Progressive Collapse Analysis of Multi-Storey Building

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Abstract- *The progressive collapse of reinforced concrete structures is initiated when one or more vertical load carrying members are removed due to man-made or natural hazards. The building's weight transfers to neighboring columns in the structure, leads to the failure of adjoining members and finally to the failure of partial or whole structure system.The research material available for progressive collapse failure of structures suggests that buildings designed to resist seismic actions have good robustness against progressive collapse. However, no detailed investigations have been conducted so far to assess this robustness. In the present study the demand capacity ratio (DCR) of reinforced concrete nineteen storey framed structure are evaluated as per U.S. General Services Administration (GSA) guidelines. The Linear static analysis is carried out using software, ETABS V16.The structural behavior of the building for progressive collapse. Further loading are assigned to model according to IS codes. Analysis is carried out for member forces and reinforcement details. From the analysis, DCR values of columns and beams are calculated.*

Keywords- Progressive Collapse, Demand Capacity ratio (DCR), U. S. General services administration (GSA) Guidelines, ETABS

I. INTRODUCTION

Progressive collapse is the result of a localized failure of one or two structural elements that lead to a steady progression of load transfer that exceeds the capacity of other surrounding elements, thus initiating the progression that leads to a total or partial collapse of the structure.

As the small structural element fails, it initiates a chain reaction that causes other structural elements to fail in a domino effect, creating a larger and more destructive collapse of the structure. A good example of progressive collapse is a house of cards; if one card falls near the top, it causes multiple cards to fall below it due to the impact of the first card. Progressive collapse as a structural engineering point of view started taking attention when partial collapse of 22 storey Ronan Point apartment building occurred in London on May 16, 1968. This collapse generated considerable concern over the adequacy of existing building codes. After the partial collapse of Ronan Point apartment building, number of other collapses around the world took place, which could be placed in to category of progressive collapse.

In normal design practice, the abnormal events like, gas explosions, bomb attack, vehicle impacts, foundation failure, failure due to construction or design error etc are not considered. When any element fails, the remaining elements of the structure seek alternative load paths to redistribute the load applied to it. As a result, other elements may fail due to insufficient resistance capacity causing partial or total failure mechanism. It is 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.

It is not economical as well to design the structures for accidental events unless they have reasonable chance of occurrence. Considering these aspects, many government authorities and local bodies have worked on developing some design guidelines to prevent progressive collapse. Among these guidelines, U.S. General Services Administration (GSA) provide detailed stepwise procedure regarding methodologies to resist the progressive collapse of structure. In this procedure, one of the important vertical structural elements in the load path i.e. column, load bearing wall etc. is removed to simulate the local damage scenario and the remaining structure is checked for available alternate load path to resist the load.

II. GUIDELINES PROVIDED BY THE U.S

A. GENERAL SERVICES ADMINISTRATION (GSA)

The purpose of these Guidelines is to [6]:

- Assist in the reduction of the potential for progressive collapse in new Buildings
- Assist in the assessment of the potential for progressive collapse in existing Buildings
- Assist in the development of potential upgrades to facilities if required

B. LLINEAR STATIC ANALYSIS

In the linear static analysis column is removed from the location being considered and linear static analysis with the gravity load imposed on the structure has been carried out. From the analysis results demand at critical locations are obtained and from the original seismically designed section the capacity of the member is determined. [8] Check for the DCR in each structural member is carried out. If the DCR of a member exceeds the acceptance criteria, the member is considered as failed. The demand capacity ratio calculated from linear static procedure helps to determine the potential for progressive collapse of building.

C. Analysis Loading

For static analysis purposes the following vertical load shall be applied downward to the structure under investigation: Load = 2(DL + 0.25LL) Where, DL = dead load LL = live load

D. Acceptance Criteria

An examination of the linear elastic analysis results shall be performed to identify the magnitudes and distribution of potential demands on both the primary and secondary structural elements for quantifying potential collapse areas. The magnitude and distribution of these demands will be indicated by Demand-Capacity Ratios (DCR).

$$DCR = \frac{Q_{UD}}{Q_{CE}}$$

Q_{UD} = Acting force (demand) determined in component or connection/joint (moment, axial force, shear, and possible combined forces)

Q_{CE} = Expected ultimate, un-factored capacity of the component and/or connection/joint (moment, axial force, shear and possible combined forces)

Using the DCR criteria of the linear elastic approach, structural elements and connections that have DCR values that exceed the following allowable values are considered to be severely damaged or collapsed.

The allowable DCR values for primary and secondary structural elements are:

- DCR < 2.0 for typical structural configurations

III. MODELING OF BUILDING

For the Analysis of an existing building in bengaluru,, a G+18 a typical building of height 57m is considered. It is modeled using ETABS v16 software. The column cross section, Beam cross section, Slab cross section and Wall cross section were fixed based on the preliminary analysis. All the supports were modeled as fixed supports.

Here the structure is designed for the Seismic loads. The gravity load and wind load acting on the structure is carried out as per IS 875 part 1&2 and IS 875 Part3. Seismic loading is carried out as per IS: 1893.

