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Analysis and study of progressive collapse ofstructures under seismic loading conditions

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Abstract-Progressive collapse is a structural phenomenon and it can be the limit as a failure of complete structure or single element of structure precipitated by collapse of relative tiny part of the structure. Accidental loads which cause progressive collapse of structures are of unknown intensities which may affect critically on some parts of structure which leads to transfer of forces into other corresponding structural elements which also may lead to overloading. Owing to the explanation the aim of the paper is to find out the mechanism of transfer of load path. The structure shall be designed for the seismic loadings as per Indian standards and columns shall be removed at 3 different specified location as per GSA guide lines. Then the critically affected beams and columns are found out and percentage variations of the loads in other members shall be represented in the form of axial load percentage variations for the columns and DCR values for the beams. With the help of these results the critically affected case, members and path for the load transfer shall be determined.
Index terms-Alternate Load path, axial percentage variations, Column removal cases, DCR ratios.

I. INTRODUCTION

Progressive collapse is a structural phenomenon which can be the limit as a complete failure of the structure or single element of that structure precipitated by collapse of relative small part of the structure. The term progressive collapse is such a hazardous effect used to indicate the initial spread of local failure from one element to adjacent elements, eventually results in collapse of whole structure. Local damage to buildings is caused by man-made or natural disasters to withstand the strength of the structure without being disproportionate to the cause of the start. This state indicates that the progressive collapse is kind of disproportional failure when local system failure which leads to the global failure of building. Under the influence of unexpected events, a reasonable sorting method of structural robustness under the action of critical accidental load is established. If the structural part is invalidated by an exception injunction, the load exceeds the limit capacity, or when the load mode or boundary conditions change, the structural element fails, the incremental crash occurs, and then the structure finds another load path to reassign the load applied to it, so the remaining members may fail to cause the failure mechanism. It is a dynamic process, attained usually by large deformations in which deformed frame of structure continuously search for alternative load path to withstand and transfer the loads.

II. ANALYSIS METHODS

Various methods used for stepwise collapse analysis are linear static analysis, nonlinear static analysis, linear dynamic analysis and nonlinear dynamic analysis. The linear method adopts nominal linear stress-strain relation, but allows the whole structure deformation and material acceptance standard to make better use of the nonlinear characteristics of seismic response. The nonlinear method is also called pushover analysis, and a simple nonlinear method is used to calculate seismic deformation. Nonlinear dynamics methods are generally referred to as time history analysis and require appropriate knowledge and predictive capabilities.

2.1 Linear static analysis[1]

This method is very simple and appropriate only for the regular structures and the response to PC potential is known from Demand Capacity Ratio1(DCR) which should be within 2.
Analysis procedure as per GSA guidelines.

1. Build a 3-D model using E TABS 13. Software and assign all necessary member properties and fixity conditions and analyse with a gravity loads i.e. DL+LL and find out the results (moment, shear) without removing any column.
2. Remove the column as per specification and static load1 combination are applied as per GSA specified positions for different column removed conditions.
3. Then linear static analysis is performed1 for the static load combination
4. Find out the demand for the adjacent columns which are critically affected.
5. Then calculate the DCR value for affected structural members as per GSA1guidelines.

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6. If DCR1 value exceeds the limiting values then building will be subject to the Progressive1 collapse.

