Non Linear Static Analysis of RC Frames with & Without Infill Walls

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ABSTRACT

A RC frame is made up of different type of components that are Beams, Columns, Slabs and others. When we took analysis of RC frame, as specified by architect's masonry wall are considered as infill and used in as a partition so in that way they do not take a part in vertical load bearing capacity of building but in most of the cases, ignorance made to this property of masonry during designing of the RC frame may get an unsafe design. Infill walls protect the internal part of building from natural hazards and also creates the separation inside, a part of this infill walls have subsequent strength and stiffness, and they have notable effect on the seismic response of the structural systems. In most of the times two types of structural damages observed caused by infill walls in earthquake i.e. soft stories and short columns. In present study two methods are used to calculate the effect of earthquake in RC frame that are considering with and without the stiffness of infill wall. The present study aims for the analysis of a bare frame and an infill frame by using ETABS 2015 software and the behaviour of both frames are compared in respect of different parameters. The models of G+19 RC frame has been prepared in ETABS 2015 software and has been performed for analysis as per IS 1893:2002. Story drift, story displacement, base shear and lateral forces are the parameters considered in this study for bare frame and infill frame. Pushover analysis is carried out on bare frame and infill wall frame using FEMA 440 approach method. The results of bare frame and infill wall frame are discussed and conclusions are made in this study

Keywords: RC Frame, Infill Walls, FEMA 440 etc.

Introduction

Earthquakes made high level of disasters and damages in past years, many reinforced concrete buildings collapsed due to this natural disaster. Millions of earthquakes occur on earth every year some of them are of very large intensity and cause destructive effects on structures and huge number of loss of life. However, many of them are of very small intensity and cause no damage to structures and life.

In practices the masonry infill walls are used as a partition in structures. These masonry walls are made with bricks/stones/hollow blocks and mortar mix. Brick made from burning clay is a unique construction material available in this sub-continent. It is used widely in our country as one of the principal construction material due to unavailability of stones and hollow blocks. Brick is used for partition walls in virtually all framed structures in our country, which also acts as infill to the frame so these walls are referred as masonry infill walls. They are constructed after completion of concrete frames, are considered as non-structural elements in the analysis and design of the structure in current practice. Although they are designed to perform architectural functions, but these walls do resist lateral forces with substantial structural action.

Literature Review

Polyakov (1956) has studied the infill frames that are subjected to racking loads, for this he carried out a research in CRIIS at Moscow. At first, the infill frame members of RC frame responded to behave like monolithic frame until they had separated from each other except for the smaller regions at the opposite side corners which were diagonally situated to each other. This was noticed during research that the failure mode of infill frame was showing cracks on opposite side compression diagonals. In this study all failure found was of cracking around the periphery of frame that was allowing the separation of frame except near the compression side corners. The study proposed to analyse the RC frame having infill frames by assuming them as "diagonal bracing struts"

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except near the compression side corners. The study proposed to analyse the RC frame having infill frames by assuming them as “diagonal bracing struts”

\[ \lambda_h = \sqrt[4]{\frac{E_m t_m h_m^3}{4E_c I_c}}, \quad \alpha = \frac{\pi}{2\lambda} \]

Where,

- \( E_m \) is the elastic modulus of the infill,
- \( t_m \) is thickness of the infill,
- \( E_c, I_c \) is the column rigidity and
- \( h_m \) is the height of the infill.

Stafford Smith and Carter (1969) extended his previous study that is discussed above and included the square infill frames to rectangular walls. For this the equivalent strut width is defined as the function of \( \lambda_h \)

\[ \lambda_h = \sqrt[4]{\frac{E_m t_m \sin 2\theta h_m^3}{4E_c I_c}} \]

Code Provisions on Seismic Forces

**Design Load**

A building has to perform many functions satisfactorily. Hence, it should be designed for the minimum requirements recommended for these functions. The minimum requirements pertaining to the structural safety are being covered in IS: 875 (Part I to III). This code has provided the minimum design loads which have been considered as part of dead load, imposed load, wind loads. Following are the design load, which has been considered for analysis of the structure. Seismic load is considered as per IS: 1893.

**Dead Load IS: 875(Part 1)-1987**

Dead load has been calculated for each floor and consists of the self-weight of slab, floor finishing, self-weight of beams and columns.

**Imposed Load IS: 875(Part 2)-1987**

The magnitude of minimum imposed load that has been considered for the structural safety is provided in IS: 875 (Part 2)-1987. Imposed load depends on the occupancy class of the building. Here imposed load of intensity 3 KN/m\(^2\) has been adopted on floor and 1.5KN/m\(^2\).on roof.

**IS: 1893(PART-1)-2002 “CRITERIA FOR EARTHQUAKE RESISTANT DESIGN OF STRUCTURE”**

This is the fifth revision of the standard; in this revision the code is divided into five parts, which deals with different types of structures. Part-1 deals with general provisions and buildings, part-2 deals with liquid retaining Tanks-Elevated and ground supported.

**IMPORTANCE FACTOR (I)**

Certifies higher design seismic force for more important structures.

