PROGRESSIVE COLLAPSE OF RC BUILDING WITH DIFFERENT STRUCTURAL SYSTEMS

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ABSTRACT

Progressive collapse of building structure is initiated when one or more vertical load carrying members particularly columns are seriously damaged or collapse during any of the abnormal loads i.e. vehicle impact, fire, Earthquake, or other man-made or natural hazard such event is referred to as "Progressive Collapse". In the present study progressive collapse of 10-storey symmetric concrete framed building is evaluated. Linear Static analysis is performed by following the General Service Administration and Department of Defense guidelines for evaluating progressive collapse potential. Modeling, analysis and design of the building is performed using ETABS2015 for four different threat-independent column removal conditions by following the alternate load path method. It is observed that demand capacity ratio (DCR) in beam and columns are exceeding the allowable limit for all the cases. This indicates the building considered for study is having high potential of progressive collapse. To reduce the potential of progressive collapse various approaches for mitigation of the progressive collapse are presented in this paper. Two different approaches like providing bracing at top storey of the building and bracing at side face of the building are studied. Comparison between two approaches is presented for building taken into study. Among two approaches, bracing at side face of the building as the most effective and economic approach for mitigating the potential of progressive collapse except case-4. From the two mitigation strategies presented, provision of bracing in the building is most economical solution to reduce the potential of progressive collapse except case-4.

Keyword: - *Progressive collapse, RC Building, ETABS2015, Liner Static Analysis, GSA and UFC guidelines, Column removal.*

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1. INTRODUCTION

Progressive collapse of existing building is initiated by the sudden failure of one or more of its major load bearing elements, typically columns or walls. Once a column is removed due to a vehicle impact, fire, earthquake, or other man-made or natural hazards, the buildings weight (gravity load) transfers to neighboring columns in the structure. If these columns are not properly designed to resist and redistribute the additional gravity load that part of the structure fails. The vertical load carrying elements of the structure continue to fail until the additional loading is stabilized. As a result, a substantial part of the structure may collapse, causing greater damage to the structure than the initial impact. Progressive collapse of a structure takes place when the structure has its loading pattern or boundary conditions changed such that structural elements are loaded beyond their ultimate capacities and fail.

When any element fails, redistribution of the loads and failure of the next elements in the vicinity in a chain-like reaction until the failure of the whole building.

Progressive collapse of the building structure is generally occurred under the abnormal loads. A number of potential abnormal load hazards, which could trigger progressive collapse, are considered like Gas Explosions, Bomb explosion, Fire, Vehicular collision etc. Considering these aspects, many government authorities and local bodies have worked on developing some design guidelines to prevent progressive collapse. Out of these guidelines, US General Services Administration (GSA) and Department of Defense (DoD) illustrated step wise procedure to minimize the progressive collapse, US General Services Administration (GSA) issued in 2000 and revised in 2003.

In the present paper 10 storey symmetric building reinforced concrete building is analysed to ascertain progressive collapse potential as per GSA and DoD guidelines. To reduce the progressive collapse potential different mitigation strategies are discussed.

1.1 Objectives

The aim of present study is to check DCR (Demand Capacity Ratio) value of beam subjected to various column removal cases using linear static analysis in ETABS2015. Also, compare the two guidelines DCR value using linear static analysis method. The specific objectives stated as: (1) Study the various causes of the progressive collapse. (2) Check the DCR value for flexure and shear for the beam, using the two guidelines for progressive collapse analysis. (3) Check the DCR value for the column, using the two guidelines for progressive collapse analysis. (4) Perform liner static analysis for evaluation of the progressive collapse resistance of high rises building. (5) Use the mitigation measures of progressive collapse and various techniques to improve the capacity of building to resist progressive collapse.

1.2 Scope of Paper Work

In order to understand above objective the scope of work is decide as: (1) Study the various causes of the progressive collapse. (2) Study and comparison of the two guidelines/specification for progressive collapse analysis of building, (i) U.S. General Service Administration (GSA-2003), (ii) Unified Facilities Criteria, UFC 4-023-03(2009), (iii) Study of various analysis approaches for progressive collapse resistance design. (iv) Perform linear static analysis procedure using ETABS2015 to study the behaviour of R.C.C. building by removing interior/external column. (v) Study of two different structural systems to reduce progressive collapse of the building.

