Pushover Analysis of High Rise Reinforced Concrete Building with and without Infill walls

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Abstract - Masonry walls are built in between reinforced concrete frame and generally considered as non-structural element. In design of building self weight of wall is considered as uniformly distributed load on beam without considering the stiffness and strength contribution of wall. In this study the effect of masonry walls on high rise building is studied. Nonlinear static analysis on high rise building with different configuration is carried out. For the analysis G+10 reinforced concrete framed building is modeled. The width of strut is calculated by using equivalent strut method. Seismic performance of various configurations of infill in reinforced concrete frames is obtained by performing nonlinear static analysis in SAP2000. The results of infill frames are compared with bare frame model.

Key Words: Infill wall, equivalent strut, high-rise building, nonlinear static analysis, stiffness

1. INTRODUCTION

Unreinforced brick masonry walls used as infill in reinforced cement concrete moment resisting frames are very common in India and in other developing countries. Masonry is a commonly used construction material in the world. The primary function of masonry is to either protect inside of the structure from the environment or to divide inside spaces for functional utility. When masonry infill is considered to interact with their surrounding frames, the lateral stiffness of the structure largely increases. In many countries situated in seismic regions, reinforced concrete frames are used as infill fully or partially by brick masonry panels with or without openings. Although the infill panels significantly enhance both the stiffness and strength of the frame, their contribution is often not taken into account because of the lack of knowledge of the composite behavior of the frame and the infill.

The effect of masonry infill panel on the response of reinforced concrete frames subjected to seismic action is widely recognized and has been subject of numerous experimental investigations, while several attempts to model it analytically have been reported. Infill wall can be modeled in several forms such as, equivalent diagonal strut, equivalent frame model, continuum model i.e. shell or membrane element, pier and spandrel model, finite element model, etc. In present study, infill walls are modeled as equivalent strut approach and seismic performance of various configurations of infill in reinforced concrete frames are compared with bare frame model. The main objective of this was to investigate the effect of masonry infill walls on the seismic behavior of reinforced concrete High-Rise building G + 10 stories with nonlinear static analysis method.

2. DESCRIPTION OF STRUCTURAL MODEL

The available modeling approaches for masonry infill can be grouped into micro and macro models. Micro models (continuum or finite element model) capture the behavior and its interaction with frames in much in detail, but these models are computationally expensive. While, macro models (equivalent strut and equivalent frame) try to capture overall behavior of the infill are approximate but computationally efficient. The diagonal strut model can be single diagonal strut, two diagonal strut or three-strut model. The single strut model is efficiently used in capturing behavior of infill in seismic analysis [1; 2; 3]. Three-strut model can estimate force resultants in RC members with sufficient accuracy, in addition to modeling the local failures in infill and in beams and columns due to interaction between masonry infill and RC frame. It was also observed that the single-strut model can be effectively used in cases soft or open storey buildings [4; 5]. Infill behaves like compression strut between column and beam and compression forces are transferred from one node to another. Masonry infill panels have been modeled by two strut elements along the two diagonals. Nonlinear gap elements have also been used, which are active in compression only [6]. There are various formulae derived by research scholars and scientist for width of strut. In this study, stiffness of wall is considered in plane of loading. For infill wall located in a lateral load resisting frame the stiffness and strength contribution of the infill are considered by modeling the infill as an equivalent strut approach given by FEMA- 356 [7] as below

\[ a = 0.175(\lambda_i h_{col})^{-0.4}f_{inf} \]  

(1)
\[ \lambda_1 = \left( \frac{F_{m} t \sin(\theta)}{4E_{f e} I_{col} h_{inf}} \right)^{1/4} \]  

(2)

where,
- \( h_{col} \) = Column height between centre lines of beams
- \( h_{inf} \) = Height of infill panel
- \( E_{fe} \) = Expected modulus of elasticity of frame material
- \( E_{m} \) = Expected modulus of elasticity of infill material
- \( I_{col} \) = Moment of inertia of column
- \( r_{inf} \) = Diagonal length of infill panel
- \( t \) = Thickness of infill panel and equivalent strut
- \( \theta \) = Diagonal angle
- \( f_{m} \) = Compressive strength of masonry