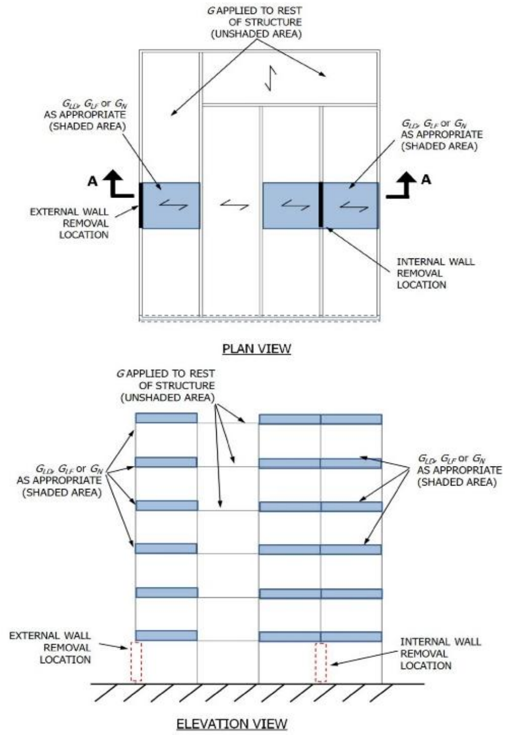

Fig 1 Loads to be applied in the Loads and Load Locations for External and Internal Column Removal for Linear and Nonlinear Static Models

2.2 .Load case for1 deformation-controlled1 actions (qud)

To find out the deformation-controlled actions, apply the following combination of gravity loads

Increased Gravity Loads1 for Floor Areas above Removed1 Column or Wall: Apply these following increased gravity loads to those bays which are immediately above to the removed member as shown in fig

$GLD = \Omega LD[1.2\ D + (0.5\ L \text{ or } 0.2\ S)]$

Where, GLD = Increased gravity loads for deformation-controlled actions for Linear Static analysis D=Dead load including façade loads (KN/m2) L=Live load including live load reduction ΩLD= Load increase factor for calculating deformation- controlled actions for Linear Static analysis

Gravity Loads1 for Floor Areas Away From Removed Column or Wall. Apply these following gravity loads to rest of the structure as shown in fig

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

Where G = Gravity loads

DL= Dead Load LL= Live load

2.3 Load case for force-controlled actions (QUF)

Increased Gravity Loads for Floor Areas Above Removed Column or Wall. Apply the following increased gravity loads to those bays which are immediately above the removed column and at all floors above the removed element as shown in fig

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

Where GLF = Increased gravity loads for force-controlled actions for Linear Static analysis

D = Dead load including façade loads (kN/m2)

L = Live load ΩLF = Load increase factor for calculating force-controlled actions for Linear Static analysis

Increased1 Gravity Loads for Floor1 Areas above Removed1 Column or Wall. Apply the following increased gravity loads to those bays which are immediately above the removed element and at all floors above the removed element as shown in above fig

$GN = \Omega N\ [1.2\ D + (0.5\ L \text{ or } 0.2\ S)]$

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Where GN = Increased gravity loads for Nonlinear Static Analysis
D = Dead load including façade loads (kN/m2) L=Live load.
ΩN =Dynamic increase factor for calculating deformation-controlled and force-controlled actions for Nonlinear Static analysis; use appropriate value for framed or load-bearing wall structures
DCR=Qud/Que
Qud= demanding or the acting force in the member or connection or joint.
Que= Un factored capacity of the member or Expected ultimate strength of the member.
As per GSA allowable DCR values are,
Demand Capacity Ratio < 2.0 for regular structures.
Demand Capacity Ratio< 1.5 for irregular structures.
Demand Capacity Ratio< 3.0 for steel structures

2.4.Nonlinear static analysis

The nonlinear static [2] analysis program involves amplifying the regular increment of the vertical load until it exceeds the yield1 strength or collapse of the structure. This is a complex approach, depending on the load step integration steps1 and tolerances, and the analysis requires more rerun, which is also known1 as vertical push over analysis. Analysis procedure1 is given below as per GSA guidelines

2.5. Linear dynamic analysis

Under the action of abnormal load, the collapse of vertical bearing unit is an extremely dynamic process. These procedures study the response of buildings more accurately1because they are constitutionally involved1 in inertia, damping, and dynamic amplification factors. Through time history analysis, linear static analysis can be carried out. It involves the1 nominal analysis process of the dynamic response of the structure to a particular load, which changes over time and can be determined by time history analysis. Linear dynamic analysis is carried1 out by using the initial condition method Analysis1 procedure is given below as per GSA guidelines.

