Progressive Collapse Analysis of RC Buildings with Consideration of Effect of Slab

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Abstract— To study the effect of failure of load carrying elements i.e. columns on the entire structure; 15 storey moment resistant RC buildings is considered. The buildings are modeled and analyzed for progressive collapse using the structural analysis and design software SAP2000. Normally it has been considered only the failure of primary load carrying members like columns, beams, struts, foundations etc. to understand the progressive collapse scenario. This paper involves the effect of slabs in progressive collapse with the failure of column.

Key words: Progressive Collapse; RC Building; Slab; Design software SAP2000

I. INTRODUCTION

Progressive collapse can be defined as widespread propagation of structural member failures in which the resulting damage is disproportionate to the original cause. Failure of one or more primary load carrying members cause overloading of nearby other structural member due to change of load pattern which ultimately leads to failure of the members. As a result, total or partial collapse of the structure occurs, which is termed as progressive collapse. It is not always feasible to design the structures for absolute safety, nor it economical to design for accidental events unless they have a reasonable chance of occurrence. Events like gas explosions, bombs, vehicle impacts, foundation failures, failures due to construction or design errors etc. are not usually considered in normal design practices. Considering these aspects, many government authorities and local bodies have worked on developing some design guidelines to prevent progressive collapse. Out of these guidelines, US General Services Administration (GSA) has illustrated step wise procedure to minimize the progressive collapse, issued in 2000 and revised in 2003. According to GSA guidelines, Progressive Collapse is "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. Besides the immediate and localized blast effects, the structural engineer must consider the serious consequences associated with progressive collapse that could affect people and property of an entire building.

Progressive collapse is a situation where local failure of a primary structural component leads to the collapse of adjoining members, which in turn leads to additional collapse. Progressive collapse occurs when a structure has its loading pattern or boundary conditions changed such that structural elements are loaded beyond their capacity and fail. Progressive collapse of building structures is initiated when one or more vertical load carrying members (typically columns) are collapsed. Once a column is failed the building's weight (gravity load) transfers to neighboring members in the structure. If these members are not properly designed to resist and redistribute the additional load that part of the structure fails. The vertical load carrying elements of the structure continue to fail until the additional loading is stabilized. As a result, a substantial part of the structure may collapse, causing greater damage to the structure than the initial impact.

II. BUILDING CONFIGURATION

To study the effect of column removal condition on the structure, 15 storeys RC building is considered (Hypothetical Case). Progressive collapse analysis is based on the GSA guidelines. Structure considered in this analysis is assumed to be a residential building, which is designed for an importance factor 1 (IS code 1893-2002). Bay size is taken as 6m in one direction and 4m in other direction. Building size in plan is 30m x 24m. Height of base to plinth is taken as 2m, Plinth to ground floor as 4 m, which is considered as hollow plinth and height of typical floor as 3.5m. 230mm thick walls are assumed to be on all beams Figure shows typical floor plan and 3D view of regular building.

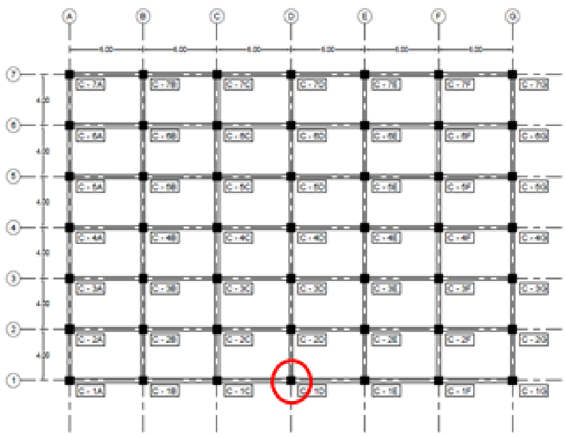


Fig. 1: Typical floor plan of regular building

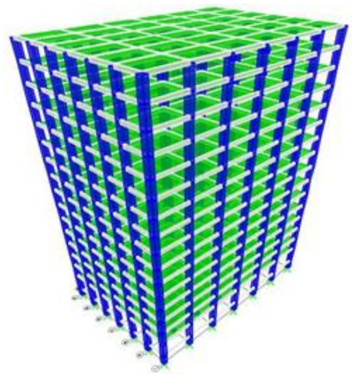


Fig. 2: Typical 3d view of regular building

A. *Building Design*

Building design and progressive collapse analysis is carried out using computer program. Final member sizes of the G+15 building, after analysis and design are as below. Beam size: 300mm × 600mm Column size: 800mm × 800mm. Slab thickness: 150mm RC design is carried out and percentage steel is provided accordingly. Steel design for this building is governed by the earthquake load combination envelope (IS 1893-2002).

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. column removal case for progressive collapse analysis is considered. For middle column from long side of the building (C – 1D).(As marked in figure)

A. Role of Slab in Progressive Collapse

GSA guideline describe that the progressive collapse of structure should be check for failure of primary load carrying members (i.e. Columns, Beams) and check the structure for progressive collapse. To simulate the actual scenario of building role of slab should be considered because the slab will hold the beams; hence the demand in beams will be reduced. To understand the phenomena of slab in Linear Static Analysis following steps should be followed.

