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SEISMIC PERFORMANCE EVALUATION OF REINFORCED CONCRETE FRAMES WITH VERTICAL IRREGULARITIES

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ABSTRACT

Reinforced concrete multi storey buildings are subjected to most dangerous earthquakes. It was found that main reason for failure of RC building is irregularity in its plan dimension and its lateral force resisting system. The provision of soft storey reduces the stiffness of the lateral load resisting system and a progressive collapse becomes unavoidable in a severe earthquake. In this paper an investigation is made to study the seismic behaviour of a reinforced cement concrete framed structure with and without infills in all the floors and soft storey effect. Infills were modelled using the equivalent strut approach. Non-linear pushover analysis (assigning the hinge properties to beams and column sections) was performed using SAP software. It is observed that seismic demand at the soft storey level is significantly large when infill stiffness is considered, with larger base shear and larger displacements.

Key words: Soft storey, Pushover analysis, SAP.

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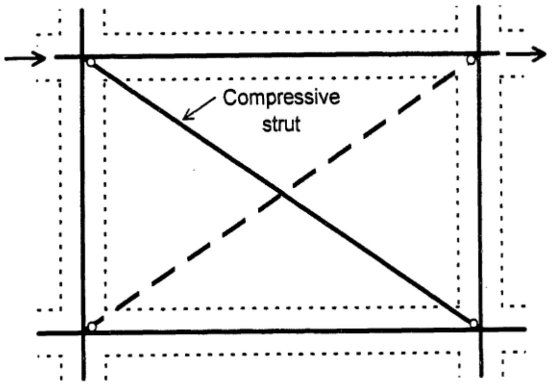
1. INTRODUCTION

Earthquakes are naturally occurring devastating events due to the sudden release of energy creating seismic waves. Recent earthquakes in India have demonstrated the power of nature and the catastrophic impact of such power on normal life. There are many reasons contributing to structural damage and collapse of buildings due to earthquakes. These include inappropriate land use decisions, low quality concrete, inadequate engineering especially at floor-column junctions, incorrect construction techniques, poor detailing and inadequate construction supervision. Reinforced concrete (RC) building frames with in-fill walls are usually analysed and designed as bare frames, without considering the strength and stiffness contribution of the in-fills. The presence of masonry in-fills can result in higher stiffness; however sudden reduction of stiffness due to damage of infill walls can lead to the formation of a soft storey mechanism, which, due to the introduction of joint damage, can occur at any floor level and independently of the distribution of the in-fills along the elevation.



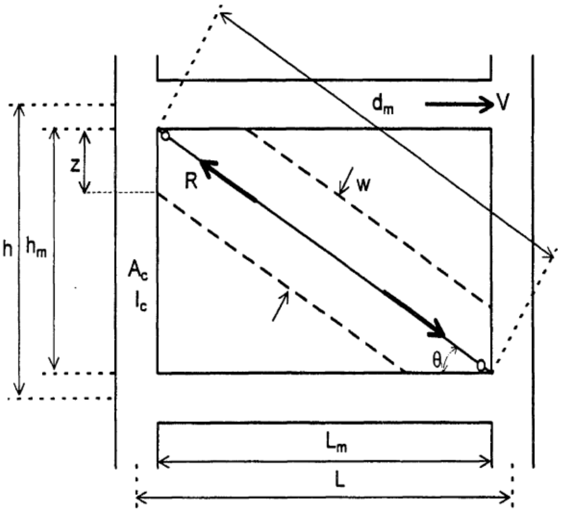


Figure 1.1 Diagonal strut model for in-filled frame **Figure 1.2** Effective width of diagonal strut

The width of the equivalent strut was proposed by Holmes, is

$$w = \frac{d_m}{3}$$

1.1. Earthquake Behaviour of the Construction with Soft Storeys

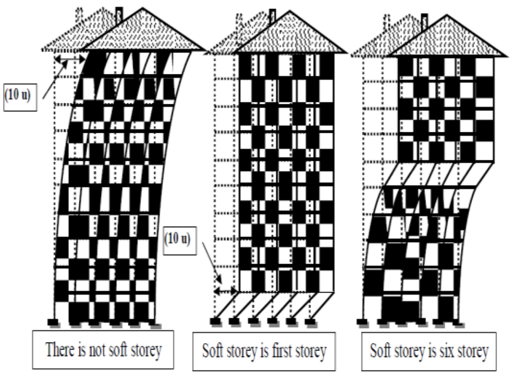
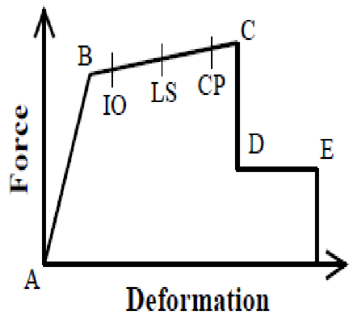