In this study, four different models of eleven story building symmetrical in plan are considered. Buildings are modeled using 40% masonry infill, but arranging them in different configuration as shown in fig. 2. The building has four bays in x-direction and y-direction with plan dimensions 20m×16m and storey height of 3.0m for each floor. Size of beam is 450mm×600mm and size of column is 750mm×750mm for bottom four stories and 450mm×600mm for upper stories. The columns are assumed to be fixed at the ground level. Depth of slab is considered as 120mm. Weight of floor finishes is 1.5 kN/m². Imposed load is considered as 2kN/m² on roof and 4kN/m² on floor. Slab loads have been distributed to frame elements according to yield line pattern.

M20 grade of concrete is used with modulus of elasticity 22360MPa, Fe415 grade of steel is used with yield strength of 415MPa with elastic modulus 2×10⁶MPa and unit weight of brick masonry is 20kN/m² with modulus of elasticity 2035MPa. Seismic zone V is considered for analysis.

To observe effect of infill on the behavior of frame building, following four different models are considered in the study.

Model I: Bare frame
Model II: Masonry infill are arranged in outer periphery
Model III: Masonry infill are arranged in outer periphery with soft storey
Model IV: Masonry infill are arranged as lift core
Plan

Sectional elevation
Model II

Sectional elevation
Model III
3. NONLINEAR ANALYSIS

In present study, nonlinear pushover analysis is used to determine the seismic response of structural system. Nonlinear analysis procedures help to demonstrate how building really works by identifying modes of failure and the total potential for progressive collapse. Under the Nonlinear Static Procedure, a model is subjected to gravity analysis (DL+0.5LL) and simultaneously displaced using preselected lateral load pattern until roof displacement reaches to a target displacement, and resulting internal deformations and forces are determined. Three different lateral load pattern used are:

1. Uniform load distribution in which forces are proportional to product acceleration and storey masses,

\[ F_i = m_i \phi_i \]

where,

\[ \phi_i = \text{Amplitude of the elastic first mode of the storey} \]

2. Modal which is proportional to product of the amplitude of first elastic mode and mass (m) of each storey

\[ F_i = m_i \phi_i \]

3. Codal in which lateral load distributed across the height of the buildings based on equation as per IS: 1893-2002 are used for the analysis.

\[ V_B = A_n W \]

\[ Q_i = V_B \frac{w_i h_i^2}{\sum w_i h_i} \]

where,

\[ V_B = \text{Design base shear as per IS: 1893 (Part-I): 2002} \]

\[ Q_i = \text{Lateral force at floor i} \]

\[ W_i = \text{Seismic weight at floor i} \]

\[ H_i = \text{Height of floor I measured from base} \]

\[ n = \text{No. of storey of building} \]

Columns and beams are modeled as frame elements. Default M3 hinges are assigned to beams and interacting PMM hinges are assigned to columns as per FEMA356. Masonry infill panels are modeled as single strut element with both ends pinned and active in compression only. Pushover analysis is carried out by displacement control method with the target displacement 4% of total height of building as per ATC40, 1996 [8]. Depending upon the properties of elements, acceptance criteria are defined according to FEMA356 and ATC40, as Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP) as shown in fig. 2. Here, these three points are defined as 10%, 60% and 90% of plastic hinge deformation capacity.
The resulting base shear and top displacements are considered to plot pushover curve. Performance evaluation using uniform lateral load pattern resulted in higher base shear and then in decreasing order for first modal and codal load pattern. Model II, III and IV (with infill) has increased base shear and decreased displacement with application of three different load patterns than Model I (bare frame). This shows that lateral strength and stiffness in increased due to presence infill panels.

