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PROGRESSIVE COLLAPSE ANALYSIS OF REINFORCED CONCRETE SYMMETRICAL AND UNSYMMETRICAL FRAMED STRUCTURES BY ETABS

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ABSTRACT: Progressive collapse is a chain reaction of failures that propagates either throughout or a portion of the structure disproportionate to the original local failure. The progressive collapse of building structure is initiated when one or more vertical load carrying members are removed. Once a column is removed or made weak, due to man-made or natural hazards, load carried by column removed is transferred to neighbouring columns in the structure, if the neighbouring 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. 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. 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. Hence this study is made to examine the potential ability of seismically designed building against progressive collapse. A Five storey reinforced concrete framed structure symmetrical and Unsymmetrical was considered in the study to evaluate the Demand Capacity Ratio (D.C.R.), the ratio of the member force and the member strength as per U.S. General Services Administration (GSA) guidelines. The Linear static analysis is carried out using software, ETABS V 9.7 according to Indian Standard codes. Analysis and design is carried out to get the final output of design details. To study the collapse, typical columns are removed one at a time, and continued with analysis and design. Many such columns are removed in different trials to know the effects of progressive analysis. Member forces and reinforcement details are calculated. From the analysis, DCR values of beams are calculated.

Keywords:- Progressive Collapse Analysis, U.S. General Service Administration (GSA) Guidelines, Removal of Columns, Special Moment resisting frames, Demand Capacity Ratio (DCR), Potential ,Linear Static Analysis, ETABS V 9.7 .

I. INTRODUCTION

Buildings are structurally designed to support anticipated loads adequately and safely in addition to fulfil clients' needs which include functional and aesthetic requirements. However, since the partial progressive collapse of the 22-storey Ronan Point apartment building in 1968 which was triggered by a gas explosion, an obvious attention in civil engineering community had been provoked to consider unanticipated loading events. Nevertheless, the ordinary designs do not normally account for the extreme loading events that may cause progressive collapse. Recently, progressive collapse of buildings became one of civil engineering significant issues after the progressive collapse of the World Trade Center in 2001. Inherently progressive collapse is different from other collapses that may happen to structures and buildings in which it is disproportionate to the collapsing event.

Figure 1.1 Partial collapse of Ronan Point apartment building

Progressive collapse can be defined by a chain failure of structural members triggered by local failure or damage and causing partial or entire collapse of the structure (ASCE, 2005). The local failure or damage in well-engineered structures and buildings usually results from unanticipated abnormal loads. The abnormal loads arise from extraordinary events which are characterized by low probability of occurrence, short time effect and high intensity. Abnormal loads may include pressure loads (gas explosions and bomb blasts), impact loads (aircraft and vehicular collision and failing debris) and deformation loads (softening members resulting from fire and foundation subsidence) (ASCE, 2005).In many cases, extraordinary events are indirectly avoided by nonstructural measures. However, the increase in potential extraordinary events and the difficulty of applying nonstructural measures increase the risk of the progressive collapse. Also, recent facilities and architectural requirements to construct buildings with large panels and needs for high rise building increase the hazards of the extraordinary events that may lead to the progressive collapse.

II. GUIDELINES BY THE U.S. GENERAL SERVICES ADMINISTRATION (GSA)

The aim of GSA guidelines is to help in evaluating the risk of progressive collapse criteria in new and existing structures. This document offers compact & direct guidelines. They do not qualify for exemption from consideration of progressive collapse, contains guidelines for the analyses of “typical” and “atypical” structural systems. A typical structure is defined as having relatively simple layout with no unusual structural configurations. Both “typical” and “atypical” structures are discussed in this paper. To determine the potential of progressive collapse for a “typical” and “atypical” structure, designers can perform structural analyses in which the instantaneous loss of one of the following first floor columns at a time is assumed. For the determination of analysis we have taken 4 x 3 bays model, and analyzed for Seismic zone (V). The following analysis case should be considered:

1. An exterior column near the middle of the long side of the building.
2. An exterior column near the middle of the short side of the building.
3. A column located at the corner of the building.
4. A column interior to the perimeter column lines for facilities that have underground parking and/or uncontrolled public ground floor areas.

