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Progressive Collapse Analysis of Vertical Irregular Steel Structure

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Abstract: *The structural engineer's role becomes challenging when such buildings which are irregular in plan as well as in elevation. All these structures are analyse and design as per Indian standard (IS800:2007, IS1893:2016) with all combination of loading. After that these structure are again analysis for progressive collapse. These types of analysis are considered i.e. linear static and non-linear static with load six case and critical location suggested by GSA guidelines. From this study following observation are made, as height of structure affect the collapse behaviour, as height increases progressive collapse decreases which is seen from D.C.R. values, joint displacement, and bending moment. Linear static analysis results are more conservative than nonlinear static analysis.*

Keywords: *Progressive collapse*

I. INTRODUCTION

Progressive collapse of structures is initiated by the loss of one or more load-carrying members. As a result, the structure will seek alternate load paths to transfer the load to structural elements, which may or may not have been designed to resist the additional loads. Failure of overloaded structural elements will cause further redistribution of loads, a process that may continue until stable equilibrium is reached. Equilibrium may be reached when a substantial part of the structure has already collapsed. The resulting overall damage may be disproportionate to the damage in the local region near the lost member. Loss of primary members and the ensuing progressive collapse are dynamic nonlinear processes.

Progressive collapse implies disproportional global structural system failure originated by local structural damage. Itis a rare event, as it necessitates an initiation of local element removal criteria either due to the inevitable forces of nature or due to manmade hazards. The gravity load of the structure is now transferred to neighboring columns; these columns should resist the additional abnormal gravity loads & redistribute loads to avoid failure of the major part of the structure. Present day structure design practices and lesser integral ductility and continuity, gets more prone to progressive collapse. However, there should be certain provisions needed for additional consideration to ascertain the safety of structure after any local failure.

1.1 Background of Progressive Collapse

Progressive collapse is not a new problem for structural engineers, who have always been in some way concerned with the possibility that the loss of load-carrying capacity of a relatively small portion of a structure could lead to a disproportionate level of damage. Following are some example given in table

Table-1 the past cases of progressive collapse

Year	Description
1968	Roman point apartment newham, east London due to gas explosion
1973	26 story skyline towers building in Fairfax county, Virginia because of premature removal of shoring from beneath newly poured floors.
1985	22 story Wedbush building due to over loading on floors so lead to progressive collapse.
1995	The murrah federal office building in Oklahoma city was destroyed by a

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	bomb
2001	World trade Centre tower 1 and 2 collapse due to jetliner crashed with a high speed in a building
2005	28 story Windsor tower in Madrid, Spain suffered the collapse on 11th floor of the building
2013	8 story rana plaza commercial office complex in saver, Bangladesh due to improper use of building.
2017	Plasco building, Tehran due to fire attack

1.2 Aim
Modelling and analysis of vertical irregularity of steel structure due to progressive collapse

1.3 Objective
- Study of progressive collapse analysis.
- Discuss guidelines for column removals in structure.
- To study the effect of vertical irregularity of steel structure due to progressive collapse
- To find the critical location of removal of column as per GSA guidelines

1.4 Problem statement
There are very few studies of progressive collapse of irregular steel structure. In this study analytical approach concentrated on simulation structural response of three dimensional vertical irregular steel structure models were considerded. many guides allows linear static procedures designing against progressive collapse.
In this study of different heights of structure such as 5x7, 7x 9,9x11 stories considered. And analyzed for all combination of loading. And maintain demand capacity of structure between 0.5 to 0.9 which is consider as an economical. Then apply GSA-2013 guide lines and then structure analyzed for progressive collpase.and compare before and after result of DCR, displacement of removal location of column and from which finding the critical location of column

II. METHODOLOGY
This chapter describes the various methods approaches used for analysis and design of steel structure. This structure provided with material and section properties for column and beams. Presented below. The details of modelling of irregular structure such as 5x7,7x9,9x11 story structure and location of column removal at different level for progressive collapse are discussed.

Design Methodology
our study is based analysis of vertical irregular steel frame structure such as 5x7,7x9,9x11 for on progressive collapse, considering sudden loss of column as a design scenario and the structure analysis for effect of vertical irregularity on progressive collapse that there are many codes and guideline available worldwide but most of the research work uses the GSA guideline

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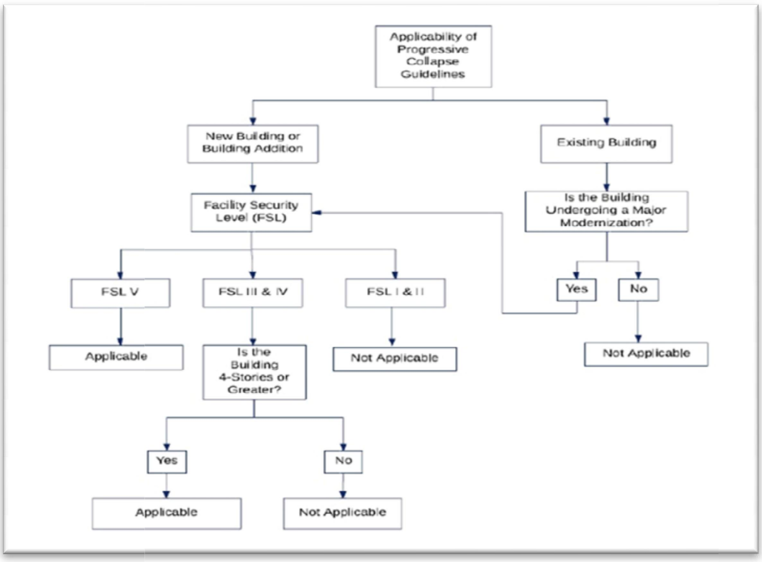

Figure 1: location of external column removal

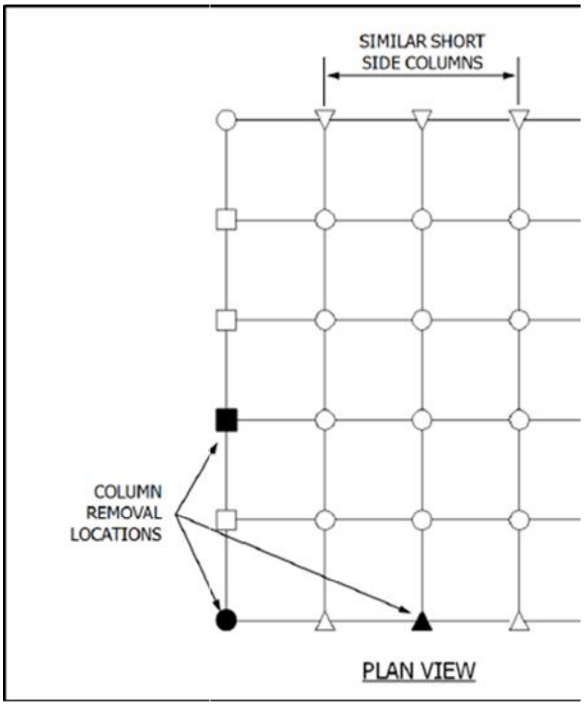

Figure 1: location of external column removal

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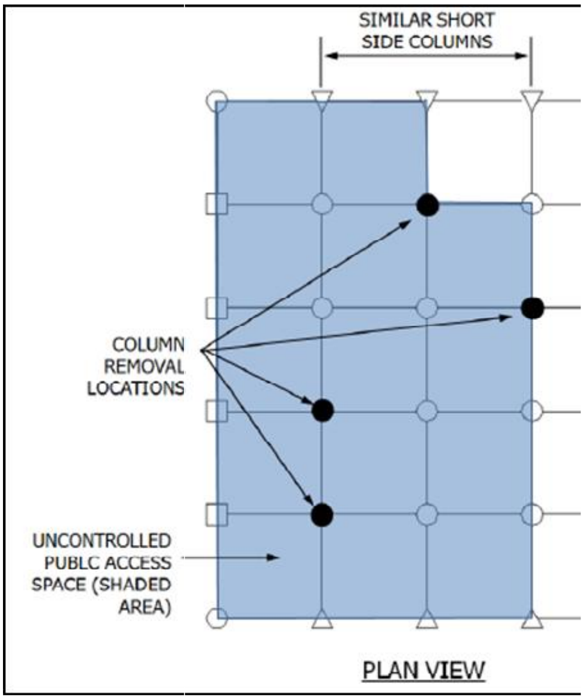

Figure 3: location of external column removal

Design procedure of progressive collapse.

For our research work there are various methods to analyse the structures and investigate their response to the progressive collapse phenomenon, these methods vary extensively in respect to time consumption and the structural knowledge required to perform the analysis.

We use the latest GSA-2013 for further guideline. The main aim is to reduce progressive collapse over theloss of a structural element, limiting the extent of damage to a localised area and redundant and balance structural system along the height of building.

The most common analysis methods have been used to explore the general structural behaviour in order of increasing complexity are linear static procedure (lsp), linear dynamic procedure (ldp), nonlinear static procedure (nsp), and nonlinear dynamic procedure (ndp).several researchers in the realm of progressive collapse examined the advantages and drawbacks of the different analysis methods in terms of time and accuracy.

Linear static method:

Linear static procedure is very effective for less than or equal to 10 stories. There are two cases deformation control can be calculated by using case i and force control action will be calculated by using case ii. For ductile actions' analysis, the applied load is increased through the use of an lif that considers dynamic and nonlinear effects both. Linear static model, which has one removed column, wall section or another load-bearing member, Irregularity limitations

A structure is considered irregular if any one of the following is true:

1. Significant discontinuities exist in the gravity-load carrying and lateral force-resisting systems of a building, including out-of-plane offsets of primary vertical elements, roof "belt-girders", and transfer girders (i.e., non-stacking primary columns or load-bearing elements). Stepped back stories are not considered an irregularity.
2. At any exterior column except at the corners, at each story in a framed structure, the ratios of bay stiffness and/or strength from one side of the column to the other are less than 50%. Three examples are; a) the lengths of adjacent bays vary significantly, b) the beams on either side of the column vary significantly in depth and/or strength, and c) connection strength and/or stiffness vary significantly on either side of the column (e.g., for a steel frame

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Building, a shear tab connection on one side of a column and a fully rigid connection on the other side shall be considered irregular).

3. For all external load-bearing walls, except at the corners, and for each story in a load-bearing wall structure, the ratios of wall stiffness and/or strength from one side of an intersecting wall to the other are less than 50%.

4. The horizontal lateral-load resisting elements are not parallel to the major orthogonal axes of the lateral force-resisting system, such as the case of skewed or curved moment frames and loadbearing walls.

Loading cases for linear static method:

As per mention in paragraph in 3.3.1 there are two cases which are mention below.

