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NONLINEAR ANALYSIS OF STRESSES FOR TWO BAY THREE STOREYED REINFORCED CONCRETE INFILL FRAME

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ABSTRACT

The reinforced concrete (RC) moment-resisting frames with masonry infill walls is widely used in buildings. In most cases the masonry Infill is neglected from the design which causes a negative impact in the framed system during a seismic behavior. In this study, two-bay and three-storeyed RC Bare Frame (BF), RC Infill frame (IF) with Cement mortar (CM) interface combinations scaled to a factor (1:6) are analyzed. The influence of constructional details of infill walls on the seismic behavior of RC frames is analyzed. Literature survey carried out in this area indicates that not much work has been done in studying the influence of interface material's properties on the behavior of IF frame. The objective is achieved by analytical studies. To investigate this, we modelled the behavior of frame structures with masonry IF in three ways such as a linear method and Pushover (PO) method. It is found that with the addition of masonry infill wall rigidly connected to the frame, the lateral strength, the stiffness of the BF RC frame increase significantly while the displacement ductility ratio decreases significantly. Numerical simulation of the BF and the IF frames is done with SAP2000 (Structural Analysis Package) a FEM (Finite Element Method) based software.

Key words: Bare frame, Infill frame, Infill, Interface, Linear, Nonlinear.

INTRODUCTION

Masonry Infill RC frames are very commonly seen in most of the part of the world. Primary reasons for the same are easily available construction materials, good insulation properties of masonry wall against heat and electricity, and the traditional practices in some cases. Under the lateral loads, caused by earthquakes, the response of such structures may be quite unpredictable, owing mainly to the brittle nature of IF walls.

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Past earthquakes have demonstrated the vulnerability of IF RC frames such as short-column effect, soft-storey effect, torsion and out-of-plane collapse. It is evident that the presence of infill walls can significantly enhance the lateral stiffness and strength of RC frames and result in a good energy dissipation capacity of the structure. The IF walls are not considered in design as the final distribution of these elements may be unknown to the engineers, or because masonry walls are regarded as non-structural elements.

Separation between masonry walls and frames is often not provided and, as a consequence, walls and frames interact during strong ground motion. This leads to structural response deviating radically from what is expected in the design. These are some of the negative effects of using IF frames. The IFs may cause a devastating effect if their arrangement results in a soft storey, especially in the ground floor. In addition, interaction between frame and IF may result in shear failure in frame members depending on the relative strength of frame and IF.

A very strong IF may result in a brittle post-peak behaviour besides causing shear failure in frames. However, force deformation behaviour of frames with stronger IF may be better than weak IF even if shear failure takes place in columns.

The following potentially negative effects of infill walls on the failure mode of RC frame structures should be considered: torsional effects induced by irregular arrangement in plane, soft-story effects induced by irregularities in elevation, short-column effects due to openings, and concentration of forces in elements of the frame due to the connection with the infill wall.

Methodology

The objective of this research work is to study the IF behavior of two bay three storeyed RC BF and IF. The scope of this analytical study is achieved by using SAP2000 (FEM based software) for 1:6 scaled RC 2D IF and BF. Numerical analysis of models will be carried out. IF forms a major role in seismic response of a building since not much knowledge is yet gained on the topic. Hence, this topic is chosen. Theoretical knowledge about the topic and the work to be done is gained from reading several journals. The modelling of BF and IF frame is done in FEM based software. Linear analysis is done for both the BF and the IF frames. Nonlinear analysis using push over analysis is done for better clarity of the frame behavior. The bare frame and infill frame details is shown in Fig. 1.

