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Study of Progressive Collapse Analysis of Flat Slab Building

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Abstract: ***Progressive collapse is a catastrophic phenomenon that occurs in structures due to human-made and natural hazards. Nowadays, conventional RC frame buildings are commonly used for the construction. Flat slab building provides many advantages over conventional RC frame building. This paper deals with progressive collapse analysis of a flat slab building by means of non-linear static analysis procedure normally called pushover analysis. In this type of analysis a computer model of a structure is subjected to a predetermined lateral load pattern. The (G+11) structure is modelled using ETABS software and pushover analysis is performed.***

Keywords: flat slab building, static analysis, progressive collapse, ETABS

1. Introduction

The term progressive collapse is typically used to refer the spread of an initial local failure within a structure. The local failure is triggered by the loss of one or more load carrying members and lead to partial or total collapse of the structure. Following the initial event, the structure seeks alternative load paths to transfer the load originally carried by the damaged portions to the adjacent undamaged members. Since the latter may or may not have adequate resistance to withstand the additional loads, further failures of overloaded structural elements are likely to occur, which in turn will cause more redistribution of loads until an equilibrium state is reached. However due to magnitude of the loads involved, equilibrium may only be achieved when a substantial part of the structure has already collapsed. Therefore, the main feature of progressive collapse is that the final damage state is disproportionately greater than the local damaged that initiated the collapse.

In present era, conventional RC Frame buildings are commonly used for the construction. The use of flat slab building provides many advantages over conventional RC Frame building in terms of architectural flexibility, use of space, easier formwork and shorter construction time. In this paper nonlinear static and dynamic method is used to analyze the progressive collapse in a flat slab building. Nonlinear analysis is widely used to understand the behaviour of structure after its elastic limit. In this analysis method, structural elements are pushed to deform beyond their elastic limit and hence it undergoes inelastic behaviour. Nonlinear static analysis is also known as vertical pushover analysis. Pushover analysis is mainly deformation controlled and force controlled. Deformation controlled method is generally used for lateral pushover analysis where, earthquake or wind load governs. In this method structure is pushed to undergo maximum permissible deformation under lateral load and at that time, maximum attained load is measured, while in force controlled method load is applied step by step until maximum load is attained or structure collapses. At that time, maximum deformation is measured. In Non-linear analysis, the elements affected due to column removal are generally located in or nearby bay of column removal location i.e. elements far from initiating damage may not be affected hence may not yield, This can be visualized from hinge formation in the building. In Non-linear analysis, results are observed in the form of hinge formation, force-deformation characteristics and collapse load. This method is widely used for detailed investigation.

2. Modeling of Building

2.1 Geometric Model

The building is modelled using the flat slab feature in ETABS. The complete detail of the structure is given in Table 1.

Table 1: Details and dimension of the building models

Type of structure	Flat slab with column drop
Plan dimension	40mx30m
Number of stories	12
Floor height	3.6m
Column size:	0.7mx0.7m
Slab Thickness	250 mm
Drop size	1mx1m
Drop thickness	0.12
Grade of concrete & steel	M 25 Fe415

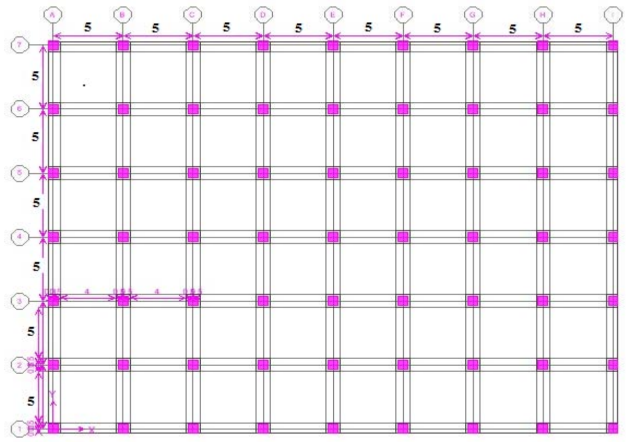

Figure 1: Plan of flat slab building

3. Analysis and Design

Load is defined and assigned before analysis. The dead load, live load, earthquake loads are defined. Self weight multiplier 1 is used to calculate dead load as default. Earthquake loads are defined along X direction as well as Y direction for zone III, importance factor 1, Type II soil, zone factor 0.16. Live load of 1.5 kN/m^2 is applied over roof slab and 2 kN/m^2 is applied on all the other slabs. By default load combinations analysis and design of the structure is performed.