Case i: deformation control action qud

G ld = ω ld [1.2 d + (0.5 l or 0.2 s)]

Where

G ld = increased gravity loads for deformation-controlled actions for linear static analysis

D = dead load including façade loads (lb/ft2 or kn/m 2)

L = live load including live load reduction, not to exceed the maximum of 50-lb/ft2 or 244-kn/m 2

S = snow load (lb/ft2 or kn/m 2)

Ω ld = load increase factor for calculating deformation- controlled actions for linear static analysis; use appropriate value for framed or load-bearing wall structures.

Case ii: force control action quf

G lf = ω lf [1.2 d + (0.5 l or 0.2 s)]

G lf = increased gravity loads for force-controlled actions for linear static analysis

Ω lf = load increase factor for calculating force-controlled actions for linear static analysis; use appropriate value for framed or load-bearing wall structures

Table 2 : dynamic increasing factor for lsp

Material	Structure type	Ωld, deformation-controlled	Ωlf, force-controlled
Steel	Framed	0.9 mlif + 1.1	2.0
Reinforced concrete	Framed	1.2 mlif + 0.80	2.0
	Load-bearing wall	2.0 mlif	2.0
Mesonary	Load-bearing wall	2.0 mlif	2.0
Wood	Load-bearing wall	2.0 mlif	2.0
Cold-formedsteel	Load-bearing wall	2.0 mlif	2.0

Acceptance criteria for lsp

Acceptance criteria are classified on type of component i.e. primary & secondary. Thereafter classifications are made on the basis of actions controlling them i.e. deformation-controlled or force-controlled.

Force controlled action: $\phi\ Q_{CL} \geq Q_{UF}$

Deformation controlled action: $\phi\ m\ Q_{CE} \geq Q_{UD}$

Nonlinear static method:

Once the nonlinear model, both materially and geometrically, is made, the loads are increased with a dynamic increase factor (dif) that takes into account the inertia effects only. The consequent load is then applied to the model when the column is eliminated. The preferred performance level indicates the deformation limits which are compared with the consequent member deformation from deformation- controlled actions. However, in the case of force controlled actions, modification of member strength does not occur. This member strength is compared with the maximum internal member forces (actions).

To model, analyze, and evaluate a building, employ a three-dimensional assembly of elements and components. Create one model for either framed or load-bearing wall structures, respectively. Inclusion of secondary components in the

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model is optional. However, if the secondary components are omitted, they must be checked after the analysis, against the allowable deformation-controlled criteria.

Include the stiffness and resistance of primary components. Note that the strength reduction factors are applied to the nonlinear strength models of the deformation controlled components (e.g., the nominal flexural strength of a beam or connection is multiplied by the appropriate φ factor). Analyze the model for the nonlinear static load case. Use the stiffness requirements of asce 41 [10] chapters 5 through 8 to create the model. Discretize the load-deformation response of each component along its length to identify locations of inelastic action. The force-displacement behavior of all components shall be explicitly modeled, including strength degradation and residual strength, if any. Model a connection explicitly if the connection is weaker or has less ductility than the connected components, or the flexibility of the connection results in a change in the connection forces or deformations greater than 10%. If there is any possibility that the presence of the short section will affect the taller section in a negative manner.

To calculate the deformation-controlled and force-controlled actions, simultaneously apply the following combination of gravity loads:

Increased gravity loads for floor areas above removed column or wall.

Apply the following increased gravity load combination to those bays immediately adjacent to the removed element and at all floors above the removed element.

Gn= Ωn [1.2 d + (0.5 l or 0.2 s)]

Where, Gn = increased gravity loads for nonlinear static analysis

D=dead load

S= snow load

Ωn = dynamic increase factor for calculating deformation-controlled and force controlled actions for nonlinear static analysis.

Gravity loads for floor areas away from removed column or wall. Apply the gravity load combination in below equation to those bays not loaded with gn

G = 1.2 d + (0.5 l or 0.2 s)

For those bays not immediately adjacent to there moved element the load combination is the same for both deformation and force- controlled action.

Dynamic increasing factor:

The nonlinear static dynamic increase factors (Ωn) are provided in table below par is the plastic rotation angle given in the acceptance criteria tables in asce 41 [10] and this document for the appropriate structural response level (collapse prevention or life safety for the particular element, component or connection;

Θy is the yield rotation. For steel, θy is given in equation 5-1 in asce 41 [10]. For reinforced concrete, θy is determined with the effective stiffness values provided in table 6-5 in asce 41 [10]. Note that for connections, θy is the yield rotation angle of the structural element that is being connected (beam, slab, etc) and θpra is for the connection(determined from asce 41 [10]). Columns are omitted from the determination of Ω_n.to determine Ω_n for the analysis of the entire structure, choose the smallest ratio of θpra/θy for any primary element, component, or connection in the model within or touching the area that is loaded with the increased gravity low

Table 3: dynamic increase factors (ωn) for nsp

Material	Structure type	Ωn
Steel	Framed	1.08 + 0.76/(θpra/θy + 0.83)
Reinforced concrete	Framed	1.04 + 0.45/(θpra/θy + 0.48)
	Load-bearing wall	2.0
Mesonary	Load-bearing wall	2.0
Wood	Load-bearing wall	2.0
Cold-formedsteel	Load-bearing wall	2.0

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III. MODELLING AND ANALYTICAL STUDY

Theoretical model selected for the study of progressive collapse having symmetrical base with vertical irregularity of 3x5, 5x7, 7x9, 9x11 is steel structure building. The structure consists of seven bays of 4 m in the longitudinal direction and seven bays of 4 m in the transverse direction

Detail description of model is given in table.

Table 4: Description of model

Sr.no.	**Particulars**	**Description**
1	Type of structure	Moment resisting frame
2	Type of building	Commercial building
3	Number of stories	5x7,7x9,9x11
4	Height of building	3 meter
5	Spacing in x direction	5 meter
6	Spacing in y direction	5 meter
7	Material	Fe345,fe250,m25(concrete)
8	Thickness of slab	150 mm thk
9	Codal provision	Is 800:2007,is1893:2002

Table 5:loading data for structure:

Sr. no.	Particulars	Description
1	Dead load	Self-weight of structure
2	Live load	2.5 kn/m^2
3	Floor finish	1.25kn/m
4	wall load	10kn
5	Wall load on roof	3kn
6	Seismic load	Is1893:2002
6.a	Importance factor	1
	Zone	Iii
	Soil type	Medium
	Type of structure	Special moment resisting frame
	Response reduction factor	5

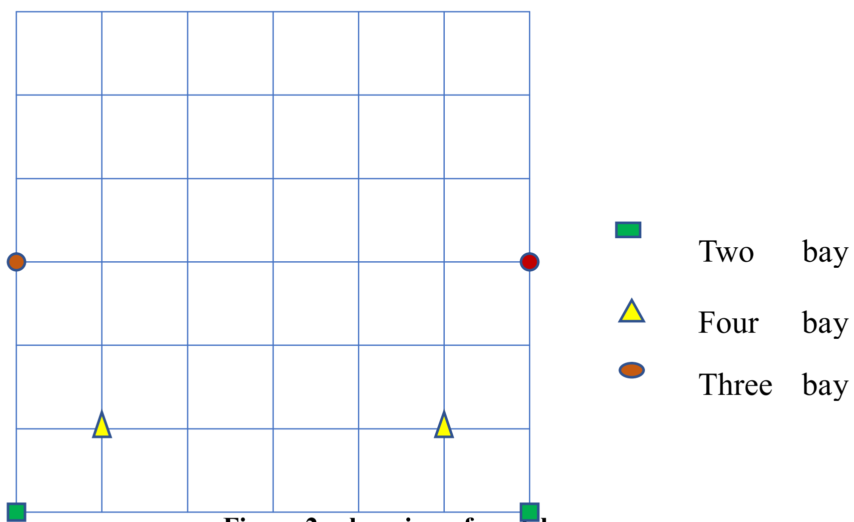

Figure 2: plan view of models

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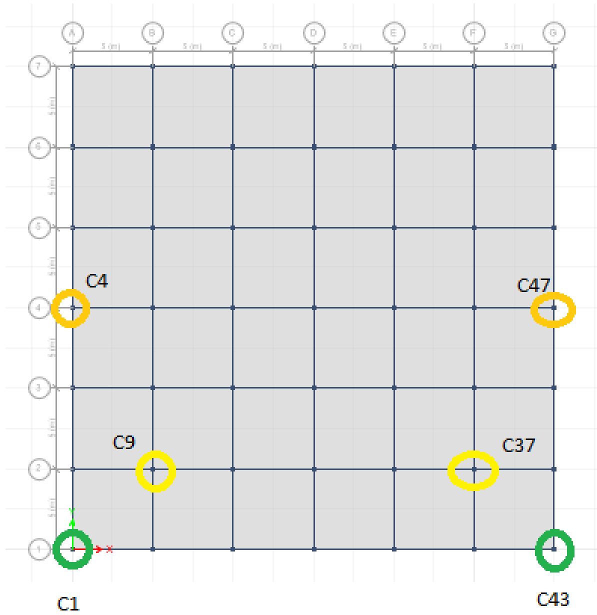