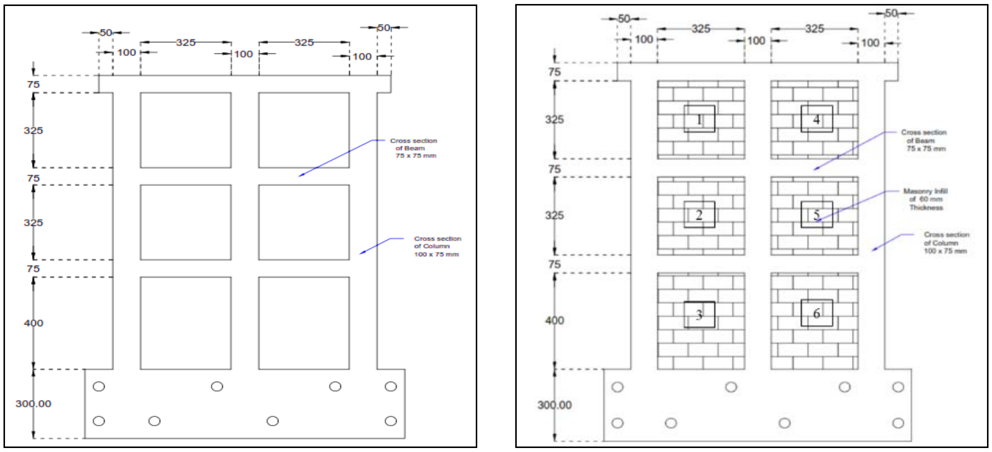
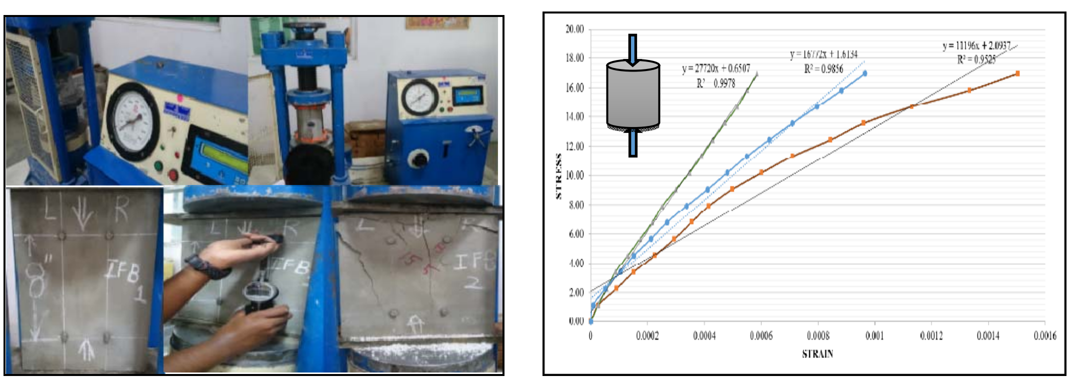


Fig. 1: Bare frame details and infill frame details

Properties of specimens

Experimental works are undertaken for calculating the material property to be used in the FEM based software. The mix design is carried out for a characteristic compressive strength of 20 N/mm2 at 28 days using Indian Standard method, IS 10262-2009. The mix proportion used is 1: 1.435: 2.782 by weight of cement, sand and coarse aggregate with water cement ratio 0.55 for casting all the specimens. For CM IS 4326 recommends minimum 1:6 mix proportion of cement and sand. The compression test of cubes was done in Compression testing machine and it is found to be 23.49 N/mm^2. The Modulus of elasticity of concrete cylinders was done using an Extensometer with a dial gauge arrangement and it is found to be 19.549 x 10^9 N/m^2. The modulus of elasticity of brick masonry was found using DEMEC strain gauge and it is found to be 18.635 x 10^9 N/m^2. The compression test of cylinders, prisms and their graphical representation and the test snaps are shown in Fig. 2.



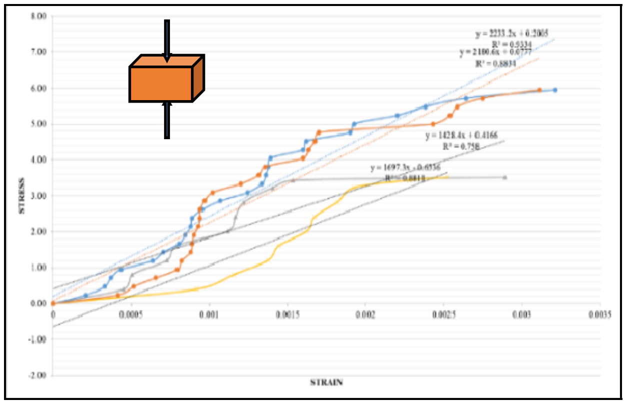


Fig 2: Experimental setup and results

Analytical studies

Finite element analysis can also be used to model the behavior numerically. Finite element analysis, as used in structural engineering, determines the overall behavior of a structure by dividing it into a number of simple elements, each of which has well-defined mechanical and physical properties. Modeling the complex behavior of RC, which is both non homogeneous and anisotropic, is a tedious task in the finite element analysis. Hence for simplified modelling, finite element based software is used.

Modelling

Material properties and frame member properties are assigned. The beams and columns are assigned as line elements. The base beam column joints are assigned with fixed restraints. The BF is two bay, three storeyed RC frame. The model created is a scaled model of an actual prototype building scaled to a factor of 1:6. The reinforcement details are inputted appropriately in frame properties for beams and columns. The 3D BF modelled in sap is shown in Fig. 6. The bare frame modelled before is taken. The IF is modelled in the FEM based software by discretizing the area element in the three storeys with 8 x 8 divisions. The interface at top and bottom of an area element is divided as 8x1 and the interface at left and right of the brick masonry IF as 1x8 divisions. The brick masonry and the BF RC frame has to be connected with link elements with a stiffness value of 100 N/m based on the convergence. In this case springs with a are used for effective transfer of stresses from frame to the IF. Without the links the frame and the interface, the IF combination is unique and doesn’t act as a single unit. The models are discretized to understand the behavior of the frame with more clarity. This discretization is done in other FEM based software packages by meshing. The 3d IF frame and IF with interface modelled in sap is shown in Fig. 3.

