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PROGRESSIVE COLLAPSE ANALYSIS OF COMPOSITE STRUCTURE BY USING SOFTWARE

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ABSTRACT

Progressive collapse implies a phenomenon of sequential failure of part of the structure orthe complete structure initiated by sudden loss of vertical load carrying member (mostly column).. Progressive collapse is defined as a situation where local failure of a primary structural component leads to the collapse of adjoining members, which in turn leads to additional collapse. For the case of progressive collapse, damage is included in the model through the removal of a key element of the structure. For this reason, it is very important for the engineering community to develop simple and reliable analytical tools which could provide useful information on the response of a structure to a column loss. The progressive collapse design guidelines typically recommend simplified analysis procedures involving instantaneous removal of specified critical columns in a building. The study of analytical approaches for evaluating progressive collapse is carried out by linear static analysis using Alternate Path Method (APM) recommended in General Service Administration (GSA) guidelines and the same is presented in in this study. This study investigates the effectiveness of such commonly used progressive collapse evaluation and design methodologies through numerical simulation and experimental data. For this study, a multistoried composite building is considered. The prime objective of this study is to analyze the composite building by removing columns at different locations and finding out critical location of column vulnerable to progressive collapse and also prevention of progressive collapse of structure using linear static analysis. Impact of number of floors, column removal location, vertical irregularity and design of frames is also investigated.

Keywords: Alternate Path Method, Finite Element Model,General Service Administration (Gsa) Progressive Collapse

INTRODUCTION

Now a days, designers consider all the probable load in the form of dead load, imposed load, wind load, temperature load, earthquake loads etc. and their combinations for assuring safety of structure and people residing in the structure. Interest on research work on progressive collapse in civil engineering first started in early 1968 after partial collapse of Ronan point apartment building in London, U.K. [1]. Design for mitigation of progressive collapse has always been a challenge in structural engineering due to a heightened awareness of blast and terrorist hazards. These research efforts led to many provisions in U.K. standards [1]. Many alternatives and suggestions have been proposed by numerous structural engineers and blast experts, and with continued research more alternatives are to be expected in the near future. Later in year 1995, disproportionate collapse of Alfred P. Murrah Federal Building in Oklahoma City and total collapse of World Trade Center towers in year 2001, which were caused by terrorist attacks, gained interest of engineering community in advanced research approaches for progressive collapse analysis [2-8]. However, phenomenon of progressive collapse is becoming more recognized in the field of structural engineering with the advancement of research investigation in this area. It is to be noted that progressive collapse is the collapse of all or a large part of a structure precipitated by damage or failure of a relatively small part of it.

A normal structural design of building consists of designing structural members for dead load, live load, wind load, earthquake load etc. and their combinations. Though, structural members will be safe for above mentioned loads and their combinations, building will collapse if, one of the important structural members gets failed. Many government authorities and local bodies have worked on developing some design guidelines to prevent progressive collapse. Among these guidelines, U.S. General Services Administration (GSA) and Department of Defense (DoD) guidelines by United Facilities Criteria (UFC) – New York, provide detailed stepwise procedure regarding methodologies to resist the progressive collapse of structure [1]. The competence for progressive collapse is downcast in three independent stages based on the ductility demand, strength and supply in the critical regions of affected structural members. A noteworthy advantage of developed course of action is that it can categorically account for dynamic effects associated with the instantaneous column removal through a simplified energy equivalence approach, thus avoiding the need for nonlinear dynamic analysis. In progressive collapse mechanism, a single local failure may cause a significant deformation which may then lead to collapse of entire structure. Thus, progressive collapse is a catastrophic structural phenomenon that can occur because of human-made or natural hazard. The challenge exists in making decisions about the best solutions because of the inherent uniqueness that are to be encountered for each project. Also, there is little to no official design standards or guidelines available for engineers to follow to aide their decisions. Instead, the engineer must be well versed in blast resistance and progressive collapse research in order to have a good understanding of what it takes to build or retrofit a robust structure

GENERAL SERVICES ADMINISTRATION GUIDELINES

The General Services Administration (GSA) is an independent agency of the United States government, established in 1949 to help manage and support the basic functioning of federal buildings [1].

2.1 Guidelines of GSA

As recommended by the GSA guidelines, risk for progressive collapse of a building is assessed considering the suddenly removal of a first-storey column located in four distinct zones [1]:

Case C1 – removal of an exterior column located at the middle of the short side,

Case C2 – removal of an exterior column located at the middle of the long side,

Case C3 – removal of a corner column, and

Case C4 – removal of an interior column.