2. BUILDING CONFIGURATION

The typical floor plan of 10 –storey symmetric reinforced concreted framed structure considered for study is shown in Figure 1. Typical floor to floor height 3 m and bottom storey (Ground floor) height 3.4 m. AAC block walls 200 mm thickness are considered on all beams. Slab thickness is considered as 150 mm.

Primary loading considered on the building for the study are as:

1. Gravity loading:
   a. Dead load : Self weight of the structural elements
   b. Live load at typical floor : 4.0 (kN/m2)
   c. Live load at terrace floor : 2.0 (kN/m2)
   d. Floor finish at typical floor : 1.5 (kN/m2)
   e. Floor finish at terrace floor : 2 (kN/m2)
   f. Wall load : 4.5 (kN/m)
   g. Parapet load : 1.5 (kN/m)
2. Seismic loading :
   a. Z : 0.16 (zone III) [Table 2 , IS 1893 (Part 1) : 2002]
   b. Soil type : II (Ahmedabad)
   c. I : 1 [Table 6 , IS 1893 (Part 1) : 2002]
   d. R : 5 [Table 7 , IS 1893 (Part 1) : 2002]
3. Material properties :
   a. Grade of concrete : M25
   b. Grade of steel : Fe415

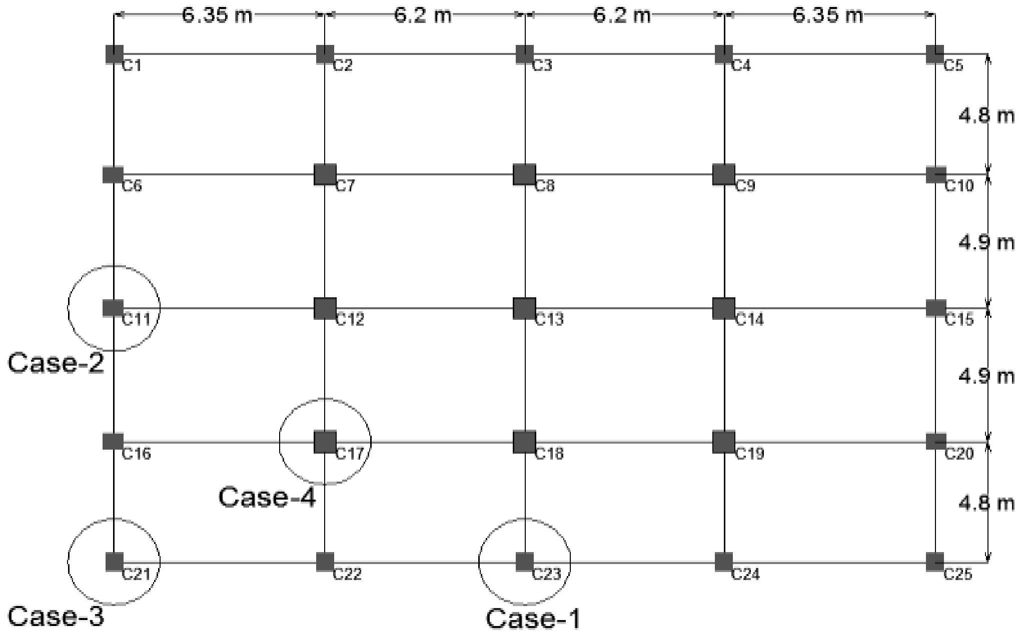


Fig-1: Typical floor plan of the building

The building is designed considering appropriate load combination as specified in IS 1893 (Part-1)-2002, for this building the lateral load resisting elements are oriented along orthogonal horizontal direction, the structure shall be designed for the effects due to full design earthquake load in one horizontal direction plus 30 percent of the design earthquake load in the other direction as specified in IS 1893 (Part-1)-2002. The beam size of 300 X 450 mm all typical floors and column sizes various as per storeys 450 X 500 mm all typical floor periphery, 600 X 600 mm typical floor middle portion up to 1-5 storeys and 450 X 450 mm typical floor middle portion up to 6-10 storeys are considered for 10-storey building.

2.1 Analysis Methodology

Progressive collapse analysis of 10-storey symmetric concrete framed building is carried out by following the U.S. General Service Administration (GSA), and Department of Defence (DoD) guidelines. These guidelines have suggested three a nalysis methods: Alternate load path method, Tie force method and Local resistance method. Four analysis procedures are suggested to evaluate the potential of progressive collapse like linear static, linear dynamic, nonlinear static and nonlinear dynamic. In this paper linear static analysis is performed by following Alternate load path method.