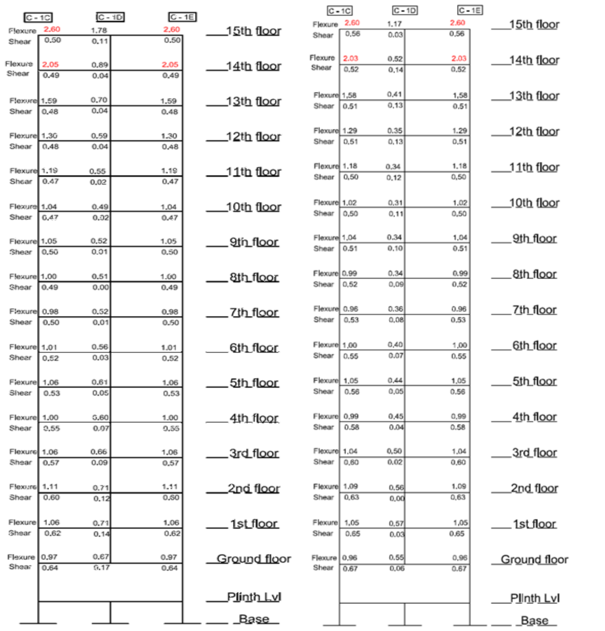
- Step 1: Build a computer model and define slab as membrane.
- Step 2: Design the Structural members and find out the capacity of Members.
- Step 3: Unlock the model and modify the Slab as SHELL.
- Step 4: Remove the column from the model, apply strength increase factor and apply the load combinations as per GSA guidelines 2(DL+0.25LL).
- Step 5: Perform linear static analysis with zero initial conditions, a standard analysis procedure in SAP2000.
- Step 6: Evaluate the results based on demand-to-capacity ratio (DCR).

In conventional practice, for modeling the slabs are modeled as membrane. When we define the slabs as membrane it will not take part in bending hence it will directly transfer the loads on members. But for analyze the structure to considered the slab in action for progressive collapse the slabs should be modeled as SHELL. So it will take part in bending and co-relate the actual scenario. Figure 3 and Figure 4 show the reduction in DCR while considered the slab in progressive collapse.

B. Calculation of DCR (Demand Capacity Ratio)

Local damage scenario is created by removing the external long bay column C - 1D and Linear Static Analysis is performed. After performing the progressive collapse analysis, flexure and shear demand of the beams are found. Figures show the DCR values for given frame with and without consideration of Slab effect.

- DCR For Flexure = (Demand Moments / Flexure Capacity of Member) Should < 2 as per GSA.
- DCR for Shear = (Demand Shear Force / Shear Capacity Of member) should < 1 as per GSA.



Linear Static (Long Bay with-Out action of Slab) Linear Static (Long Bay with action of Slab)

Fig. 3: DCR for Case 1 Linear Static with out and with Slab Role Long Bay

Linear Static (Transvers Bay with Out Slab) Linear Static (Transvers Bay with Slab)

Figure 4 – DCR for Case 1 Linear Static with out and with Slab Role Transvers Bay

C. Stresses in Slab

When primary load carrying member get fail, the stress distribution and load distribution are take place. The stress distributions in slabs after column removal (C – 1D) are shown in Figure 5 at each floor level. The tensile strength of concrete is considered as 0.7 x SQRT (fck) (IS 456-2000). If it is greater than this value the concrete get crack and then reinforcements will come in the role. In normal condition there are compression at top face and tension at bottom face in slab, there is also little bit tension at top and compression at bottom where the slabs are connected with each other. (Edge restrain condition)

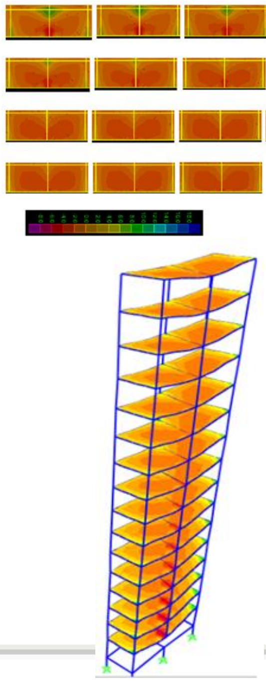


Fig. 5: Stress distribution in slabs after column removal (C – 1D)

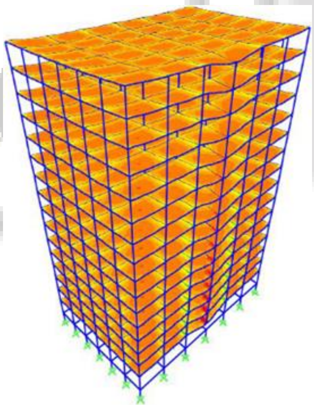


Fig. 6: 3D view of Structure - Stress distribution in slabs after column removal (C – 1D)

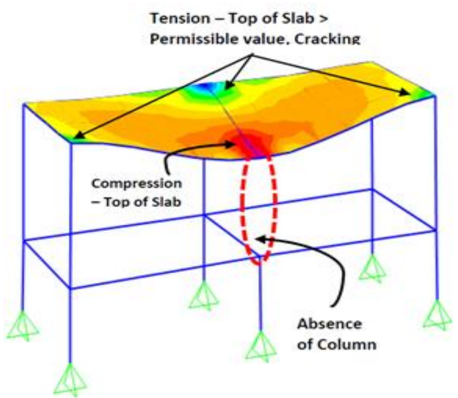


Fig. 7: Stress distribution in slabs after column removal (C – 1D) Closer View

IV. RESULTS AND DISCUSSION

It is observed that DCR for flexure in beams found with consideration of effect of slab are not much reduced. There is slight reduction in DCR at the same time the stresses in slabs are exceed the permissible value and the cracks are generated at the top face of slab as shown in figure, And these are the one kind of type of failures. Hence the close study, concluded that the slab above the failure of column is highly stressed as compare to the subsequent slabs of above storey as shown in figure. So it is recommended that the building should be check for potential for progressive collapse with failure of primary load carrying members only (i.e beams, columns) and these consideration will always be safer side.

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