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Progressive Collapse Analysis of RC Building

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Abstract - *In this study it is proposed to carry out the progressive collapse analysis of RC frame building by removing different column one at a time as per U.S. General Services Administration (GSA) guidelines. For the study 11 storey moment resistant RC building is considered. Building consists of 4x4 bay 5m in both direction and designed by the Indian code as a special moment frame. The building is modeled and analyzed for progressive collapse analysis using the structural analysis and design software ETAB 2015. As per GSA guidelines three column removal cases are studied, namely corner column, exterior column and interior column removal. For three cases the Demand Capacity Ratio (DCR) calculated for beams and columns and checked for the limitation criteria as per GSA. The obtained DCR values shows that columns are safe and beams not safe for progressive collapse and need to be reinforced additionally.*

Key Words: **Progressive collapse, Demand capacity ratio, ETABS, Column Removal, Pushover Analysis.**

1.0 INTRODUCTION

A normal structural design of building consist of designing structural members for dead load, live load, wind load, earthquake load etc. and there load combinations as per IS codes. Due to failure of one structural member load on the other members very close to it increases, those members in the closed region are going to fail if an increased load goes beyond the capacity of member. In this manner failure will transfer from one member to another which leads to collapse of whole structure. Such type of failure of structure is known as progressive collapse.

The design for mitigation of progressive collapse has been a hot topic in structural engineering due to an increased knowledge about blast and terrorist dangers.

Many other choices and suggestions have been proposed by many structural engineers and blast experts and with continued research more other alternatives are to be expected in the near future. The challenge exists in making decisions about the best solutions because of the built- in uniqueness that are to be met for each project. Also, there is little to no official design standards or guidelines available for engineers to follow to assist their decisions. Instead, the engineer must be competent in blast resistance and progressive collapse research in order to have a good understanding of what it takes to build a strong and healthy structure.

1.1 OBJECTIVES

Following are the objectives of work

- To understand the procedure of progressive collapse analysis of G+10 RC building in sudden column removal scenario.
- To check whether the RC building designed and detailed by Indian Standard codes for seismic loads provides any resistance to progressive collapse or not.
- To study the static linear and non linear static analysis method for RC building.

1.3 Acceptance Criteria

An examination of the linear static analysis will be done to identify the magnitudes and distribution of potential demands on primary and secondary structural elements for quantifying potential collapse areas. The magnitude and distribution of these demands will be indicated by Demand Capacity Ratio (DCR). Acceptance criteria for the primary and secondary structural components shall be determined as:

$$D.C.R.=Q_{UD}/Q_{CE} \quad (1)$$

where,

Q_{UD} = Acting force(demand) determined in the component or connection/joint (moment, axial force, shear and possible combined forces).

Q_{CE} = Expected ultimate, un-factored capacity of the component and /or connection or joint (moment, axial force, shear and possible combined forces).

Using the DCR criteria of linear static approach given in GSA guidelines, structural elements and connections that have DCR values that exceed the following allowable values are considered to be severally damaged or collapsed.

The allowable DCR values for primary and secondary structural components are:

- DCR<2.0, for typical structural configurations,
- DCR<1.5, for atypical structural configurations.

1.4 Consideration of column removing for progressive collapse analysis:

To calculate the DCR for the structure according to GSA guidelines, structure should be analyzed as below:

Exterior column consideration: a) Analyzing the sudden removal of column C3 in one floor above the ground floor which is located at or near of the middle of one side of the building. Corner column consideration: b) Analyzing the sudden removal of column C1 in one floor above the ground floor which located at corner side of building. Interior column consideration: c) Analyzing the sudden column removal of column C13 in one floor above the ground floor which located at middle of the building.

2.0 MODELLING OF STRUCTURE

The correct analysis will depend upon the proper modeling, behavior of the material elements and connectivity. Therefore, it is important to select the proper and accurate model to match the purpose of analysis. In progressive collapse evaluation mathematical modeling of the structure is based on earthquake loading because it tests out the actual behavior of the structure.