In Alternate load path method original structure is designed for gravity and seismic loading. Subsequently column on ground floor is removed depending on case. The structure is subjected to gravity loading as per guidelines and demand in terms of shear force and bending moment is evaluated from the analysis. Capacity at critical sections from original design and strength increase factor. If Demand Capacity Ratio (DCR) exceeds permissible values, the element is considered as failed.

Linear Static, in linear analysis column is removed from the location being considered and analysis is carried out for following vertical load which shall be applied in downward on the structure (GSA 2003 and UFC 2009):

As per GSA guidelines

For static analysis: Load = 2(DL + 0.25LL)

As per UFC guidelines

For static analysis: G = 2(0.9 or1.2) DL + (0.5 or 0.2LL)

Where, G = Gravity load, DL = Dead Load, LL = Live Load

From the analysis results demand at critical points are obtained and from the designed section the capacity of the member is determined. Check for the Demand Capacity Ratio (DCR) in each structural member is carried out. The DCR of each member of the alternate load path structures is calculated from the following equation.

$$DCR = \frac{QUD}{QCE}$$

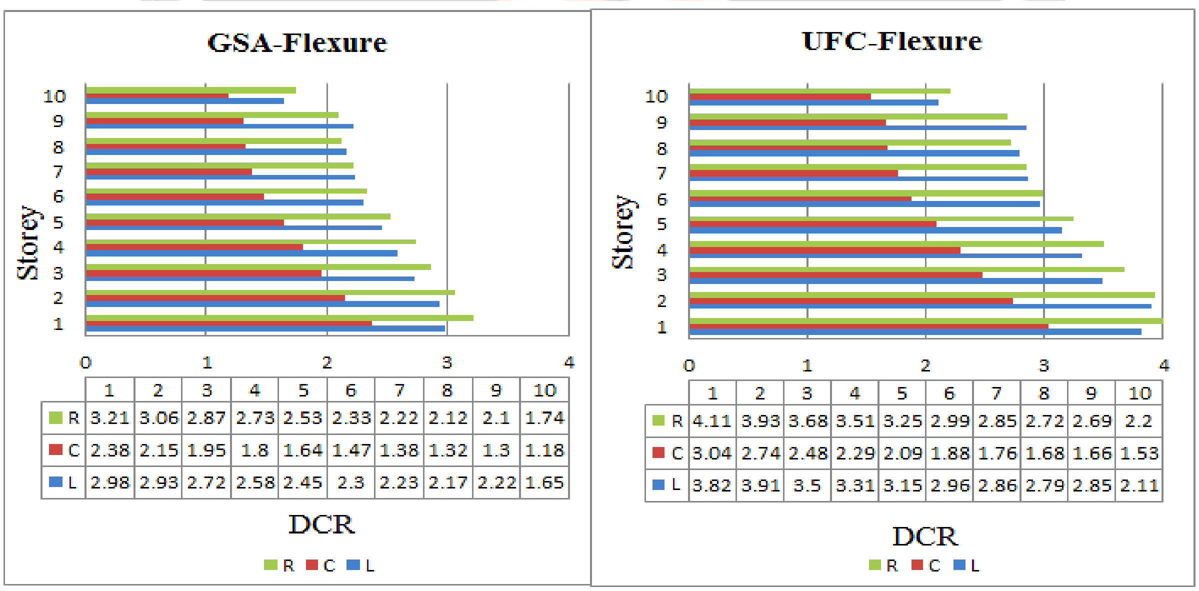
Where,

QUD = Acting force (demand) determined in component or connection/joint

QCE = Expected ultimate, un-factored capacity of the component and/or connection/joint

If the DCR of a member in flexure exceeds 2 for symmetric configuration and 1.5 for asymmetric configuaration, the member is considered as failed. In shear and in axial loading acceptable DCR is 1 for symmetric and asymmetrical structures.

Results for linear static analysis are obtained for four column removal cases highlighted in Figure 1. From analysis it is observed that case 4 of column removal is having the worst effect on the building structure. Therefore results are presented only for case 4 of column removal. The DCR in flexure in longitudinal frame in case 4 obtanied by following linear static analysis considering GSA and UFC loading are shown in Figure-2. The corresponding DCR in column considering axial force and bending moment are shown in Figure-3.



