d, 0.1d, 0.2d, 0.3d, 0.4d and 0.5, where d =diagonal length of infill panel. For a different width of diagonal strut, lateral stiffness is calculated. The variation of lateral stiffness varies almost linearly with the width of diagonal strut and the same is plotted graphically as shown in Fig 6.



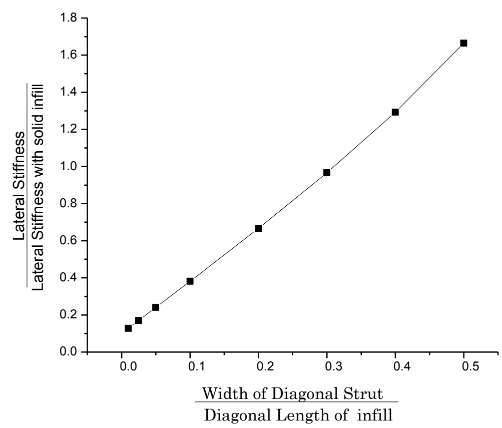


Fig 5: equivalent strut model

Fig 6: variation of lateral stiffness ratio for different width diagonal strut

For a given width of opening and height of opening, determine the value of lateral stiffness from Fig 4. For the same value of lateral stiffness from Fig 6, determine the width of diagonal strut. Following the same procedure calculate the width of diagonal strut for different configuration of opening. Tabulate the width of diagonal strut for entire range of opening. Plot a graph for Opening area ratio(O_{ar}) Vs Diagonal strut width reduction factor(D_{rf}) Where,

$$O_{ar} \quad \frac{\text{Area of opening}}{\text{Area of infill}} \qquad Drf \quad \frac{\text{Width of diagonal strut for infilled frames with opening}}{\text{Width of diagonal strut for solid infilled frames}}$$

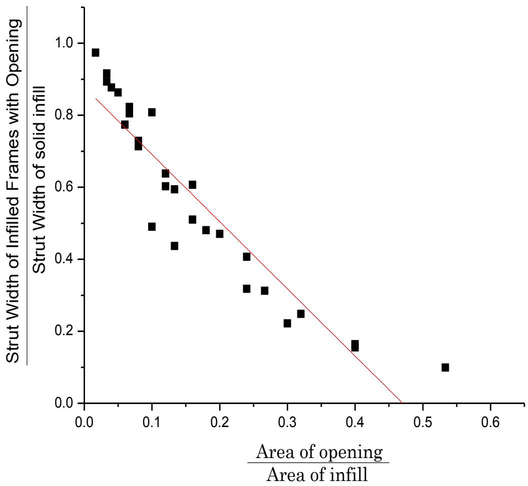


Fig 7: equivalent strut model

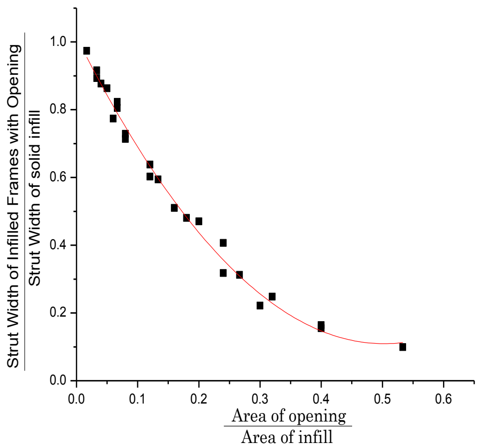


Fig 8: variation of lateral stiffness ratio for differ width of diagonal strut

Performing the regression analysis for the data acquired for the different opening ratio and strut width reduction factor to fit a best curve and to formulate an expression for the diagonal strut width reduction factor in terms of opening area ratio. To start with a linear fir was carried out as shown in Fig 7 and a regression coefficient was 0.867. Before refining the analysis, the data's corresponding to opening sizes extending to full width and full height are discarded as they don't reflect the strut action adequately. After rearranging the data, a second order regression analysis is carried out as shown in Fig 8 with the regression coefficient of 0.998. Based on this analysis, an expression for strut width reduction factor in terms of opening ratio is proposed

Strut width reduction factor(D_{rf})= $3.58(O_{ar})^2 - 3.56(O_{ar}) + 1$

The strut width reduction ratio (D_{rf}) is a variable, which accounts for the in-plane stiffness reduction when the infill has a opening. This reduction factor is multiplied to the width of the strut to calculate the width of the equivalent diagonal strut for the infilled frames with central openings.

V CONCLUSION

The macro models that can be used in everyday engineering are of practical importance. The simpler ones are the equivalent-strut models, which represent infills with a diagonal strut element. The primary objective of this paper is to provide a contribution for the simplified analysis and design procedure for the infilled frames, based on the numerical parametric study. The study of behaviour of infilled frames is carried out by micro modeling and based on the results a present a simplified formula to calculate the width of diagonal strut for infilled frames for different configuration of openings

The present study is limited for single story, single bay to infilled frames with central opening. Future work can be carried to study the effect of position of opening and stiffened openings for multi story and multi bay infilled frames for various aspect ratio and relative stiffness.

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