Figure 1.3 Behaviour of Soft storeys to earthquake

1.2. Pushover Analysis and SAP Modelling

Pushover analysis is a static, non-linear procedure in which the magnitude of the structural loading is incrementally increased in accordance with a certain predefined pattern.

The ATC-40 and FEMA-273 documents have developed modelling procedures, acceptance criteria and analysis procedures for pushover analysis. These documents define force-deformation criteria for hinges used in pushover analysis. As shown in Figure 1, five points labelled A, B, C, D, and E are used to define the force deflection behaviour of the hinge and three points labelled IO, LS and CP are used to define the acceptance criteria for the hinge. (IO, LS and CP stand for Immediate Occupancy, Life Safety and Collapse Prevention respectively.) The values assigned to each of these points vary depending on the type of member as well as many other parameters defined in the ATC-40 and FEMA-273 documents. The SAP2000 static pushover analysis capabilities, which are fully integrated into the program, allow quick and easy implementation of the pushover procedures prescribed in the ATC-40 and FEMA-273 documents for both two and three-dimensional buildings.



SAP is a sophisticated, yet easy to use, special purpose analysis and design program developed specifically for building systems. SAP version 14 features an intuitive and powerful graphical interface coupled with unmatched modelling, analytical, and design procedures, all integrated using a common database.

2. DESCRIPTION OF THE MODEL

The model frame is a three storey reinforced concrete frame with centre to centre plan dimensions of 3m x 2m with a total height of 5.4m, two bays in X-direction and single bay in Y-direction. Each storey height is 1.8 m. The longitudinal beam and transverse beam reinforcement consists of four numbers of 16 mm diameter and four numbers of 12 mm diameter bars respectively. Columns are reinforced with four numbers of 12mm diameter bars. Lateral ties in the columns and beams are 6 mm diameter two legged stirrups at a spacing of 150 mm c/c. Material used are M 25 grade concrete and Fe 415 steel. An additional mass of 1200 kg is added on each floor to represent equivalent live load. The size of longitudinal and transverse beam is 150x150mm and the size of the columns is 150x150mm. The thickness of the slab is 100mm and thickness provided for the walls is 4.5 inch i.e... 115mm. The beams and columns were modelled as 3D frame elements. Restraints at foundation were taken as fixed. The moment of inertia of section should be modelled to account for the effect of cracking in the form of set modifiers for moment of inertia. Set modifiers used for beam is 0.5 and for column is 0.7 to account for the effect of cracking as per ATC40. Slab is modelled as a rigid diaphragm and slab dead load and live load (additional mass) is applied on beams. The hinge properties are calculated using FEMA 356 and ATC 40. M-hinge is assigned for the beams and columns for the model analysed in this project. The pushover analysis is performed in the longer direction. The predominant mode shape is a parabolic, hence parabolic distribution of lateral load pattern is used and applied along the longer direction.

3. EFFECT OF VERTICAL IRREGULARITY ON REINFORCED CONCRETE FRAMES

Vertical irregularity refers to sudden change of strength, stiffness and mass, geometry results in irregular distribution of forces and/or deformation over the height of building.

These vertical irregularities should be considered if discontinuities in the load path, irregularity in strength and stiffness, irregularity in mass distribution and proximity of adjacent buildings. The irregularity in strength and stiffness represents a soft storey and weak storey. A “soft storey” is one in which the lateral stiffness is less than 70 percent of that in the storey immediately above, or less than 80 percent of the combined stiffness of the three stories above. A “weak storey” is one in which the storey’s lateral strength is less than 80percent of that in the storey above. The deficiency that usually makes a storey weak is inadequate strength of frame columns. The essential characteristic of a “weak” or “soft” storey consists of a discontinuity in strength or stiffness, which occurs at the second storey connections. This discontinuity is caused by lesser strength, or increased flexibility, the structure results in extreme deflections in the first storey of the structure, which in turn results in concentration of forces at the second storey connections. The result is a concentration of inelastic action.