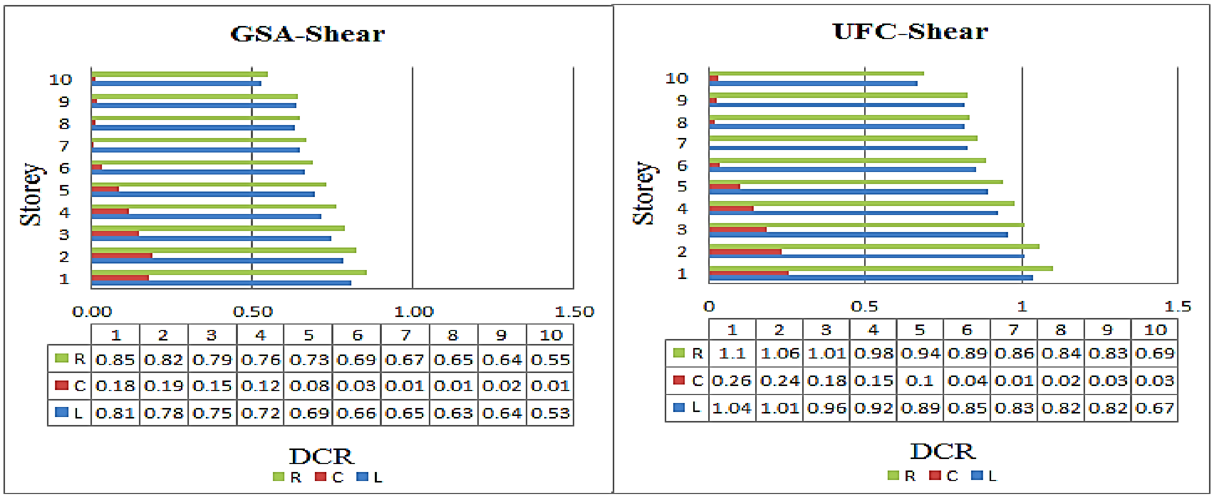
GSA-Flexure

	1	2	3	4	5	6	7	8	9	10
R	3.21	3.06	2.87	2.73	2.53	2.33	2.22	2.12	2.1	1.74
C	2.38	2.15	1.95	1.8	1.64	1.47	1.38	1.32	1.3	1.18
L	2.98	2.93	2.72	2.58	2.45	2.3	2.23	2.17	2.22	1.65

UFC-Flexure

	1	2	3	4	5	6	7	8	9	10
R	4.11	3.93	3.68	3.51	3.25	2.99	2.85	2.72	2.69	2.2
C	3.04	2.74	2.48	2.29	2.09	1.88	1.76	1.68	1.66	1.53
L	3.82	3.91	3.5	3.31	3.15	2.96	2.86	2.79	2.85	2.11

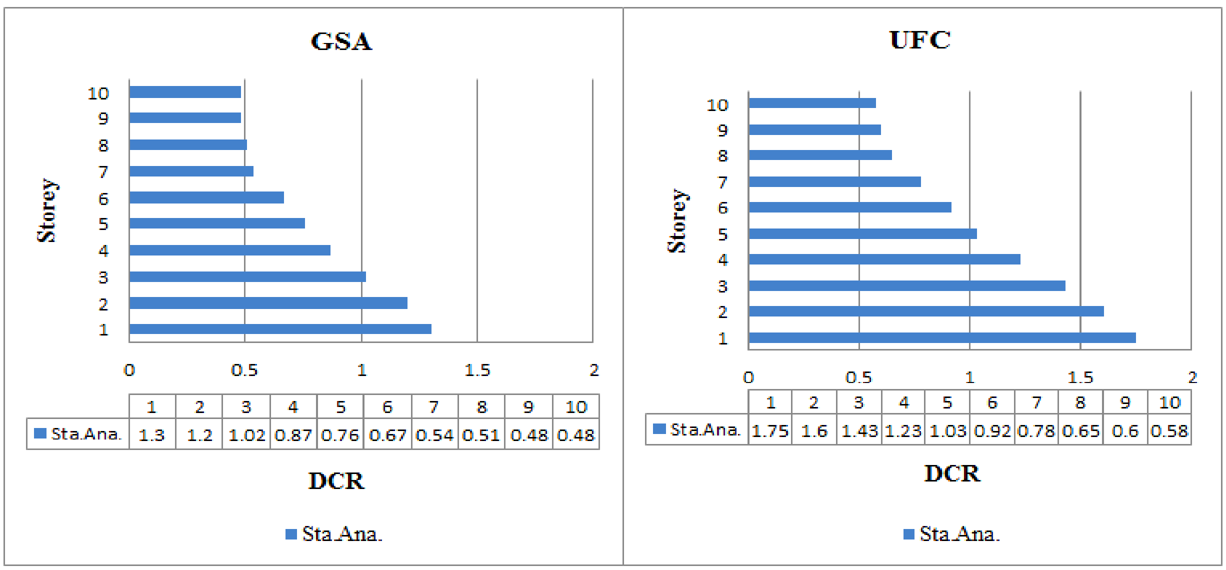
Fig-2: DCR of Flexure for Case-4 for GSA and UFC Loading