2.1 Linear 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. 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.

2.2 Analysis Loading

For static analysis purpose the following vertical load shall be applied downward to the structure under investigation:

$$\text{Load} = 2(DL + 0.25\ LL)$$

Where,

DL = Dead Load, LL = Live Load

2.3 Acceptance Criteria

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

$$D.C.R. = Q_{UD} / Q_{CE}$$

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

Q_{CE} = Expected ultimate, unfactored capacity of the component and/or connection/joint (moment, axial force, shear, and possible combine 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 collapsed. The allowable DCR values for Symmetrical and unsymmetrical structural elements are:

- DCR $\leq$ 2.0 for Symmetrical structural configuration.
- DCR $\leq$ 2.0 for Unsymmetrical structural configuration

2.4 Scope

For the study of five story reinforced concrete structure symmetrical and Unsymmetrical is considered. The progressive collapse is initiated by removing verticals load carrying members.

III. METHODOLOGY

For the analysis, symmetrical and Unsymmetrical frame model of plan as shown in Fig.1 & 2 and of height 16.0 m. The ground and the rest of the storey are taken to be 3.2 m high. The column cross section is taken as 0.30m x 0.45m. Beam size is taken as 0.3m x 0.45 m. The floor slabs are modeled as plates of 0.12m thickness. Wall having 200 mm thickness is considered on all the beams. All the supports are modeled as fixed supports. Linear analysis is conducted on each of these models.

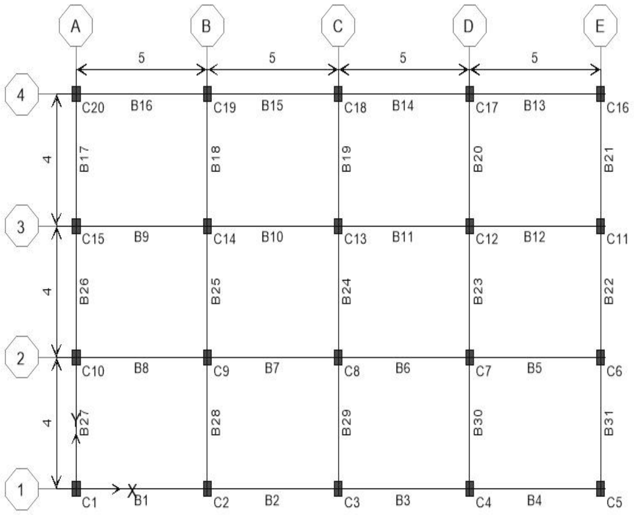

Fig.1 *Plan of Symmetrical Framed structure*

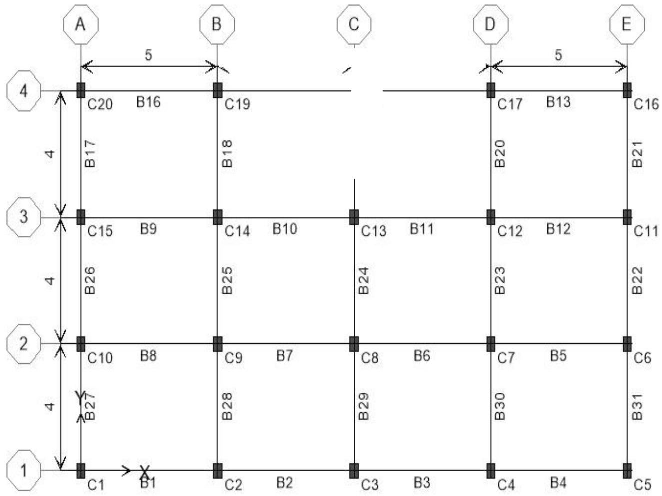

Fig.2 *Plan of Unsymmetrical Framed structure*

Load Considered are as follows:

1. Dead Load as per IS 875 (Part I).
2. Live Load IS 875 (Part II)
   On Roof 1.5 KN/m^2 and on Floors 3.0 KN/m^2
3. Wind Load as per IS 875 (Part III).
4. Self-weight of the Structural elements, Floor Finish =1.5 KN/m^2.
5. Seismic loading as per IS: 1893 (Part I): 2002.

Zone – V, Zone factor = 0.36, Soil Type = Type –II, Medium Class, Importance Factor = 1.0 and Response Reduction Factor = 5.0.The characteristic compressive strength of concrete (fck) is 25 N/mm2 and yield strength of reinforcing steel (fy) is 415 N/mm2. Analysis and design of building for the loading is performed in the ETABS 9.7. Five storey building is designed for seismic loading in ETABS 9.7 according to the IS 456:2000.

IV. ANALYSIS

To evaluate the potential for progressive collapse of a five storey symmetrical & Unsymmetrical reinforced concrete building using the linear static analysis four column removal conditions is considered. First building is designed in ETABS v 9.7 for the IS 1893 (Part-I) load combinations. Then separate linear static analysis is performed for each case of column removal. Demand capacity ratio for the moments and forces at all storeys is calculated for four cases of column failure. Fig.3 & 4 are shown Column C1, C3, C9 and C10 are removed for progressive collapse analysis in different cases.

