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Progressive Collapse Analysis of Moment Resisting Steel Frames for Failure Performance Improvement

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Abstract – Progressive collapse analysis of moment resisting steel frame is presented. Structural model and its analysis executed using STAAD PRO V8 for three different threat-independent column removal conditions by following the alternative load path method. Column removal is permitting to the General Service Administration (GSA-2003) guidelines for estimating progressive collapse potential. Results are shown for recreation in which a critical structural member is removed.

Keywords – GSA (2003}, Progressive Collapse

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1. INTRODUCTION

Progressive Collapse:

Progressive Collapse is the spread of an primary local failure from a structural element resulting, eventually, in the collapse of an entire structure. Progressive collapse involves a phenomenon of sequential failure of part of the structure or the complete structure initiated by sudden loss of vertical load carrying member i.e. column, failure of a member in the primary load resisting system leads to relocation of forces to the adjoining members and if redistributed load surpasses member capacity it fails. Nowadays Steel Frame Structure (buildings) are establishing, Building technique with a "skeleton frame" of vertical member and horizontal member of various I-beams, constructed in frame to support the floors, roof and elements attached to the frame.

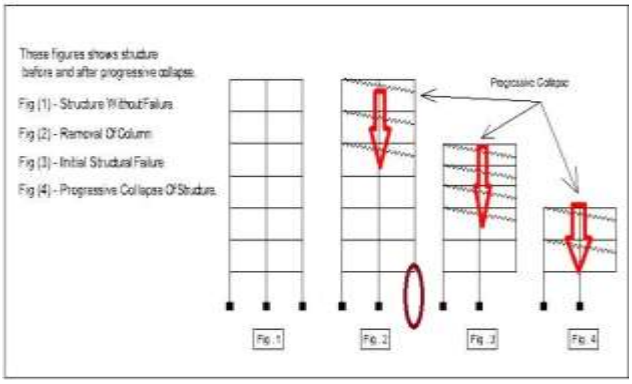


Fig.1.1 Progressive collapse of structure

Alternate Load Path Method:

Alternate load path method is the procedure in which structure is analyzed for a collapse potential after the exclusion of column. In this research work whole structure is designed and analyzed, bending moment results of vertical structural member were taken in consideration. The member which observes lowest bending moment should be removed this in result gives the lowest number of failed structural member after reanalyzing.

2. RECENT RESEARCH WORK

Vikas Tiwari and Sambhav Gangwal [2019] presented a paper on Progressive Collapse Analysis for Asymmetrical G+11 Story Tall Building using STAAD PRO. For progressive Collapse Analysis GSA (2003) guidelines were considered. Analysis shows the structural member adjacent to the damaged/removed column joint under goes more damage as compared to the structural member which are away from the removed column joint. Corner column case is found critical in the incident of progressive collapse. It is also observed that to avoid the progressive failure of structural members, after failure of column due to extreme loading from blast, adequate reinforcement can also be useful to limit the DCR within the acceptance criteria.

Jain and Patil [2018)] has done a research work on a linear static analysis method for progressive collapse analysis to determine strength against the local failure and accidental occurrences for a RC framed structure to calculate the demand capacity ratio and the safety of the structure. In this research, A finite element model had been is considered and analyzed for the G+9 storey building and then the analysis was carried under critical column removal consequence as per the guidelines provided in GSA (2003) considering the provisions of IS 1893:2002 to simulate dynamic collapse mechanism using ETABS software v16.2.1 (software for modelling or analysis of structure) to assess the exposure to progressive collapse of a representative RC framed structures.

Sonawan et al. [2013] studied the seismic capacity of earthquake exposed buildings or earthquake damaged structures for the future use. In the research, it had been detected that majority of buildings damaged due to earthquake may be safely reused, if they were adapted into seismically resistant structures by employing retrofitting measures. This work underlined on the seismic evaluation & different retrofitting strategies of R.C. structures.

Tavakoli et al. [2012] engrossed on gravity and explosion loading. Remarks of structures damaged by earthquake had shown that earthquake load also may cause local partial or complete failure of critical elements and may lead to progressive failure. This research was established on the three and two-dimensional forming and push-over analysis of seismically calculated special dual system steel frame structures with concentrically braced frames with complete loss of critical elements.