Figure 3: plan view of removal of location of column

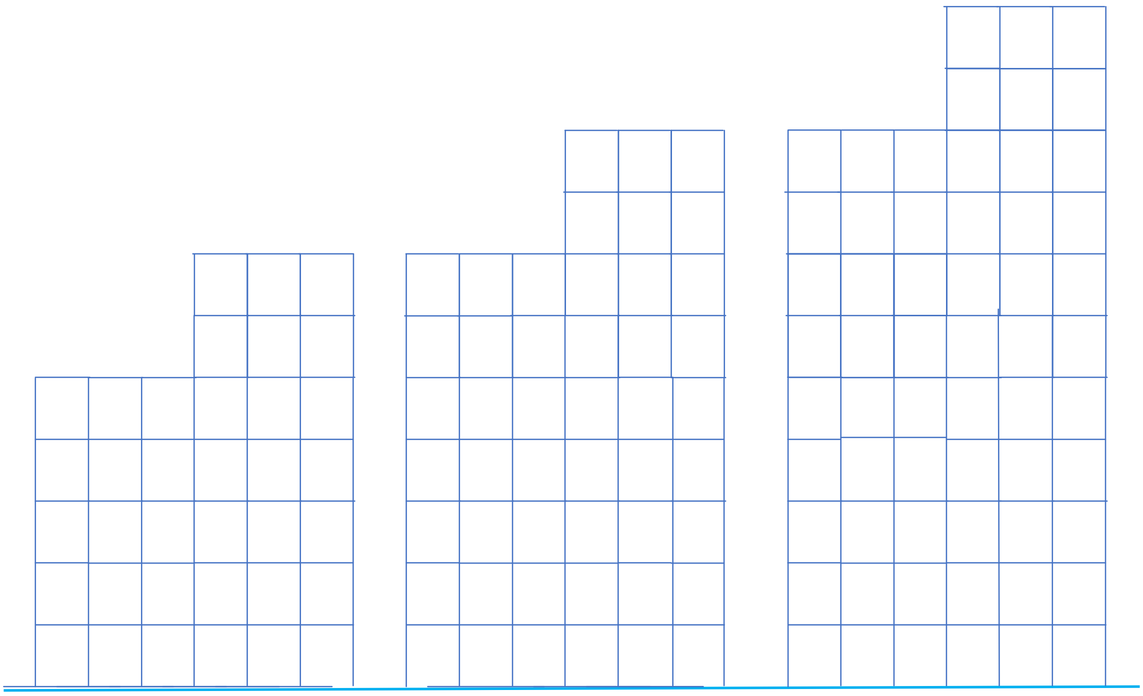

Figure 4: elevation view of 2d models

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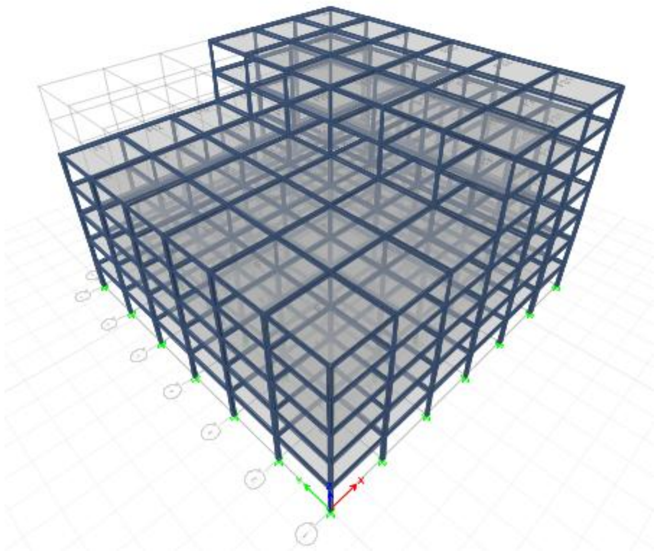

Figure 5:elevation view of 3d models

IV. RESULT AND DISCUSSION

This chapter basically deals with presentation of results obtained until & graphs plotted using the same. Their interpretation is also done after the results to understand the actual behaviour of progressive collapse of steel framed structures.

The linear elastic static analysis using etabs 2015 bending moment diagram, shear force, axial force in beams, column axial force, demand capacity ratios and joint displacement is obtained, the DCR values for member under consideration loaded with GSA code of practice is worked out to know the behaviour of columns and beams in the structure.

For all models such as 5x7,7x9,9x11 following load cases are considered for linear static and nonlinear static

Case i : location of column removal no. 1

Case ii : location of column removal no. 4

Case iii : location of column removal no. 9

Case iv : location of column removal no.37

Case v : location of column removal no.43

Case vi : location of column removal no.47

Results and graphs for all models

In progressive collapse analysis through linear static analysis and nonlinear static analalsis has been observed the various parameters to study behaviour of structures in such abnormal events.

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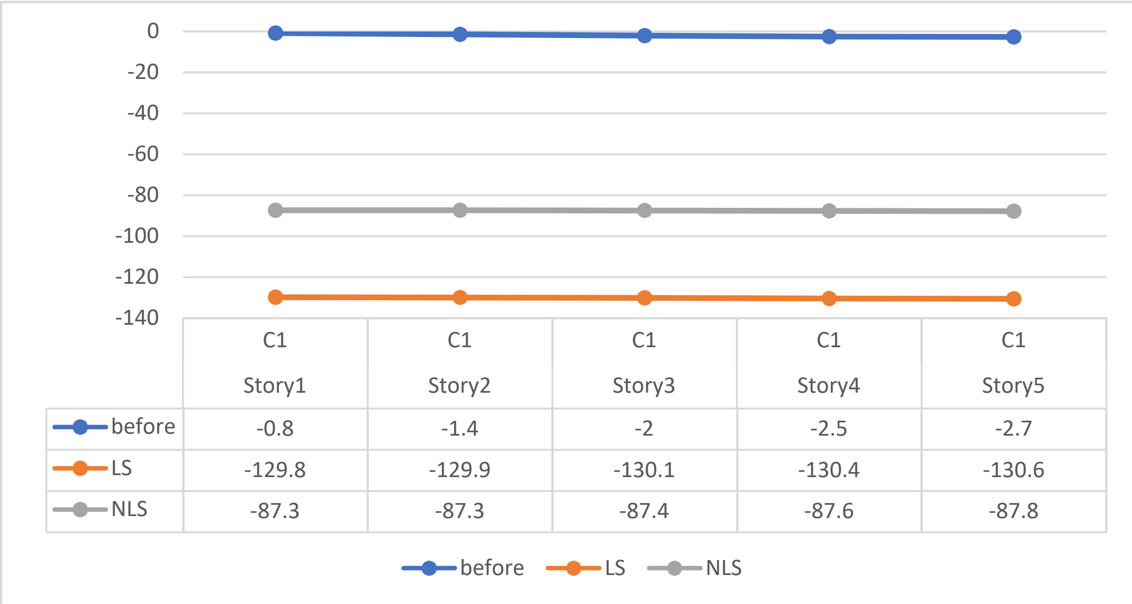
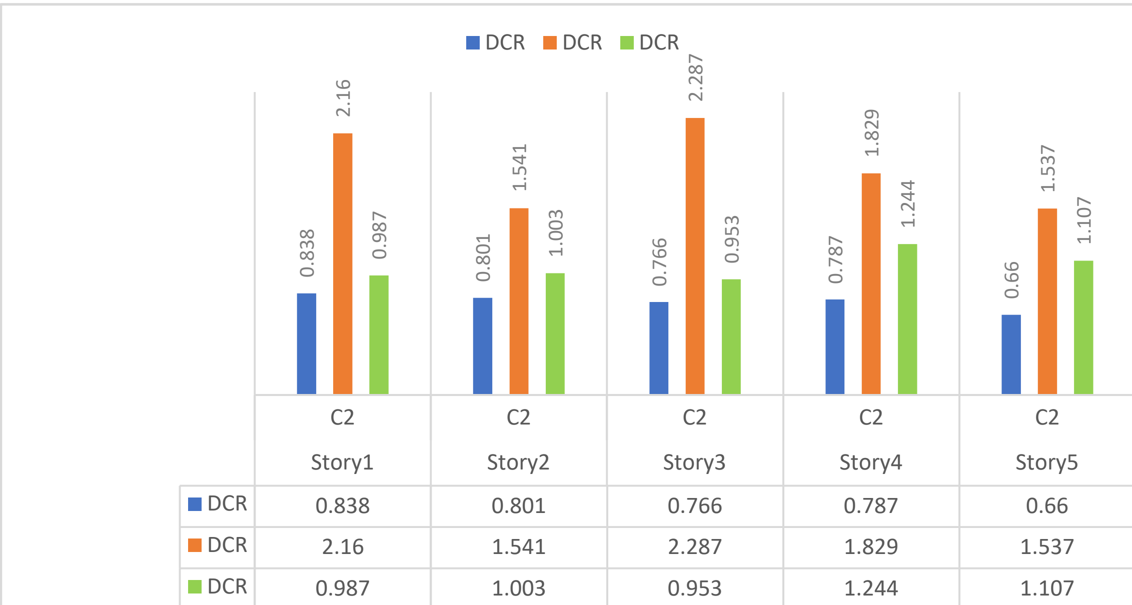
Graph 1: displacement DCR ,bending moment for column no. 1(5x7)

Joint displacement for column no.c1



This graph shows displacement behavior of structure before removal of column and after removal of column for linear static and nonlinear static. The nonlinear static displacement is less due to less amplification factor is used for nonlinear static analysis.

Demand capacity ratio of column after removal of c2



The graph shows for original structure D.C.R. values are within the limit i.e.less than 0.9 but linear static column removal case values are larger at ground floor and reduces to top story. As compare to nonlinear static analysis.

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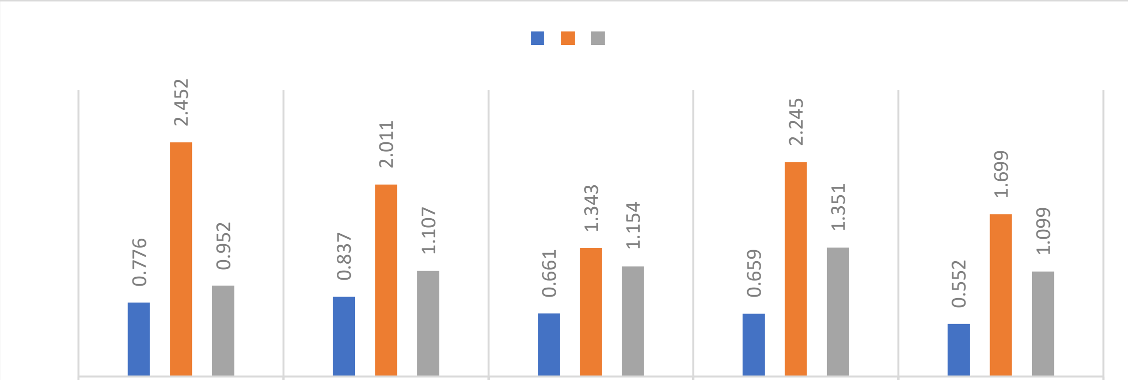
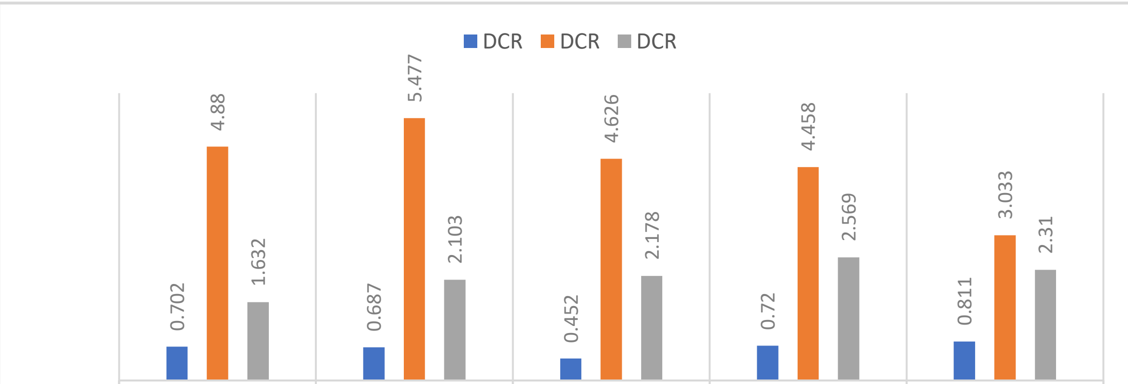


	C8 Story1	C8 Story2	C8 Story3	C8 Story4	C8 Story5
■ (blue)	0.776	0.837	0.661	0.659	0.552
■ (orange)	2.452	2.011	1.343	2.245	1.699
■ (grey)	0.952	1.107	1.154	1.351	1.099

The graph shows for original structure D.C.R.values are in between 0.5 to 0.9 but linear static column removal case values are larger at ground floor is 2.452 and reduces to top story is 1.699.as compare to nonlinear static values.

