PROGRESSIVE COLLAPSE ANALYSIS ON REINFORCED CONCRETE STRUCTURES

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ABSTRACT

Progressive collapse implies disproportional global structural system failure originated by local structural damage. It is a rare event, as it necessitates an initiation of local element removal criteria either due to the inevitable forces of nature or due to manmade hazards. 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. In which the collapsing system continually seeks alternative load paths in order to survive. 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. In which the collapsing system continually seeks alternative load paths in order to survive. A linear static analysis is worked out using ETABS Software Ver. 15.0 respectively. The demand capacity ratio is assessed in the critical region of the RC portion associated with the column removed, as per the provisions of GSA guidelines.

KEYWORDS: Progressive Collapse, DCR ratio, GSA, ETABS, Removal of Column.

A building undergoes progressive collapse when a primary structural element fails, resulting in the failure of adjoining structural elements, which in turn causes further structural failure. It is sometimes also called a disproportionate collapse, which is defined as a structural collapse disproportionate to the cause of the collapse. As the small structural element fails, it initiates a chain reaction that causes other structural elements to fail, creating a larger and more destructive collapse of the structure. Progressive collapse is a consistent destruction of the bearing structures of the building (structure) due to the initial local damage to the individual carriers of structural components and leading to the collapse of the entire building or substantial part. Progressive collapse is the spread of local damage, from an initiating event, from element to element resulting, eventually, in the collapse of an entire structure or a disproportionately large part of it; also known as disproportionate collapse.

This era is the modern era of construction of high rise buildings and towers. The strength of such construction should be constantly checked for its stability. It should be checked for the equal distribution of loads, reductant reactions and for the ground motions. The structures are not only affected by the unequal distribution of load but also due to uncertain ground motion. In this present analysis, the behavior of RC framed buildings with 5 stories to progressive collapse located in different areas of seismic zone v is investigated. A linear static analysis is worked out using ETABS Software Ver. 15.0 respectively. The demand capacity ratio is assessed in the critical region of the RC portion associated with the column removed, as per the provisions of GSA guidelines.

In this collapse mechanism a single deformation may lead to entire collapse in the structure, it can be inferred that progressive collapse is triggered more due to the sudden removal of column than the collapse of a structure due to earth quake loads.

Once a column is removed or made weak, due to man-made or natural hazards, load carried by column removed is transferred to neighboring columns in the structure, if the neighboring column is incapable of withstanding the extra load, leads to the progressive failure of adjoining members and finally to the failure of partial or whole structure.

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. The collapse of Skyline Plaza in Virginia, the Civic Arena roof in Hartford, the Murrah Federal Building in Oklahoma City, the Khobar Towers - Saudi Arabia, the U.S. embassies in Kenya and Tanzania, WTC Towers in New York were important collapse events in the history of progressive collapse which changed the perspective of the structural design.

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.

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LITERATURE REVIEW

The study of progressive collapse analysis is important for designing sustainable and safe structure that can withstand unexpected high magnitude loading. Various theories were developed to analyse the progressive collapse of structure. The literature related to Progressive collapse analysis is given as under:-

Narinen Pekka et al. (2013) The purpose of the study was to describe the process of progressive collapse and to find more methods and approaches to design the structure for preventing from this kind of failure. And the last aim was to find Russian norms and standards and make calculations on progressive collapse of the trade center, according to them. The destruction of World Trade Centre leads to the analysis of progressive collapse.

Rakshith K G, Radhakrishna et al. (2013)The study shows the result of analysis of progressive collapse of framed RCC structure. The study is based on determining the most critical combination of column and beams that may lead to disproportionate collapse. The analysis is carried out using software ETABS V9.7. The structural behavior of the building for progressive collapse, a finite element model is considered using the preprocessing function of structural analysis program. Further loading are assigned to model according to IS codes. Analysis is carried out for member forces and reinforcement details. The obtained DCR values show that columns are safe and beams to be reinforced additionally.

Shivaraju G D, Ashfaque Ahmed Khan et al. (2015) This study is based on the analysis of progressive collapse in RC frame structure for different seismic zones. When a building gets exposed to any natural hazards say Tsunami or Earthquake or due to manmade hazards such as fire, explosion of gases, impact of vehicles, etc., it affects the behavior of structure and causes collapse of a portion of structure or entire building.

Kumar S. Mohan et al. (2016) The research work was focused on progressive collapse analysis of reinforced concrete framed structure under column removal consideration using commercially available computer program ETABS. Pushover analysis was carried out. Then critical columns were identified and removed to initiate the progressive collapse. And parameters such as Demand capacity ratio and Robustness indicator were checked for the acceptance criteria.

S.M. Al Hafian and I.M. May [8](2012)." Seismic Progressive Collapse of Reinforced Concrete Framed Structures (2013) The emphasis of most studies of seismic collapse is on sideway collapse using the incremental dynamic analysis approach, IDA (Vamvatsikos and Cornell, 2002). Uncertainties in ground motions as well as in simulating the seismic collapse behavior associated with modeling the parameters that define lumped plasticity models of the structural component are the focus of these studies.

METHODOLOGY

In this present study, the behavior of RC framed buildings to progressive collapse located in different seismic zones is investigated. The building with 5 storeys is analyzed for different seismic zones. The demand capacity ratio is assessed in the critical region of the RC portion associated with the column removed, as per the provisions of GSA guidelines. The provision of the range & type of progressive collapse in different situation provides much important information with particular regard to progressive collapse resistance, by complementing additional measures in the design. In order to secure structural safety against progressive collapse additional considerations such as abnormal loadings must be taken.