Farzin Zareian, et. al. [2007] illustrates a probabilistic-based practice for measuring the collapse potential of structural systems, which can provide us with more precise estimates of losses prompted by earthquakes. Applications of this methodology for assessment of collapse potential of existing buildings and design for collapse safety are demonstrated by equations and example. The potential to collapse is signified by the probability of collapse at discrete threat levels and on an annualized basis (mean annual frequency). The basic ingredient of the proposed methodology is a 'collapse fragility curve' which states the probability of collapse as a function of the selected ground motion intensity measure The execution encounters are to develop mathematical models for structural systems that can mimic performance close to collapse, identify structural parameters that suggestively affect the structure's collapse capacity

3. METHODOLOGY

A. General Service Authority (GSA-2003)

The United States General Service Authority (GSA) out a document permitted "Progressive collapse analysis and design guidelines for new federal office building and major modernization projects" in November 2000 and revised in June 2003.

The (GSA, 2003) guideline monitors a risk independent methodology for analysis and design of structures to moderate the threat of progressive collapse.

This guideline was the first articles which signify explicit stepwise process to support the structural engineering to evaluate the potential of progressive collapse of federal facilities.

B. GSA Guidelines – Exterior Considerations

Analyze the structure after the notional removal for a load-carrying structural member for the first floor positioned at or near the mid of short side, intermediate of long side, or at the corner of the structure as shown in Figure

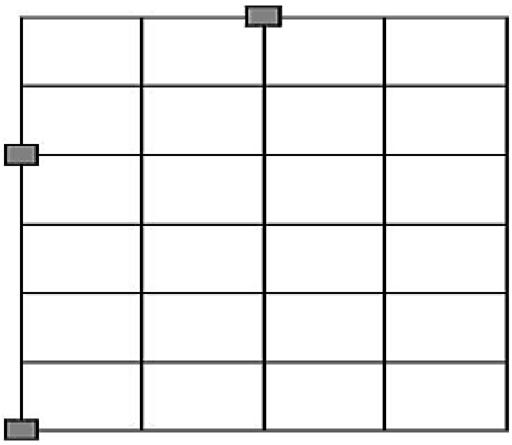


Fig.1.2 Notations of columns

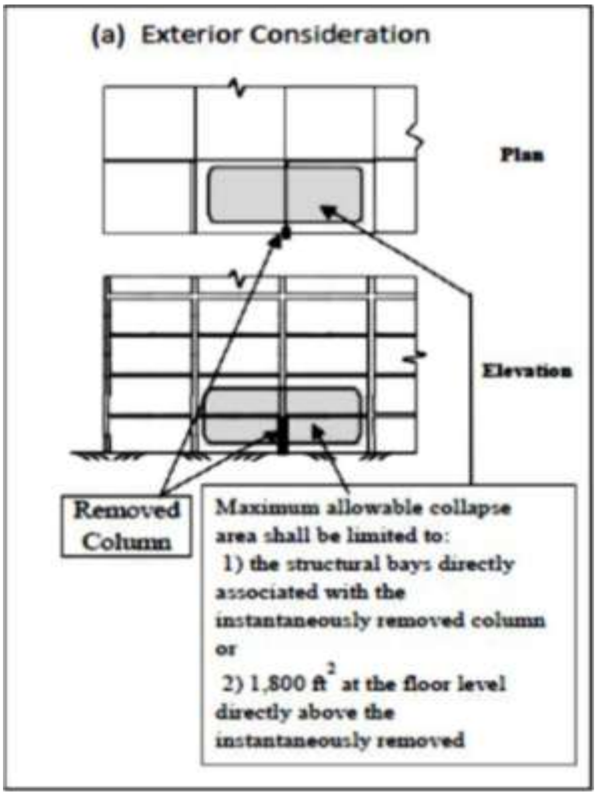


Fig.1.2 Exterior Considerations

C. GSA Guidelines- Load Combination

The (GSA, 2003) guideline states that only 25 percent of the live load essential to be applied in vertical load combination because of the probability of presence of the complete live load during the collapse being very low.

A magnification factor of 2 is used in the static analysis approach to account for dynamic effects.