Demand capacity ratio of beam no b1



	B1 Story1	B1 Story2	B1 Story3	B1 Story4	B1 Story5
DCR	0.702	0.687	0.452	0.72	0.811
DCR	4.88	5.477	4.626	4.458	3.033
DCR	1.632	2.103	2.178	2.569	2.31

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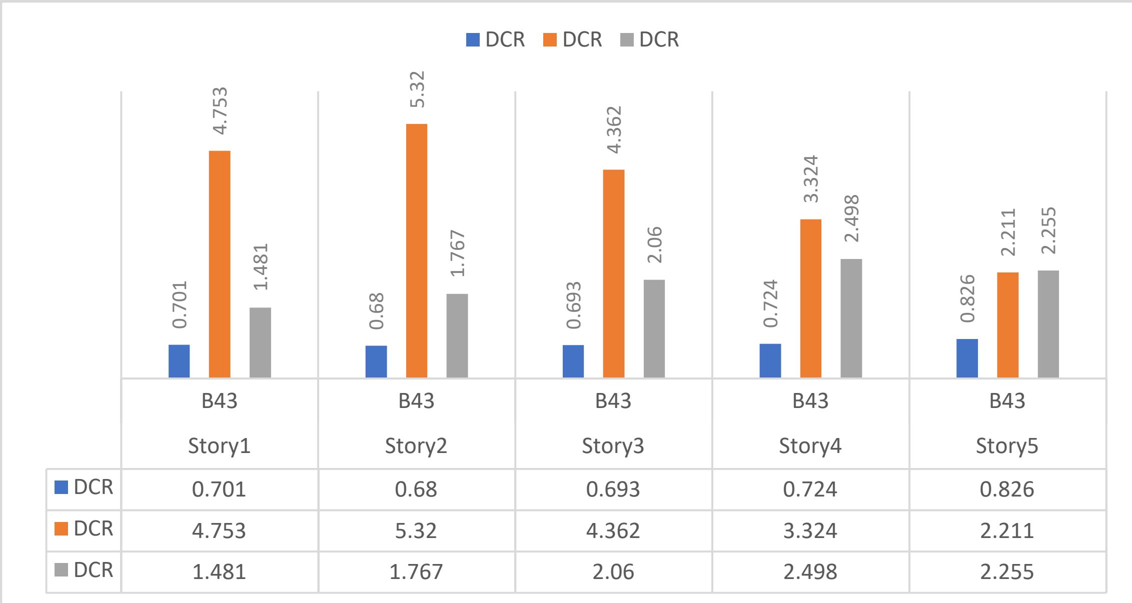
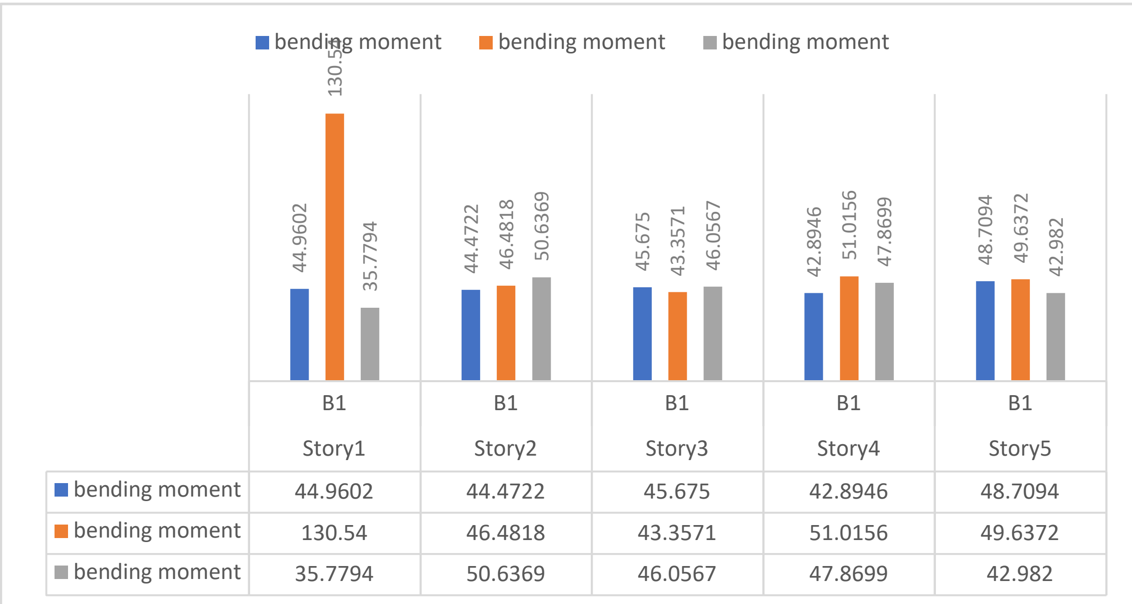
Demand capacity ratio of beam no b43



	B43 Story1	B43 Story2	B43 Story3	B43 Story4	B43 Story5
DCR	0.701	0.68	0.693	0.724	0.826
DCR	4.753	5.32	4.362	3.324	2.211
DCR	1.481	1.767	2.06	2.498	2.255

Graph shows large increasing in DCR value in beam because beam no1 and beam no.43has not transfer the load to adjacent column because of removal column no.c1

Bending moment of beam no 1



	B1 Story1	B1 Story2	B1 Story3	B1 Story4	B1 Story5
bending moment	44.9602	44.4722	45.675	42.8946	48.7094
bending moment	130.54	46.4818	43.3571	51.0156	49.6372
bending moment	35.7794	50.6369	46.0567	47.8699	42.982

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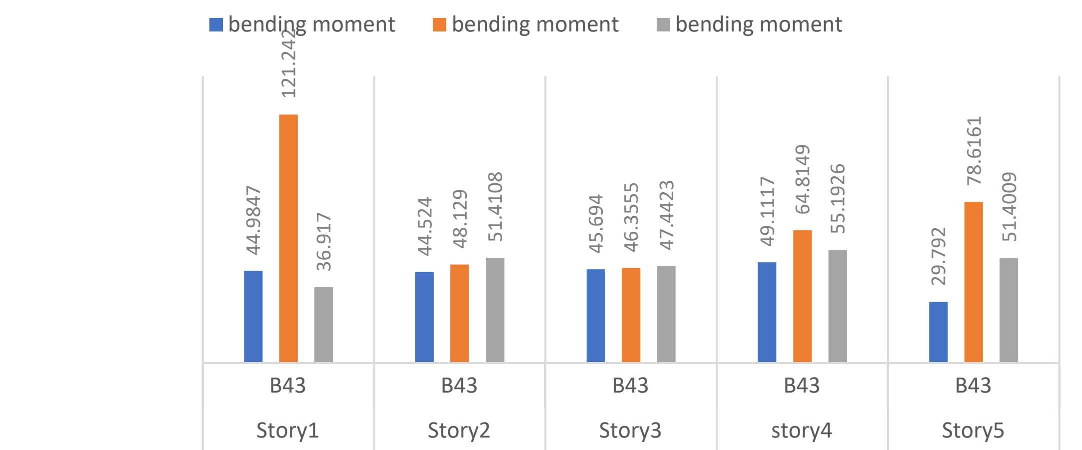
Bending moment of beam no 43

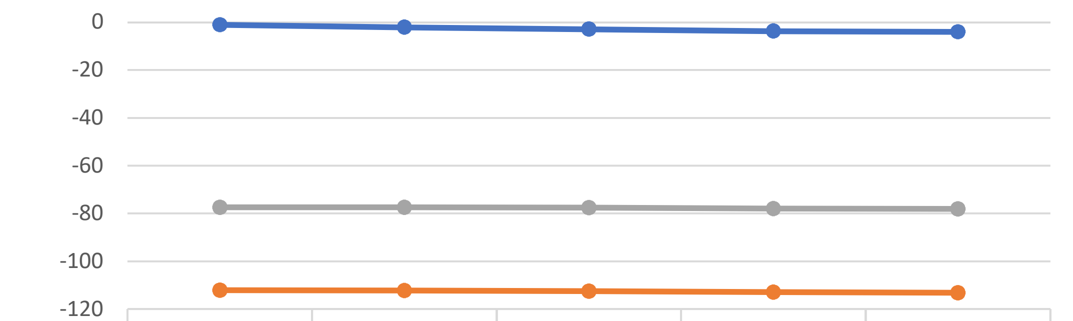


	B43 Story1	B43 Story2	B43 Story3	B43 story4	B43 Story5
bending moment	44.9847	44.524	45.694	49.1117	29.792
bending moment	121.242	48.129	46.3555	64.8149	78.6161
bending moment	36.917	51.4108	47.4423	55.1926	51.4009

The bending moment values for beam no b1 and b43 are abruptly changes when removal of column c1 as compare to original structure this is seen maximum at ground story than other stories.

Graph 2:displament, DCR ,bending moment for column no 4(5x7)

Joint moment displacement for c4



	C4 Story1	C4 Story2	C4 Story3	C4 Story4	C4 Story5
before	-1.1	-2.1	-2.9	-3.7	-4
LS	-112.1	-112.2	-112.5	-112.9	-113.2
NLS	-77.4	-77.4	-77.6	-77.9	-78.1

This graph shows displacement behavior of structure before removal of column and after removal of column for linear static and nonlinear static. The nonlinear static displacement is a reduced amount of due to less amplification factor is used for nonlinear static analysis.