2.6. Nonlinear dynamic analysis

Nonlinear dynamic analysis method is a very accurate and efficient method of stepwise collapse analysis, which includes removing vertical bearing structure and material being affected by nonlinear behavior.
This method is similar to linear dynamic analysis and only allows structural elements to pass through within the elastic range, and it takes more time to determine and validate the output. However, it takes a time-consuming process.
The maximum bending and energy dispersion are allowed by the nonlinear dynamic analysis of yield and fracture.

Exterior consideration

- Analyse the structure by removing exterior Corner columns on Ground floor.
- Analyse the structure by removing exterior Edge columns on Ground floor.

Interior consideration

- Analyse the structure by removing interior centre columns on Ground floor.

Loadings:
Dead load : self weight of the building
Live load: 3 kN/m2
Floor finish : 1.5 kN/m2
Wall load: Exterior = 13.8 KN/m2
interior = 9kN/m2
Parapet load : 4.2 KN/m2
Seismic lodings (IS 1893:2002):Designed for Zones II.
Soil type : I.
Response reduction factor :5.
Importance factor : 1
Time period : 0.873s

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III. ANALYSIS AND RESULTS

Reinforced concrete building is modelled in E TABS 13.0, using a linear static method to analyze the structure using the load specified by is456:2000 and the seismic load combination described in IS: 1893:2002. The gradual collapse of buildings under the condition of demolition of different columns is analysed. Columns are deleted and parsed. The building was designed and analysed

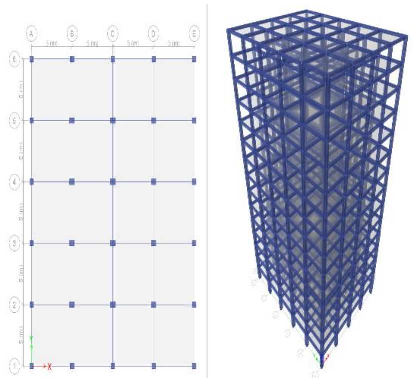


Fig 2 Plan view and elevation view of the model

IV. AXIAL FORCE VARIATIONS

4.1. Exterior corner column removal at ground floor.

When A1 is removed at ground critically affected columns are A2 and B1

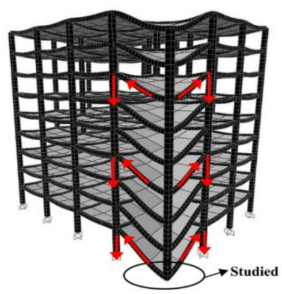
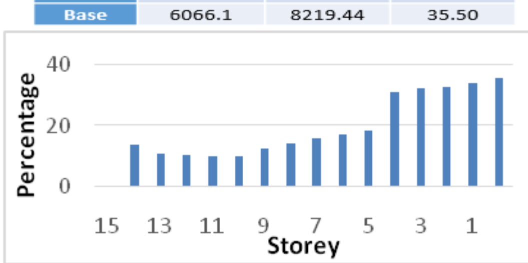


Fig 3 load path distribution when corner column is removed

Storey	Before removal	After removal	%Increase
15	0	0	0
14	254.8	289.56	13.64
13	655.78	727.39	10.92
12	1056.56	1164.91	10.25
11	1457.41	1603.05	9.99
10	1857.44	2042.28	9.95
9	2268.64	2549.19	12.37
8	2679.1	3061.13	14.26
7	3089.79	3576.42	15.75
6	3500.91	4095.69	16.99
5	3911.47	4625.67	18.26
4	4345.59	5691.55	30.97
3	4774.82	6297.14	31.88
2	5204.93	6905.59	32.67
1	5635.38	7532.96	33.67
Base	6066.1	8219.44	35.50



4.2. Exterior edge column removed at ground floor.
When C1 is removed at ground floor critically affected columns are B1,D1andC2