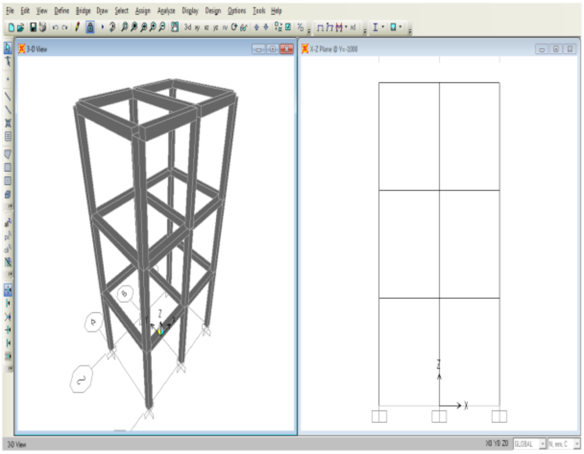


Figure 3.1 Basic SAP model of the Bare frame

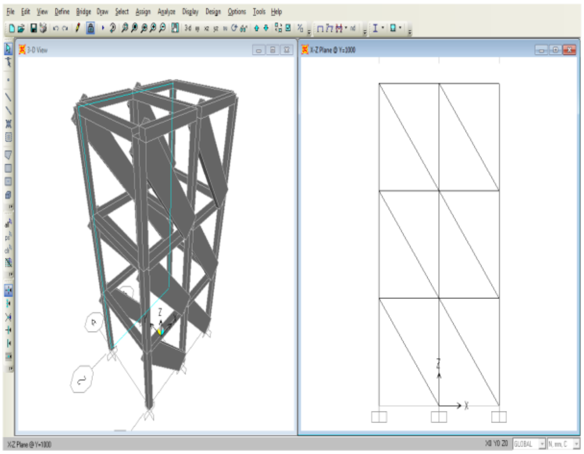


Figure 3.2 Basic SAP model of the In-filled frame

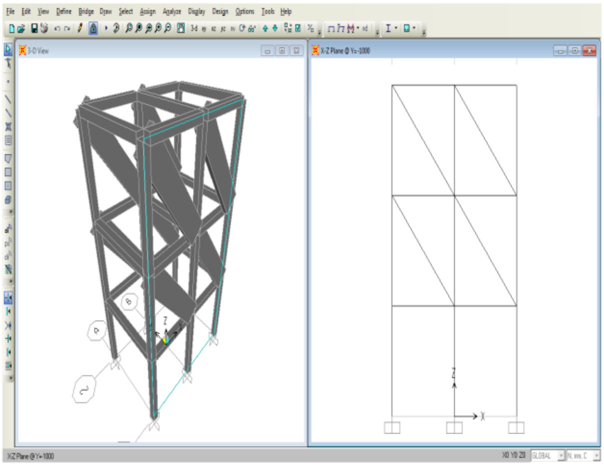


Figure 3.3 Basic SAP model of the Soft storey frame

4. ANALYSIS RESULTS

The in-filled frame has maximum base shear of 110 KN and displacement of 154mm. The bare frame has maximum base shear and displacement of 60KN and 88mm respectively. The soft storey frame has maximum base shear of 50KN and maximum displacement of 77mm. Among the bare frame, in-filled frame and soft storey frame the in-filled frame has maximum base shear and maximum displacement than the bare frame and soft storey frame.