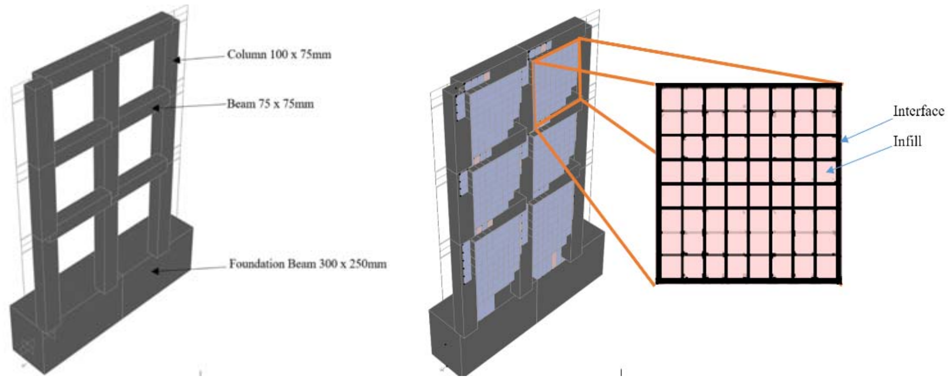


Fig. 3: 3D Bare and infill frame

Non linear analysis

Nonlinear analysis of RC structures has become increasingly important over the last decade. Although elastic analysis gives a good indication of elastic capacity of structures and shows where yielding will first occur. It cannot predict the redistribution of forces during the progressive yielding that follows and predict its failure mechanisms. The problem of developing a good material model for RC frame and IF frame is probably the most difficult task. Pushover analysis (PO) is a non-linear analysis procedure to estimate the strength capacity of a structure beyond its Limit State up to its ultimate strength. It can help demonstrate how progressive failure in buildings most probably occurs, and identify the mode of final failure. The method also predicts potential weak areas in the structure, by keeping track of the sequence of damages of each and every member in the structure. PO analysis uses a non-linear computer model for the analysis. This is done by incorporating hinges. These are points on a structure where one expects cracking and yielding to occur in relatively higher intensity so that they show higher flexural/shear displacement, under loading. Now select a lateral load pattern apply unit lateral point load. In this pattern the monotonic increasing lateral load will be applied to your structure until failure. Assign hinges to beams and columns on both the ends (SAP has inbuilt hinge properties of beam and column as per FEMA356/ASCE-41). The locations where one expects to see cross diagonal cracks in an actual building structure after a seismic mayhem would be at either ends of beams and columns, the 'cross' being at a small distance from the joint. This is where hinges are inserted in the corresponding computer model as in Fig. 4 and Fig. 5 showing typical moment hinge property.

These hinges have non-linear states defined within its ductile range as 'Immediate Occupancy' (IO), 'Life Safety' (LS) and 'Collapse Prevention' (CP).The analysis is done with gravity, dead and push load cases. Now run analysis. Each point on the PO curve or capacity curve obtained is consecutively checked to see whether the Sa-Sd at that point intersects the Response Spectrum curve known as Demand curve. For each point on the Capacity curve, the Demand curve has to be checked for intersection with the Response Spectrum curve. When the curves intersect, that meeting point is known as the Performance Pt. For the performance point the effective period is noted down and the steps coming under the effective period is checked if the frame exhibit any disastrous hinge behavior. The performance point is kept as references and all the steps with nearby time period is checked to be safe from hinge failure.