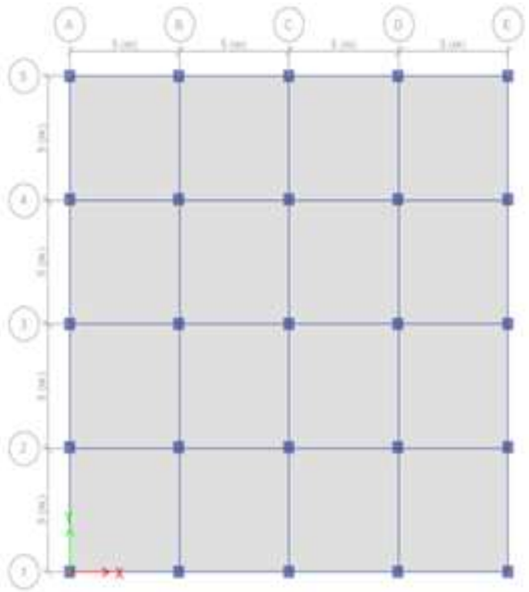

Fig.-1: Plan of Building

2.1 Properties

Table-1: General details of building

Number of storey	G+10
Type of frame	SMRF
Seismic zone	IV
Importance factor	1.5
Response reduction factor	5

Table-2: Structural members of building

Thickness of beam	150 mm
Beam	300 x 600 mm
Column	500 x 500 mm

Table-3: Material properties of building

Grade of concrete	M30
Grade of steel	Fe415
Density of concrete	25 Kn/m^2
Density of masonry	20 Kn/m^2

Table-4: Assumed load intensity

Load	Floor	Roof
Live Load	3 Kn/m^2	2.5 Kn/m^2
Floor Finish Load	1.0 Kn/m^2	1.5 Kn/m^2

2.2 Method of analysis

For the analysis two approaches are used

1. Linear static analysis
2. Non linear static analysis

The column removed at different three positions one at a time. The locations of column removed are shown in below figure.

Fig.-2: Corner column removal location

Fig.-3: Exterior column removal location

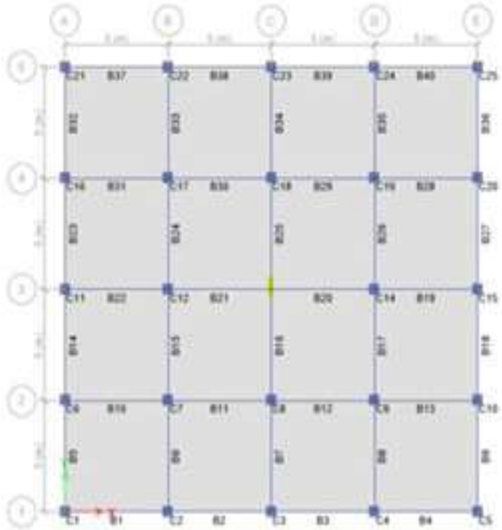

Fig.-4: Interior column removal location

3.0 RESULTS:

3.1 Linear static analysis: The DCR for critical columns and critical beams are mentioned in the chart**.**

Case 1: Corner column C1 removal.