Load Combination = 2(DL + 0.25LL)

where,

DL = dead load

LL = live load

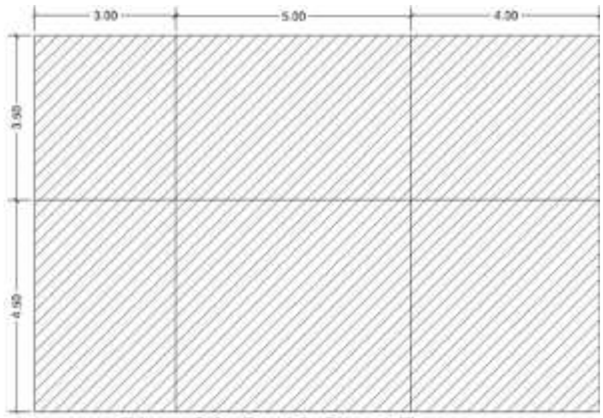
4. STRUCTURAL MODELLING

For the analysis work, three models of steel frame building (G+10) floors are made to know the realistic behavior of building during earthquake. The length of the steel frame structure is 12m and width is 8m. Height of typical story is 3.5m. Column sizes changes first at 5 storey, 8 story and 9 story. Building is asymmetrical. Material concrete grade M20 is used, while steel Fe 250 (mild steel) is used. Analytical modeling that contains all components which impact the mass, strength and stiffness. The non-structural element and components that do not considerably influence the behavior of structure were not modeled. Beams (horizontal structural member) and columns (vertical structural member) are modeled as frame element and joined node to nodes. The effect of soil structure interaction is ignored in analysis. The vertical structural members are assumed to be fixed at the ground level.

4.1 DETAILS OF THE BUILDING PLAN, MEMBER SIZE AND MATERIALS

4.1.1 Plan

Plan of the steel building which is used for the study is shown in figure 4.1.1



Plan Of G+10 Steel Frame

4.1.2 Member size of the Beams, Columns and Bracing

Member size used for beams, columns and bracing are shown in table 3.1

Table 4.1.3: Size of Beams, Columns and Bracings

Storey Level	Column Schedule		Beam Schedule	
	Column No	Size	Beam No	Size
G+4	C1	ISMB 350	B1	ISMB 300
5 to 8	C2	ISMB 300	B2	ISMB 250
9 to 11	C3	ISMB 250	B3	ISMB 200

4.1.4 Material Properties used for analysis

Concrete- M 20, Density-2400 Kg/m^3, Young's Modulus E= 22360 N/mm^2, Shear Modulus 8000N/mm^2, Poisson's Ratio-0.2

Structural steel- Fe 250, Density-7850 Kg/m3, Young's Modulus E= 2.1x10^{5}N/mm^2, Shear Modulus 80000N/mm^2 Poisson's Ratio-0.3

4.1.5 Load Combinations

Dead Load = DL = 1.5 kN/m^2, Live Load = LL = 3.5 kN/m^2

Load Combinations

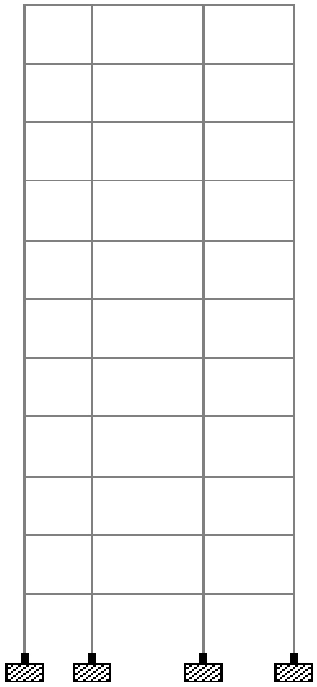
1. 1.5 X DL : 1.5 X LL

2. 2 X DL : 1.2 X LL

3. 1.5 X DL

4. 0.9 X LL

(NOTE= ZONE – NON SEISMIC ZONE)



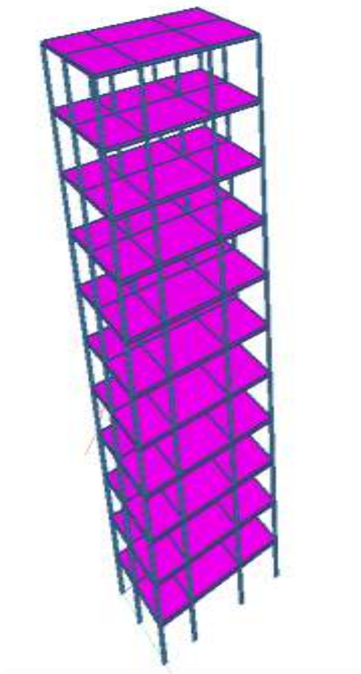


Fig 4.1.5: Model Asymmetrical G+11 Structure (2D)&(3D)

Analysis of above structure shows zero member failure which indicates structure observed safe in linear static analysis.