The building is situated in Zone II and Soil type is II. The characteristic compressive strength of concrete (fck) is 30N/mm2 and yield strength of reinforcing steel (fy) is 550N/mm2.

A. Building Description.

The total height of the building is 57m. The building plan is showing with dimension is given in the below figure. The column sizes are (950mmx300mm), (1000mmx300mm), (1200mmx300mm), (1300mmx300mm), (1600mmx300mm), (600mmx900mm) and (625mm x600mm) and beam sizes are (300mm x450mm), (300mm x 550mm) and (300mm x 750mm) are considered for the building. The walls having 230mm thickness is present on all the beams and slab thickness is taken as 125mm. The characteristic compressive strength of concrete (fck´) is 30 N/mm2and yield strength of steel (fy) is 550 N/mm2.

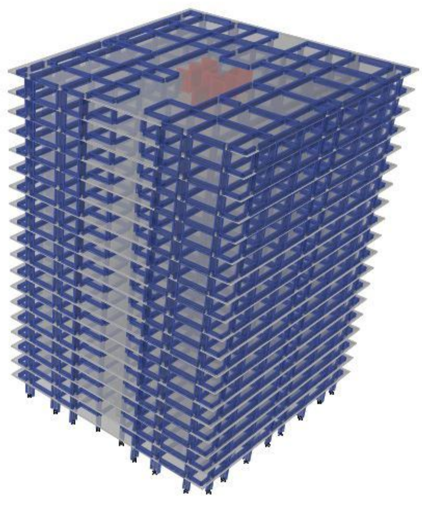


Fig.1. 3D View 19 storey building considered for study

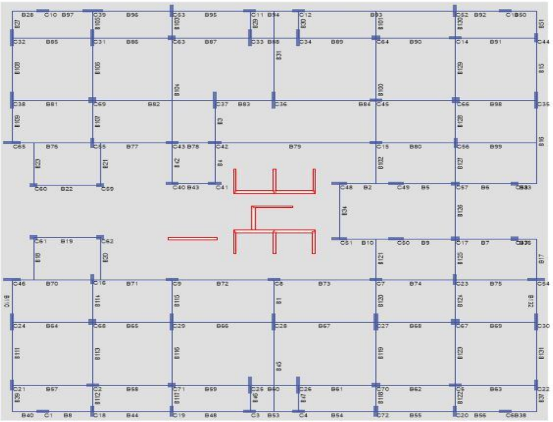


Fig 2: Plan of RC Framed Structure

Do not use abbreviations in the title or heads unless they are unavoidable.

B. Analysis procedure

To evaluate the potential for progressive collapse of a nineteen storey symmetrical reinforced concrete building using the linear static analysis five column removal conditions is considered. First building is designed in ETABS v16 for the IS 1893 load combinations. Then separate linear static analysis is performed for each case of column removal. Demand capacity ratio for flexure at all storeys is calculated for different cases of column failure.

C. Dead load

The dead load is obtained from IS 875(part1). The unit weight of concrete is taken as 25 kN/m3. Self-weight of the structural elements. Floor finish = 1.5 kN/m2 and Wall load on all beams is 10.5 kN/m

D. Live load

The live load is obtained from IS 875(part2).
On roof 1.5 kN/m^2
On floor 3 kN/m^2
Seismic loading as per IS: 1893 [10] Zone II, &V Soil type II, Response Reduction Factor = 3 Importance factor =1.

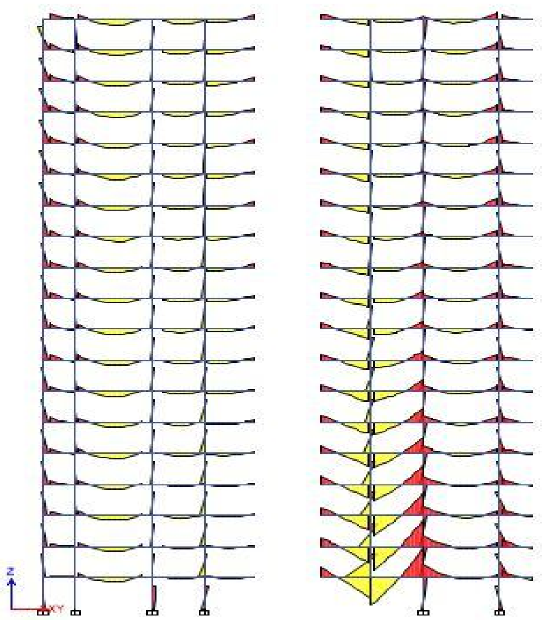
E. Progressive collapse analysis

The reinforced framed structure in the earthquake zones 2, and 5 is designed using ETABS program for dead, live, wind and seismic loads. For progressive collapse analysis columns C14, C15, C19, C28 and C54are removed. The specified GSA load combination was applied and the forces are calculated for all members using ETABS program.