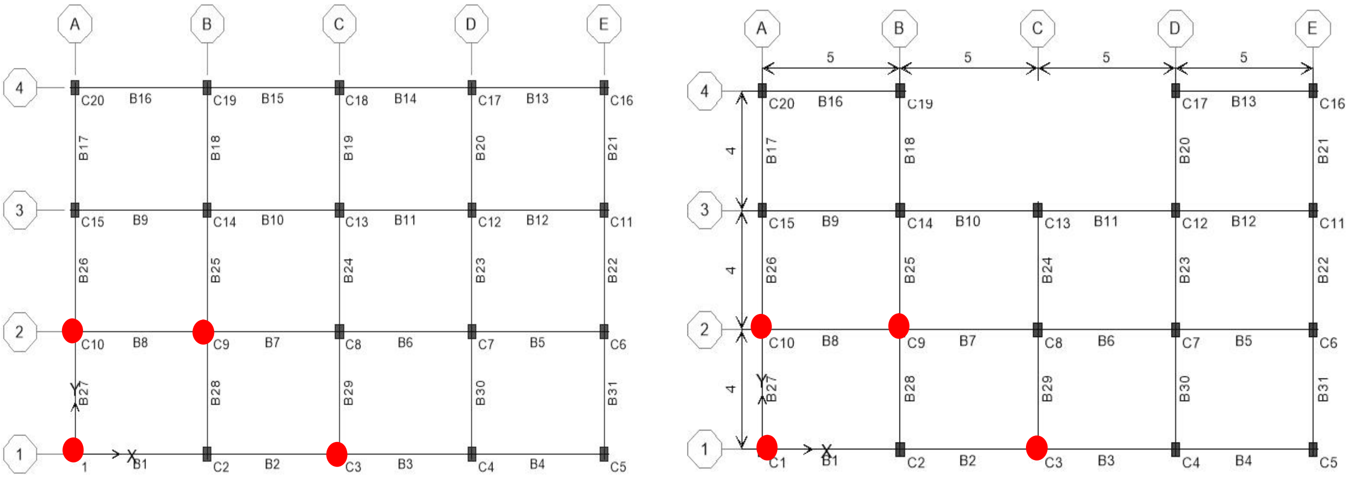

Fig.3 & 4 Removed Columns C1, C3, C9, C10

V. CALCULATION OF DEMAND CAPACITY RATIO

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 9.7

5.1 INTERPRETATION AND DISCUSSION OF RESULT

The DCR values for the columns in all four cases do not exceed the acceptance criteria value suggested by GSA guidelines and hence columns are safe against progressive collapse. But for a removed column adjacent beams DCR values exceed the acceptance criteria value suggested by GSA guidelines. The DCR values of unsafe beams in all seismic zones are summarized below:

5.2 FOR SYMMETRICAL AND UNSYMMETRICAL FRAMED STRUCTURES.

After getting all the DCR values for all case of column removal for Zone-V.

For Column C3 removed Beams B2, B3, and B29 have demand capacity ratios (DCR's) less than the limit of 2 the acceptance criteria value suggested by GSA guidelines and, therefore, do not need additional reinforcement to resist progressive collapse as in Table -1 and 2 respectively.

For Column C10 removed Beams B26, B27, and B8 have demand capacity ratios (DCR's) less than the limit of 2 the acceptance criteria value suggested by GSA guidelines and, therefore, do not need additional reinforcement to resist progressive collapse as in Table -1 and 2 respectively.

For Column C1 removed Beams B1 and B27 have demand capacity ratios (DCR's) less than the limit of 2 the acceptance criteria value suggested by GSA guidelines and, therefore, do not need additional reinforcement to resist progressive collapse as in Table -1 and 2 respectively.

For Column C9 removed Beams B7, B8, B25 and B28 have demand capacity ratios (DCR's) less than the limit of 2 the acceptance criteria value suggested by GSA guidelines and, therefore, do not need additional reinforcement to resist progressive collapse as in Table -1 and 2 respectively.