2.2 GSA Criteria

The Demand Capacity Ratio (DCR) of each primary and secondary member of the alternate path structure is calculated from the following equation [1]:

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

Where,

Q_{UD} = Acting force determined in the structural element.

Q_{CE} = Expected ultimate, un-factored capacity of the structural element.

In order to prevent collapse of alternate path structure, DCR values for each structural element must be less than or equal to the following:

$DCR \leq 2.0$ for symmetrical structure.$DCR \leq 1.5$ for unsymmetrical structure

METHODOLOGY

In this paper, progressive collapse analysis of a composite building (steel beam, steel column and RCC slab) of G+7 floors is carried out.. The building is analyzed and designed in STAAD-PRO®software. A basic model of G+7 storey is designed and analyzed for no loading (no external loads are applied) condition. After this analysis of basic model is completed, same model is subjected to earthquake loads (lateral loads) and the analysis is carried out. The model is then subjected to wind loading wherein, behavior of the structure under wind effects is studied. The load combination is applied by referring to IS 800:2007 for limit state of strength and limit state of serviceability. Progressive collapse analysis by linear statics is carried out as per General Service Administration (GSA) guidelines. Then, by referring to GSA guidelines, columns are removed one at one time and static linear analysis is carried out. Here, three cases of column removal (corner column, side column, interior column) are studied. After columns are removed according to the three cases, reactions developed and the maximum bending moment occurred in the members are computed.Displacement of the members in structure is also premeditated. A comparative study of all the results is carried out wherein; most critical members of the structure are obtained. DCR ratios are evaluated for critical sections in the line of column removal. After complete analysis of the structure for all the three cases is completed and results are obtained and respective plots for the obtained results are out.

RESULTS AND DISCUSSION

A model of G+7 story composite structure is analysed and designed by using STAAD-PRO®software. Then, by following GSA guidelines linear static analysis is carried out and condition of three cases of column removal are applied. In corner column removal model, load of removed column is transferred to the adjacent column and maximum bending moment is observed to occur in beam B1 and B4. In the side column removal model, load of removed column is transferred in the adjacent column in the vicinity of that column and the maximum bending moments is observed in beams B1, B2 and B3. When interior column is removed, load is balanced by adjacent column and the maximum bending moment is observed to occur in beams B3, B5, B6, and B7. Then dividing bending moments by the respective capacity of beam, DCR values for the beams are computed. The reactions and displacements are also computed. A comparative study is carried out between the three column removal cases and accordingly the results are reported.

Table 1: Bending moments (kN-m) for general model (Model 1) underEarthquake loading

	BASIC MODEL						
Story	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**
7	171.5	169.7	125.0	111.8	186.1	188.5	127.1
6	212.3	216.4	221.5	211.2	227.5	232.7	191.7
5	266.0	267.7	326.2	312.8	280.8	288.1	251.2
4	312.3	312.4	402.1	387.9	330.6	335.8	299.0
3	343.3	341.9	453.4	439.7	363.7	366.6	330.4
2	352.8	350.2	485.1	472.6	373.6	374.3	348.3
1	331.3	327.8	501.7	490.5	350.2	349.0	358.4
GF	257.5	254.0	53.23	520.2	270.7	268.3	350.9

Table 2: Bending moments (kN-m) for corner column removalmodel (Model 2) under earthquake loading

	CORNER COLUMN REMOVED						
Story	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**
7	459.1	329.8	128.3	297.0	190.8	213.2	142.2
6	489.2	358.3	222.7	349.4	237.1	260.7	212.5
5	504.5	391.1	332.5	369.2	295.5	319.3	270.9
4	522.3	424.8	411.9	422.3	351.5	371.7	319.7
3	542.6	451.5	466.1	459.8	389.5	405.5	351.3
2	567.6	458.7	501.0	484.9	402.5	413.8	368.9
1	597.9	440.8	520.9	501.0	378.9	385.3	378.7
GF	637.3	346.8	556.5	482.8	293.3	294.9	370.2

Table 3: Bending moments (kN-m) for interior colum removal model (Model 3) under earthquake loading

