Progressive Collapse Analysis of Two Reinforced Concrete Frame Shear Wall Structure

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Abstract*- In this project, it is put forward to carry out a progressive collapse analysis of 2 models of G+9 storey Reinforced Concrete frame Shear Wall Structure, by considering sudden column removal cases at different locations according to GSA guidelines. A structural model of the structure has been modeled in ETABS v19.0.0. And loads are applied as per GSA guidelines for the assessment of progressive collapse. The structure is composed of 7 bays in both directions, 10 m distance between each bay in both directions. The total structure is designed and detailed by IS codes as a special moment-resistant frame linear static method of analysis is used. As per GSA guidelines four-column removal cases, one at a time on the ground floor has been studied, namely a Corner column, an Exterior column, and two interior columns. For all four cases, the linear static analysis method has been done and Demand/Capacity ratios (DCR) are evaluated. Member having DCR ratio greater than 2 will going to fail for alike column removal case. It is obtained from previous research that shear in a beam is not cynical in any case, columns are also not cynical in Progressive collapse. However, as per linear static analysis, it is captured that beams are going to fail in flexure.*

Keywords- Progressive collapse analysis, RC frame shear wall structure, ETABS, Linear Static Analysis, GSA guidelines 2013, Demand/Capacity Ratio .

I. INTRODUCTION

The progressive collapse has been one of the major issues in building failures since the collapse of the Ronan Point apartment building in 1968 which is in Canning Town in Newham, East London. Progressive collapse is also known as disproportionate failure which is a failure sequence that relates local damage caused by a single member to large-scale collapse in a structure. The local failure can be interpreted as a loss of the load-carrying capacity of one or more structural components that are segments of the whole structural system. Ideally, once any structural member fails, the structure should facilitate a substitute load-carrying path. After the load is redistributed through a structure, every structural member will support different loads. It will cause another local failure If any load goes beyond the load-carrying capacity of any member.

Such sequential failures can propagate through the structure. If more no. of members fails, it may result in partial or complete collapse. Such kind of collapse nature may appear in framed structures, buildings such as Ronan Point(Canning Town in Newham, East London), Murrah Federal Office(Oklahoma City, USA), and Twin Towers of World Trade Centre(New York, USA). On the morning of 16 May 1968, an occupant on the 18th floor of the 22-story Ronan Point apartment building in Newham, East London, struck a match in her kitchen. A gas explosion takes place by virtue of that match and due to the explosion, it knocked out load-bearing precast concrete panels near the corner of the building. The above floors also collapsed due to the loss of support on the 18th floor. The colliding impact of these collapsing floors set off a domino effect and collapses all the way to the ground. The consequent outcome can be seen in Figure-1(a). Only the corner bay of the Ronan Point building has collapsed comprehensively. The building in Oklahoma City, named “Murrah Federal Office” was demolished by a bomb on 19 April 1995. The bomb, which was in a truck at the bottom of the structure, destroyed or badly damaged 3 columns. The supports have been affected due to these columns and it caused the failing of the transfer girder. Breakdown of the transfer girder coming from the collapse of columns supported by the girder and floor areas supported by those columns, which are failed. The result was the general collapse, which is shown in Figure-1(b).

Figure 1(a)- Ronan point building after 16 May 1968.

Figure 1(b)- Murrah Federal Office Building after 19 April 1995 attack.

The whole world has witnessed, both of the twin towers of World Trade Centre(New York, USA) collapse on 11 Sept 2001 following this sequence of events, A Boeing 767 jetliner crashed into the tower at high speed; the crash affected structural damage at and near the point of impact on both towers and also set off an excessive fire within the building, the structure near the impact zone lost its competence to support a load of all the above floors. Hence, some combination of impact damage and fire damage; the structure above collapsed. Having lost its support, the weight and impact of the collapsing upper part of the tower caused a sequence of failures extending downward all the way to the ground. This is an example of complete or global collapse.

II. OBJECTIVE

1. To understand the process of progressive collapse of G+9 storey RC shear wall structure in sudden column removal scenario.
2. To check whether a RC building (Special moment resisting frame) designed and detailed by Indian codes for seismic loads provides any resistance to Progressive Collapse or not.
3. To study change in intensity of progressive collapse due to change in location of triggering incidents (column removal locations)
4. To study the behavior of beams and columns during progressive collapse of structure.

III. MODEL DESCRIPTION

Progressive collapse analysis is done by Linear static analysis method on 2 models of G+9 storey structure.

MODEL A- Reinforced concrete structure with shear walls at corner and at the edges of the strcture.

MODEL B - Reinforced concrete structure with shear walls at corner and at the centre of the structure.