Demand capacity ratio for the column no c3

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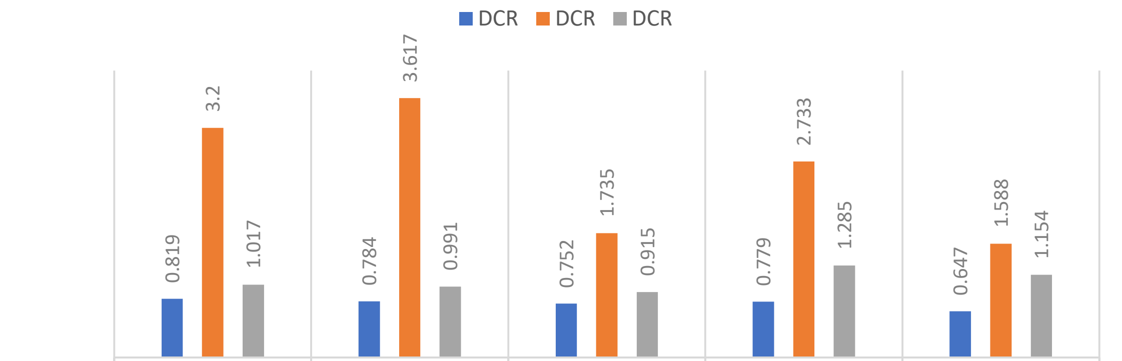
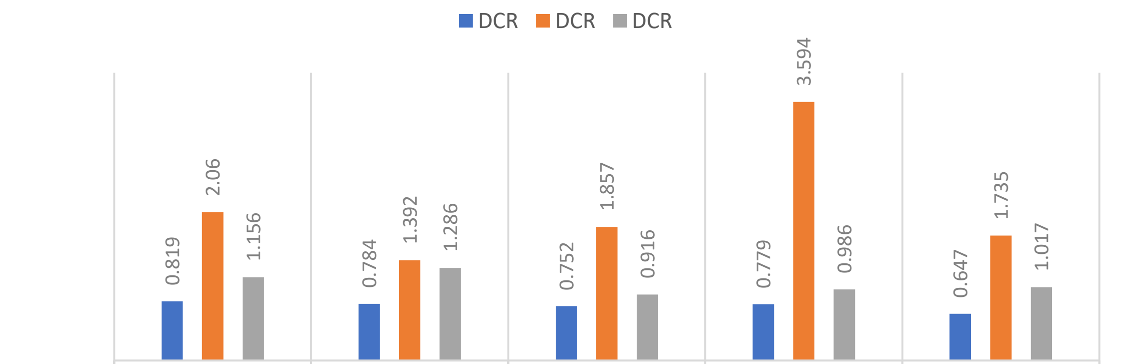


	C3 Story1	C3 Story2	C3 Story3	C3 Story4	C3 Story5
DCR	0.819	0.784	0.752	0.779	0.647
DCR	3.2	3.617	1.735	2.733	1.588
DCR	1.017	0.991	0.915	1.285	1.154

Demand capacity ratio for the column no c5



	C5 Story1	C5 Story2	C5 Story3	C5 Story4	C5 Story5
DCR	0.819	0.784	0.752	0.779	0.647
DCR	2.06	1.392	1.857	3.594	1.735
DCR	1.156	1.286	0.916	0.986	1.017

The graph shows for original structure D.C.R.values but linear static column removal case values are larger at ground floor is 3.2 for c3 and 2.05 for c5 and reduces to top story is 1.154 for c3 and 1.735 for c5.as compare to nonlinear static values.

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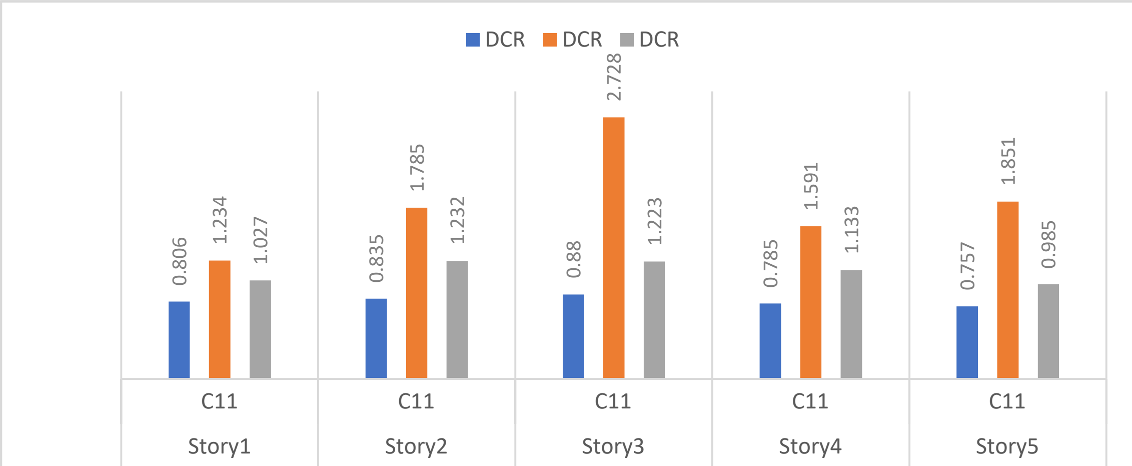
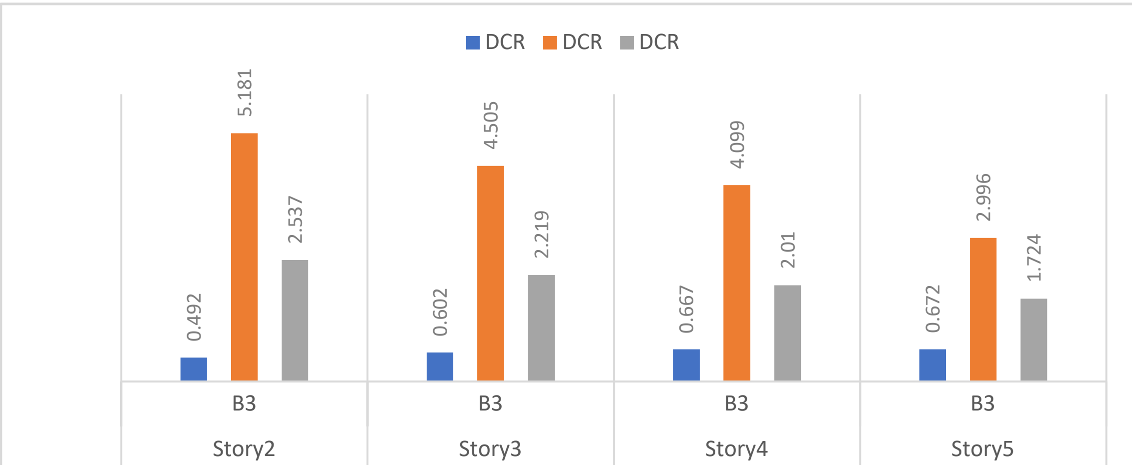
Demand capacity ratio for the column no c11



	C11 Story1	C11 Story2	C11 Story3	C11 Story4	C11 Story5
DCR	0.806	0.835	0.88	0.785	0.757
DCR	1.234	1.785	2.728	1.591	1.851
DCR	1.027	1.232	1.223	1.133	0.985

Demand capacity ratio for beam no b3:



	B3 Story2	B3 Story3	B3 Story4	B3 Story5
DCR	0.492	0.602	0.667	0.672
DCR	5.181	4.505	4.099	2.996
DCR	2.537	2.219	2.01	1.724

Graph shows large increasing in DCR value in beam because beam no3 has more value on ground floor is 5.181 which is reducing at top floor is 2.996 for linear static than nonlinear static

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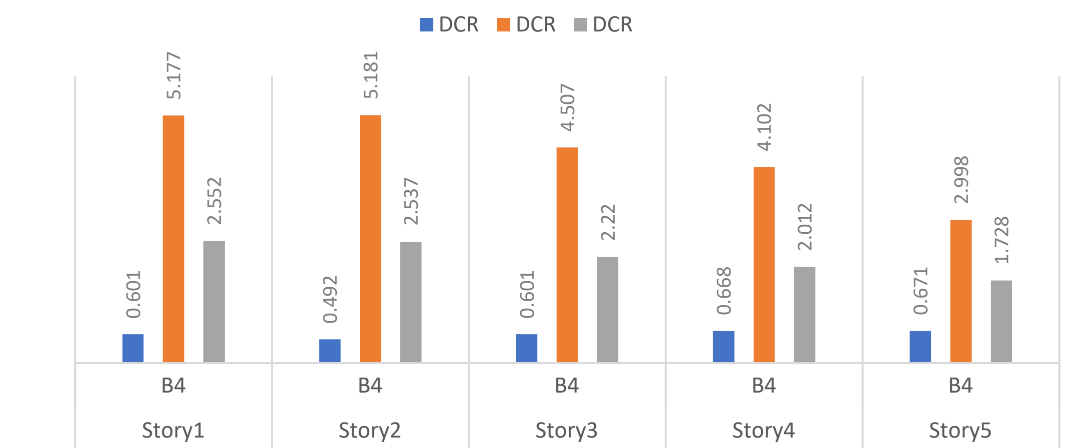
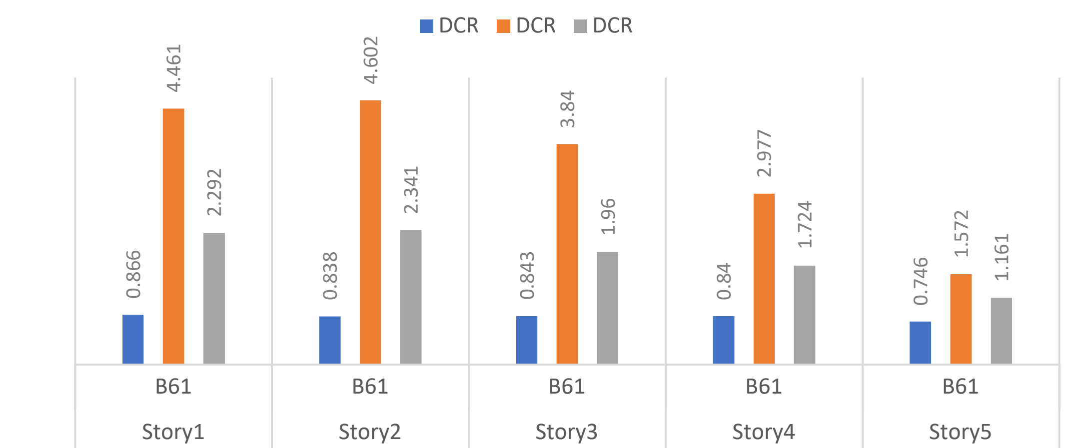
Demand capacity ratio for beam no b4:



	B4 Story1	B4 Story2	B4 Story3	B4 Story4	B4 Story5
DCR	0.601	0.492	0.601	0.668	0.671
DCR	5.177	5.181	4.507	4.102	2.998
DCR	2.552	2.537	2.22	2.012	1.728

Demand capacity ratio for beam no b61:



	B61 Story1	B61 Story2	B61 Story3	B61 Story4	B61 Story5
DCR	0.866	0.838	0.843	0.84	0.746
DCR	4.461	4.602	3.84	2.977	1.572
DCR	2.292	2.341	1.96	1.724	1.161

Graph shows large increasing in DCR value in beam because beam no.4 has not transfer the load to adjacent column because of removal column no.c4