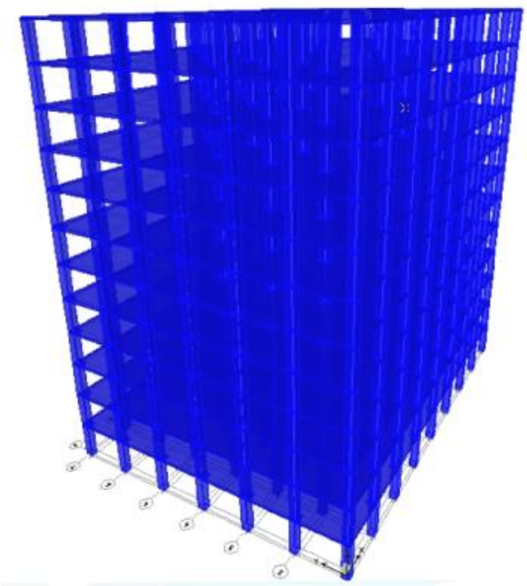

Figure 2: 3D model of the building

4. Pushover Analysis

The non linear static analysis procedure normally called Pushover Analysis, POA, is a technique in which a computer model of a structure is subjected to a predetermined lateral load pattern, which approximately represents the relative inertia forces generated at locations of substantial mass. The intensity of the load is increased, i.e. the structure is „pushed", and the sequence of cracks, yielding, plastic hinge formations, and the load at which failure of the various structural components occurs is recorded as function of the increasing lateral load. This incremental process continues until a predetermined displacement limit.

Here progressive collapse analysis is done by comparing the results obtained by means of pushover analysis. For this middle column of the longer side, middle column of the shorter side, column at the corner and an interior column are removed one by one and pushover analysis is carried out each time. For nonlinear analysis automatic hinge properties are assigned to a frame element. For default moment hinges, ETABS uses Tables 5-6 of FEMA-356. For each degree of freedom, there is a force-displacement (moment-rotation) curve that gives the yield value and the plastic deformation following yield. This is done in terms of a curve with values at five points, A-B-C-D-E, as shown in Figure 3. Point A is always origin. B represents yielding. Point C represents the ultimate capacity for pushover analysis. Point D represents a residual strength. Point E represents total failure. There are additional deformation measures at points IO (immediate occupancy), LS (Life safety), and CP (Collapse prevention). These are informational measures. FEMA defines permissible values for plastic rotation of hinges at each stage i.e. IO, LS and CP. P-M2-M3 hinges are assigned to columns at both the ends.

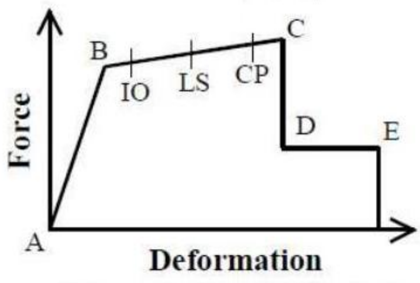

Figure 3: Force vs Displacement curve

5. Analysis Results

Following are the observations made after pushover analysis.

5.1 Before column removal

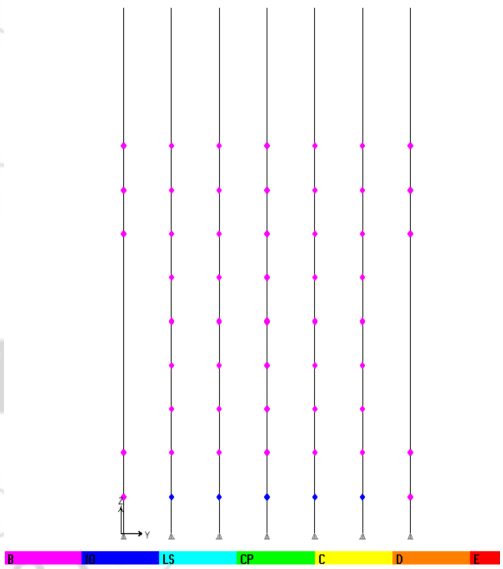

Figure 4: Hinges formed before column removal

From Figure 4 it is observed that hinges are within immediate occupancy.

5.2 Column Removal Cases

Case 1: Removal of the C29 column

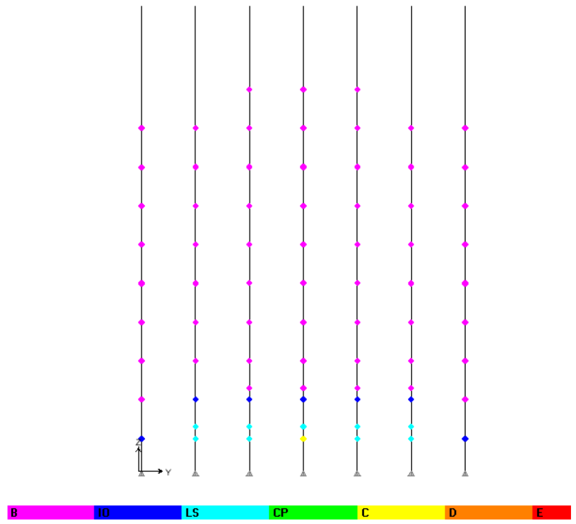

Figure 5: Hinges formed after removing column C29

From Figure 5 it is observed that hinges are within collapse prevention stage and have reached stage C, i.e. ultimate capacity.

