STUDY OF SEISMIC RESPONSE OF 12 STOREY RCC BUILDING CONSIDERING INFILL PANELS AS PER INDIAN STANDARDS

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ABSTRACT. Masonry infills in structures are normally considered as non-structural elements and their contribution in the stiffness of structure is generally ignored in practice, this assumption can lead to an unsafe design. The infill wall though constructed as secondary element of a structure behaves as a integral part of the structural system and also determines the behaviour and response of the structure, especially when the structure is subjected to lateral loads. This paper presents response spectrum analysis of 12 storey reinforced concrete office building considering bare frame, masonry wall infilled frame and frame with equivalent diagonal strut model of infill as specified in IS 1893 (part1):2016. The analysis was carried out in ETABS and a spreadsheet was developed to perform the manual calculation of response spectrum analysis to validate and compare the results obtained from ETABS. The results showed significant effect in the base shear and displacement of the structure. As the stiffness of the structure increased, it started attracting more force on to it thereby increasing the base shear value and reducing the maximum displacement of structure. The results obtained from manual calculations and software analysis were found to be comparable and within acceptable limits which indicates the suitability of the method provided in IS code for analysis. The paper also highlights some points, newly added in IS 1893 (part1):2016, which need some attention from authors.

Keywords: Masonry Walls, Equivalent Strut, Response Spectrum Analysis, ETABS

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INTRODUCTION

As far as structural response is concerned, the infill walls play an important role in the structural response and its behaviour to lateral loads especially seismic loads. The infill walls have a wide variability in structural behaviour due to ground motion characteristics, mechanical properties of infills, overall geometry, presence of openings etc. The presence of infill can lead to improved performance of a building as well as increase in the overall mass of the structure which results in increased base shear values. A well-designed structure with proper implementation of infill can increase the strength of the structure, the lateral stiffness and resistance which reduces lateral deflection.

Various models of analysis of buildings with infill walls have been developed by researchers through rigorous research and experiments considering the infills as integral elements of structure and thereby taking part in lateral load resistance. The equivalent strut models put forward by authors are found to be effective in simulating the behaviour of the infill walls. Polyakov (1960) first conducted the experimental tests on masonry Infill walls and proposed that the walls behaved as bracings. Holmes (1961), Stafford-Smith (1962) and Mainstone (1971) put forward their theories and methods to calculate the equivalent width of diagonal struts for infill walls supported by their test results. Many revisions were later provided by researchers based on their works.

The paper focuses on the implementation of the method of calculating equivalent strut model as recommended in IS 1893 (part1):2016. In the present work the equivalent strut model is calculated and modelled in ETABS also similar models with infill walls and without infill walls are modelled to obtain a comparative data of response of structure for lateral seismic loads and response spectrum analysis.

DIFFERENT METHODS AVAILABLE FOR CALCULATING EQUIVALENT STRUT PARAMETERS

Various methods for determining the equivalent strut parameters for an infill wall are available which are widely used in various parts of world

**Indian code IS 1893 (part1) :2016**

- The equivalent strut width as adopted by IS 1893:2016 is a modification of the formula given by Mainstone in 1971 and is given by:

  \[ W_{ds} = 0.175(\lambda H_{inf})^{-0.4}L_{ds}, \]

  Where,

  \[ \lambda = \frac{4E m t \sin^2 \theta}{4E f I_c H_{inf}} \]

- For URM walls with openings no reduction in width is required.
- Thickness of Equivalent diagonal strut shall be taken as thickness of original URM infill wall, provided \( \frac{H_{inf}}{t} < 12 \) and \( \frac{l}{t} < 12. \) (This is a major drawback)
Mainstone (1971) / FEMA 306 / ASCE/SEI 41-06 / ERDC/CERL

- Based on experimental observations, Mainstone gave formula for calculating width of equivalent diagonal strut which incorporates the relative stiffness of frame to infill as given by Stafford and Carter. This formula is widely adopted by many other future publications such as FEMA306 & ERDC/CERL.

\[ W_{ds} = 0.175(\lambda H)^{-0.4}L_{ds} \]

Where,

\[ \lambda = \frac{4 \sqrt{E_m \text{Sin}^2 \theta}}{4E_{fc}H_{inf}} \]

- If there are any openings present in the infill panel and/or there is existing infill damage, the reduced equivalent strut width must be reduced as follows:

\[ W_{ds(red)} = W_{ds}(R_1)(R_2) \]

Where, \( R_1 = \) Reduction factor for in-plane evaluation due to presence of opening
\( R_2 = \) Reduction factor for in-plane evaluation due to existing infill damage.