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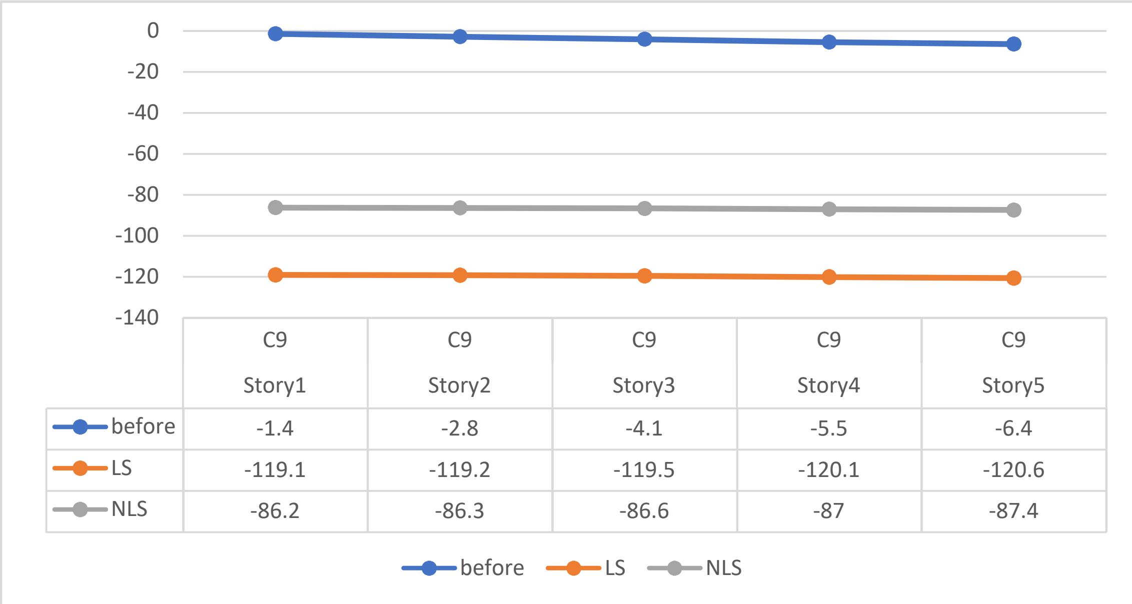
Graph 3:displacement, DCR ,bending moment for column no. 9 (5x7)

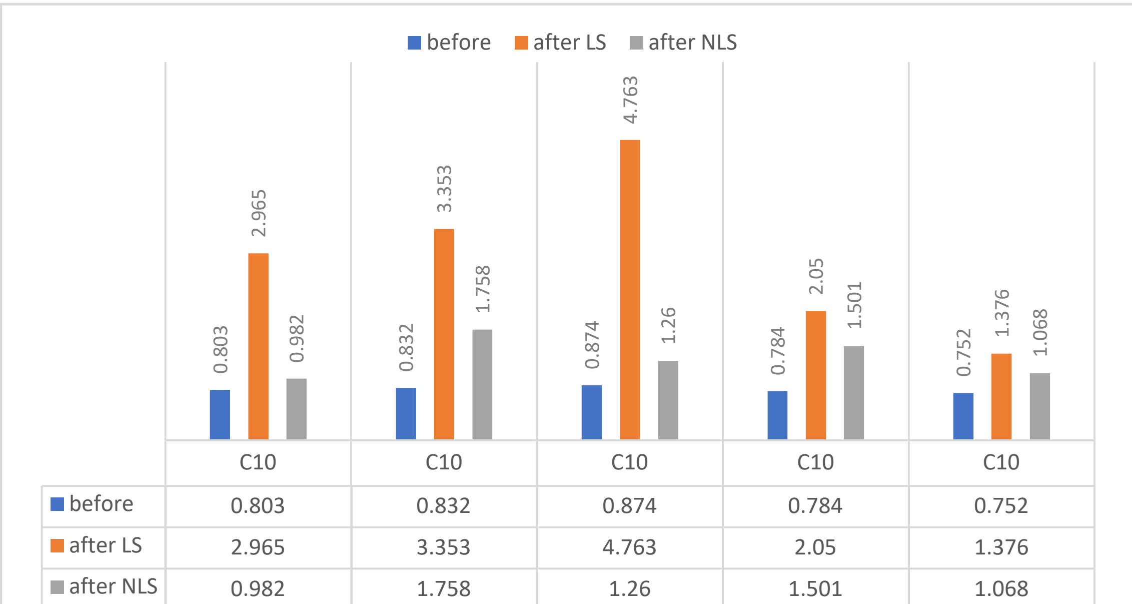
Joint displacement for column no.c9



	C9 Story1	C9 Story2	C9 Story3	C9 Story4	C9 Story5
before	-1.4	-2.8	-4.1	-5.5	-6.4
LS	-119.1	-119.2	-119.5	-120.1	-120.6
NLS	-86.2	-86.3	-86.6	-87	-87.4

Results shows that for displacement for column c9 before removal of column increases gradually as story goes on increasing but for linear static case values are more than nonlinear static case because amplification factor is large.

Demand capacity ratio for the column no c10



	C10	C10	C10	C10	C10
before	0.803	0.832	0.874	0.784	0.752
after LS	2.965	3.353	4.763	2.05	1.376
after NLS	0.982	1.758	1.26	1.501	1.068

The graph shows that d.c.r. values for before removal of column is in between 0.7 to 0.85but for after removal of location the values are suddenly increases at ground story is 2.965 and goes on reducing to 1.376 as compared to nonlinear static analysis.

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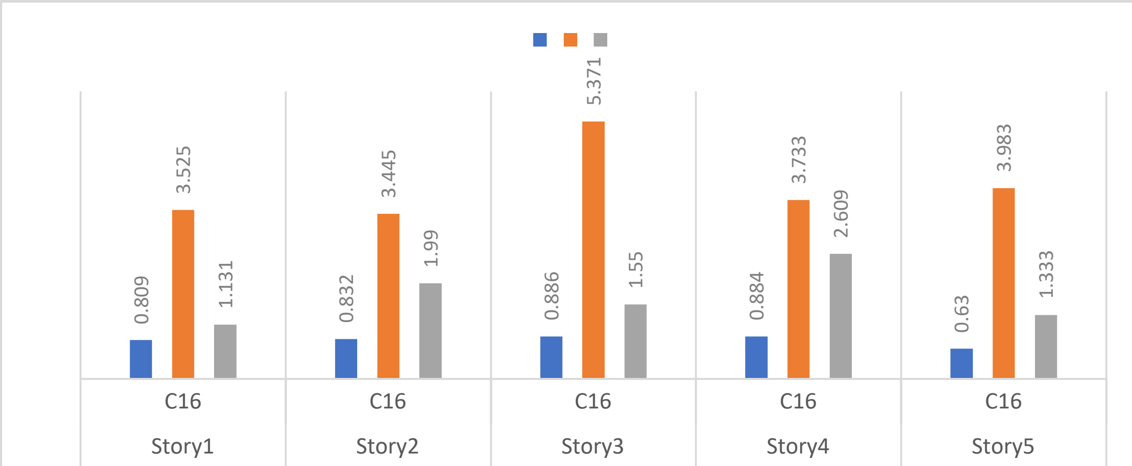
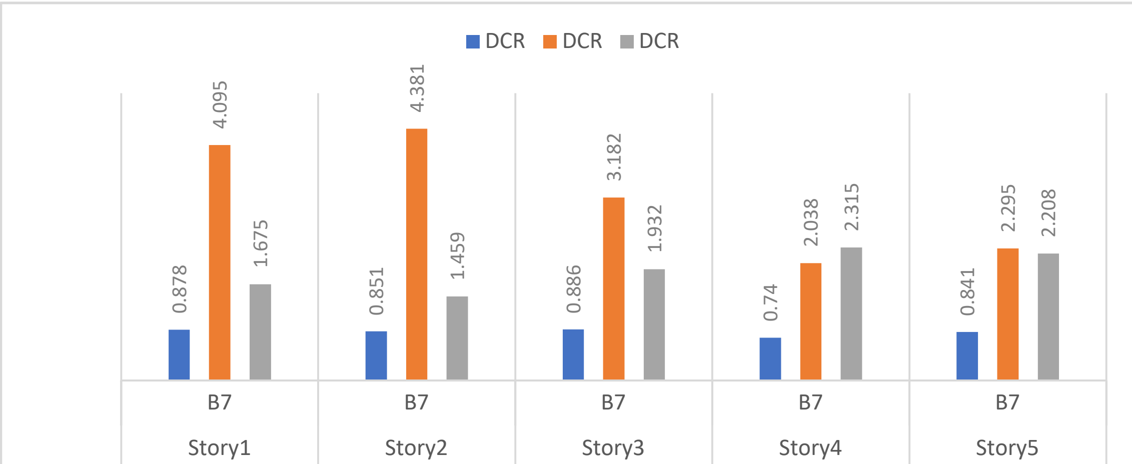
Demand capacity ratio for the column no c16



	C16 Story1	C16 Story2	C16 Story3	C16 Story4	C16 Story5
■	0.809	0.832	0.886	0.884	0.63
■	3.525	3.445	5.371	3.733	3.983
■	1.131	1.99	1.55	2.609	1.333

The graph shows for original structure D.C.R.values are in between 0.5 to 0.9 but linear static column removal case values are larger at ground floor and reduces to top story is .as compare to nonlinear static values.

Demand capacity ratio for the beam no b7



	B7 Story1	B7 Story2	B7 Story3	B7 Story4	B7 Story5
DCR	0.878	0.851	0.886	0.74	0.841
DCR	4.095	4.381	3.182	2.038	2.295
DCR	1.675	1.459	1.932	2.315	2.208

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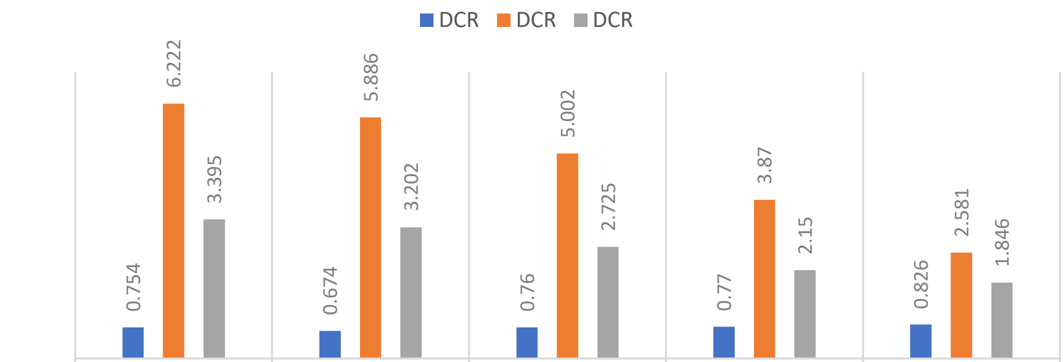
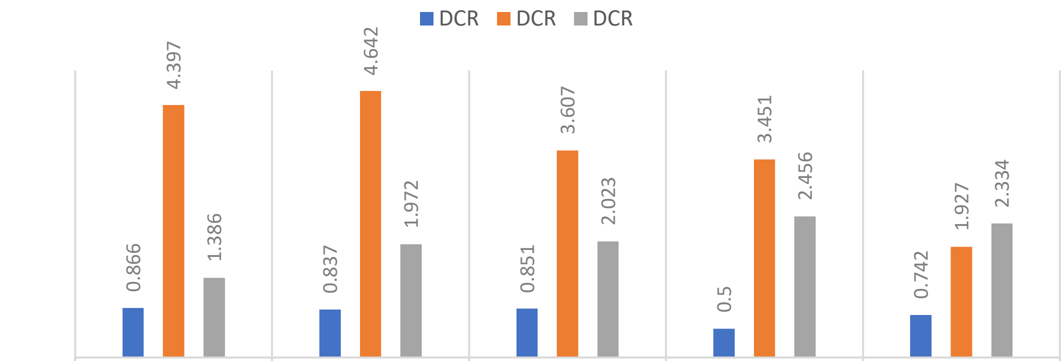
Demand capacity ratio for the beam no b8



	B8 Story1	B8 Story2	B8 Story3	B8 Story4	B8 Story5
DCR	0.754	0.674	0.76	0.77	0.826
DCR	6.222	5.886	5.002	3.87	2.581
DCR	3.395	3.202	2.725	2.15	1.846

Demand capacity ratio for the beam no b49



	B49 Story1	B49 Story2	B49 Story3	B49 Story4	B49 Story5
DCR	0.866	0.837	0.851	0.5	0.742
DCR	4.397	4.642	3.607	3.451	1.927
DCR	1.386	1.972	2.023	2.456	2.334

Above all graph shows that for original structure D.C.R.values are in between 0.5 to 0.9 but linear static column removal case values are larger at ground floor and reduces to top story is .as compare to nonlinear static values.