	INTERIOR COLUMN REMOVED						
Story	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**
7	180.8	178.0	169.0	101.4	405.2	404.6	272.9
6	219.4	221.7	331.2	214.8	461.7	458.4	369.1
5	272.2	273.0	410.8	315.9	510.6	504.7	420.3
4	318.6	317.8	473.1	391.5	554.3	548.3	461.6
3	349.7	347.3	514.4	444.2	587.2	581.0	490.8
2	359.1	355.4	540.2	479.3	604.9	598.9	509.6
1	336.9	332.6	545.8	500.7	600.5	595.8	526.4
GF	261.6	257.4	601.6	537.2	560.2	555.6	499.8

Table 4: Bending moments (kN-m) for side column removal model (Model 4) under earthquake loading

	SIDE COLUMN REMOVED						
Story	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**
7	427.2	422.2	233.5	114.5	195.6	197.8	234.7
6	482.4	474.0	289.2	212.8	237.7	239.4	298.3
5	527.2	517.4	360.3	317.7	287.5	294.5	346.4
4	567.0	558.8	412.8	395.4	337.2	342.1	383.6
3	598.5	590.7	448.6	449.7	370.1	372.7	409.5
2	615.2	608.7	471.7	485.6	379.6	380.1	427.7
1	611.0	606.9	484.4	507.0	355.4	354.1	430.8
GF	572.9	569.4	462.9	543.2	274.3	271.9	493.8

Table 5: DCR values for general model (Model 1) under earthquake loading

	BASIC MODEL						
Story	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**
7	0.79	0.79	0.58	0.52	0.86	0.87	0.59
6	0.98	1.00	1.03	0.98	1.05	1.08	0.89
5	1.23	1.24	1.51	1.45	1.30	1.33	1.16
4	1.45	1.45	1.86	1.80	1.53	1.56	1.39
3	1.59	1.58	2.10	2.04	1.68	1.70	1.54
2	1.63	1.62	2.25	2.19	1.73	1.73	1.61
1	1.53	1.52	2.32	2.27	1.62	1.62	1.66
GF	1.19	1.18	2.46	2.41	1.25	1.24	1.63

Table 6: DCR values for corner column removal model (Model 2) under earthquake loading

	CORNER COLUMN REMOVED						
Story	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**
7	2.13	1.53	0.59	1.38	0.88	0.99	0.66
6	2.27	1.66	1.03	1.62	1.10	1.21	0.98
5	2.34	1.81	1.54	1.71	1.37	1.48	1.25
4	2.42	1.97	1.91	1.96	1.63	1.72	1.48
3	2.51	2.09	2.16	2.13	1.80	1.88	1.63
2	2.63	2.12	2.32	2.25	1.86	1.92	1.71
1	2.77	2.04	2.41	2.32	1.76	1.78	1.75
GF	2.95	1.61	2.58	2.24	1.36	1.37	1.72

Table 7: DCR values for interior column removal model (Model 3) under earthquake loading

	INTERIOR COLUMN REMOVED						
Story	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**
7	0.84	0.82	0.78	0.47	1.88	1.87	1.26
6	1.02	1.03	1.53	0.99	2.14	2.12	1.71
5	1.26	1.26	1.90	1.46	2.37	2.34	1.95
4	1.48	1.47	2.19	1.81	2.57	2.54	2.14
3	1.62	1.61	2.38	2.06	2.72	2.69	2.27
2	1.66	1.65	2.50	2.22	2.80	2.77	2.36
1	1.56	1.54	2.53	2.32	2.78	2.76	2.44
GF	1.21	1.19	2.79	2.49	2.60	2.57	2.32

Table 8: DCR values for side column removal model (Model 4) under earthquake loading

	SIDE COLUMN REMOVED						
Story	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**
7	1.98	1.96	1.08	0.53	0.91	0.92	1.09
6	2.23	2.20	1.34	0.99	1.10	1.11	1.38
5	2.44	2.40	1.67	1.47	1.33	1.36	1.60
4	2.63	2.59	1.91	1.83	1.56	1.58	1.78
3	2.77	2.74	2.08	2.08	1.71	1.73	1.90
2	2.85	2.82	2.18	2.25	1.76	1.76	1.98
1	2.83	2.81	2.24	2.35	1.65	1.64	2.00
GF	2.65	2.64	2.14	2.52	1.27	1.26	2.29

Fig. 1 to Fig. 4 shows the bending moment for beams B2, B5, B6 and B7 under earthquake loading, respectively