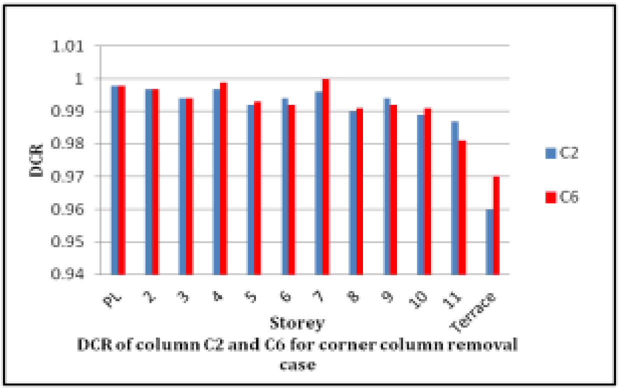

Chart-1: DCR of column C2 and C6

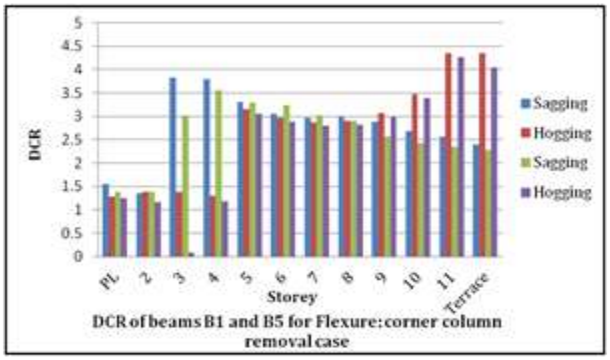

Chart-2: DCR of beams B1 and B5 for flexure

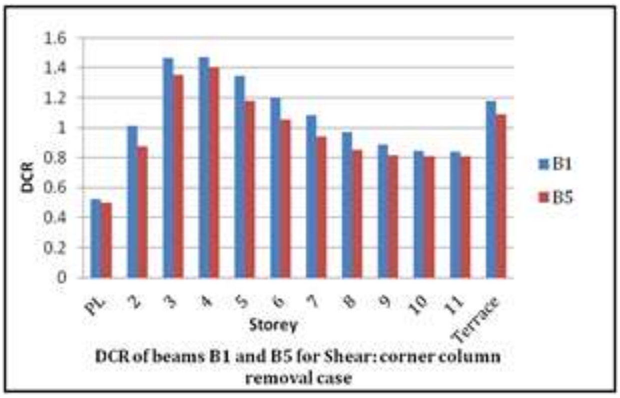

Chart-3: DCR of beam B1 and B5 for shear

Case 2: Exterior column removal

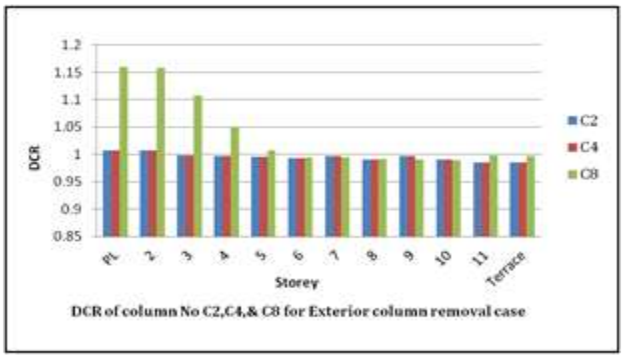

Chart-4: DCR of column C2, C4, C8

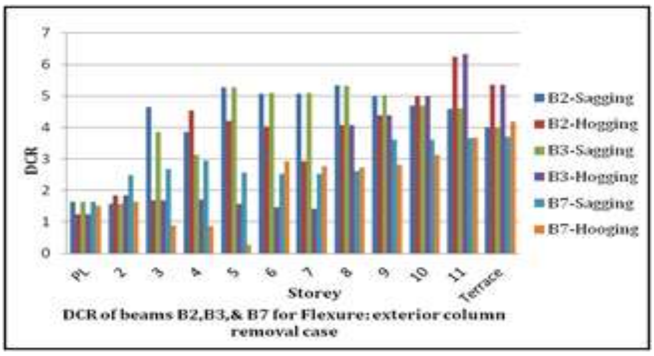

Chart-5: DCR of beam B2, B3, B7 for flexure

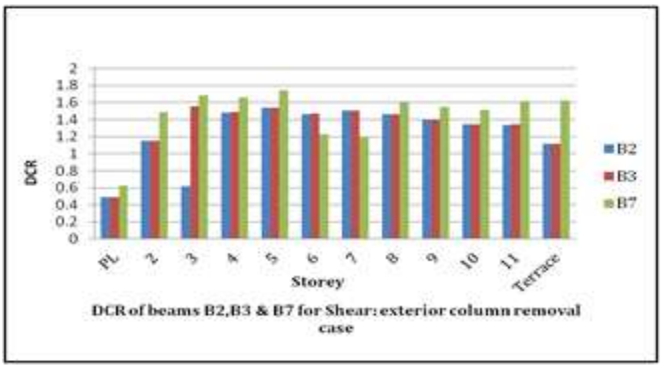

Chart-6: DCR of beam B2, B3, B7 for shear

Case 3: Interior column removal case

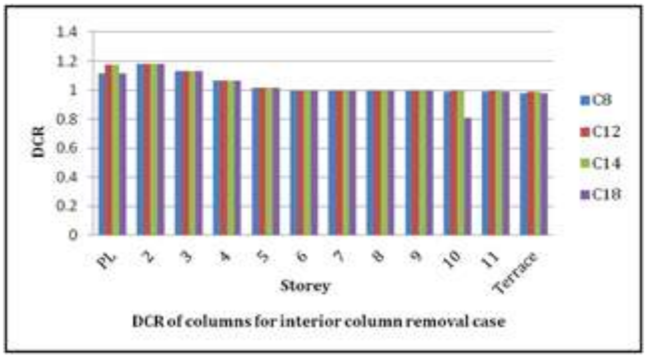

Chart-7: DCR of column C8, C12, C14, C18

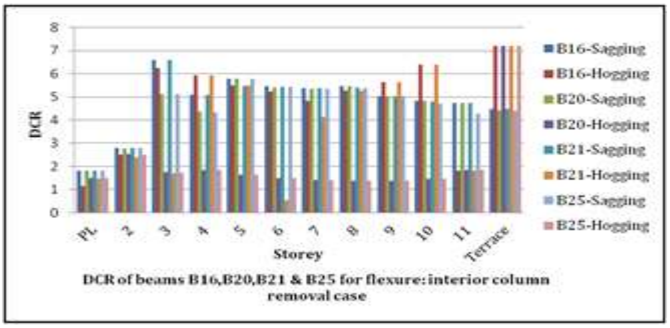