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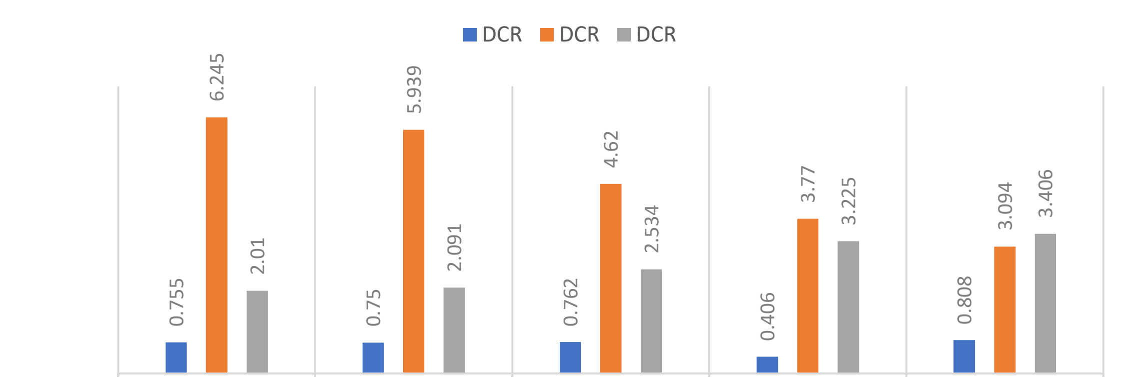
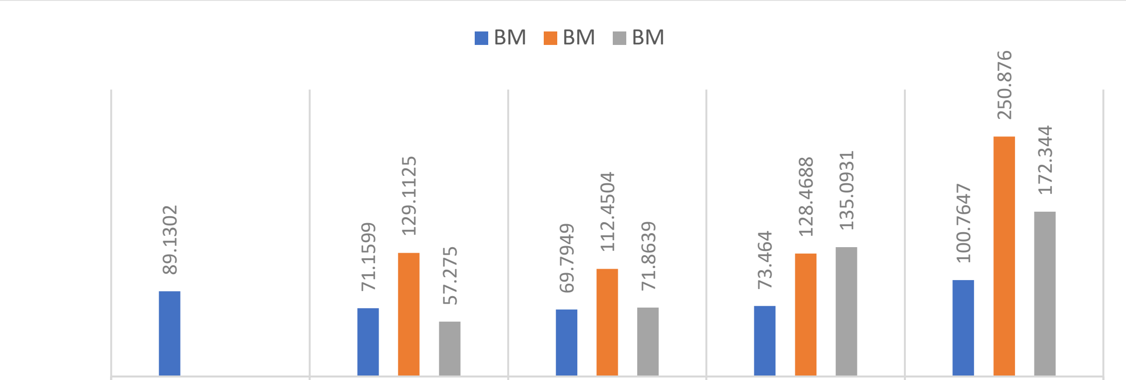
Demand capacity ratio for the beam no b50



	B50 Story1	B50 Story2	B50 Story3	B50 Story4	B50 Story5
DCR	0.755	0.75	0.762	0.406	0.808
DCR	6.245	5.939	4.62	3.77	3.094
DCR	2.01	2.091	2.534	3.225	3.406

Above all graph shows that for original structure D.C.R.values are in between 0.5 to 0.9 but linear static column removal case values are larger at ground floor and reduces to top story is .as compare to nonlinear static values.

Bending moment for beam no b7



	B7 story	B7 Story1	B7 Story2	B7 Story3	B7 Story5
BM	89.1302	71.1599	69.7949	73.464	100.7647
BM		129.1125	112.4504	128.4688	250.876
BM		57.275	71.8639	135.0931	172.344

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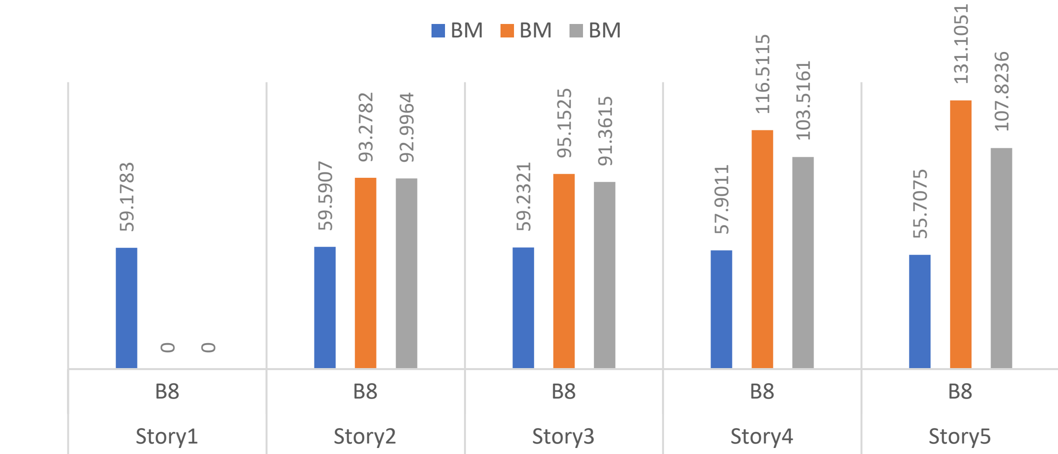
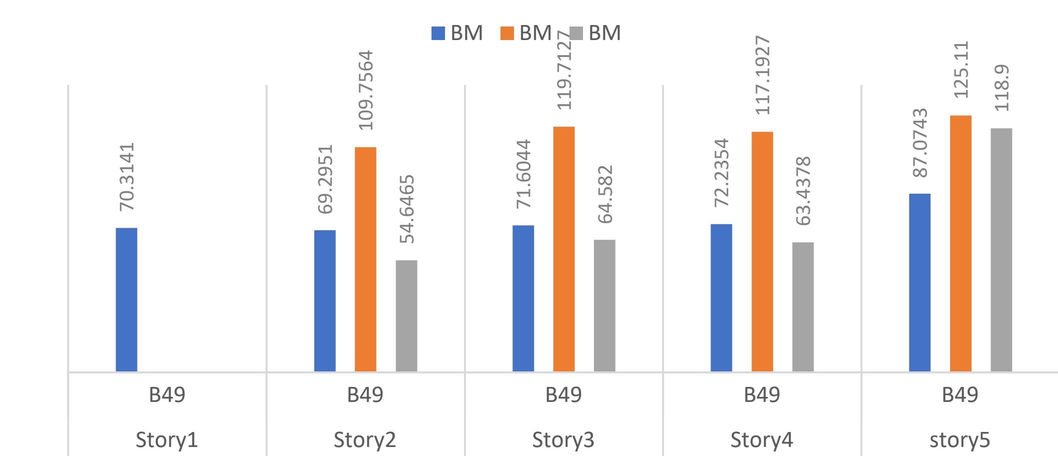
Bending moment for beam no b8



	B8 Story1	B8 Story2	B8 Story3	B8 Story4	B8 Story5
BM	59.1783	59.5907	59.2321	57.9011	55.7075
BM	0	93.2782	95.1525	116.5115	131.1051
BM	0	92.9964	91.3615	103.5161	107.8236

Bending moment for beam no b49



	B49 Story1	B49 Story2	B49 Story3	B49 Story4	B49 story5
BM	70.3141	69.2951	71.6044	72.2354	87.0743
BM		109.7564	119.7127	117.1927	125.11
BM		54.6465	64.582	63.4378	118.9

From all above graphs shows that bending moment for before removal of column are in a range between 70 to 90 kn but after removal of column there is an drastic change in linear static analysis as compared to nonlinear static analysis.

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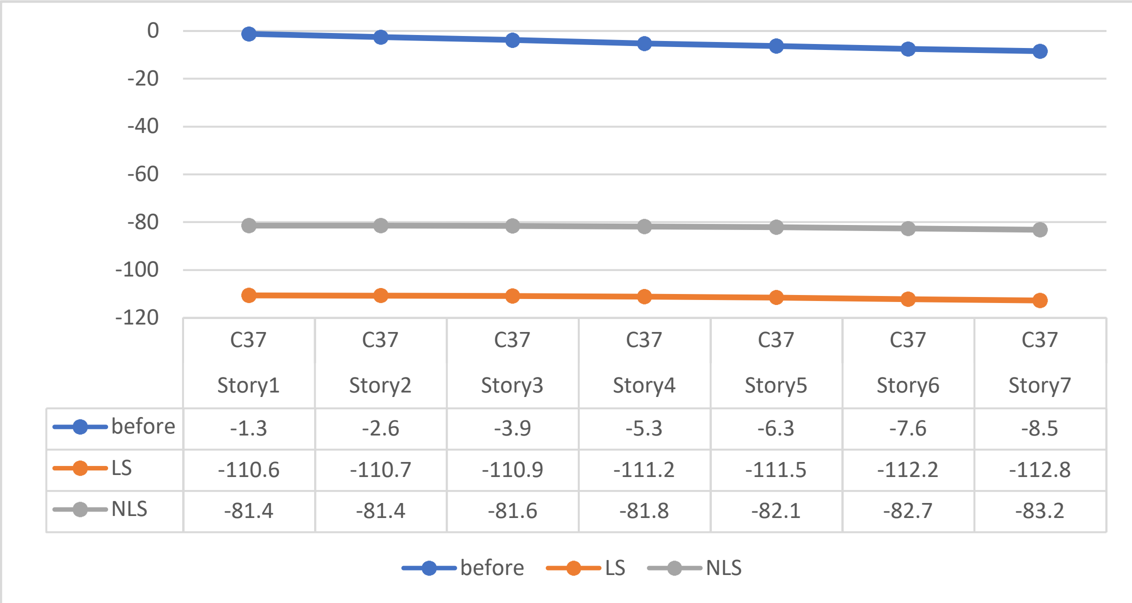
Graph 4:displacment,DCR,bending moment for column no. 37 (5x7)