For the Linear Static Analysis, a G+9 RC shear wall structure of height 70.0m is considered. It is modeled using ETABS v19.0.0 software. The column cross-section, Beam cross-section, Slab cross-section, wall cross-section, and shear wall cross-section were fixed based on the preliminary analysis. All the supports were modeled as fixed supports. Bot the models here are designed for the Seismic loads also. The gravity load acting on the structure is carried out as per IS 875 part 1 and IS 875 part 2. Seismic loading is followed as per IS: 1893:2016

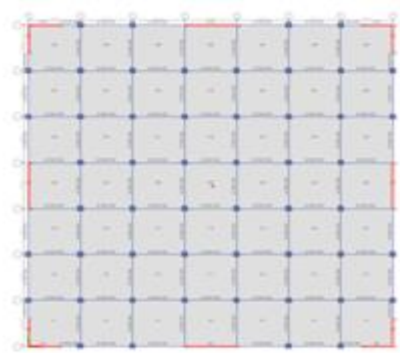

Figure 3(a): Model A

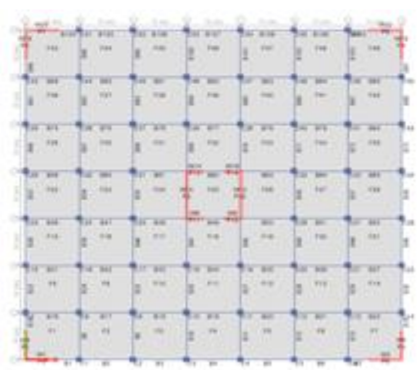

Figure 3(b): Model B

Table 1: Geometry and Loading data for building

1	Span in both direction	70m
2	No. of bays	7 in both direction
3	Height of each floor	4m
4	Live load	4 KN/m²
5	Floor finish load	1.5 KN/m²
6	Service and Utilities load	0.5 KN/m²
7	Partition load	1.5 KN/m²
8	Zone factor	0.16
9	Soil type	II
10	Importance factor	1.2
11	Response reduction factor	5.0
12	Slab thickness	250mm
13	Shear wall thickness	300mm
14	Beam Dimensions	700mmx1000mm
15	Column dimensions	1200mmx1200mm
16	Concrete and Steel Grade	M40 and Fe500

IV. METHODOLOGY

Even though there are several methods: Specific local resistance, alternate load path method, prescriptive design rules for analyzing a structure for progressive collapse analysis, the alternate path method has gained a lot of popularity in the scientific and engineering community due to Its simplicity in application, the same has been recommended by GSA 2013 guidelines. In the alternate path method, key structural members (typically a single column) are removed, and the structure is analyzed to determine its capacity to span across or "bridge" across that "missing" member. For this study, GSA 2013 guidelines are used for progressive collapse behavior simulations for the procedure Linear static.

4.1 Linear Static Analysis Procedure (LSA): In general, LSA is effective for the structures less than or equal to 10-stories. To calculate the force-controlled actions, simultaneously following combination of gravity loads are calculated using equation {1} and applied to those bays immediately adjacent to the removed element and at all floors above the removed element.

$$GLF = \Omega LF\,[1.2\,D + (0.5\,L \text{ or } 0.2\,S)] \qquad \{1\}$$

Where GLF = Increased gravity loads for Linear Static analysis
ΩLF = Load increase factor for linear Static method = 2

Gravity loads for floor areas which are not in the vicinity of removed column or wall are calculated using equation {2}.

$$G = 1.2\,D + (0.5\,L \text{ or } 0.2\,S) \quad \{2\}$$

Where G = gravity loads, D = dead loads, L = live loads and S= Snow loads.

4.2 Acceptance criteria as per GSA guidelines: The purpose of GSA guidelines 2013 (General Services Administration) is to provide guidance to reduce and assess the potential for progressive collapse of Federal buildings, for latest or old or existing construction.

Demand Capacity Ratio: Demand Capacity Ratio (DCR) is the ratio of Internal force or moments(Q_{udlim}) to the Expected strength of the component(Q_{CE}).

$$DCR = Q_{udlim} / Q_{CE}$$

Allowable values of DCR< 2, for typical structural configuration,

DCR < 1.5, for atypical structural configuration.

Along with this for each model, analysis of the structure was done according to GSA guidelines for following cases:

a) Corner Column Removed in originalStructure.
b) Middle of Entire Model Column Removed in original Structure.
c) Middle of Short Side Column Removed in original Structure.
d) Middle of Long Side Column Removed in original Structure.

4.3 Column Removal Locations for Model A & Model B :

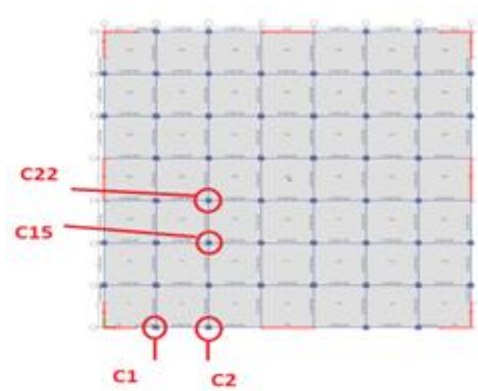

Figure 4(a): Column removal cases for Model A

MODEL A:

Case 1: C1 Removed

Case 2: C2 Removed

Case 3: C22 Removed

Case 4: C15 Removed

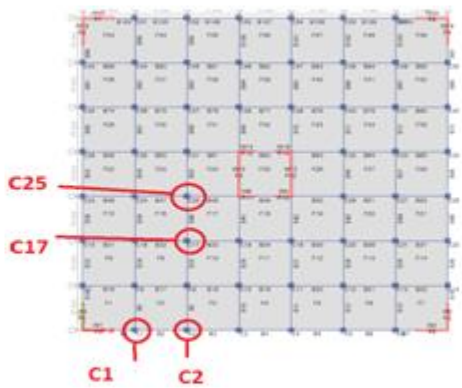

Figure 4(b): Column removal cases for ModelB

MODEL B:

Case 1: C1 Removed

Case 2: C2 Removed

Case 3: C25 Removed

Case 4: C17 Removed

4.4 D/C Ratio of beams in flexure: In both the models for each column removal scenario, the load application is being followed according to GSA 2013 guidelines. From the software, the Bending Moments of beams of respective grids in X-direction and Y-direction are captured and dividing the Bending Moment by respective Expected capacity of beam gives D/C ratio for beam in flexure.

V. RESULTS AND DISCUSSION

MODEL A:

1. After removal of column C1 , beam B1 fails on storey 1&2
2. After removal of column C2, beams B2,B3,B4,B5,B8,B24,B39,B53,B67,B82,B98 are failed on all stories.
3. After removal of column C22, beams B45,B46,B47,B48,B49,B50,B51 are failed upto storey 2 and beams B8,B24,B39,B53,B67,B82,B98 are failed on all stories.
4. After removal of column C15, beams B30,B31,B32,B33,B34,B35,B35,B8,B24,B39,B53,B67,B82,B98 are failed on all stories.

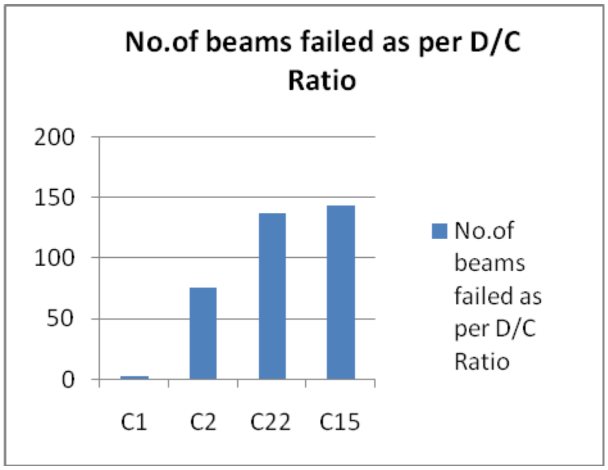

Figure 5(a): No. of beams failed as per D/C Ratio

MODEL B:

1. After removal of Column C1, not a single beam is failed in D/C ratio.
2. After removal of Column C2, beams B2 & B3 are failed on storey 1.
3. After removal of column C25, beam B47 is failed on storey 1 and Terrace and B48 is failed on all stories. Also B40 is failed on Storey 1 and Terrace and B55 is failed on Storey 1, Storey 2 & on Terrace.
4. After removal of Column C17, beams B25&B40 are failed on Storey 1, 2, 3 &Terrace. Also B32 is failed on Storey 1 &Terrace and B33 is failed on Storey 1 & Storey 9.

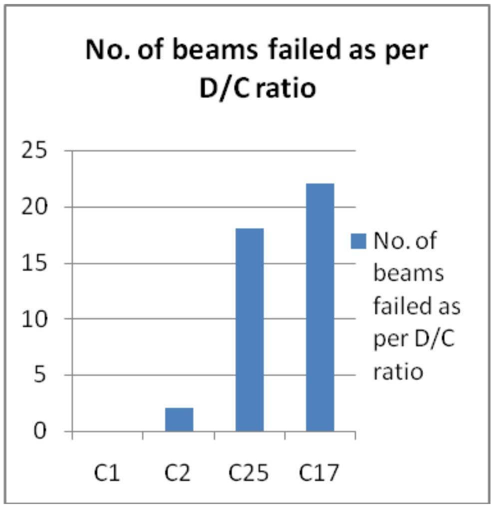

Figure 5(b): No. of beams failed as per D/C Ratio

VI. CONCLUSIONS

1. Model A is better than Model B as per Earthquake Resistant Design of Structure point of view, but Model B is better in resisting progressive collapse of the structure.
2. Damage due to loss of interior column is more than damage due to loss of exterior column and corner column. Hence interior column removal case is the most critical one.
3. Top floor column removal case gives less damage as compared to ground or bottom storey column removal case.
4. Columns that are in the region of removed columns have a higher PMM ratio than columns that are away from column removal locations. This is due to the fact that when one column has lost, adjacent columns have to share the load of it. In both the structures PMM ratio is not exceeding 2, this means that columns are not critical in this case of progressive collapse.
5. If RC shear wall building is designed and detailed according to IS codes, it will prevent progressive collapse. A local collapse will occur, but progressive collapse will not start.

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