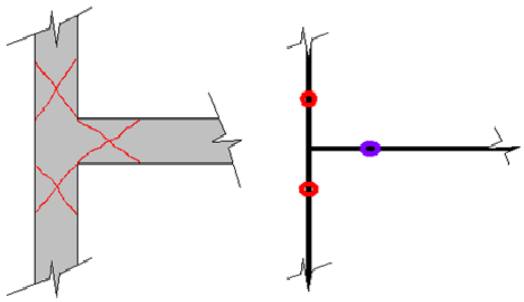


Fig. 4: Location of hinges and crack formation

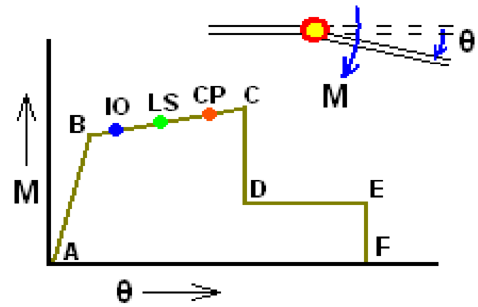


Fig. 5: Typical moment hinge property

Nonlinear results for infill frame

For IF frame the performance point is found to be at a Time Period of 0.020 seconds. Based on the Performance point the hinge formation between step 67 and step 73 in the IF frame has been checked for safety. The components of normal direct stress are called the principal stresses and are denoted as S11, S22 as in Fig. 6 and Fig. 7. The components of Shear stress along plane xy is denoted as S12 as in Fig. 8. These components of stress represent the maximum possible magnitude of tensile and compressive stress at the particular point under consideration. SVM is the plane element internal Von Mises stress at the specified point element as in Figure-9. For ease of understanding the compression and tensile stresses let the diagonal running from top left to bottom right be Sinister Diagonal (SD) while the other is Baroque Diagonal(BD).

S11: Direct stress (force per unit area) acting on the positive and negative 1 faces in the 1-axis direction.

S22: Direct stress (force per unit area) acting on the positive and negative 2 faces in the 2-axis direction.

S12: Shearing stress (force per unit area) acting on the positive and negative 1 faces in the 2-axis direction and acting on the positive and negative 2 faces in the 1-axis direction.

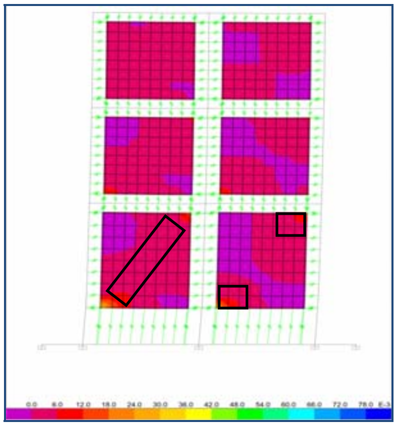


Fig. 6: Inplane direct stress along x axis

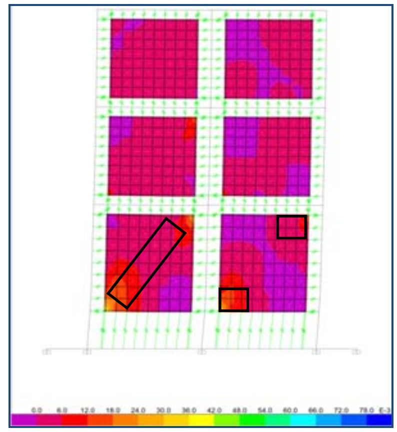


Fig. 7: Inplane direct stress along y axis

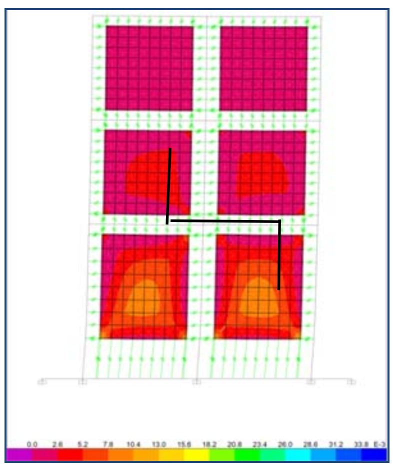


Fig. 8: Inplane shear stress along XY axis

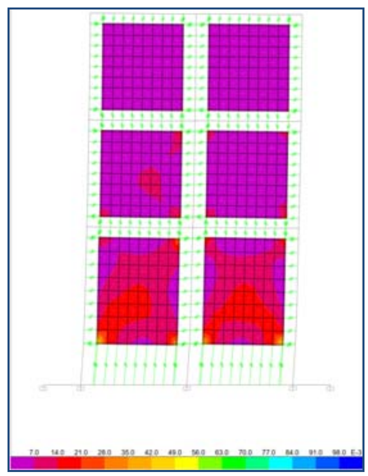


Fig. 9: Von mises stress at collapse stage

CONCLUSION

From the Nonlinear Pushover analysis, for the Performance points of Bare Frame and Infill frame the hinge formation is found to be safe. It shows that the resistance to yielding to higher hinge states in the case ofInfill frame is less when compared to that of the Bare Frame. In case of Bare Frame, the yielding period of the frame to collapse is long which makes the frame more ductile while in case of Infill Frame the collapse state is achieved at an earlier instant which makes it less ductile due to the increase in Stiffness.

The Maximum value of Von Mises Stress at collapse stage shows that the stress created at the planes causes material damage to the infill along the diagonal. Inplane Stresses shows that the corner crushing occurs at the beam column junctions and diagonal compression along Baroque Diagonal. Shear slip occurs in the infills due to the shear stress.

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