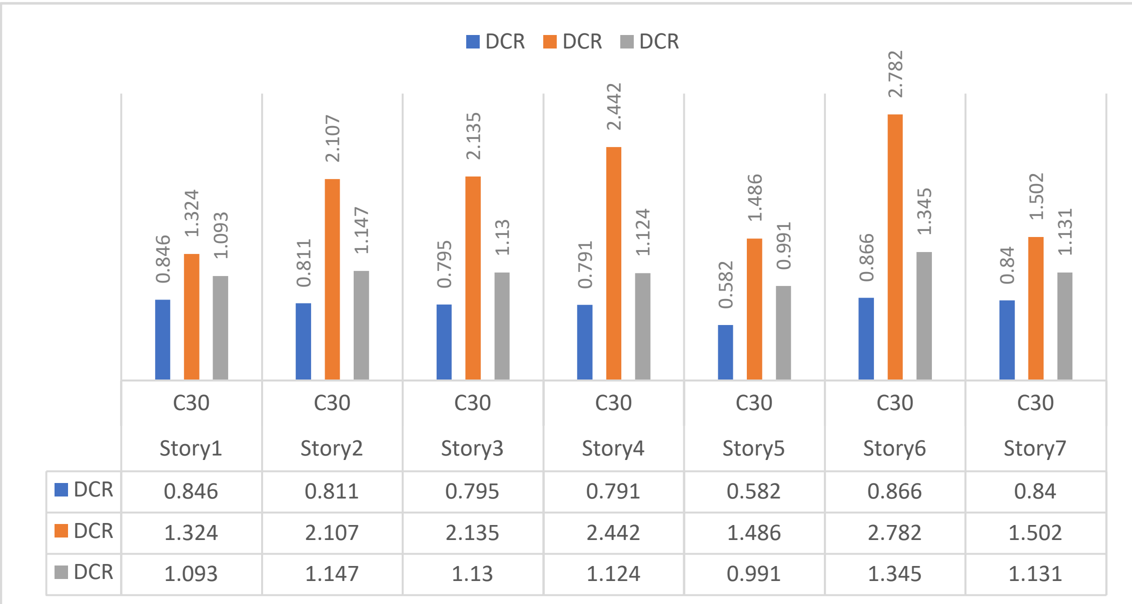
Joint displacement for column no 37



	C37 Story1	C37 Story2	C37 Story3	C37 Story4	C37 Story5	C37 Story6	C37 Story7
before	-1.3	-2.6	-3.9	-5.3	-6.3	-7.6	-8.5
LS	-110.6	-110.7	-110.9	-111.2	-111.5	-112.2	-112.8
NLS	-81.4	-81.4	-81.6	-81.8	-82.1	-82.7	-83.2

Joint displacement of column c37 before column removal was -1.3mm but due to sudden loss of column c37 and after linear static joint displacement was suddenly increased to 110.6mm and after nonlinear static analysis is -81.4 mm due to less load carrying elements carries extra load.

Demand capacity ratio for the column no c30



	C30 Story1	C30 Story2	C30 Story3	C30 Story4	C30 Story5	C30 Story6	C30 Story7
DCR	0.846	0.811	0.795	0.791	0.582	0.866	0.84
DCR	1.324	2.107	2.135	2.442	1.486	2.782	1.502
DCR	1.093	1.147	1.13	1.124	0.991	1.345	1.131

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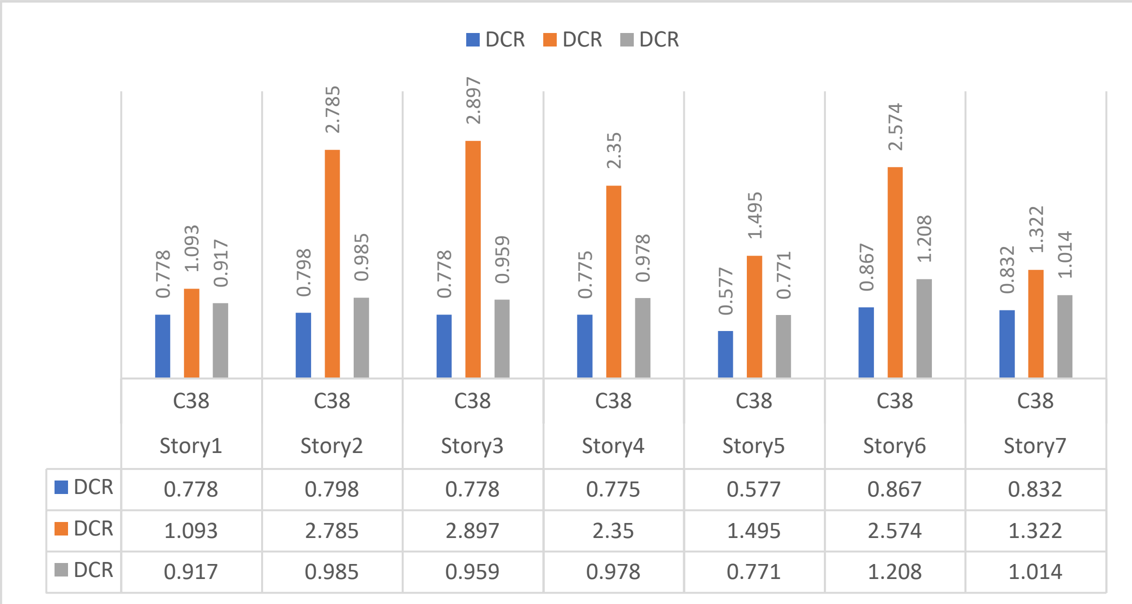
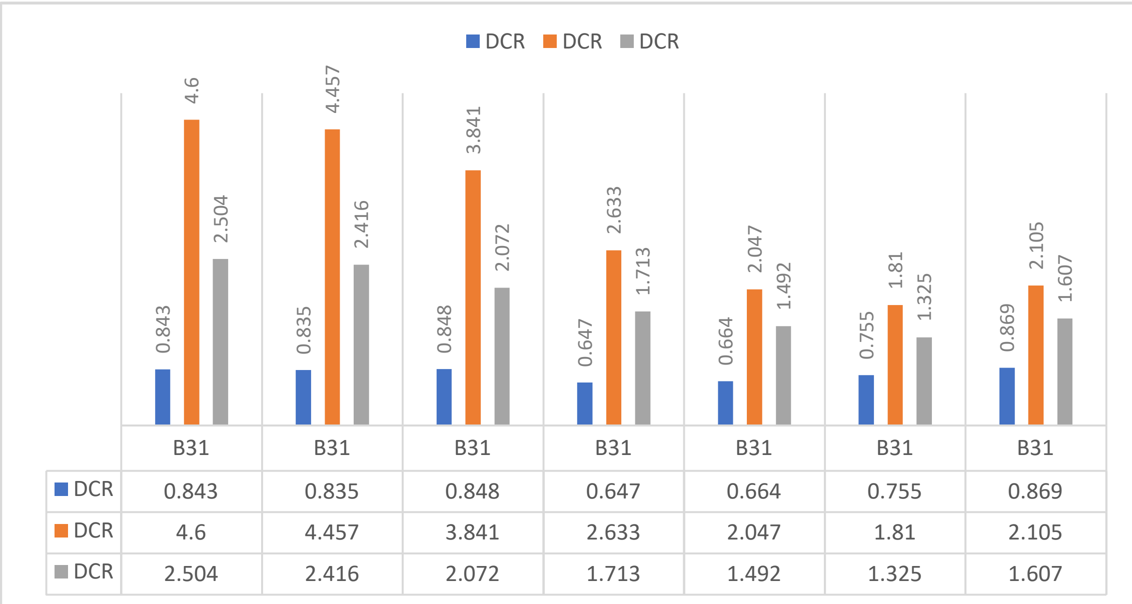
Demand capacity ratio for the column no c38



	C38 Story1	C38 Story2	C38 Story3	C38 Story4	C38 Story5	C38 Story6	C38 Story7
DCR	0.778	0.798	0.778	0.775	0.577	0.867	0.832
DCR	1.093	2.785	2.897	2.35	1.495	2.574	1.322
DCR	0.917	0.985	0.959	0.978	0.771	1.208	1.014

Demand capacity ratio for the column no b31



	B31	B31	B31	B31	B31	B31	B31
DCR	0.843	0.835	0.848	0.647	0.664	0.755	0.869
DCR	4.6	4.457	3.841	2.633	2.047	1.81	2.105
DCR	2.504	2.416	2.072	1.713	1.492	1.325	1.607

VI. CONCLUSION

- From result it has been observe that as displacement before removal of columns very small after removal these displacement are largely increase in case of linear static analysis as compare to nonlinear static analysis because dynamic increasing factor so large.
- From graph d.c.r. value of adjacent beam are considered and the structure for all combination we maintain DCR of all of structural element is in between 0.5 to 0.9.after removal of column there is an drastic change in DCR of adjacent beams in linear static analysis as compared to nonlinear static analysis.
- It has been conclude that there is an gradual increase in bending moment before removal of column but there is an abruptly change in bending moment in linear static analysis as compared to nonlinear static analysis

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- Sudden increase in shear force and bending moment values indicate increase in the strength of beam to avoid the progressive collapse in a structure. Therefore, even though it is a very basic model simulation, it gives in depth fundamental understanding about the progressive collapse
- Nodal displacement for lower height of structure is more as we increase the height of structure the displacement goes on reducing.
- Demand capacity ratio of nearer to removal location is maximum for restructure changes with respect increasing height of structure.
- Bending moment at corner location of lower storey structure is maximum as compare to other two cases.
- Height of structure affect the collapse behavior as height increases progressive collapse decreases which is seen from d.c.r.values, joint displacement, and bending moment.
- It is observed that when an element is removed loads are distributed to its surrounding elements and maximum effect is on neighboring horizontal and vertical elements which defines a progressive collapse.
- Demand capacity ratios for nearby column and beams clearly seen for maximum changes occurs in nearby removed locations; nodal displacement of joint changes abruptly which indicates that beam-column junction becomes critical.
- All the results discussed show the increase in various parameters in the member just in the vicinity of the vertical element removed.
- Further extensions of this research work can includes similar portal frame analysis with and with out different types of bracing for all analysis technique such as linear static ,nonlinear static, linear dynamic, on-linear dynamic analysis for three dimensional frames are also being considered with material non-linearity

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