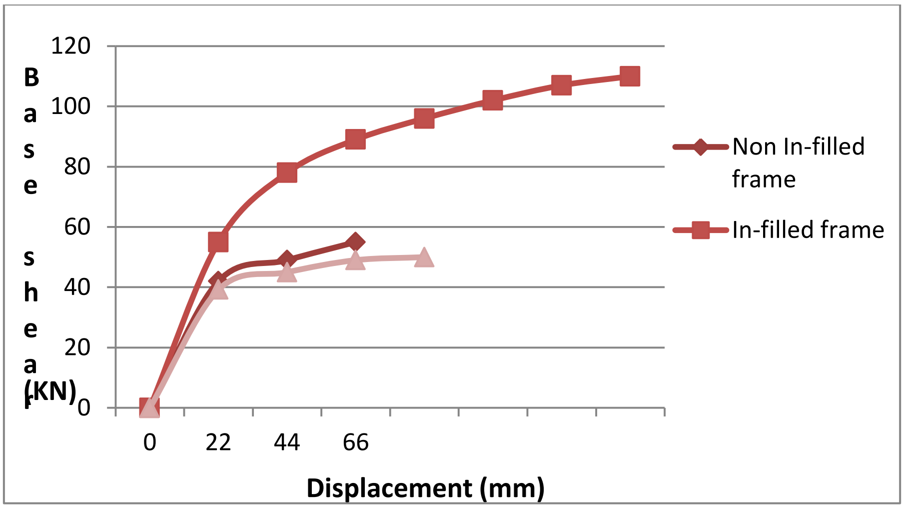
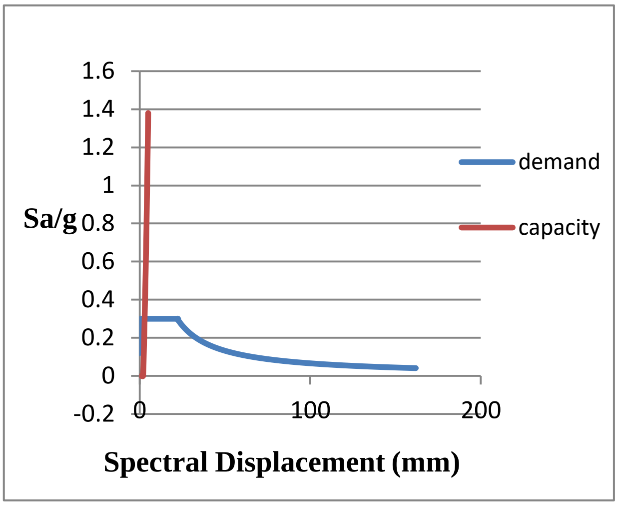
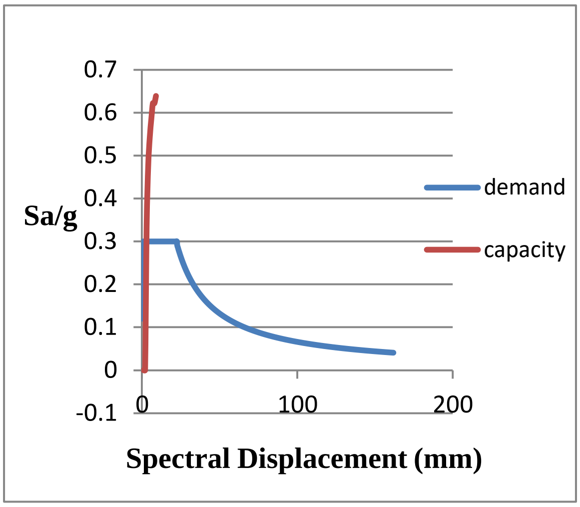


Figure 4.1 Pushover curves for bare frame, In-filled frame and Soft storey

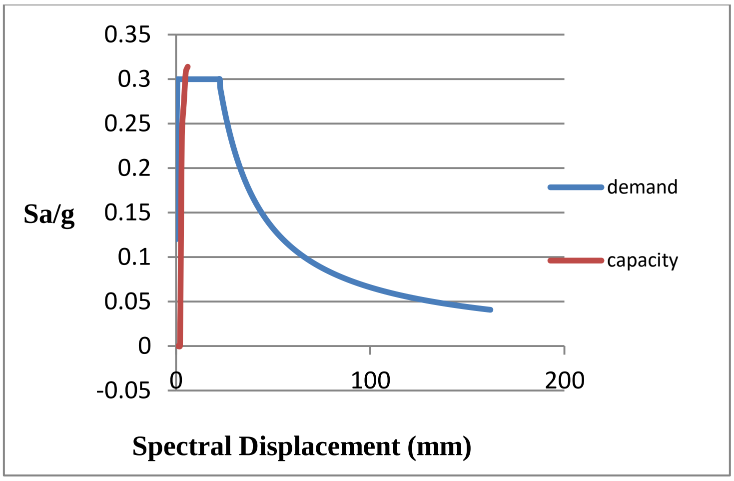
This pushover curve obtained from the pushover analysis should be converted to capacity curve then plot the capacity curve with demand spectrum.