Chart-8: DCR of beam B16, B20, B21, B25 for flexure

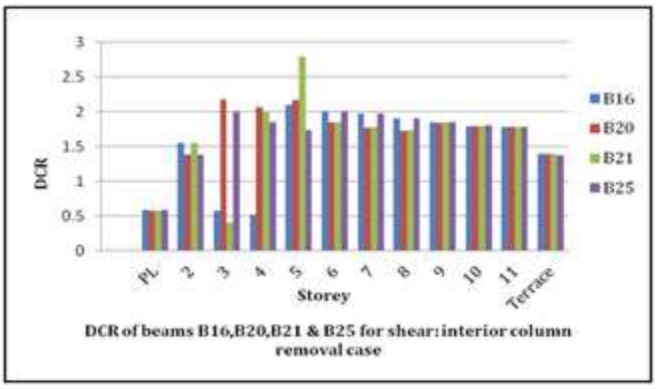

Chart-9: DCR of beam B16, B20, B21, B25 for shear

3.2 Non linear static analysis: Non linear static analysis is widely used to analyze a building for a lateral load known as pushover analysis. It increases applied loads step by step until maximum load achieved or maximum load attained.

The automatic hinges are assigned and building analyzed for PUSH Gravity and PUSH X loading cases. The base shear and roof displacement induced at performance point are summarized in tables for three different column removal cases.

3.2.1 Base shear and roof displacements results

Case 1: The building is analyzed for lateral loads without any column removal.