**Zone Factor (Z):**

It is a factor to obtain the design spectrum depending on the perceived maximum seismic risk characterized by Maximum Considered Earthquake (MCE) in the zone in which the structure is located. The basic zone factors included in this standard are reasonable estimate of effective peak ground acceleration.

<table>
<thead>
<tr>
<th>ZONE FACTORS, Z</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Seismic zone</strong></td>
</tr>
<tr>
<td>Seismic intensity</td>
</tr>
<tr>
<td>Z</td>
</tr>
</tbody>
</table>

**Response Reduction Factor/Ductility(R):**

It is the factor by which the actual base shears force that would be generated if the structure were to remain elastic during its response to the Design Basis Earthquake (DBE) shaking, shall be reduced to obtain the design lateral force. Earthquake resistant structures are designed for much smaller seismic forces than actual seismic forces that may act on them.

**Response acceleration coefficient**

Average response acceleration coefficient for rock or soil sites as given by Fig. 2 and Table 3 based on appropriate natural periods and damping of the structure. These curves represent free field ground motion. It is a factor denoting the acceleration response spectrum of the structure subjected to earthquake
ground vibrations and depends on natural period of vibration and damping of the structure depends on structural characteristics and soil condition. Structural characteristics include time period and damping.

Modelling and Analysis

The stone work infill has been demonstrated by equal inclining struts. Ordinarily in basic investigation it is viewed as that the Equivalent Static Analysis is more moderate against ground shaking for consistent structures or structures of littler tallness. Infilled outline structures are utilized to give horizontal protection in districts of high seismicity, particularly in those spots where brick work is as yet a helpful material, because of prudent customary reasons. Furthermore, infilled outline structures composed and built before the advancement of real seismic codes constitute a vital piece of the high-hazard structures in various countries. The rehabilitation of these buildings to resist seismic action implies, as a first step, the assessment in the code of practices of any country. Consequently, the analytical modelling of this type of structure represents an important issue for engineers and researchers involved in seismic design.

Modelling of Masonry Infill Walls

Basic architects have to a great extent disregarded the impact of brick work boards while choosing the auxiliary arrangement, accepting that these boards are fragile components when contrasted and the edge. The outline routine with regards to dismissing the infill amid the plan of the numerical model prompts significant mistake in foreseeing the sidelong firmness, quality and ductility. It is means observing that most of the computer programs commonly used by designers are not provided with some rational and specific elements for modelling the behavior of the masonry infills.

As of late, in view of commitments from numerous examiners, it has been demonstrated that there is a solid association between the infill brick work divider and the encompassing edge, prompting .

Structural Details:

- Unit weight of Reinforced Concrete = 25 kN/m³
- Unit weight of Brick = 19 kN/m³
- Zone factor = 0.36 (zone 5)
- Importance factor = 1.0
- Soil condition = Medium soil
- Damping = 5%

Parameters to find the equivalent diagonal strut:

- Size of beam = 400mm*400mm
- Size of column = 400mm*450mm
- Thickness of masonry infill, t = 0.230 m
- Diagonal length of masonry infill, d = 5.831 m
- Moment of Inertia of Beam / Column = 1.08 x 10⁻⁸ m⁴
- Modulus of elasticity of concrete = 2.5 x 10⁷ kN/m²
- Modulus of elasticity of masonry infill = 1.38 x 10⁷ kN/m²

Modelling and Analysis Using E-TABS

Description of Building Model

For the present study, a Reinforced Concrete Structure is selected. It has symmetrical layout and consists of twenty stories with each storey height of 3.5 m. Floor plan of all stories is rectangular with length of 16 m in x-direction and length of 16 m in z-direction. The number of bays in x-direction is 5 and number of bays in y-direction is 5. The width of each bay is 4 m in both x-direction and y-direction. All the columns of the building are located at the axes intersections.

MODELLING ASSUMPTIONS

All the macro models that are developed to determine the width of diagonal strut on performance of the building was created in E-TABS. While creating 3-D models, some basic assumptions were taking into consideration to decrease the complexity of the program and analysis run time. Also, it is known that there are lots of parameters that affect the behavior of the building system under loading, especially lateral loading. Material properties of the concrete and masonry are fixed for all the cases. Material properties of concrete are listed in Table 4.2.

STRUCTURALANALYSIS PROCEDURE (USING E-TABS)

The modelling of the building using E-TABS can be described in the following steps:

1. Pre-processing
2. Post-processing
3. Analysis and design of the model
4. Results
Pre-processing

Define Prototype model data
First of all, we start with a new model by taking force units as Kilo-Newton and length unit as meter. Then select the frame type by open the structure wizard option in E-TABS and after that define the length, height and width in X, Y and Z direction by entering the sufficient number of bays in respective direction.

Define Member properties
After deciding the frame, we define the material of beam and column and also assign the properties to the beams and columns.

Define type of Support
In order to perform the analysis of the structure, it is necessary to assign the type support. In this project, fixed supports are used at the base of the building.

Define load cases and load combinations
Before defining load combination, we need to define the different load cases which are considered in the analysis.