For Progressive Collapse of above structure any load carrying element should be removed, for this vertical member of ground story are taken consideration

4.2 Selection of Structural Member Removal

(A) According To GSA (2003) Guidelines

Which suggest?

- Vertical member near centre to shortest side of structure (case 1)
- Vertical member near centre to longest side of structure (case 2)
- Any corner vertical member (case 3)

Bending Moment Consideration:

189	88	3.500	1:DEAD LOAD	Max +ve	3.500	0.096	0.000	1.340
				Max -ve	0.000	-0.049	3.500	-3.425
			2:LIVE LOAD	Max +ve	0.000	1.820	3.500	8.814
				Max -ve	3.500	-3.719	0.000	-3.265
			3:GENERATEL	Max +ve	0.000	2.656	3.500	8.084
				Max -ve	3.500	-5.480	0.000	-2.887
			4:GENERATEL	Max +ve	0.000	2.125	3.500	6.467
				Max -ve	3.500	-4.384	0.000	-2.309
			5:GENERATEL	Max +ve	3.500	0.100	0.000	2.010
				Max -ve	0.000	-0.074	3.500	-5.137
			6:GENERATEL	Max +ve	3.500	0.060	0.000	1.206
				Max -ve	0.000	-0.044	3.500	-3.082
190	89	3.500	1:DEAD LOAD	Max +ve	3.500	0.030	3.500	2.431
				Max -ve	0.000	-0.035	0.000	-1.386
			2:LIVE LOAD	Max +ve	0.000	1.972	0.000	3.517
				Max -ve	3.500	-4.032	3.500	-5.907
			3:GENERATEL	Max +ve	0.000	2.905	0.000	3.196
				Max -ve	3.500	-6.002	3.500	-5.215
			4:GENERATEL	Max +ve	0.000	2.324	0.000	2.557
				Max -ve	3.500	-4.802	3.500	-4.172
			5:GENERATEL	Max +ve	3.500	0.048	3.500	3.646
				Max -ve	0.000	-0.053	0.000	-2.079
			6:GENERATEL	Max +ve	3.500	0.027	3.500	2.188
				Max -ve	0.000	-0.032	0.000	-1.247

Fig 4.2.1: Maximum bending moment

Vertical Members of Ground Story	Highest +Bending Moment
Beam 34	1.890
Beam 35	2.068
Beam 35	3.519
Beam 36	3.482
Beam 111	1.250
Beam 112	1.110
Beam 113	0.959
Beam 114	0.629
Beam 188	2.020
Beam 189	2.010
Beam 190	3.646
Beam 191	4.005

Fig 4.2.2: Maximum bending moment table

Combination of (A) & (B)

Moment results of vertical structural member were taken in consideration. The member who observes lowest bending moment should be removed this in result gives the lowest number of failed structural member after reanalyzing.