Fig. 1: Bending moment comparison of beam B2 for earthquake loading

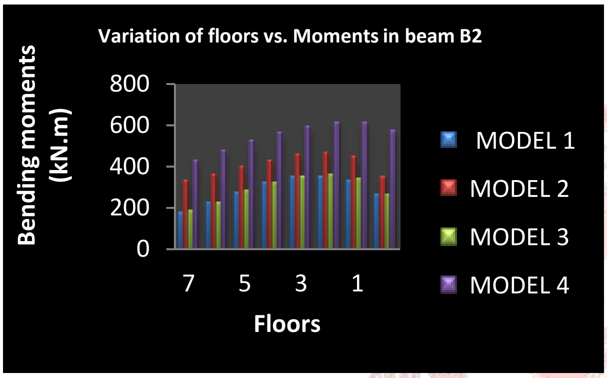


Fig. 2: Bending moment comparison of beam B5 for earthquake loading

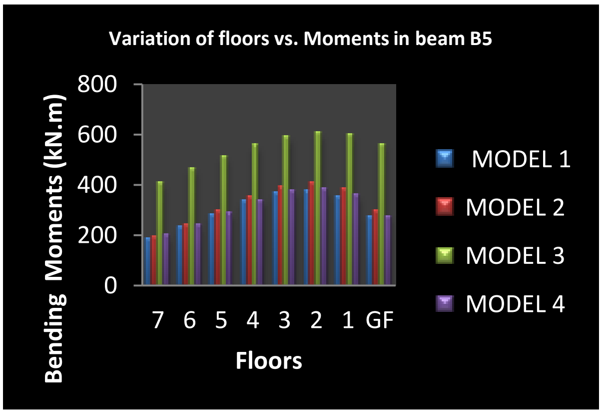


Fig. 3: Bending moment comparison of beam B6 for earthquake loading

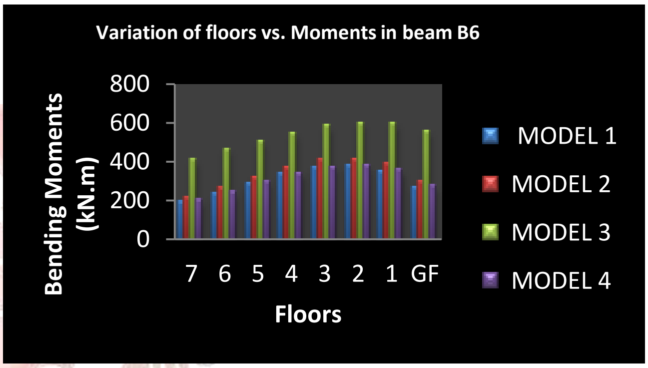


Fig. 4: Bending moment comparison of beam B7 for earthquake loading

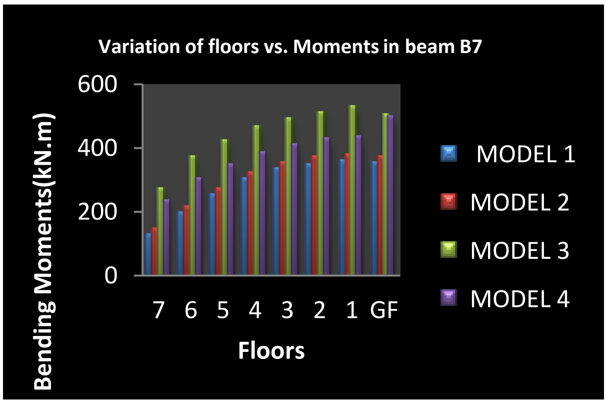


Fig. 5 to Fig. 8 shows the DCR for beams B2, B5, B6 and B7 under earthquake loading, respectively.

Fig. 5: DCR ratio comparison of different models of beam B2 forearthquake loading

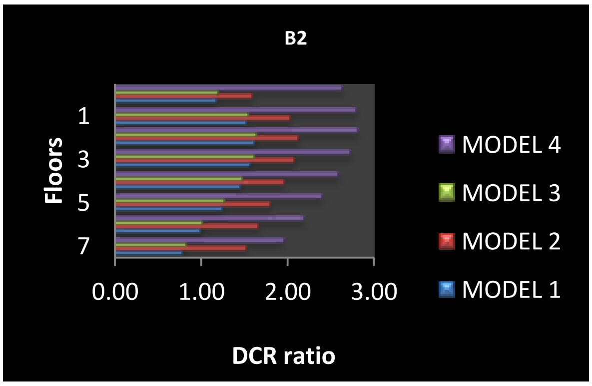


Fig. 6: DCR ratio comparison of different models of beam B5 for earthquake loading