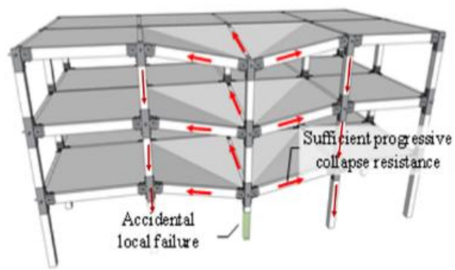
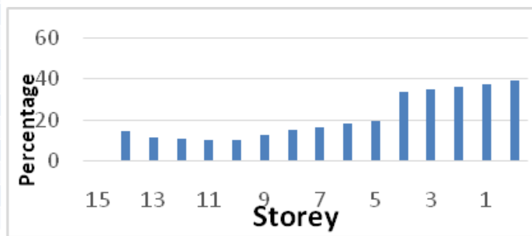


Fig 4 load path distribution when edge central column is removed

Storey	Before removal	After removal	%Increase
15	0	0	0
14	481.45	532.2	10.54
13	1173.15	1274.56	8.64
12	1865.51	2018.28	8.19
11	2558.07	2763.14	8.02
10	3251.01	3509.55	7.95
9	3952.69	4352.91	10.13
8	4654.36	5200.63	11.74
7	5357.58	6256.24	16.77
6	6062.14	6921.24	14.17
5	6768.77	7798.24	15.21
4	7498.79	8765.59	16.89
3	8229.43	9747.49	18.45
2	8962.6	10748.9	19.93
1	9697.97	11772.23	21.39
Base	10436.52	12934.61	23.94



4.3. Interior centre column removed at ground floor
When C3 is removed at ground floor critically affected columns are C2,C4,B3 and D3

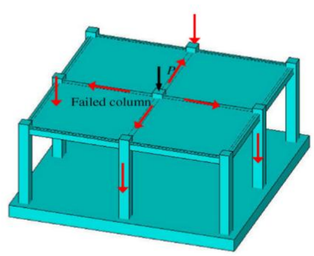
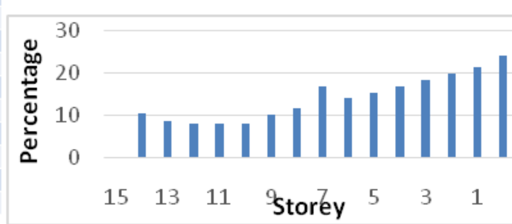


Fig 5 load path distribution when interior centre column is removed

Storey	Before removal	After removal	%Increase
15	0	0	0
14	254.8	293.19	15.07
13	655.78	732.25	11.66
12	1056.56	1171.65	10.89
11	1457.41	1611.82	10.59
10	1857.44	2053.03	10.53
9	2268.64	2569.77	13.27
8	2679.1	3089.65	15.32
7	3089.79	3614.78	16.99
6	3500.91	4145.17	18.40
5	3911.47	4688.74	19.87
4	4345.59	5834.63	34.27
3	4774.82	6462.2	35.34
2	5204.93	7098.15	36.37
1	5635.38	7753.46	37.59
Base	6066.1	8482.3	39.83



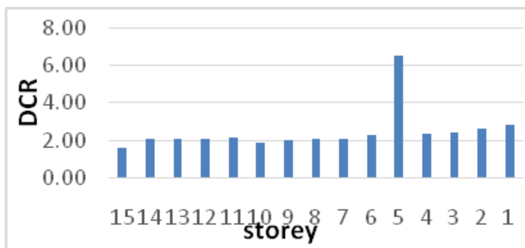
4.4. Calculation of DCR for the structural member

Data required:
Breadth, b = 300mm
Depth, d = 450mm
Cover, d' = 30mm
Effective depth, = D- d' = 450-30 =420 mm
fck= 25N/mm2
fy= 415N/mm2
Member force, Mu = 164.27kn-m
Calculation of ultimate moment: Mulimit =0.138*fck*b*d*d
=0.138*25*300*420*420
= 182.57 Kn-m
DCR = Mu/ Mulimit
=164.27/182.57 =0.901 < 2.0
Hence safe
DCR variations

