Progressive Collapse Assessment by Linear Static and Non-Linear Static Analysis of a Regular Structure

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***Abstract*— Structure is supposed to be designed to withstand the accidental loading like; fire, impact loading and blast loading. Structures designed as per IS code should be safe and not life threatening. Safety of the structure can be assured by making the structure ductile and redundant, so that when a major load carrying member fails the alternate load path is initiated hence the failure is not sudden. To study the effect of failure of load carrying elements i.e. columns on the entire structure; 10 storey moment resistant regular RC building is considered. The buildings are modeled and analyzed for progressive collapse using the structural analysis and design software SAP2000. There are total two analysis procedures namely linear static and nonlinear static analysis to evaluate the potential for progressive collapse of RC buildings.**

Keywords*— Progressive Collapse; RC Building; Linear Static; Non-Linear Static; SAP2000.

I. INTRODUCTION

Progressive collapse may be described as a situation originated by the failure of one or more structural members following an abnormal loading event. This local failure leads to load redistribution in the structure, which results in an overall damage to an extent disproportionate to the initial triggering event. The General Services Administration (GSA) of the United States defines this phenomenon as ‘a situation where local failure of a primary structural component leads to the collapse of adjoining members which, in turn, leads to additional collapse. Hence, the total damage is disproportionate to the original cause’. While a number of different definitions of progressive collapse coexist, the notion of dis-proportionality is common to all of them. It is a dynamic process, usually accompanied by large deformations, in which the collapsing system continually seeks alternative load paths in order to survive. One of the important characteristics of progressive collapse is that the final damage is not proportional to the initial damage.

Progressive collapse of a structure takes place when the structure has its loading pattern or boundary conditions changed such that structural elements are loaded beyond their ultimate capacities and fail. Once a column is damaged due to some accidental loading like; fire, impact loading and blast loading, the building’s weight (gravity load) transfers to the neighboring columns in the structure. It is a process in which elements of the structural system which is taken the desired gravity load distributes the gravity load to prevent the loss of critical element like column.

Plan irregular structures are more susceptible to different type of failures than regular structures. In the present study the performance of regular building designed for seismic loading is evaluated under progressive collapse. Linear static and nonlinear static analysis are performed to evaluate the potential of progressive collapse of building. Alternate load path method is used in the evaluation for potential of progressive collapse. The ability of the structure to bridge over the missing element is determined by following the US general service administration (GSA) guidelines.

II. BUILDING CONFIGURATION

A 10 storey reinforced concrete residential building of an importance factor 1 (IS code 1893-2002) was selected for performing progressive collapse analysis as per GSA guidelines. Bay size is taken as 6m in one direction and 5m in other direction. Building size in plan is 24m x 20m. Height of base to plinth is taken as 1.5m, Plinth to ground floor as 3.5 m, which is considered as hollow plinth and height of typical floor as 3m. The walls having 230mm thickness are assumed on all the beams. Main beam size: 300mm × 600mm, Secondary beam size: 300mm × 400mm, Column size: 550mm × 550mm and Slab thickness: 150mm which is considered as a shell element are considered for the building. Reinforced concrete design is carried out and percentage steel is provided accordingly. Steel design for this building is governed by the earthquake load combination envelope. Figure below shows typical floor plan and 3D view of regular building.

