Effect of Openings and Aspect Ratio on RC Framed Brick Infilled Building

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Abstract— Openings are inevitable parts of infill walls for functional reasons. The openings may be single or multiple as per requirement and aesthetic appearance purpose. Providing multiple openings may further reduces the lateral stiffness. It is essential to understand the effect of openings and aspect ratio on strength, stiffness and seismic behavior of wall.

In the present paper the effect of openings in infill wall treating the infill as equivalent diagonal strut and also the effect of aspect ratio on the seismic response is studied and presented. The reduction in the width of the equivalent diagonal strut of the infill with openings and behavior of an infilled RC frame will affect the seismic performance of the structure as a whole. Aspect ratio is also an important parameter that affects the strength and stiffness of wall. In Present work infill walls are modelled as finite elements with and without openings and the single equivalent diagonal strut (SEDS) widths are calculated from the numerical studies. The effect of location of openings on the infill strength and lateral stiffness is also investigated. Regression analysis is carried out to arrive at the empirical expressions for the reduced width of the diagonal strut model of the infill with openings.

Keywords— Infill walls, Aspect ratio, Finite Elements, Equivalent diagonal strut.

I. INTRODUCTION

The infill walls are generally used to fill the void between the framed elements of the building with the assumption that this infill will not take part in resisting any kind of lateral load hence its analysis is generally neglected. But, the contribution of infill walls in resisting the lateral loads cannot be neglected in seismic zones, as they provide the stiffness and strength to the building. Hence, modeling of infill along with the frame is inevitable. The presence of openings decreases stiffness and strength of infilled frames. There are many methods for modeling masonry infill such as equivalent diagonal strut method, equivalent frame method and finite element method with masonry wall discretised into several elements etc. There are many formulae to estimate the width of equivalent diagonal strut.

However, recently in IS1893 (Part-1):2016, the FEMA expression has been considered to find the effective width of diagonal strut with-out opening. A numerical study has been done in this paper for effective width of diagonal strut with openings in RC brick infilled frames as shown in figure 1. However, there is no provision for the calculation of the width of equivalent diagonal strut with openings in the Indian standard code of practice.

In the present paper an effort is made to arrive at the expressions of equivalent diagonal strut width of infill with openings based on various geometrical, strength and stiffness parameters. The effect of aspect ratio of the infill on strength, stiffness and the SEDS is studied for a specific plan area and height. The finite element analysis has been carried out on single-bay single-story, single-bay two-story and single-bay three-story infilled frames to examine the effect of openings of different sizes at different location. There are some analytical methods to estimate the stiffness and strength of infilled frames with openings such as equivalent frame model, single diagonal strut model and multi diagonal strut model.

Figure 1: Equivalent diagonal strut

Wakchaure M.R, Ped S. P¹[1] studied the effect of masonry walls on high rise building is studied. Linear dynamic analysis on high rise building with different arrangement is carried out.
For the analysis G+9 R.C.C framed building is modelled. Earthquake time history is performed. The results show that infill wall reduce displacements, time period and increases base shear. So, it is essential to consider in analysis.

Prof. P. B. Kulkarni, Nikhil. S. Agarwal[2] made an attempt to access the performance of masonry infilled reinforced concrete frames with soft storey of with and without opening. In this paper, symmetrical frame of college building located in seismic zone m is considered and linear static analysis is to be carried out on the models such as strut frame with 15%, 20%, and 25% centre and corner opening using STAAD Pro software. Results indicate that considering the masonry infill increases the overall stiffness of structure, while the increase in size of the openings leads to a decrease in the lateral stiffness of infilled frame.

Hemant B. Kaushik, Durgesh C. Rai, Sudhir K. Jain[3] carried out a comparative study considering different analytical models for masonry infill which include single strut model, 3- strut model, finite element models. By linear and non linear analysis it was observed that 3- strut model gives sufficient accuracy. It was also observed that the single strut model can be effectively used in cases where masonry infill walls are discontinued in the first storey to generate parking space.


A.Dongre, R. Pradeep kumar[5] studied the effect of aspect ratio on overall performance of RC framed brick infilled building. Finite element analysis has been done in finding lateral stiffness of frame with different aspect ratios.