4.3 Structural Member Removal and Analysis of Structure

Case 1: Vertical member near to shortest side of structure

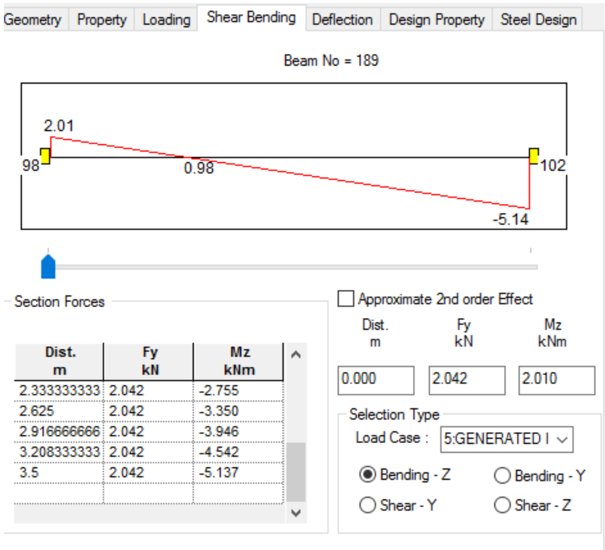


Fig 4.3.1Shows Member with Lowest BM

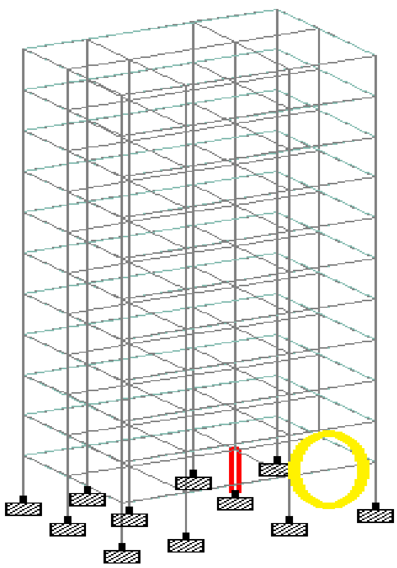


Fig 4.3.2 Shows Vertical Member Removed & Failed Member Highlighted

4.4 Overcome Failure and Improving Performance of Structure

After finding location of failure to achieve this objective different remedial measures for improving performance of structure like removal of failure causing member, strengthening structure are adopted

Strengthening structure:

Strengthening can be done in different ways,

Two Adopted Methods -

1) Strengthening of column by increasing its size.

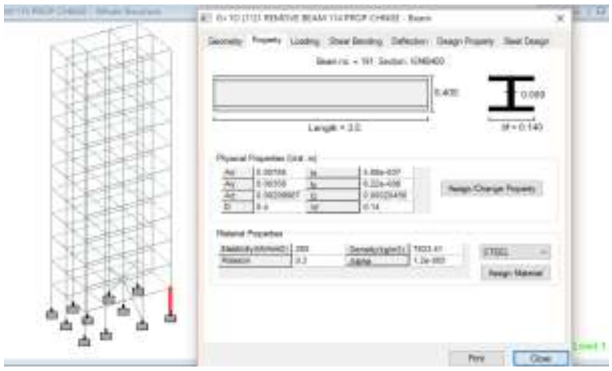


Fig 4.4.1: Strengthening of column

Storey Level	Column Schedule Before Collapse		Column Schedule After Strengthning	
Ground Story	C1	ISMB 350	C1	ISMB 400

2) Bracing added next to failed member was embraced.

There are various types of bracings are as follows-

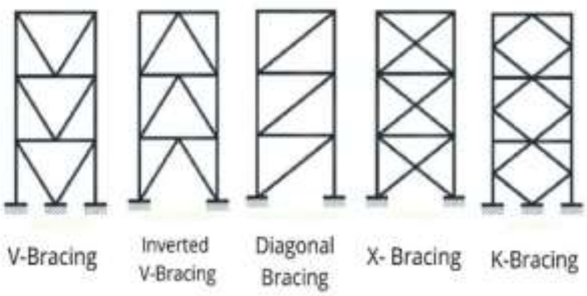
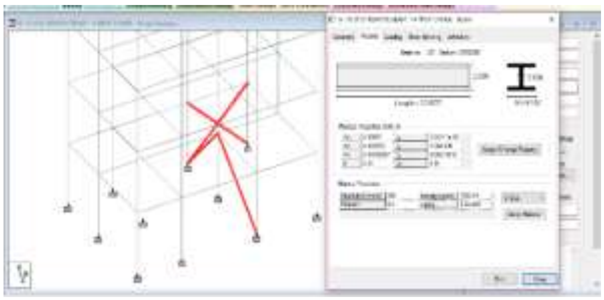


Fig4.4.2: Types of Bracing



4.4.3: Fig Inverted V bracing and X bracing are used in structure

Table 4.4.1: Size Bracings

Type of Bracing	Size of Bracing
'X' Bracing	ISMB 350
Inverted 'V' Bracing	ISMB 350