HOLMES (1961)

Holmes based on his observation of steel frame and corresponding values of horizontal thrust and deflection the width of equivalent diagonal strut was given as:

\[ W_{ds} = \frac{L_{ds}}{3} \]


- Non-integrated infilled frames are those in which the infill and the frame are not bonded together.
- Through experimental and analytical methods, they studied nonlinear behavior of non-integral infilled frames.
- Using their experimental results, the following formula was given:

\[ W_{ds} = \frac{0.95H_{inf} \text{Cos} \theta}{\sqrt{\lambda H_{inf}}}, \quad \text{when friction is included} \]

and least of \( W_{ds} = 0.45H_{inf} \text{Cos} \theta \) and \( \frac{0.86H \text{Cos} \theta}{\sqrt{\lambda H_{inf}}}, \) when friction is not included.

Turkish code, TEC (2007)

The Turkish code has specified the width of equivalent strut as given in the expression below
\[ W_{ds} = 0.175(\lambda H)^{-0.4}L_{ds} \]

Where,
\[ \lambda = \frac{4E_m\sin^2\theta}{\sqrt{4E_fI_cH_{inf}}} \] and \[ E_m = 200f'_m \]

In all the above expressions,
- \( I_c \) = Moment of inertia of the adjoining column
- \( E_m \& E_f = \) Modulus of elasticity of masonry wall and RC frame
- \( t = \) Thickness of infill wall
- \( \theta = \) Inclination of strut with horizontal
- \( h = \) Clear height of RC frame between top and bottom slab
- \( L_{ds} = \) Length of equivalent strut (Fig. 1)

**MECHANICS INVOLED IN INFILL PANEL**

Figure below shows a frame ABCD with a wall infill subjected to a horizontal shear force, \( H \), giving rise to complementary vertical shear forces of \( H\tan\alpha \). The resultants of these shear forces are compressive forces \( \frac{H}{\tan\alpha} \) acting at B and D along the diagonal BD. At failure the wall and frame will only be in contact near B and D, as shown in figure 1. The equivalent strut is also shown in the same figure, where the wall panel has been replaced by an equivalent strut BD and the shear forces carried by the frame alone are also shown:

![Figure 1 Application of horizontal shear force to frame](image)

Hence from the above figure it is clear that the masonry infill panels behave as a diagonal strut during loading and finding the width of this diagonal strut has been given primary importance by many researchers as it influences the infill behaviour which in turn influences stiffness and strength properties of frame with infill.

**MODELLING DETAILS**

The details of the framed building model along with loading are provided in the Table 1. All loadings such as dead loads, live loads and seismic load are calculated and applied on the structure as per Indian standard recommendations such as IS 875-Part-1(1987), IS 875-Part-2(1987), and IS 1893-Part-1(2016).
### Table 1 Model and Loading details

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
</tr>
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<tbody>
<tr>
<td>NUMBER OF STORIES</td>
<td>G+11</td>
</tr>
<tr>
<td>Plan Dimension</td>
<td>22.5m x 22.5m</td>
</tr>
<tr>
<td>Spacing between frames</td>
<td>7.5m along both directions</td>
</tr>
<tr>
<td>Floor Height</td>
<td>Ground Floor 5.2m</td>
</tr>
<tr>
<td></td>
<td>Other floors 5m</td>
</tr>
<tr>
<td>Elevation from depth of fixity</td>
<td>60.2m</td>
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<tr>
<td>Size of Beam</td>
<td>0.3m x 0.6m</td>
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<tr>
<td>Size of column</td>
<td>0.5m x 0.5m</td>
</tr>
<tr>
<td>Depth of slab</td>
<td>100mm</td>
</tr>
<tr>
<td>Thickness of infill panel</td>
<td>0.23m</td>
</tr>
<tr>
<td>Grade of concrete</td>
<td>M30</td>
</tr>
<tr>
<td>Grade of steel</td>
<td>Fe415</td>
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<tr>
<td>Unit weight of Concrete</td>
<td>25 kN/m³</td>
</tr>
<tr>
<td>Unit weight of steel</td>
<td>78.5 kN/m³</td>
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<td>Unit weight of Infill</td>
<td>20 kN/m³</td>
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<tr>
<td>Damping factor</td>
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<td>Location</td>
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<td>Seismic zone</td>
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<td>Importance factor</td>
<td>1</td>
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<tr>
<td>Response reduction factor</td>
<td>5</td>
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</tbody>
</table>