II. AIMS AND OBJECTIVES

The objectives of the present work are:
1. To study the effect of aspect ratio of the infill on the strength and stiffness of the structure.
2. To determine the width of single equivalent diagonal strut for various openings by conducting numerical and regression studies.

III. METHODOLOGY

A. An analytical study has been done to obtain the effect of aspect ratio on RC brick infill frame.

In this study, G+10 storey building with plan area of 12 m × 12 m , column size: 470 mm × 470 mm, beam size: 300 mm × 400 mm.

1. Modeling of multi-storied building frame with infill as diagonal strut using equivalent strut method using STAAD PRO.
2. To find the width of diagonal strut with opening the FE analysis and performing SED analysis.
3. Performing Seismic analysis for different aspect ratios and determining the lateral stiffness.
4. Performing the comparative study

B. Strut-Width Reduction Factor:

1. To perform the numerical study on single-story-single bay, two-story single-bay and three-story single-bay frames with various sizes of openings at various locations.
2. To find the reduced width of single equivalent diagonal strut by determining Strut-width reduction factor.

IV. NUMERICAL STUDY

4(A): In this present study a multistoried building frame of G+10 located in seismic zone-v is considered. The Moment resisting frame is modelled in STAAD PRO with infill as equivalent diagonal strut.

The geometric parameters of the model considered are as below:

| Plan area | 12m x 12m shown in figure II. |
| Bay width | 3m, 2.4m, 2m, 1.5m |
| No. of floors | G+10 |
| Floor height | 3m |
| Grade of concrete | M30 |
| Grade of steel | HYSD 415 |
| Seismic zone | V |
| Frame type | SMRF |
| Beam size | 300mmx500mm |
| Column size | 470mmx470mm |
| Ext. wall thk | 230mm |
| Int. wall thk | 115mm |
| Slab thickness | 200mm |
| Live load | 3kN/m² |
| Earthquake load | As per IS 1893: 2002 (part 2) |

Seismic analysis is performed for the multistoried building frame with infills. Indian standard code suggests IS: 1893:2002 part-1: General provisions and building code book for the relevant data to be considered for the analysis.
Base shear was calculated using the formula:

\[ V_b = A_h W \]

Where,

- \( W \): Seismic weight of building
- \( A_h \): Design hor. seismic coefficient
  - \( (Z/2) \times (I/R) \times (S_a/g) \)
- \( Z \): Zone factor = zone-\( v \) = 0.36
- \( I \): Importance factor = 1
- \( R \): Response reduction factor = 5
- \( S_a/g \): Response acceleration coefficient
- \( T \) = \((0.09/\sqrt{d}) = 0.77\)

The figure 2 and figure 3 shows the plan view & elevation of models respectively for different aspect ratios considered.

**Figure 2: Plan view of model**

**Figure 3: Elevation view of models**

Equivalent diagonal strut:

4(b). A Numerical study is performed to obtain lateral stiffness of infilled with varying size of opening. In this Finite element analysis and Single Equivalent Diagonal Strut (SEDS) method (Fig. 4). In this study the number of stories and size of openings are considered. A single-story-single bay, two-story single-bay and three-story single-bay are analyzed and their lateral stiffness is determined. To determine the lateral stiffness of infilled frames, the finite element model is first analyzed using STAAD Pro. The beams and columns are modelled as two-node frame elements with two translational degrees of freedom and one rotational degree of freedom at each node. The infill is taken as a four node plane stress rectangular or square area elements. The width of equivalent diagonal strut for SED method are taken as 0.001d, 0.01d, 0.025d, 0.05d, 0.1d, 0.15d, 0.2d, 0.25d, 0.3d, 0.4d and 0.5d, where \( d \) is the diagonal length of infill. The strut is connected to the diagonal nodes at the beam-column joint so that it can take only axial forces. The thickness of the strut is taken as the thickness of wall. The beams and columns are modelled as frame elements.
The effect of openings on lateral stiffness of infilled frame can be represented by a diagonal strut of reduced width. It is defined as ratio of reduced strut-width to strut-width corresponding to fully infilled frame.