The Demand Capacity Ratio (DCR), the ratio of the member force and the member strength is calculated. The member strength is calculated from Area of Steel obtained in the design results of ETABS program according to IS 456-2000 code. The member force is taken directly from obtained design forces values of ETABS program.

IV. RESULTS AND DISCUSSIONS

A. The bending moment diagram obtained by ETABS software for loadings assigned as per GSA is drawn to know behavior of columns and beams in the structure.
B. The removal of column C15 caused moment reversal in the beams B79, B80,B100 and B102 intersecting at the removed support. Fig 3 shows the distribution of moments in different elevation after the removal of the column. The figures show that values of the reversed moment diminish in the upper floors and for beams away from the vicinity of removed column.



C. Summary of Column DCR for Zone II

The Demand Capacity Ratios for all the columns removed were calculated and the values were less than 2 which suggests that all columns have the potential to resist progressive collapse. When the particular column removed the DCR value of that column in all the other stories was very less. These values indicate that the major load is transferred to the connecting beams. When the C15 column was removed adjacent columns C45, C66 and C96 of first storeys DCR values were greater than 1. The DCR of columns for remaining stories was lesser than 1. Columns exhibit descending pattern in DCR values when moved to higher stories. The same trend was observed in all the cases of removed column.

D. Summary of Column DCR for Zone V

The DCR values for building designed for zone 5 exhibit the same fashion as in remaining zones. The demand capacity ratios for all the columns were less than 2 as in the rest of zones. This indicates that all columns have the potential to resist progressive collapse in both II & V earthquake zones. The DCR values were slightly increased compared to rest of zones. The columns which are adjacent to removed column exhibit DCR values more. But the values are decreased in upper stories. As DCR is less than 2 in all the columns, they are safe and can avoid the progressive collapse which leads failure of structure when single vertical load carrying member is removed.

V. CONCLUSION

1. By linear static analysis for most of the beams DCRratio for bending has value greater than 2 which shows that they are going to fail under sudden column loss conditions, these beams needs to redesign to arrest progressive collapse.
2. Alternative Path Method (APM) is effective in assessing vulnerability of structures to loss of critical load-bearing members. It does not, however, provide information about the reserve capacity of a system
3. By linear static method it is observed that in case of column loss scenario Lower storey beams are critical than upper storey beams.
4. Columns which are in vicinity of removed column has PMM ratio higher than other column this is due to fact that when one column has lost adjacent column have to share load of it. In no case column PMM ratio exceeds than 2, this means that columns are not critical in this case of progressive collapse
5. Collapse pattern is in such a way that the Demand Capacity Ratio of the beam increases near the removed column and further away from it decreases.
6. Linear static analysis procedure of GSA (2003) guidelines is relatively more conservative than non-linear static and non-linear dynamic analyses

REFERENCES

[1] Feng Fu; (2010) 3-D nonlinear dynamic progressive collapse analysis of multi-storey steel composite frame buildings — Parametric study, Journal of Engineering Structures; 32:3974-80.

[2] Elizabeth A. and Shalva M.; (2006) Dynamic analysis procedure for progressive collapse, Structure Magazine.

[3] GSA, (2003). Progressive collapse analysis and design guidelines for new federal office buildings and major modernization projects, The US General Services Administration.

[4] Abhay A. Kulkarni, Rajendra R. Joshi- “Progressive Collapse Assessment of Structure”. International Journal of Earth Sciences and Engineering ISSN 0974-5904, Volume 04, No 06 SPL, pp. 652-655, October 2011.

[5] Raghavendra C and Pradeep AR, “Progressive Collapse Analysis of Reinforced Concrete Framed Structure”, International Journal of Civil and Structural Engineering Research, Vol. 2, Issue 1, pp: (143-149), Month: April 2014 - September 2014.

[6] Cheol-Ho Lee, Seonwoong Kim, Kyu-Hong Han, Kyungkoo Lee- “Simplified nonlinear progressive collapse analysis of welded steel moment frames”. Journal of Constructional Steel Research, pp. 1130_1137, 2009.

[7] ETAB v 9.6 analysis reference manual, Computers and Structures, Inc., Berkeley.

[8] Feng Fu- “Progressive collapse analysis of high-rise building with 3-D finite element modelling method”. Journal of Constructional Steel Research 65, pp. 1269_1278, 2009

[9] B.A. Izzuddin, A.G. Vlassis, A.Y. Elghazouli, D.A. Nethercot.

[10] Kapil Khandelwal et al. Progressive collapse analysis of seismically designed steel braced frames. Journal of Constructional Steel Research, Vol.65:699-708, 2009.

[11] Usman Ilyas, S H Farooq, I. Shahid and M. Ilyas, “Progressive Collapse of Reinforced Concrete Frame Structure under Column Damage Consideration”, Pak. J. Engg. & Appl. Sci. Vol. 16, Jan., 2015 (p. 61–66)

[12] IS: 1893-2002, 875 (1,2,3,4,5) Indian Standard General Construction in Steel-Code of Practice