GSA-Shear	1	2	3	4	5	6	7	8	9	10
R	0.85	0.82	0.79	0.76	0.73	0.69	0.67	0.65	0.64	0.55
C	0.18	0.19	0.15	0.12	0.08	0.03	0.01	0.01	0.02	0.01
L	0.81	0.78	0.75	0.72	0.69	0.66	0.65	0.63	0.64	0.53

UFC-Shear	1	2	3	4	5	6	7	8	9	10
R	1.1	1.06	1.01	0.98	0.94	0.89	0.86	0.84	0.83	0.69
C	0.26	0.24	0.18	0.15	0.1	0.04	0.01	0.02	0.03	0.03
L	1.04	1.01	0.96	0.92	0.89	0.85	0.83	0.82	0.82	0.67

DCR in Column 18 for case -4 DCR in Column 18 for case -4



GSA	1	2	3	4	5	6	7	8	9	10
Sta.Ana.	1.3	1.2	1.02	0.87	0.76	0.67	0.54	0.51	0.48	0.48

UFC	1	2	3	4	5	6	7	8	9	10
Sta.Ana.	1.75	1.6	1.43	1.23	1.03	0.92	0.78	0.65	0.6	0.58

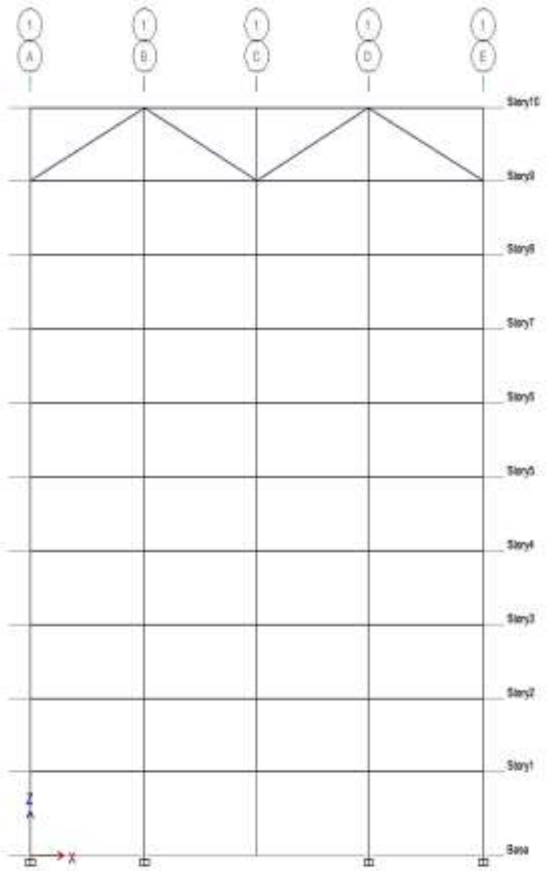
Fig- 3: DCR of column for Case-4 for GSA and UFC Loading

3. METHODS TO MITIGATE PROGRESSIVE COLLAPSE

For an important building having high potential for progressive collapse, it is necessary to reduce the potential of progressive collapse. If DCR for beam and column members exceed the permissible value specified by guidelines, then it is said that building is having high potential for progressive collapse. In order to minimize the potential of the progressive collapse necessary structure change are required. Significant structure changes like provide elevation bracing, the addition of reinforcement and developing structural actions which provide resistance like vierendeel, catenory, suspension and arch action, enhance the type of connection to moment resistance connections etc. are required based on type and configuration of building.