**Soil type**  
Medium (type II)

**Live load on floor**  
- Up to 11th storey: 4 kN/m²  
- On roof: 1.5 kN/m²

Figure 2 Plan and 3D view of 12 Storey building with equivalent diagonal strut
Three cases were considered for the models for analysis and comparison. In the first case, models with the below mentioned properties were modelled in ETABS with just the RC frame present. The infill walls were not considered here. In the second case, Infill walls were modelled in all directions with the above-mentioned properties and dimensions the 12-story building.

**METHODOLOGY**

- Three cases were considered for the models for analysis and comparison.
- In the first case, models with the below mentioned properties were modelled in ETABS with just the RC frame present. The infill walls were not considered here.
- In the second case, Infill walls were modelled in all directions with the above-mentioned properties and dimensions the 12-story building.

Figure 3 Plan and 3D View of the structure with modelled infill walls

Figure 4 3D view of the bare frame
In the third case, the instead of the infill walls the calculated equivalent strut was modelled between the frames as Pin-Ended Diagonal compression members as suggested by the latest addition in the Indian code IS 1893-Part 1-2016.

The resultant 3 models were analysed for Seismic loadings as per Indian standards.

The response of these cases was compared such as Base Shear and Maximum Joint Displacement.

The steps followed for the manual calculation of the response of the structure can be summarised in the following points:

i. Dead Loads were calculated as per the dimensions and Live loads were obtained according to IS 875: Part I and II respectively. The total load on each floor was calculated and the structure is converted to be a lumped mass system.

ii. The stiffness between the masses were obtained by combining the stiffness of the columns as well as the infill panels (converting it to equivalent diagonal strut as per is 1893:2016).

a) Stiffness of columns

\[ k_c = \frac{12EI}{l^3} \]

- k = Stiffness of a column in kN/m (to be multiplied by the number of columns to get the total stiffness of a set of columns)
- E = Modulus of Elasticity of Concrete in kN/m²
- I = Moment of Inertia of column in m⁴
- l = effective length of column in m

b) Stiffness of Infill Panels as per IS 1893:2016

Width of equivalent diagonal strut

\[ w_{ds} = 0.175\alpha_h^{-0.4}L_{ds} \]

\[ \alpha_h = h \left[ \frac{\sqrt{\frac{E_m t \sin 2\theta}{4E_f I_c h}}} {4E_f I_c h} \right] \]

- \( E_m \) = Modulus of Elasticity of infill material in kN/m²
- \( t \) = Thickness of the infill panel in m
- \( \theta \) = angle made by the diagonal strut with the horizontal in degrees
- \( E_f \) = Modulus of Elasticity of RC Frame material in kN/m²
- \( I_c \) = Moment of Inertia of column in m⁴
- \( h \) = height of the column
- \( L_{ds} \) = Diagonal Length of the equivalent strut

\[ k_p = \frac{A E_m}{L_{ds}} \times \cos^2 \theta \]

c) Stiffness of a floor in a direction = \( \Sigma k_c + \Sigma k_p \) (in that direction)

iii. The combined stiffness and mass matrix for the lumped mass system is obtained. Using MATLAB, the eigen value problem is solved to obtain the modal matrix(\( \Phi \)) and the corresponding frequency matrix(\( \omega \)) from which the time periods corresponding to each mode is calculated(\( T \)).

iv. Simplified method for dynamic analysis of buildings

a) Modal mass \( (M_k) \)
\[ M_k = \frac{\left[ \sum_{i=1}^{n} W_i \Phi_{ik} \right]^2}{g \sum_{i=1}^{n} W_i (\Phi_{ik})^2} \]

\( g = \text{acceleration due to gravity} \)

\( \Phi_{ik} = \text{mode shape coefficient at floor } i \text{ in mode } k \)

\( W_i = \text{Seismic weight of floor } I \text{ of the structure} \)

\( n = \text{number of floors of the structure} \)

b) Mode participation factor

\[ P_k = \frac{\sum_{i=1}^{n} W_i \Phi_{ik}}{g \sum_{i=1}^{n} W_i (\Phi_{ik})^2} \]

c) Design lateral force at each storey

\[ Q_{ik} = A_k \Phi_{ik} P_k W_i \]