Step	Monitored Displ.	Base Force	A-B	B-C	C-D	D-E	>E	A-IO	IO-LS	LS-CP	>CP	Total
	mm	kN										
0	0.123	0	1558	0	0	0	0	1558	0	0	0	1558
1	37.193	2768.31	1557	1	0	0	0	1558	0	0	0	1558
2	57.138	3902.79	1443	115	0	0	0	1558	0	0	0	1558
3	76.489	4336.92	1361	197	0	0	0	1558	0	0	0	1558
4	130.958	4850.45	1277	281	0	0	0	1455	101	0	2	1558
5	166.037	5034.68	1234	324	0	0	0	1377	178	0	3	1558
	166.318	5035.65				Performance point						
6	174.041	5062.55	1232	326	0	0	0	1374	180	0	4	1558
7	174.042	5062.49	1232	326	0	0	0	1374	180	0	4	1558
8	174.042	5062.5	1232	326	0	0	0	1374	180	0	4	1558
9	174.068	5062.6	1232	326	0	0	0	1374	180	0	4	1558
10	174.096	5062.65	1232	326	0	0	0	1374	180	0	4	1558
11	174.15	5062.85	1232	326	0	0	0	1374	180	0	4	1558
12	174.151	5062.86	1232	326	0	0	0	1374	180	0	4	1558
13	174.151	5062.86	1232	326	0	0	0	1374	180	0	4	1558

Chart-10: Base shear and roof displacement

Case 2: Corner column removal

Step	Monitored Displ.	Base Force	A-B	B-C	C-D	D-E	>E	A-IO	IO-LS	LS-CP	>CP	Total
	mm	kN										
0	1.262	0	1558	0	0	0	0	1558	0	0	0	1558
1	24.435	1685.4712	1557	1	0	0	0	1558	0	0	0	1558
2	57.96	3809.5394	1450	108	0	0	0	1557	0	0	1	1558
3	77.886	4276.1311	1355	203	0	0	0	1556	0	0	2	1558
4	124.338	4754.1315	1273	285	0	0	0	1483	71	0	4	1558
5	170.283	5015.558	1212	346	0	0	0	1377	174	0	7	1558
	173.5	5027.2				Performance point						
6	177.68	5040.0316	1199	359	0	0	0	1373	177	0	8	1558
7	177.684	5040.0044	1199	359	0	0	0	1373	177	0	8	1558
8	177.758	5040.2525	1199	359	0	0	0	1373	177	0	8	1558

Chart-11: Base shear and roof displacement

Case 3: Exterior column removal

Step	Monitored Displ.	Base Force	A-B	B-C	C-D	D-E	>E	A-IO	IO-LS	LS-CP	>CP	Total
	mm	kN										
0	0.021	0	1558	0	0	0	0	1558	0	0	0	1558
1	24.424	1787.278	1557	1	0	0	0	1558	0	0	0	1558
2	56.706	3785.503	1452	106	0	0	0	1558	0	0	0	1558
3	77.733	4278.333	1361	197	0	0	0	1558	0	0	0	1558
4	135.74	4822.036	1262	296	0	0	0	1457	100	0	1	1558
5	173.88	5020.341	1224	334	0	0	0	1380	176	1	1	1558
	177.22	5030.856				Performance point						
6	186.1	5058.818	1209	349	0	0	0	1378	177	1	2	1558
7	186.1	5058.819	1208	350	0	0	0	1378	177	1	2	1558
8	186.1	5058.819	1208	350	0	0	0	1378	177	1	2	1558
9	186.1	5058.82	1208	350	0	0	0	1378	177	1	2	1558
10	186.1	5058.82	1208	350	0	0	0	1378	177	1	2	1558
11	186.1	5058.82	1208	350	0	0	0	1378	177	1	2	1558
12	186.1	5058.82	1208	350	0	0	0	1378	177	1	2	1558
13	186.1	5058.821	1208	350	0	0	0	1378	177	1	2	1558

Chart-12: Base shear and roof displacement

Case 4: Interior column removal

Step	Monitored Displ.	Base Force	A-B	B-C	C-D	D-E	>E	A-IO	IO-LS	LS-CP	>CP	Total
	mm	kN										
0	0.015	0	1532	26	0	0	0	1558	0	0	0	1558
1	0.233	18.3191	1532	26	0	0	0	1558	0	0	0	1558
2	54.079	3715.7474	1408	150	0	0	0	1558	0	0	0	1558
3	61.69	3965.3746	1349	209	0	0	0	1558	0	0	0	1558
4	102.067	4533.8789	1249	309	0	0	0	1551	7	0	0	1558
5	183.075	5029.7266	1171	386	1	0	0	1327	231	0	0	1558
	183.077	5003.0316				Performance point						
6	183.089	4856.5835	1168	388	0	2	0	1319	237	2	0	1558
7	186.582	4922.6461	1168	388	0	2	0	1319	237	2	0	1558
8	192.382	4974.6546	1165	390	1	2	0	1308	248	2	0	1558
9	192.396	4933.1198	1165	390	0	3	0	1308	247	3	0	1558
10	193.036	4942.3065	1165	388	2	3	0	1308	247	3	0	1558
11	188.049	4568.1233	1165	388	2	3	0	1308	245	5	0	1558