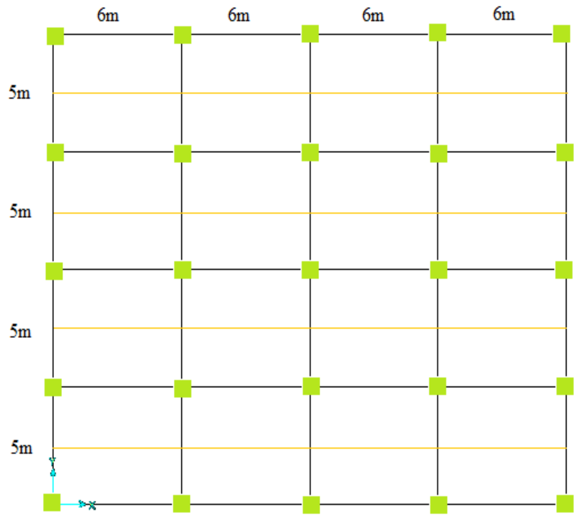

Fig. 1 Typical floor plan of regular building

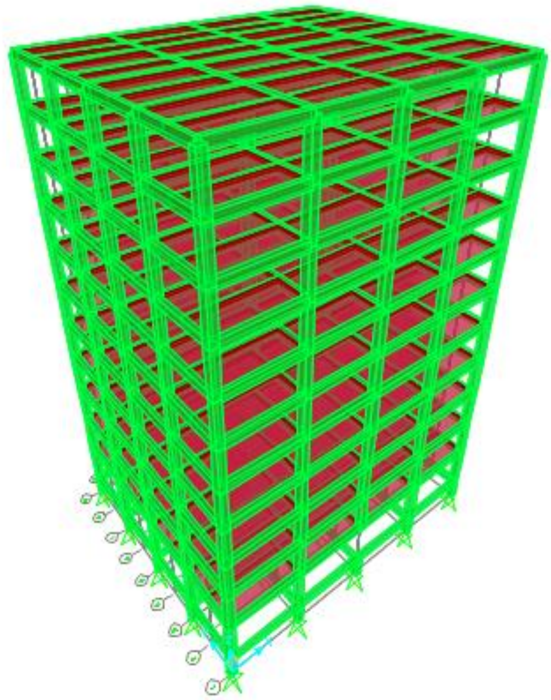
Fig. 2 3D view of regular building

III. PROGRESSIVE COLLAPSE ANALYSIS

Progressive collapse analysis is performed by instantly removing one or several columns and analyzing the building's remaining capability to absorb the damage. The key issue in progressive collapse is in understanding that it is a dynamic event, and that the motion is initiated by a release of internal energy due to the instantaneous loss of a structural member. This member loss disturbs the initial load equilibrium of external loads and internal forces, and the structure then vibrates until a new equilibrium position is found or until the structure collapses. Load case defined for linear static analysis and nonlinear static analysis are same, which is 2 (DL + 0.25 LL),

Where DL= Dead Load and LL = Live Load. Four column removal cases for progressive collapse analysis are considered as shown in Fig.3.

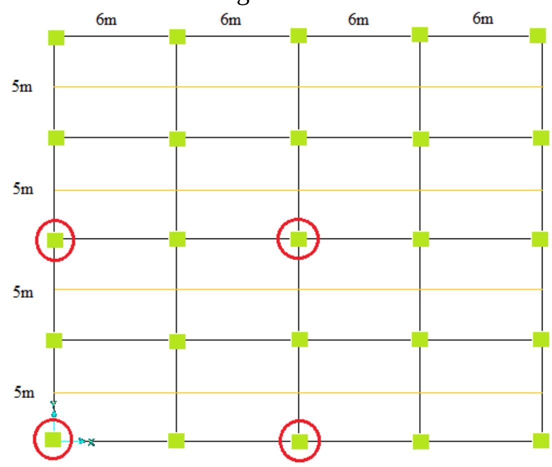

Fig. 3 Column removal scenarios of regular building

A. Linear Static Analysis

GSA guideline has provided following stepwise procedure to carry out linear static analysis.

Step 1: Prepare three dimensional model of structure and perform concrete design and determine the reinforcement to be provided in members.

Step 2: Based on the reinforcement provided, calculate the capacity of the member in flexure, "strength increase factor" is considered during progressive collapse.

Step 3: Column loss scenario are created by removing ground floor column from the specified location one at a time as mentioned in GSA guidelines.

Step 4: static linear analysis is performed and the demand for the specific column removal case are determined.

Step 5: Calculate the "demand to capacity ratio (DCR)" and evaluate the results as per the acceptance criteria provided in GSA guidelines.

The performance of structure is evaluated by demand to capacity ratios (DCR), which should not exceed 2 for regular structures and 1.5 for irregular structures or else they are considered as severely damaged or failed. GSA has defined DCR as below.

$$DCR = Demand / Capacity$$

Where, Demand equals the moment demand calculated using bending moment diagram in linear static analysis. Capacity equals the expected ultimate, unfactored capacity of the component.

B. Non-Linear Static Analysis

GSA guideline has provided following stepwise procedure to carry out Non-linear static analysis.

Step 1: Prepare three dimensional model of structure and perform concrete design and determine the reinforcement to be provided in members.

Step 2: Define and assign plastic hinges to beams and columns.

Step 3: Define the load combination as per GSA and define non-linear case.
Step 4: Remove the column and perform the static non-linear analysis.
Step 5: Observe the hinge formation pattern for failure.

Load case defined for static nonlinear analysis is same as static linear analysis, which is 2 (DL + 0.25 LL),
Where DL= Dead Load and LL = Live Load.

For nonlinear analysis automatic hinge properties are assigned to the frame element. For default moment hinges, SAP2000 uses Tables 5-6 of FEMA-356. M3 and V2 hinges are assigned to beams at both the ends. P-M2-M3 hinges are assigned to columns at both the ends. Figure below shows hinge formation of longer bay in horizontal and traverse direction.