Post-Processing

Assign load to the structure
Loads play a vital role in the design of the building, so it should be carefully applied to the building. All the loads are assigned to the structure. Earthquake forces are assigned to the node created at the center of area of each floor level as per seismic forces calculated. Wind loads are also assigned to the structure. In order to assign uniformly distributed load (U.D.L.), member to which load is to be assigned is selected. Then the value of suitable load and distances are entered and assigned to the selected members of the structure as shown in figure 4.9. Floor load is assigned to the floors of the structure. Values of floor load and the range into which load has to be applied is entered and then assigned.

Analysis and design of the model
Analysis of the model is performed for all the static load cases. Analysis of the model is to be done before it is designed. After analysis is performed, suitable design code (IS 456) is selected from the dropdown list for designing the concrete frame. All the load combinations are selected for the design. E-TABS will design the frame members (i.e. beams and columns) for most critical load combination.

Fig. Elevation and 3-D view of Deflection in Infilled Frame
Result and Discussions

In this chapter mainly six types of results shown:

1. **Storey displacement for bare and infill frame**
   
   We see that the top floor displacement of bare frame due to static pushover analysis observed as 337.9 mm, the story displacement increases with the height of the floor from the base and get maximum value at top storey.

2. **Base shear for bare and infill frame.**
   
   We observed that maximum storey drift occur at fourth floor. The value of storey drift at fourth floor is 0.012328 mm also observed that storey drift increase first and reach to its maximum value at fourth floor then after the story drift again reduce its value till top floor.

3. **Storey drift for bare and infill frame.**
   
   We observed that the maximum storey forces of bare frame on bottom surface of first floor. The value of maximum storey force is 41606.6602 kN. From above results observe the values of story forces are reduced progressively to top floor. Lowest value of story force observed at top floor bottom surface is 2080.333 kN.

4. **Storey Forces Of Infill Frame**
   
   We observed that the maximum storey forces of infill frame on bottom surface of first floor. The value of maximum storey force is 69039.1722 kN. From above results observe the values of story forces are reduced progressively to top floor. Lowest value of story force observed at top floor bottom surface is 2290.253 kN.

5. **Storey Drift Of Infill Frame**
   
   We observed that maximum storey drift of infill frame occur at fourth floor. The value of storey drift at fourth floor is 0.012632 mm. also observed that storey drift increase first and reach to its maximum value at fourth floor then after the story drift again reduce its value till top floor.

6. **Max. Storey Displacement Of Infill Frame**
   
   We see that the top floor displacement of bare frame due to static pushover analysis observed as 348.7 mm. As shown in figure 5.6 the story displacement increases with the height of the floor from the base and get maximum value at top storey. The interval between the storey displacements is less in top floors as compare to the bottom floors.

![Figure 3.1: Max Story Displacements bare frame](image1)

![Figure 3.2: Max Story Drift bare frame](image2)
Figure 3.3: Storey Force Infill frame

Figure 3.4: Storey drift of infill frame

Figure 3.5: Max Storey Displacements infill frame

Figure 3.6: Comparison of Max Storey forces of bare frame to infill frame
Conclusions

In present study two types of models are considered, G+19 Bare frame and G+19 Infill frame. Above models are analysed in non linear static analysis or pushover analysis in ETABS 2015. After the simulation process the results compared between two models following conclusions are drawn:

A. **Base Shear**
   - The value of base shear increased by .... % in case of infill frame as compared to the bare frame. This phenomenon specifies that in case of infill frame the base shear has larger values as compared to bare frame. Due to increasing behavior in mass of the structure the inertia force at each floor level also increases, and after that the cumulative addition (Base Shear) of lateral forces also increases.

B. **Top Floor Displacements**
   - In case of infill frame top floor displacements are showing larger value as compared to the bare frame this is because of non linear static analysis. This analysis fractionate the dead weight of the structure in smaller segments and whole structure go through non linear range of increment in dead weight so the plastic hinges formed and structure reaches to its ultimate strength, in that way infill frame have larger dead weight in compare to the bare frame. In case of infill frame stiffness is also increasing, but the less increment in stiffness is showing more increment in mass of structure, this behavior leads to increment of overall displacement in case of infill frame.

C. **Storey Drift**
   - Storey drift in Infill frame are showing larger values that are in Bare frame. The results in both frames show that storey drift is increasing in between bottom storey to 4th storey and after that till the top storey (20th Storey), storey drift is decreasing. This is due to the dead weight till 4th storey is weighed for the total stories but stiffness is as of the 4th storey cumulative, and after 4th storey stiffness is playing an incremental role as dead weight is decreasing storey by storey till the top most storey.

D. **Stiffness in Bare frame** is less than that of Infill frame as compared, But as such the dead weight is more in infill frame than that of bare frame, Due to this the first fundamental frequency of loading and unloading is decreasing in infill frame and that results to the increment of 'Time Period', this leads to the less response of infill frame as compare to the bare frame.
E. The comparative behavior of storey displacements shows that infill frame have larger
displacements than that of bare frame, this leads to increase the overall capacity of infill frame
structure.

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