The aim of GSA guidelines is to help in evaluating the risk of progressive collapse. For the determination of analysis we have taken 4x6 bays model with storey as 5 storeys, and analyzed for seismic zone (v). The following analysis cases should be considered.

Case1. Analyze for the sudden loss of a column for one floor above ground level (grade) situated at the corner of the building.

Case2. Analyze for the sudden loss of a column for one floor above ground level (grade) situated at or near the middle of the shorter directions side (X-direction in this case) of the building.

Case3. Interior column removal analysis at any suitable location should be carried out for buildings that have underground parking and/or uncontrolled public gatherings at ground floor areas.

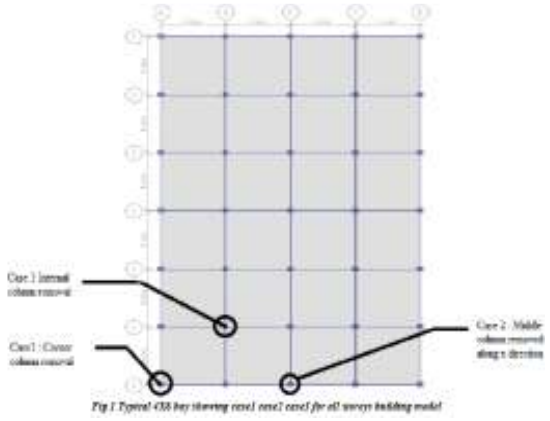

Figure 1: Typical 4X6 bay showing cas1, 2, 3 for all storeys building model

Linear static analysis this analysis is the most fundamental and the easiest type for progressive collapse analysis. It involves statically removal of major structural elements. Since this method is most basic & almost accurate, most conventional load conditions are applied with highly moderate assessment conditions.

Step1. First,the building is analyzed with gravity load (Dead Load+Live Load)…Eq 1, and obtain the output results for moment and shear without removing any column.

Step2. Now remove a vertical support (column) from the position under consideration and carry out a linear static analysis to the altered structure and Load this model with 2{Dead Load + 0.25(Live Load)}…Eq 2.

Step3. The Static load combinations were entered into the ETABS 2015 V15.0 program and a model of the structure was generated. An ETABS 2015 computer simulation was executed for each case of different Column removal location on the model and the results are reviewed.

Step4. Further, from the analysis results obtained, if the DCR for any member end connection or along the span itself is exceeded the allowable limit based upon moment and shear force, the member is expected as a failed member.

Step5. If DCR value surpass its criteria then it will leads to progressive collapse.

Permissible Criterion For Progressive Collapse The GSA guidelines Advised the use of the Demand–Capacity Ratio (DCR) which is defined as the ratio of the structural member force after the sudden removal of a column to the member strength (capacity) ,as a benchmark to determine the failure of major structural members by the linear static analysis procedure (GSA 2003).

$$DCR = Qud / Que \quad \ldots Eq\ 3$$

Where, Qud = Acting force (demand) observed in member or connection (shear, axial force, bending moment, and possible combined forces) Que = Expected ultimate, unfactored capacity of the member or connection (axial force, moment, shear and possible combined forces) the permissible DCR values for primary and secondary structural elements are:

- Demand capacity ratio (DCR) < 2.0 for typical structural configurations.
- Demand capacity ratio (DCR) < 1.50 for atypical structural configurations.

The analysis of structure is to be done by using ETABS V 15.0. The software is based on the concept of Finite Element 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. 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.

Gravity loads were calculated as per IS 875 part 1 and assigned, Wind loads were calculated as per IS 875 part 2 and assigned, Seismic loads were calculated as per IS 1893, Design load Combinations and service load combinations were given as per IS 875 part 5.

The building analysis is carried out according to the load combination of IS 875 Part 5. The gravity load and Lateral loads are imposed on the frame structure and the analysis is carried out. The Bending Moment behavior in all the three cases are studied for structural elements and the load flow of alternate path method is studied and checked. The demand to capacity ratios (DCR) were calculated to assess the state of the building with damaged column. And the vulnerability of the building with respect to all the three cases is checked by determination of Robustness indicator. Finally check for the demand capacity ratio (DCR) in each structural member is carried out. If the DCR value of a member exceeds the criteria for acceptance as per GSA guidelines, the member is considered as failed. The DCR

values calculated from linear elastic method helps to define the possible potential for progressive collapse of frame structure.

Guidelines of GSA

The purpose of these Guidelines is to-

- 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

CONCLUSION

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.

For the analysis, a typical frame model of plan is formed using ETABS. All the supports are modeled as fixed supports. Linear analysis is conducted on each of these models. To evaluate the potential for progressive collapse of a five storey symmetrical reinforced concrete building using the linear static analysis four column removal conditions is considered. First building is designed in ETABS v15.0 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. Capacity of the member at any section is calculated as per IS 456:2000 from the obtained reinforcement details after analysis and design. Demand capacity ratio after removal of column is found out considering the member force for the load combination as per GSA guidelines. Member forces are obtained by analysis results carried out in ETABS 15.0. And result comparison is to be done for these parameters before and after the progressive collapse of the building.

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