\( A_k = \text{Design acceleration spectrum value} \)

d) Storey shear forces in each mode – Peak shear force \( V_{ik} \) acting in storey \( i \) in mode \( k \) is given by

\[ V_{ik} = \sum_{j=i+1}^{n} Q_{ik} \]

e) Storey displacement values can be obtained by using the expression

\[ U_{ik} = P_k \Phi_{ik} \left( \frac{A_k}{w_k} \right) \]

RESULTS

The seismic analysis of all the frame models were carried out in ETABS. The models included bare frame model, framed model with masonry infill and framed model with equivalent struts. The parameters which are to be studied are Time period, Base shear and maximum storey displacement. For analysis on ETABS all three models were taken whereas for manual analysis the case considering presence of infill wall is not done.

<table>
<thead>
<tr>
<th>Floor Nos</th>
<th>Seismic WT of each floor[kN]</th>
<th>mode 1</th>
<th>mode 2</th>
<th>mode 3</th>
<th>mode 4</th>
<th>mode 5</th>
<th>mode 6</th>
<th>mode 7</th>
<th>mode 8</th>
<th>mode 9</th>
<th>mode 10</th>
<th>mode 11</th>
<th>mode 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor 1</td>
<td>4893.6/2.5/kN</td>
<td>0.01474</td>
<td>0.01497</td>
<td>0.01446</td>
<td>0.01444</td>
<td>0.01494</td>
<td>0.01436</td>
<td>0.01426</td>
<td>0.01414</td>
<td>0.01386</td>
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<td>Floor 10</td>
<td>7728.125/kN</td>
<td>0.01434</td>
<td>0.01324</td>
<td>0.01112</td>
<td>0.00812</td>
<td>0.00447</td>
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<td>0.012294</td>
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</table>

**Figure 5** Excel sheet results for mode shapes and time period for different modes (with infill panels)
Figure 6 Excel sheet displacement for each mode (with infill panels)

Figure 7 Excel sheet showing base shear for each mode (with infill panels)

Figure 8 Excel sheet showing modal matrix and time period for different modes (without infill panels)
Figure 9 Excel sheet showing base shear for each mode (without infill panels)

<table>
<thead>
<tr>
<th>Floor No.</th>
<th>U1(m)</th>
<th>U2(m)</th>
<th>U3(m)</th>
<th>U4(m)</th>
<th>U5(m)</th>
<th>U6(m)</th>
<th>U7(m)</th>
<th>U8(m)</th>
<th>U9(m)</th>
<th>U10(m)</th>
<th>U11(m)</th>
<th>U12(m)</th>
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Figure 10 Excel sheet showing displacement for each mode (without infill panels)

Figure 11 Graph showing comparison of time periods
The base shear value is more in the infilled frame than the bare frame model. This is due to the reason of inclusion of infill walls in the modal mass of the structure and increase in stiffness of the structure which as a result attracts more force.

Considerable difference in time period and storey displacement is seen, this is due to the increase in lateral stiffness of the structure.

The values obtained from the software as well as the manual calculations are comparable and within acceptable limits of difference.
CONCLUSION

The results showed significant effect in the base shear and displacement of the structure. As the stiffness of the structure increased, it started attracting more force on to it thereby increasing the base shear value significantly. As stiffness is inversely proportional to the deflection, the increased stiffness due to infill has caused almost four-fold decrease in the displacement values. Thus, it is clear from the study that the effect of infill panels cannot be neglected while designing for horizontal forces. Considering infill panels in analysis would influence the seismic behaviour of frame structure to great extent since the panels increases strength and stiffness of the structure.

The consideration of infill panels is important because analysis of bare frame leads to the under estimation of the base shear values. This results in underestimated design which may lead to the failure of the structure during earthquake. Therefore, it is important that infill panels are considered while performing analysis of structures.

In IS 1893-Part 1(2016), clause 7.9.2.2-(d) it is stated that the thickness of the equivalent diagonal strut can be taken as thickness (t) of the URM wall provided, $\frac{h}{t} < 12$ and $\frac{l}{t} < 12$ where h and l are the clear height and length of the URM. This, provision is not satisfied when the thickness of strut is calculated and the value of $\frac{h}{t}$ generally comes greater than 12 therefore, this clause needs some clarification.

There is no provision for the consideration of openings in the infill panels. Openings can affect the behaviour of the panels when subjected to lateral loads, therefore the recommendations provided in the code could be expanded with inclusion of effect of openings.

ACKNOWLEDGEMENT

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