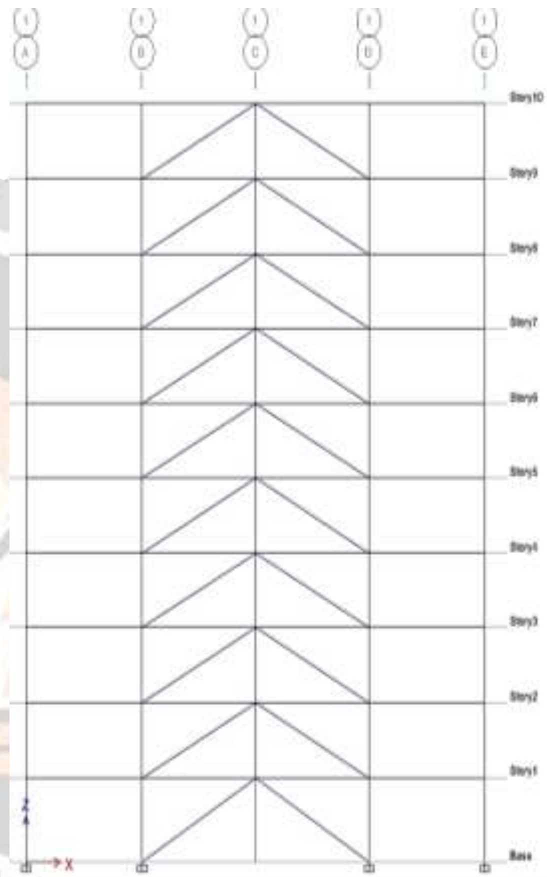
In this paper, two different alternatives are implemented to minimize the potential of progressive collapse of 10-storey symmetric reinforced concrete building. These two alternatives are as: (1) Provision of bracing at top storey level, (ii) Provision of bracing at side face of the building.

From the analysis results it is observed that linear static analysis considering UFC loading give higher DCR compared to static analysis as per GSA loading. Further case 4 column removal is governing among all cases as shown in Figure-2. Therefore effects of mitigation strategies are studied for all cases column removal and static analysis considering both GSA and UFC loading. The original and proposed sizes of structural members same as given above for 10-storey building. Typical elevation of 10-storey building with 300X300 mm bracing at top storey of the building and side face of the building shown in Fig 4 & 5 respectively.



Alternative -1

Fig- 4: Bracing at top storey of the building



Alternative -2

Fig- 5: Bracing at side face of the building

3.1 Analysis Results

The DCR is calculated at critical locations for GSA and UFC linear static load case as given above for all column removal cases, case-4 gives maximum effect on the building. All the four columns remove from the building and the demand capacity (DCR) is calculated at each storey by removing the column from ground storey. DCR for flexure and shear calculated at three points left, center and right side of the column removal position.

Result of DCR for flexure and Shear using both guidelines GSA and UFC loading for all four column removal cases is within the permissible limit except case-4 in UFC loading extra reinforcement provided to control the collapse. After mitigation it is observed that case-1, case-2, case-3 are having the permissible limit except case-4. Therefore results are presented only for case-1 of column removal. Figure 6 shows the DCR values for column for 10-storey building before and after mitigation.