Case 2: Removal of C4 column

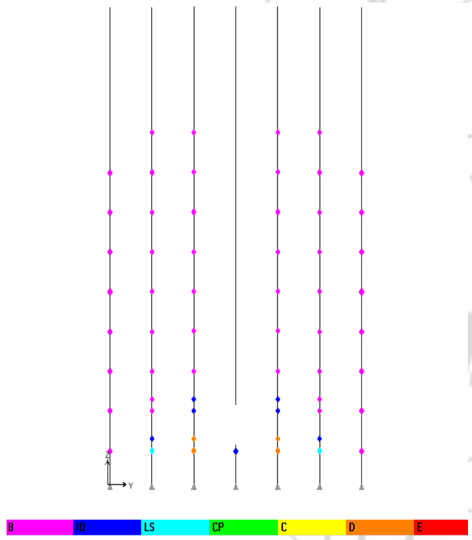

Figure 6: Hinges formed after removing column C4

From Figure 6 it is observed that hinges have reached ultimate capacity.

Case 3: Removal of column C1

From Figure 7 it is observed that the structure has started to fail.

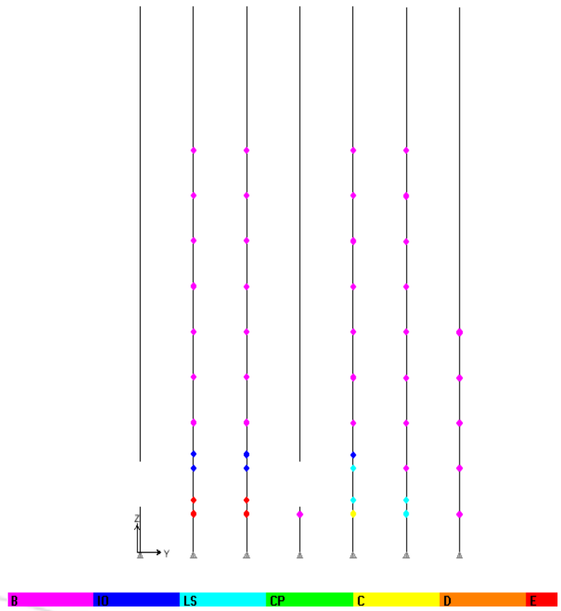

Figure 7: Hinges formed after removing column C1

Case 4: Removal of column C32

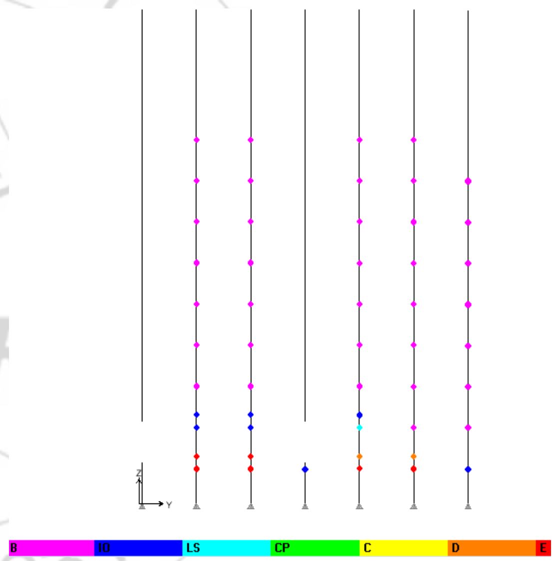

Figure 8: Hinges formed after removing column C32

From Figure 8 we can see that the structure has started to fail and Figure 9 shows that with the consequent removal of columns, the maximum displacement in each storey has increased. Displacement after removal of interior column has remained same as that of the previous removal i.e. removal of column at the corner.

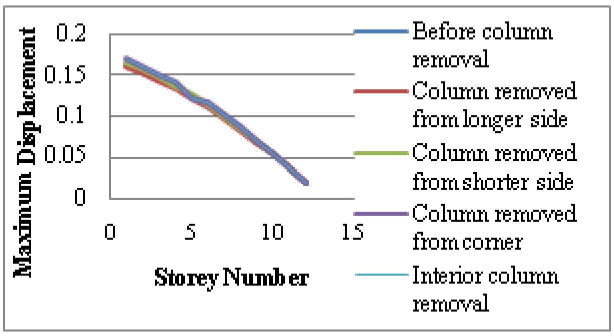

Figure 9: Maximum displacement vs Storey number

6. Conclusions and Future Scope

6.1 Conclusions

The main conclusions obtained from the analysis are the following.

- With the subsequent column removal, the energy dissipated is absorbed by the adjacent structural elements as a result plastic hinges are developed.
- During pushover analysis, when the loadings increase iteratively the number of plastic hinges developed increases and finally reach the collapse stage.
- With each column removal, performance level decreases with minimum difference.
- Maximum displacements increases in each storey with the subsequent column removal.

6.2 Future Scope

Comparative study can be done between RC frame and flat slab buildings based onprogressive collapse by means of linear and non-linear analyses.

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