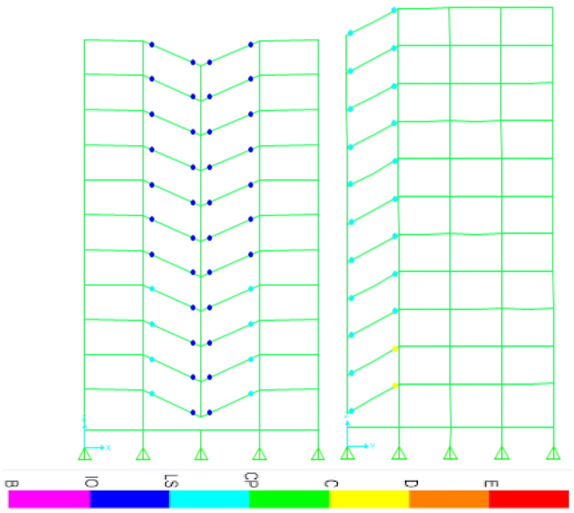

Fig. 4 Hinge formation for Non-linear static analysis

TABLE 1 - % GSA LOAD ATTEMPT IN NON-LINEAR STATIC ANALYSIS (COLUMN REMOVAL CASE)

Nonlinear static case	GSA Loading	%GSA Load attempt
Longer	2(D.L+0.25L.L)	47%
Shorter	2(D.L+0.25L.L)	48%
Middle	2(D.L+0.25L.L)	68%
Corner	2(D.L+0.25L.L)	40.27%

IV. CALCULATION OF DCR (DEMAND CAPACITY RATIO)

Local damage scenario is created by removing the external Long bay column C – 3A and Linear Static Analysis is performed. After performing the progressive collapse analysis, flexure and shear demand of the beams are found. Figure shows the bending moment and shear force diagram of before column removal condition and after column removal condition for static linear analysis. These analyses should be carried out for all four column removal cases.

DCR for Flexure = Demand Moments / Flexure Capacity of Member

The bending moment diagrams and value of DCR along the height in horizontal and transverse direction frame is shown in following figures.

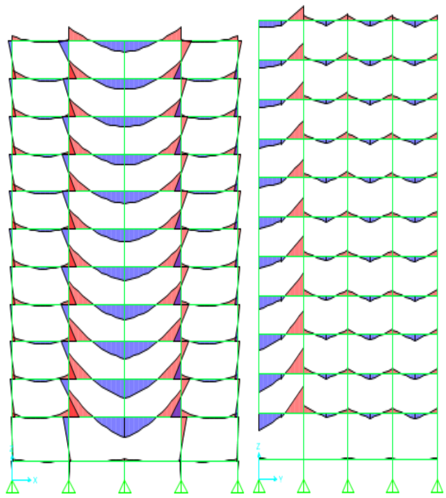

Fig. 5 Bending moment diagram for column removal in long bay.

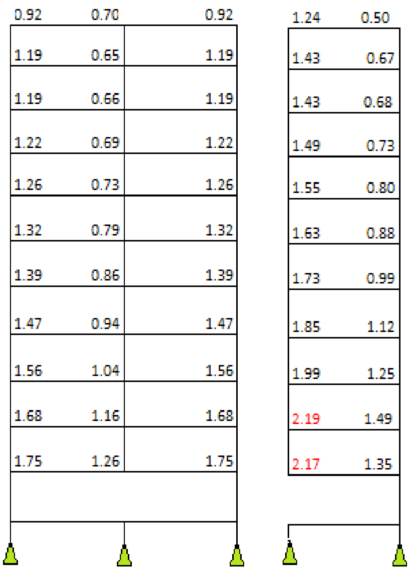

Fig. 6 DCR value for column removal case in long bay.

V. RESULTS AND DISCUSSION

In this study linear static and non-linear static analysis procedures are carried out for progressive collapse analysis of 10-storey moment resistant RC building. DCR are found out for beams and they are highly stressed nearby columns at all storeys for four column removal cases. It is observed that DCR in flexure in beam exceeds permissible limit of 2 in all column removal cases of building but the severity varies from each column removal cases. DCR calculated in flexure for beams by linear static analysis is higher on left and right side of column removal points.
Nonlinear static analysis is carried out to understand the hinge formations at yield and at collapse. Nonlinear static analysis gives maximum collapse load for all the column removal cases. In Nonlinear analysis structure is considered to have enough resistance against progressive

collapse if the percentage load carried by the structure after loss of column exceeds 50%.

From the study it can be concluded that among all the four column removal cases, corner column removal case are most affected for collapse.

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