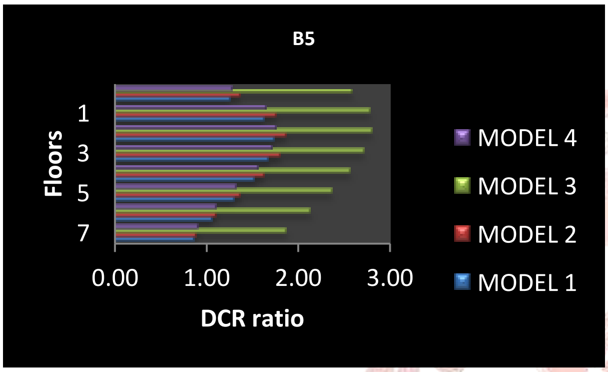


Fig. 7: DCR ratio comparison of different models of beam B6 for earthquake loading

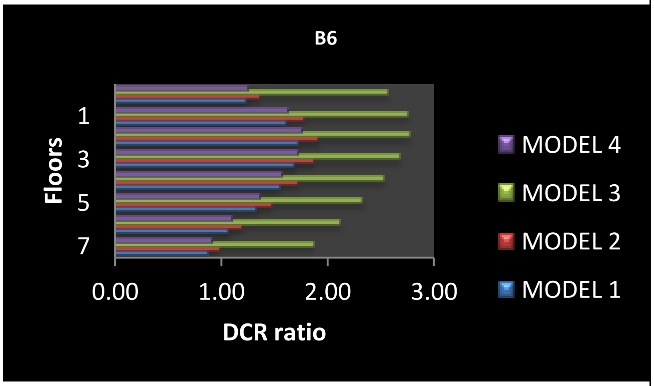
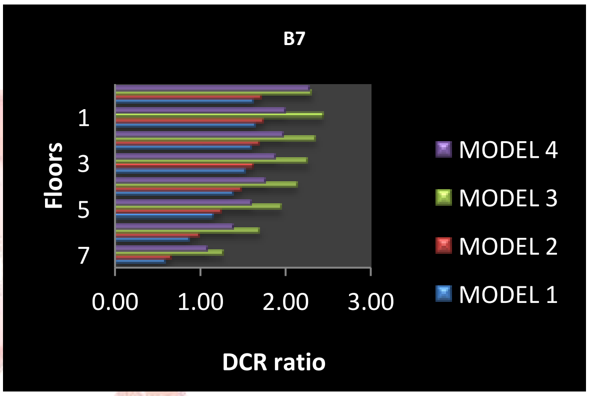


Fig. 8: DCR ratio comparison of different models of beam B7 for earthquake loading



CONCLUSION

Based on this study, following conclusions are drawn,

1. By linear static method it is found that, lower storey beams are critical than upper storey beams in column loss scenario.
2. By linear static analysis, it is observed that the beam having DCR ratio for bending moment more than 2 will fail under sudden column loss condition. Hence, these beams need to be redesigned to arrest progressive collapse.
3. From the 3 cases of column removal, interior column loss is the most damaging one.
4. A considerable difference is observed in the forces and bending moments from the initial condition (when no column is removed) due to the transfer of instantaneously applied load to the remaining undamaged structure as well as joints.
5. The nearest member of the removed column gets more affected due to transferring of load and it goes on decreasing when moving away from the removed column.

6. The alternate load path like providing bracing at floor level and increasing the size of members at outer face can be adopted advantageously to mitigate the progressive collapse.
7. Ground floor beams have maximum bending moment values as compared to the upper stories.
8. Interior column removal case develops maximum moments as compared to side and corner column removal cases.
9. Ground floor beams have maximum demand capacity ratio values as compared to upper stories.
10. CR values generated on beam in case of internal column removal are much higher than side and corner column removal.
11. Absolute displacement is maximum in case of corner column removal as compared to other in earthquake case.
12. In earthquake load case, beam B3 is connected to internal column and side column, DCR value obtained is maximum when internal column is removed.
13. In earthquake load case, beam B1 is connected to corner column and side column, DCR value obtained is maximum at GF due to corner column removal but on other floors the DCR values is maximum due to side column.
14. The reaction developed after removal of column is maximum when corner column is removed.
15. It is observed that maximum bending moments occurs in the beams when interior column is removed as compared to the side and corner column. Due to the bending moments developed, the beam deflects and the buckling of beam occurs. This buckling is maximum in case of interior column removal than that of corner and side column removal.

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