4. RESULTS AND DISCUSSIONS


Table 1: Fundamental Natural Time period (sec) of various models

<table>
<thead>
<tr>
<th>Model No.</th>
<th>Model I</th>
<th>Model II</th>
<th>Model III</th>
<th>Model IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS: 1893-2002</td>
<td>1.0326</td>
<td>0.6641</td>
<td>0.6641</td>
<td>0.6641</td>
</tr>
<tr>
<td>SAP2000</td>
<td>0.6883</td>
<td>0.6417</td>
<td>0.6447</td>
<td>0.6725</td>
</tr>
</tbody>
</table>

The analytical Fundamental Natural Time Period does not match with the Time Period from empirical expression of the IS: 1893-2002. Introduction of infill panel in the reinforced concrete frame reduces time period of bare frames. Base shear and top displacement at performance levels are tabulated in table 2 for uniform, first modal and codal load pattern respectively.

Table 2: Base shear (P) and top displacement (∆) at performance levels for different configuration subjected to lateral load patterns

<table>
<thead>
<tr>
<th>Model No.</th>
<th>Performance Level</th>
<th>IO</th>
<th>LS</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lateral Load Pattern</td>
<td>P (kN)</td>
<td>∆ (mm)</td>
<td>P (kN)</td>
</tr>
<tr>
<td>Model I</td>
<td>Uniform</td>
<td>7161.49</td>
<td>59.19</td>
<td>9628.94</td>
</tr>
<tr>
<td></td>
<td>First modal</td>
<td>5525.93</td>
<td>65.73</td>
<td>6329.14</td>
</tr>
<tr>
<td></td>
<td>Codal</td>
<td>4123.40</td>
<td>50.41</td>
<td>6665.20</td>
</tr>
<tr>
<td>Model II</td>
<td>Uniform</td>
<td>6244.89</td>
<td>30.94</td>
<td>10831.74</td>
</tr>
<tr>
<td></td>
<td>First modal</td>
<td>5222.16</td>
<td>36.78</td>
<td>13939.73</td>
</tr>
<tr>
<td></td>
<td>Codal</td>
<td>4972.67</td>
<td>41.13</td>
<td>12408.73</td>
</tr>
<tr>
<td>Model III</td>
<td>Uniform</td>
<td>5759.69</td>
<td>29.27</td>
<td>13612.41</td>
</tr>
<tr>
<td></td>
<td>First modal</td>
<td>5117.69</td>
<td>36.45</td>
<td>11986.58</td>
</tr>
<tr>
<td></td>
<td>Codal</td>
<td>4917.78</td>
<td>41.21</td>
<td>12125.26</td>
</tr>
<tr>
<td>Model IV</td>
<td>Uniform</td>
<td>6791.25</td>
<td>34.21</td>
<td>19611.21</td>
</tr>
<tr>
<td></td>
<td>First modal</td>
<td>5340.97</td>
<td>37.73</td>
<td>14325.56</td>
</tr>
<tr>
<td></td>
<td>Codal</td>
<td>4436.09</td>
<td>37.43</td>
<td>12200.94</td>
</tr>
</tbody>
</table>

Chart 1 represents resulting pushover curve for different models subjected to uniform, first modal, codal load pattern respectively.

Chart -1: Force-displacement relationship

Performance evaluation using uniform lateral load pattern resulted in higher base shear and then in decreasing order for first modal and codal load pattern. Model II, III and IV (with infill) has increased base shear and decreased displacement with application of three different load patterns than Model I (bare frame). This shows that lateral strength and stiffness is increased due to presence infill panels.

5. CONCLUSIONS

The seismic behaviors of different configurations of infill wall panels are considered. Bare frame acts primarily as a moment resisting frame with the formation of plastic hinges at the joints under lateral loads. In contrast, the infill frame behaves like a braced frame resisted by a truss mechanism formed by the compression in tension in the seismic behavior of R.C.C. Framed High Rise building to large extent.

1. Due to infill walls in the High Rise Building top story displacement is reduced.
2. Time period of Building is reduced and Base shear is increased.
3. The presence of non-structural masonry infill walls can modify the seismic behavior of R.C.C. Framed High Rise building to large extent.
4. Arrangements of infill walls also alter the displacement and base shear in case of soft story.
REFERENCES


[10] SAP2000 V-14, CSI. Integrated finite element analysis and design of structures basic analysis reference manual; Berkeley (CA, USA); Computers and Structures Inc.