(a) Bare frame



(b) In-filled frame



(c)Soft storey frame

Figure 4.4 Capacity and Demand spectrum of bare frame, In-filled frame and soft storey frame

The point where the capacity curve and demand spectrum meets is called as performance point. The performance point indicates the additional shear and displacement of the building frame.

Table 4.1 Performance points of bare frame, in-filled frame and soft storey frame

Description	Performance points		
	Without in-fills	**With in-fills**	**Soft storey**
Base shear (KN)	46.76	79.74	47.94
Displacement (mm)	40.27	47.67	50.34

Table 4.2 Time period values

S.No.	Description	Time period	Frequency
1	Without in-fills	0.447	2.237
2	With in-fills	0.489	2.045
3	Soft storey	0.497	2.012

Among the three model frames the soft storey frame has the maximum time period and its value is o.497sec. This indicates that the soft storey frame has less frequency than the bare frame.

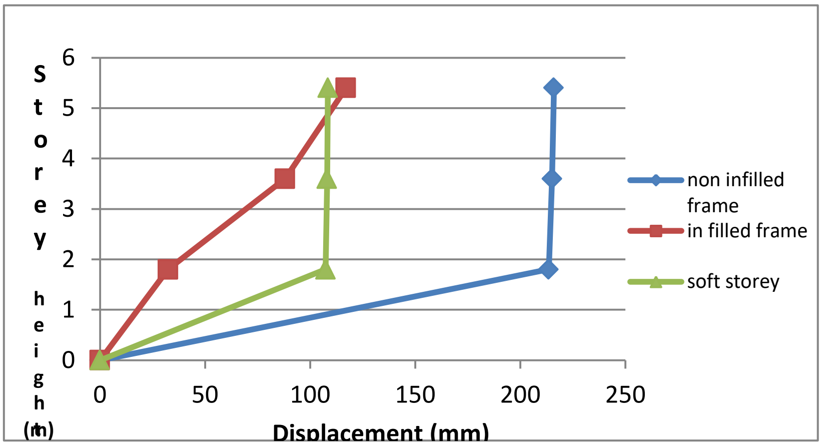


Figure 4.5 Displacement profiles of the bare frame, in-filled frame and soft storey frame.