Strut-width reduction factor \( (\rho_w) \) = 
\[
\frac{\text{Strut-width of infilled frame with openings}}{\text{Strut-width of fully infilled frame}}
\]

Area of opening \( A_{op} \), is normalized with area of infill \( A_{infill} \) and is termed as Opening area ratio, \( a_{co} \), i.e.,

Opening Area ratio = \( \frac{A_{op}}{A_{infill}} \)

Strut-width reduction factors for various cases of opening area ratios are obtained by using FE and SED analysis and the results are plotted on graphs. Regression analysis of these data is performed and linear, second-order polynomial and third-order polynomial trend lines are generated along with equations of trend lines and the coefficient of correlation (R-value). Later data of all three stories are plotted in a single figure and regression analysis is performed on combined data.

A single-bay single-story, single-bay two-story, single-bay three-story infilled frame with opening of different sizes in first one-third portion are shown in figure 5, figure 6, figure 7 (infill thickness: 230mm) of frame, height of story: 4000 mm; bay width of frame: 6000 mm; beam size: 250 mm × 300 mm; column size: 300 mm × 300 mm.

One-third openings of widths 250mm, 500mm, 750mm, 1000mm, 1250mm, 1500mm, 1750mm are taken one at a time for each of these three sets of infilled frames (G,G+1,G+2). For each width of opening, the height of openings are considered as 500mm, 1000mm, 1500mm, 2000mm and one fully infilled frame of each of these three sets of infilled frames are analyzed. So, a total of 90 models are analyzed using the software STAAD PRO V8i.

Compressive strength of masonry is taken as 5 MPa as per IS: 1905-1987 and characteristic compressive strength of concrete is taken as 30 MPa. Poisson’s ratio of masonry and concrete are taken as 0.18 and 0.2 respectively. The infills are discretized as 250 mm × 250 mm plane stress elements. A lateral load is applied at roof level in combination with gravity load.

For the same area of opening if width smaller than height or width larger than height the difference in lateral stiffness is less than 10% as shown in below Table 1. So, the lateral stiffness does not depend on the height to width ratio of opening. However, the area of opening governs the lateral stiffness thus the reduction factor is proposed based opening area ratio. The effect of openings on lateral stiffness is shown in figure 8.
As the height of opening equals to height of infill or width of opening equals to width of infill leads to a sharp decrease in lateral stiffness.

V. RESULTS AND DISCUSSION

Base Shear:
It is the total design lateral force at the base of the structure. The value of base shear is considered for different aspect ratio such as 1, 1.25, 1.5, 2 and results are plotted as shown in figure 9. As the aspect ratio increases, the base shear also increases due to increase in dead weight of the structure.

Lateral Stiffness:
The maximum lateral stiffness of a multi story building for different aspect ratios is shown in figure 10. From the figure, we conclude that the structure will have higher lateral stiffness when the aspect ratio is 2.0.

Lateral Displacement:
The maximum lateral displacement of a multi story building for different aspect ratios is shown in figure 11. From figure it can be inferred as the aspect ratio increases the structure will have less lateral displacement because of increase in the overall stiffness of the structure.

Table I

<table>
<thead>
<tr>
<th>Width Smaller than Height</th>
<th>Width Larger than Height</th>
<th>Diff. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opening Size</td>
<td>Lateral Stiffness</td>
<td>Opening Size</td>
</tr>
<tr>
<td>500x1000</td>
<td>98.67</td>
<td>1000x500</td>
</tr>
<tr>
<td>500x1500</td>
<td>98.34</td>
<td>1500x500</td>
</tr>
<tr>
<td>1000x1500</td>
<td>83.57</td>
<td>1500x1000</td>
</tr>
<tr>
<td>Two Storey</td>
<td></td>
<td></td>
</tr>
<tr>
<td>500x1000</td>
<td>23.03</td>
<td>1000x500</td>
</tr>
<tr>
<td>500x1500</td>
<td>23</td>
<td>1500x500</td>
</tr>
<tr>
<td>1000x1500</td>
<td>20</td>
<td>1500x1000</td>
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<td>Three Storey</td>
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</tr>
<tr>
<td>1000x1500</td>
<td>6.72</td>
<td>1500x1000</td>
</tr>
</tbody>
</table>
E. Story drift:

The story drift of a multi story building for different aspect ratios are presented in figure 12. From the figure as aspect ratio increases the story drift decrease till case 3 i.e., aspect ratio equals to 1.5 and later it is increased. Hence, the case 3 is the optimum one.