Table 1 Summary of DCRs for Beams Adjacent to Removed Columns for Symmetrical Structures

	Removed Column	Connected Beam	Demand			Capacity			Ratios		
			P	M2	M3	P	M2	M3	P/P	M2/M2	M3/M3
STORY	Long Side Column Eliminated C 3	B 2	-5.88	-0.054	-128.162	-5.88	-0.054	-128.162	1.0	1.0	1.0
		B 3	-5.88	0.000	-127.902	-5.88	0.000	-127.902	1.0	1.0	1.0
		B 29	-5.86	0.010	-108.996	-5.86	0.010	-108.996	1.0	1.0	1.0
	Short Side Column Eliminated C 10	B 26	6.34	0.025	-102.725	6.34	0.025	-102.725	1.0	1.0	1.0
		B 27	7.53	0.003	-119.601	7.53	0.003	-119.601	1.0	0.167	0.993
		B 8	-3.76	-0.044	-105.78	-3.76	-0.044	-105.78	1.0	1.0	1.0
	Corner	B1	-8.45	0.050	-111.308	-8.45	0.050	-111.308	1.0	1.0	1.0

N	Column Eliminated C 1	B27	-11.27	0.003	-150.480	-11.27	0.003	-150.480	1.0	1.0	1.0
O.	Interior Column Eliminated C 9	B 7	-3.45	0.004	-144.374	-3.45	0.004	-144.374	1.0	1.0	1.0
		B 8	-0.87	0.000	-157.455	-0.87	0.000	-157.455	1.0	1.0	1.0
2		B 25	4.54	0.001	-153.785	4.54	0.001	-153.785	1.0	1.0	1.0
		B 28	5.29	-0.054	-128.162	5.29	-0.054	-128.162	1.0	1.0	1.0

Table 2 Summary of DCRs for Beams Adjacent to Removed Columns for Unsymmetrical Structures

STORY NO. 2	Removed Column	Connected Beam	Demand			Capacity			Ratios		
			P	M 2	M3	P	M2	M3	P/P	M2/M2	M3/M 3
	Long Side Column Eliminated C 3	B 2	-6.13	-0.056	-128.302	-6.13	-0.056	-128.302	1.0	1.0	1.0
		B 3	-6.13	-0.056	-128.302	-6.13	-0.056	-128.302	1.0	1.0	1.0
		B 29	-5.36	0	-128.325	-5.36	0	-128.325	1.0	1.0	1.0
	Short Side Column Eliminated 10	B 26	6.31	0.011	-109.556	6.31	0.011	-109.556	1.0	1.0	1.0
		B 27	7.57	0.004	101.568	7.57	0.024	-102.25	1.0	0.167	0.993
		B 8	-3.86	-0.001	-120.476	-3.86	-0.001	-120.476	1.0	1.0	1.0
	Corner Column Eliminated C 1	B1	-8.24	-0.045	-104.849	-8.24	-0.045	-104.849	1.0	1.0	1.0
		B27	-11.3	0.054	-111.46	-11.3	0.054	-111.46	1.0	1.0	1.0
	Interior Column Eliminated C 9	B 7	-3.5	-0.001	-151.37	-3.5	-0.001	-151.37	1.0	1.0	1.0
		B 8	-0.91	0.004	-145.76	-0.91	0.004	-145.76	1.0	1.0	1.0
		B 25	4.46	0.002	-158.42	4.46	0.002	-158.42	1.0	1.0	1.0
		B 28	5.3	-0.001	140.034	5.3	-0.001	140.034	1.0	1.0	1.0

CONCLUSIONS

Based on the limited study of progressive collapse on symmetrical and Unsymmetrical reinforced framed structure the following broad conclusions can be made.

1. The DCR's values of Loads, Beams Design forces and Beam forces are less than 2 in all cases studied; it suggests that columns are safe as per GSA guidelines for progressive collapse analysis. Hence seismically designed building columns have inherent ability to resist progressive collapse.
2. The beams whose DCR values are less than acceptance criteria values suggested by GSA for progressive collapse guidelines are safe.
3. To avoid the progressive failure of beams and columns, caused by failure of particular column, adequate reinforcement is required to limit the DCR within the acceptance criteria.
4. Applying the GSA criteria to prevent progressive collapse for concrete buildings can be accomplished by the structural engineer using readily available software and for little additional construction cost.

The adequate reinforcement provided in extra to beams which are unsafe can develop alternative load paths and prevent progressive collapse due to the loss of an individual member.

RECOMMENDATIONS AND FUTURE SCOPE

- Investigating failure of columns located in floors other than the ground floor, for example in the middle level storey and just beneath the roof. Also, considering atypical building including both horizontal and vertical irregularities in the building plan.
- Conducting optimum design of the braced frame by considering different configurations.
- Conducting experimental investigations on building models built in the laboratory or on prototype reinforced concrete buildings retrofitted by the proposed mitigation scheme to compare the results with that obtained from the numerical investigations.
- The proposed mitigation scheme is a new scheme that is recommended to discuss further topics including practical issues related to the installing details and cost evaluation.

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