4.4.2. Graphs of Staad Pro Results:

Bending moments of ground story are taken in consideration

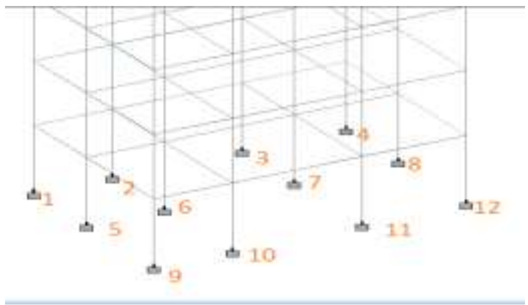


Fig 4.4.2: Numbering of Column

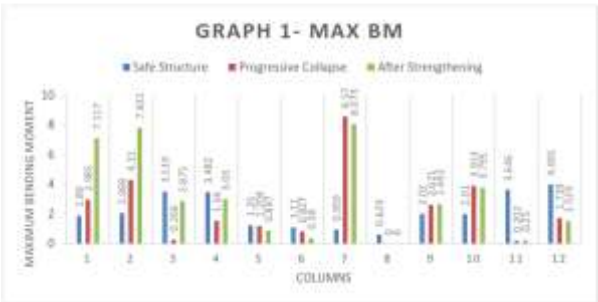


Fig.4.4.3: Maximum BM of safe structure v/s Progressive collapse v/s after strengthening

5. CASE 2:-VERTICAL MEMBER NEAR TO LONGEST SIDE OF STRUCTURE

Considering G+10 analyzed steel frame (safe structure) we are going to analyze case 2 for progressive collapse.

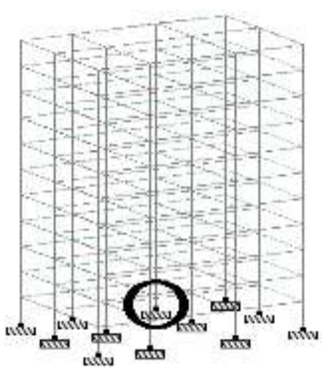


Fig 5.1 Shows longer side Member removed

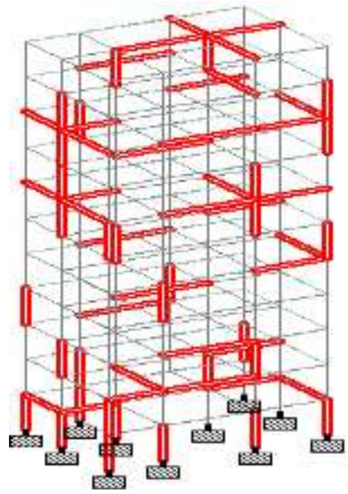


Fig 5.2 Failed members highlighted

Strengthening structure:

1) Bracing added adjacent to failed member were adopted.

There are different types of bracings are as follows-

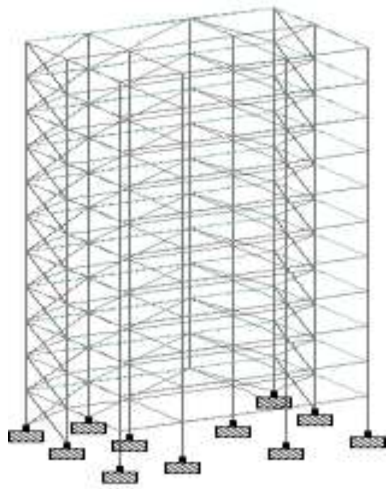


Fig 5.3 Inverted V bracing and X bracing are used in structure

Table 5.1: Size Bracings

Type Of Bracing	Size of Bracing
'X' Bracing	ISMB 175
Inverted 'V' Bracing	ISMB 175

Graphs of Staad Pro Results:

Bending moments of ground story are taken in consideration

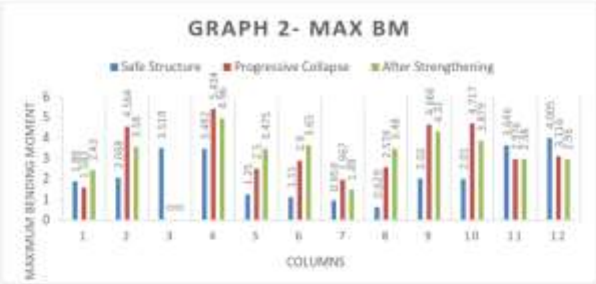


Fig. 5.4 Maximum BM of safe structure v/s Progressive collapse v/s after strengthening