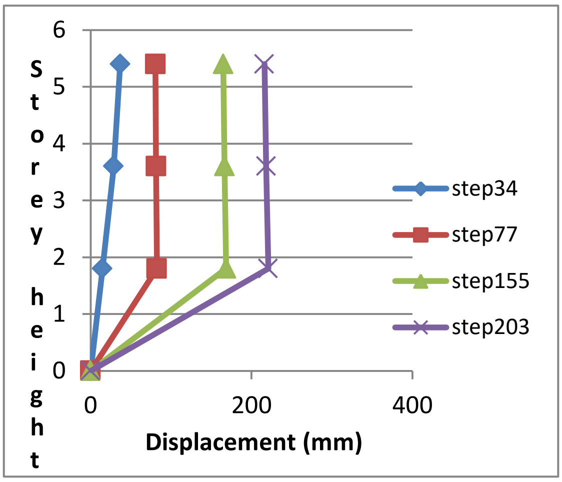


Figure 4.6. Bare frame with strong beam and weak column

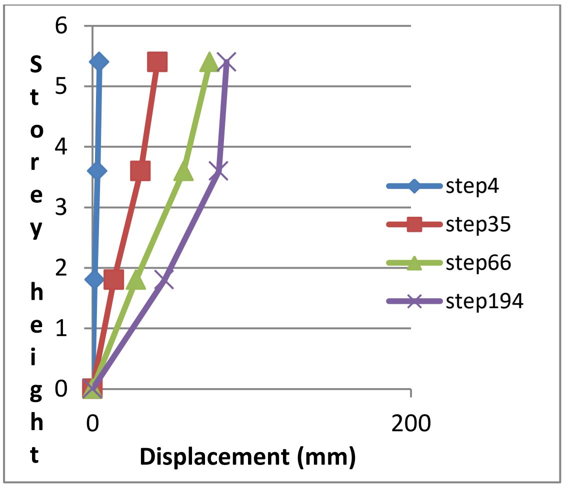


Figure 4.7.Bare frame with strong column and weak beam

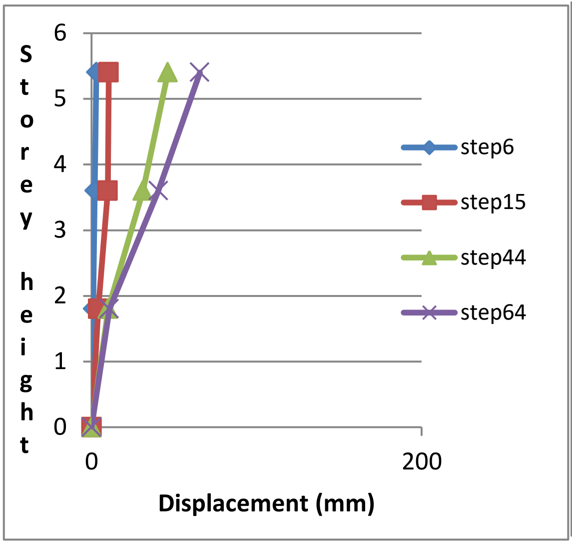


Figure 4.8 In-filled frame

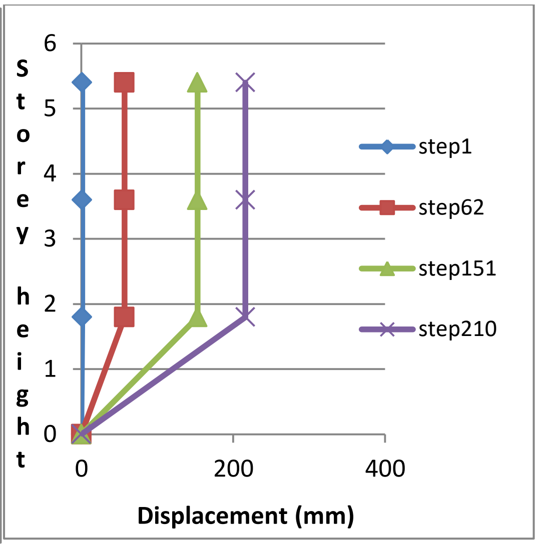


Figure 4.9. Soft storey frame

4.1. Hinge pattern of the reinforced concrete model frames

These include graphical representation of hinge status at each step of the analysis. The red hinges are in an inelastic state, meaning that the internal forces in the given element have surpassed its yielding moment limit and this affects the stiffness of the element and through that the stiffness of the entire structure. A properly designed ductile moment resisting frame will have plastic hinge formation in its beams first and after the beams the columns at the base will yield which eventually leads to the collapse of the structure.

It is important to avoid plastic hinge formation in the other columns of the structure and this often leads to the omission of plastic hinges from the columns except for the base column to speed up the analysis. If this practice is followed, it is important to check that the bending moments in the columns are below the yield moment to make sure that the columns are indeed in elastic state.