5 (b) The stiffness of infilled frames is influenced by the size and location of openings. Some analytical models have been developed to estimate lateral stiffness and strut width reduction factor with openings.

A Finite element method analysis and single equivalent diagonal strut method are used to estimate the strut width reduction factor and variation in lateral stiffness when opening sizes vary. The key to find these parameters is equivalent diagonal strut width with openings. For instance, single bay single story has been analysed by using both FEMA and SEDS method for different cases of opening sizes and the graphs are presented in figure 13 & figure 14. Now we will the equivalent diagonal strut width with opening by correlating the two graphs. For example, $h_o/h_i=0.125$, $k_o/k_i=1$ we get $w_o/w_i=0.085d$ where $d$ is the diagonal length of infill.
A. Effect of openings:

1. Finite Element Analysis:

   - Single Storey
   - Two Storey
   - Three Storey

   ![Finite Element Model](image)

   Figure 13: Effect of opening size on equivalent diagonal strut

2. SEDS Analysis:

   ![SEDs](image)
3. Regression analysis:

The regression analysis of the data obtained from FEMA and SEDS analysis has performed and linear and third order polynomials are shown in figure 15 and figure 16.

The linear fit follows the data reasonably good and the equations obtained from figure 15 are:

- For one story:
  \[ \rho_w = -2.7897\alpha_{co} + 0.99 \]
  \[ R = 0.968 \]

- For two story:
  \[ \rho_w = -7.5635\alpha_{co} + 0.9608 \]
  \[ R = 0.959 \]

- For three story:
  \[ \rho_w = -7.2432\alpha_{co} + 0.9804 \]

The data of all the three stories are plotted in a single figure 17 and regression analysis is performed. A linear fit curve follows the trend line reasonably good. The equation for strut width reduction factor can be given as follow regardless of number of stories.
Figure 15: Effect of opening area ratio on strut width reduction factor: linear fit curves of analytical results

(a) Single Storey

$\rho_w = -7.2432\alpha_{co} + 0.9804$

$R=0.919$

(b) Two Storey

$\rho_w = 1.001 - 4.0391\alpha_{co} + 27.697\alpha_{co}^2 - 148.15\alpha_{co}^3$

$R=0.973$

(c) Three Storey

$\rho_w = 886.97\alpha_{co}^3 - 189.53\alpha_{co}^2 + 3.1272\alpha_{co} + 0.8243$

$R=0.969$

Figure 16: Effect of Opening Area Ratio on Strut Width Reduction Factor: Third Order Fit Curves of Analytical Results

(a) Single Storey

$\rho_w = 886.97\alpha_{co}^3 - 189.53\alpha_{co}^2 + 3.1272\alpha_{co} + 0.8243$

$R=0.969$

(b) Two Storey

$\rho_w = 273.37\alpha_{co}^3 - 21.409\alpha_{co}^2 - 8.9592\alpha_{co} + 1.0488$

$R=0.94$

(c) Three Storey

$\rho_w = 273.37\alpha_{co}^3 - 21.409\alpha_{co}^2 - 8.9592\alpha_{co} + 1.0488$

$R=0.94$
VI. CONCLUSIONS

1. It is observed that from the results for a given plan dimensions, the seismic parameters such as base shear, lateral displacement, story drift, lateral stiffness are varying with change in aspect ratio.
2. If aspect ratio increase the lateral displacement decreases and lateral stiffness varies. Hence, aspect ratio is also a considerable factor in analysis of RC frame infilled buildings.
3. The size and location of openings are also considerable in structural analysis.
4. The lateral stiffness decreases with increase in size of opening.
5. If the height or width of openings equal to height or width of full infill then there will be a sharp decrease in lateral stiffness.
6. If two similar rectangular frames of equal areas of openings are taken then the frame having larger width of opening exhibits more lateral stiffness.

REFERENCES