6. CASE 3:- ANY CORNER VERTICAL MEMBER

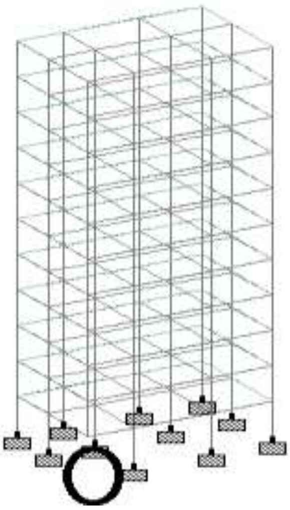


Fig 6.1Shows corner member removed

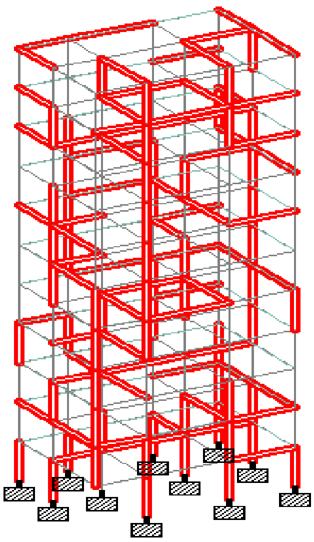


Fig 6.2 Failed members highlighted

Strengthening structure:

2) Bracing added adjacent to failed member were adopted.

There are different types of bracings are as follows-

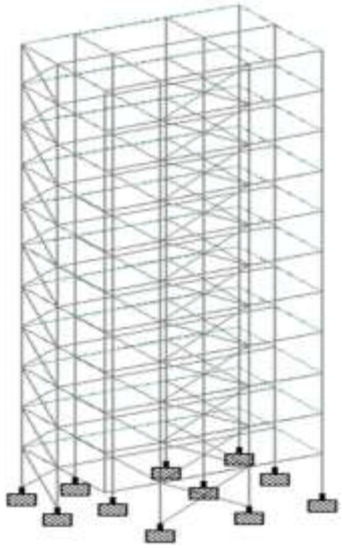


Fig 6.3: X bracing are used in structure

Table 6.1: Size Bracings

Type of Bracing	Size of Bracing
'X' Bracing	ISMB 175
Inverted 'V' Bracing	ISMB 175

6.3 Graphs of Staad Pro Results:

Bending moments of ground story are taken in consideration

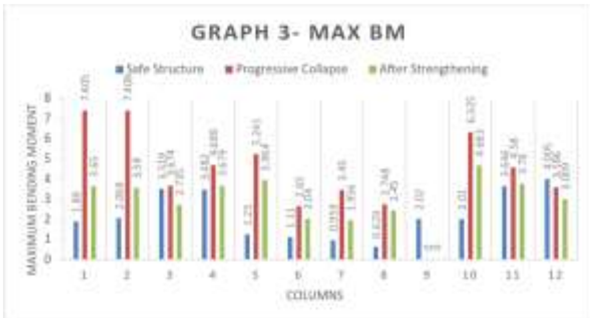


Fig. 6.3.1 Maximum BM of safe structure v/s Progressive collapse v/s after strengthening

7. OBSERVATIONS:

We observed the three types of member failed conditions , in which case one shows minimum number of failed member as that of case two as that of case three.

For other asymmetrical steel frames we can suggest case one that is removal of vertical member which is near to centre of shortest side of steel frame structure.

8. CONCLUSIONS:

Discussion on results obtained by analysis of the 3D model of asymmetrical G+11 story's steel frame structure The preferred results are based on methods following GSA 2003 guideline and stepwise analysis. Progressive collapse potential of structure is found out by considering vertical member removal cases. The results obtained are discussed below as: -

Present study shows members adjacent to the damaged/removed vertical member joint experienced more destruction as compared to the beams which are away from the removed vertical member joint. Corner column removal (case 3) is found serious in the incident of progressive collapse.

For reducing effect of progressive collapse strengthening of column become more difficult for structure having more than one failed member and for floor to floor failure. Bracing element acts as effective remedial measure to overcome progressive collapse

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