4.5. Exterior corner column removal at ground floor.

When A1 is removed at ground floor the adjacent beams connecting to removed columns are critically affected

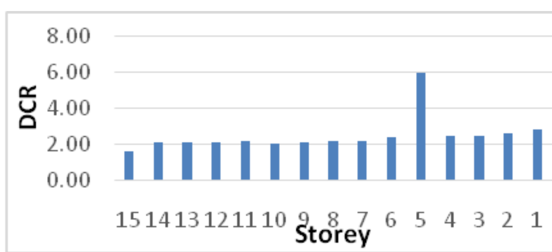
Storey	Bending Moment	Ultimate Moment	DCR
15	117.29	75.45	1.55
14	154.13	75.45	2.04
13	153.74	75.45	2.04
12	155.31	75.45	2.06
11	158.57	75.45	2.10
10	262.49	139.97	1.88
9	276.37	139.97	1.97
8	283.25	139.97	2.02
7	289.72	139.97	2.07
6	311.6	139.97	2.23
5	1183.5	182.574	6.48
4	427.7	182.574	2.34
3	434.85	182.574	2.38
2	470.66	182.574	2.58
1	507.5	182.574	2.78



4.6. Exterior edge column removal at ground floor.

When C1 is removed at ground floor the adjacent beams connecting to removed columns are critically affected

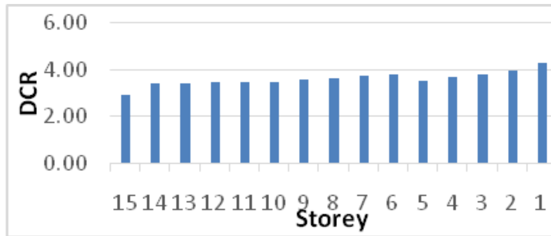
Storey	Bending Moment	Ultimate Moment	DCR
15	147.01	75.45	1.95
14	186.02	75.45	2.47
13	184.9	75.45	2.45
12	186.17	75.45	2.47
11	188.68	75.45	2.50
10	336.01	139.97	2.40
9	351.27	139.97	2.51
8	356.12	139.97	2.54
7	359.85	139.97	2.57
6	380.19	139.97	2.72
5	1424.15	182.574	7.80
4	513.68	182.574	2.81
3	522.19	182.574	2.86
2	557.76	182.574	3.05
1	600	182.574	3.29



4.7. Interior centre column removed at ground floor

When C3 is removed at ground floor the adjacent beams connecting to removed columns are critically affected

Storey	Bending Moment	Ultimate Moment	DCR
15	222.93	75.45	2.95
14	260.41	75.45	3.45
13	260.22	75.45	3.45
12	261.63	75.45	3.47
11	264.8	75.45	3.51
10	489.9	139.97	3.50
9	502.69	139.97	3.59
8	510.97	139.97	3.65
7	523.44	139.97	3.74
6	537.84	139.97	3.84
5	651.74	182.574	3.57
4	678.11	182.574	3.71
3	699.76	182.574	3.83
2	728.65	182.574	3.99
1	790.87	182.574	4.33



V. CONCLUSIONS

- Case 1 Interior centre column removal
  - At ground floor DCR is exceeds the limit(2.0) for the adjacent beams at all the storeys
  - zipper type Failure is observed.
  - Columns are least affected as compared to other cases and load is transferred to all the 4 adjacent columns uniformly.
- Case 2 Exterior edge centre column removal
  - At ground floor Similarly DCR exceeds the limit for all the adjacent beams of removed column.
  - Similar zipper type of failure pattern is observed
- Case 3 Exterior corner column removal
  - DCR limit is much less as compared to both the cases of interior centre column removal and exterior edge column removal
  - The axial forces are increased drastically in this case which means this case is also more sensitive to progressive collapse.

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