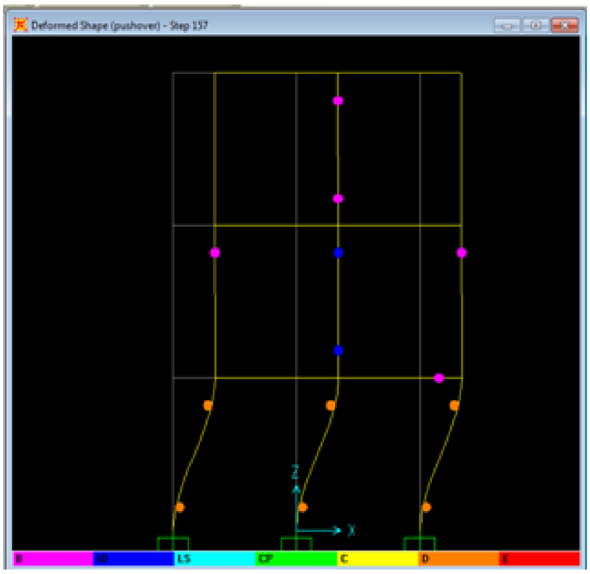


Figure 4.10. Bare frame with strong beam and weak column

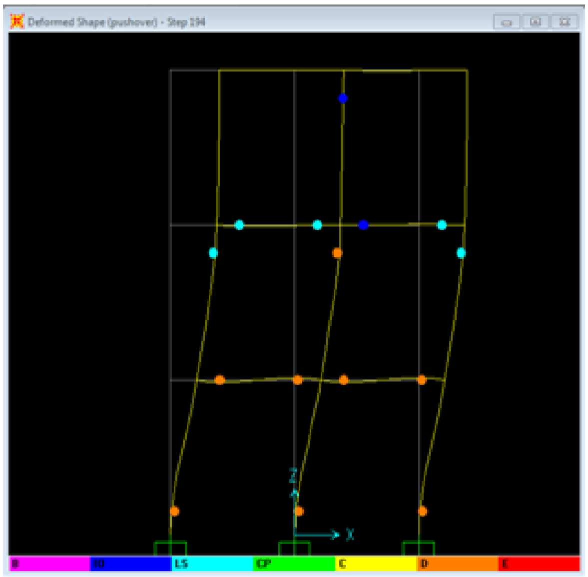


Figure 4.11.Bare frame with strong column and weak beam

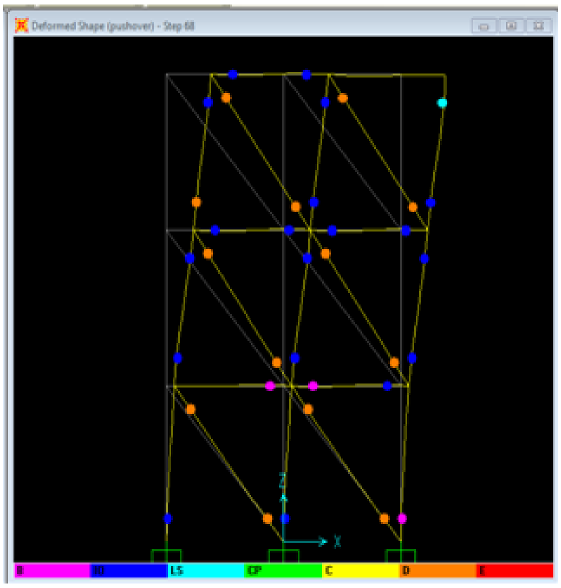


Figure 4.12. In-filled frame

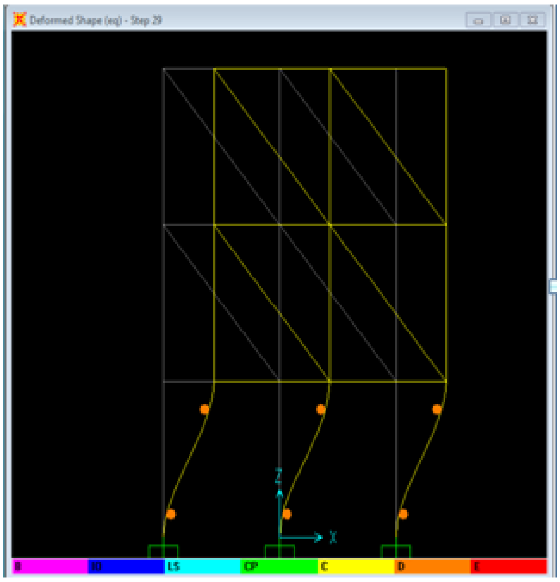


Figure 4.13. Soft storey frame

Hence predominant occurrence of damages in ground storey of the open ground storey frame is justified from pushover analysis.

5. CONCLUSIONS

The conclusions made in this project are:

- Vertical irregularity i.e.. Soft storey is one of the main reasons for the failure of reinforced concrete framed buildings.
- Soft storey construction in any floor fails at the ends of the columns in that respective storey.
- Any reinforced concrete framed building with strong beam and weak column concept represents the mechanism of soft storey i.e. column side sway mechanism.
- This vertical irregularity decreases the strength and stiffness of the structure.
- Additional bending moment value is more in the soft storey than other stories with in-fills because the deformation at the soft storey is greater than other stories.

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