Chart-13: Base shear and roof displacement

3.2.2 Bending moment variation:

After the column removal the bending moments developed in the beams are too much more than without column removed building moments. The variation in the bending moments for critical beams is shown in charts.

Case 1: Corner column removal

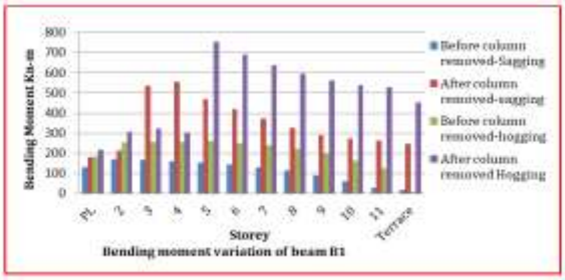

Chart-14: Bending Moment variation of beam B1

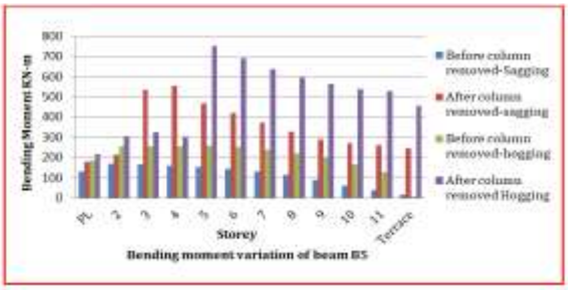

Chart-15: Bending moment variation of beam B5

Case 2: Exterior column removal

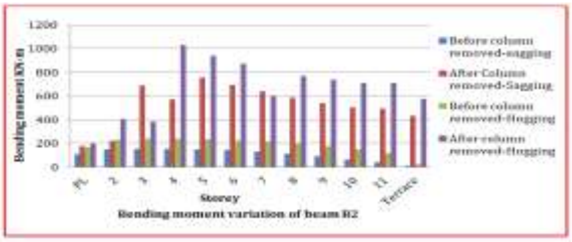

Chart-16: Bending moment variation of beam B2

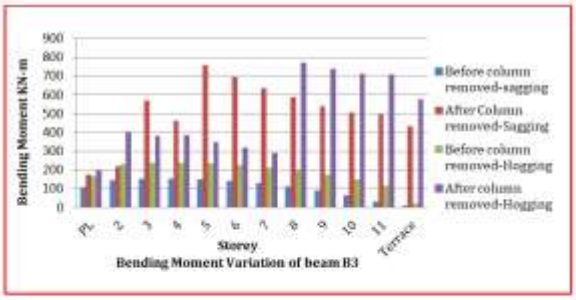

Chart-17: Bending moment variation of beam B3

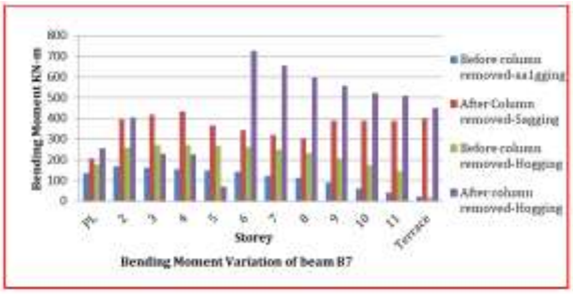

Chart-18: Bending moment variation of beam B7

Case 3: Interior column removal

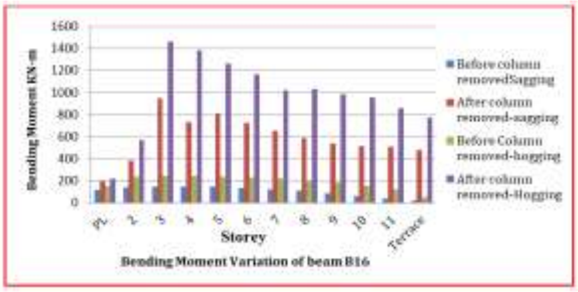

Chart-19: Bending moment variation of beam B16

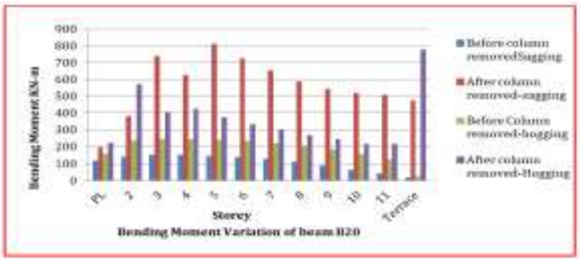

Chart-20: Bending moment variation of beam B20

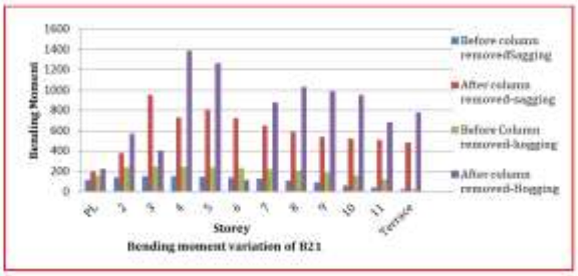

Chart-21: Bending moment variation of beam B21

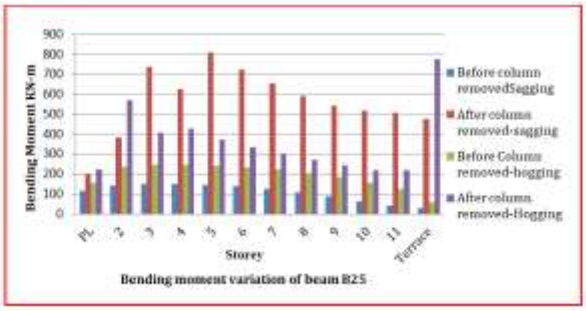

Chart-22: Bending moment variation of beam B25

4.0 CONCLUSIONS

In the result, it is extremely important to state at this point that, although several guidelines and prescribed procedures for design against progressive collapse are currently available and they might somehow produce buildings of acceptable safety still much research is needed. This is especially the case for improving the overall structural response of RC building to local failure to prevent their progressive collapse. It is wrong to say that such information is not useful in current practice, on the contrary, a lot of it is. Anyway, now-days, there is an urgent need to review knowledge on the progressive collapse phenomenon and speed up the development of agreement standards that can be used by engineers for upgrading existing building and designing new building to completely prevent the progressive collapse of RC building without any concern about the source. From the results, some conclusive points will get and that listed below:

- As the shear capacity of beams is high none of the beam in any column removal case is going to fails in shear i.e. shear in beams is not critical in progressive collapse.
- The DCR ratio of columns for all three removal cases according to linear static analysis results are less than 2.0 which is within the acceptance limit as per GSA. I.e. All columns of the building are strong to resist the progressive collapse.
- The DCR result for flexure in beams indicates the beams have value of DCR greater than 2.0. The behaviour of beams in flexure against progressive collapse is poor.
- The base shear force at the performance point for the original model is more than column removal cases. From the base shear forces, we knew that the exterior column removal case has more base shear than other cases. The building, in that case, is strong against progressive collapse.
- The interior column removal of a building is showing very poor capacity against the progressive collapse of building.
- Observing the hinge formation in all three column removal non-linear static analysis cases it has found that nonlinear hinges not going beyond the E-State (failure) which means the beams are strong to resist earthquake forces in column removal situation also.

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