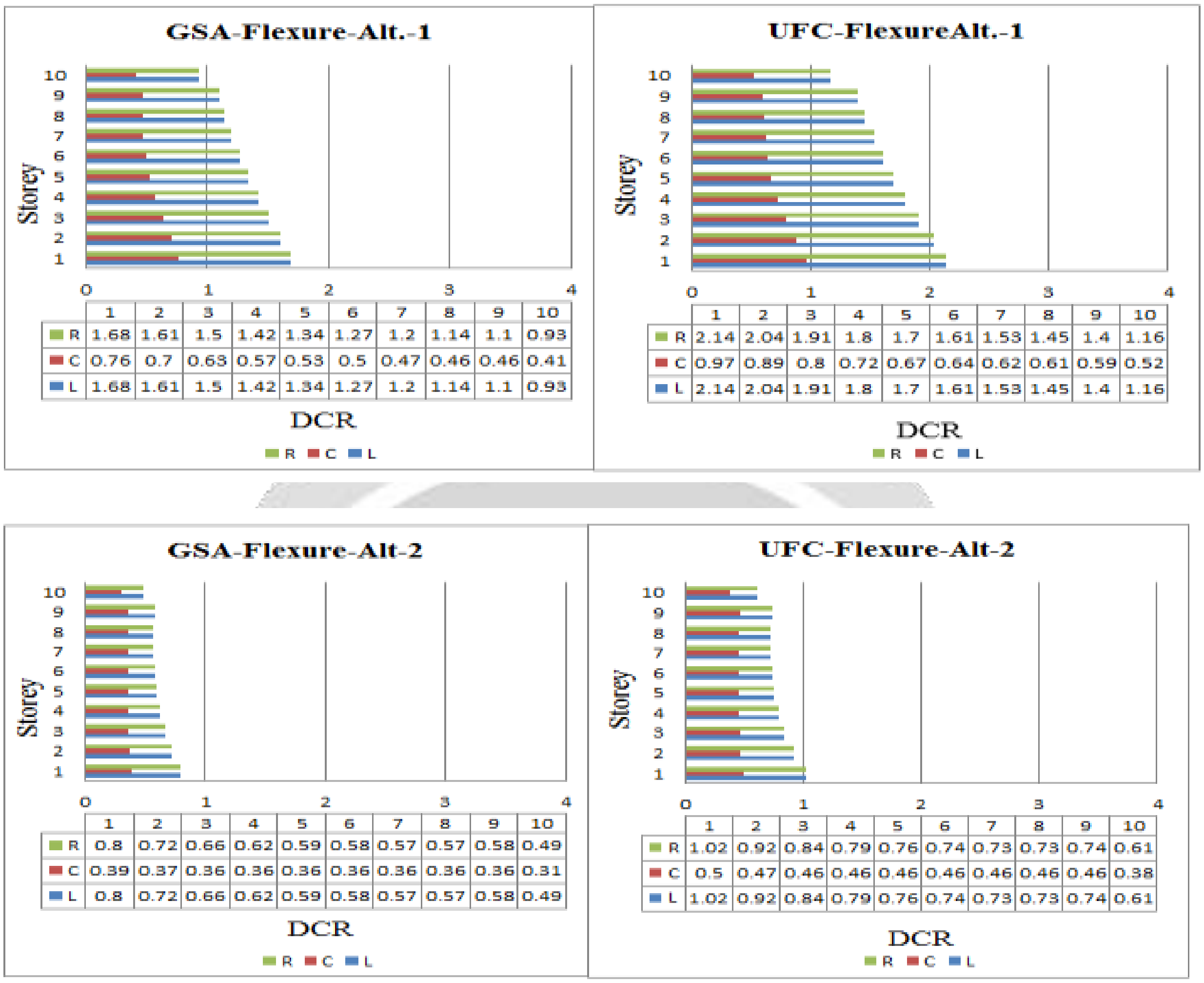


Fig- 6: DCR for flexure for case-1 of 10-storey building with two alternatives

All the other two cases except case-4 using two mitigation strategy reduce the DCR within permissible limit for flexure and Shear. Also the vertical displacement under column removal point is greatly reduced.

4. CONCLUSIONS

In this study, linear static analysis of 10-storey symmetric RC building is carried out by following GSA and DoD guidelines. Progressive collapse potential of building is found out by considering four different threat-independent column removal cases. Out of all the four cases of column removal as suggested by guidelines, case-4 i.e. internal column removal creates worst effect on the building structure.

From the results, it is observed the DCR in flexure in beam exceeds permissible limit of 2 in all storey of building for all four cases. The DCR values in beams indicate that building considered for the study is having very low potential to resist the progressive collapse. Therefore, two different alternatives are explored to mitigate the progressive collapse. When mitigation strategy is adopted, DCR value is reduced within the permissible limit. Displacement obtained under column removal point after mitigation is about 40-50% lower than that of before mitigation.

From the two mitigation strategies presented, provision of bracing in the building is most economical solution to reduce the potential of progressive collapse. The provision of bracing at side face of the 10-storey building is more effective for reducing potential of progressive collapse for the building considered in this study, but it may depends on geometry of building.

5. REFERENCES

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