ASSESSMENT OF A REINFORCED CONCRETE MULTI-STORY BUILDING AGAINST PROGRESSIVE COLLAPSE

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ABSTRACT

The progressive collapse of reinforced concrete structures occurs when one or more vertical load-bearing elements are eliminated due to man-made or natural hazards. The building's weight transfers to neighboring columns in the structure, causing the failure of adjacent members and, ultimately, the failure of a portion or the entire structure. In which the collapsing system continuously searches for alternate load paths in order to survive. This study examines progressive collapse in RC structures caused by instantaneous column removal. To investigate the collapse, typical columns are removed individually and analysis and design are continued. An eight-story reinforced concrete frame structure was considered for the study. The software ETABS V20 is used to perform a linear static analysis on a model of a regular reinforced concrete (RC) frame structure. Here, three types of column removal cases are examined: corner column removal, exterior column removal, and interior column removal. Then, the calculation of Demand Capacity Ratio (DCR) for both beams and columns are considered and compared to the GSA's acceptance criteria. The obtained DCR values indicate that columns are safe and strong enough to resist progressive collapse in all cases, whereas beams for corner column removal case are not safe for progressive collapse.

Keywords: Progressive collapse; Iraq seismic code; DCR values; RC structure; General Services Administration (GSA).

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1. INTRODUCTION

The term "progressive collapse" can be defined in a straightforward manner as the ultimate failure or proportionately large failure of a portion of a structure as a result of the spread of a local failure from element to element throughout the structure. This can be thought of as the ultimate failure or proportionately large failure of a portion of a structure. The beginning of a progressive collapse may be brought on by causes that are manmade, natural, intentional, or unintentional. A progressive collapse failure can be caused by a number of different types of disasters, including fires, explosions, earthquakes, or anything else that causes large amounts of stress and the failure of a structure's support elements. [1- 4] Progressive collapse is a complex dynamic process in which the collapsing system redistributes loads to prevent the loss of essential structural members. Beams, columns, and frame connections must therefore be designed to accommodate the possible redistribution of large loads. The collapse of the World Trade Center towers due to a terrorist attack, the bombing of the Murrah Federal Building in Oklahoma City, and the collapse of the Ronan Point building due to a gas explosion are notable examples of progressive collapse phenomena. Progressive collapse failures can be better prepared for and possibly avoided in the future as a result of studies such as the one presented here.[5,6] Some design rules and standards have recently included a requirement for buildings to be strong enough to withstand the gradual collapse of their structure. The [GSA, (2003)], [7] rules demanded that government buildings in the United States be designed with the gradual collapse in mind. [ASCE-07, (2005)], [8] suggested that the gradual collapse be taken into account throughout the design phase. In order to limit the likelihood of a gradual collapse, the Unified Facilities Criteria [UFC, 2005 and 2009] prescribed different design standards and levels of protection based on the potential hazards.

2.OBJECTIVES OF THE STUDY

1-Design a multi-story administrative RC building according to ACI (318-14), [9]. Beams and columns were designed to resist lateral loading coming from earthquakes according to the Iraq seismic code (303-2017)[10].
2-The primary goal of this project is to identify any columns or beams in the structure that, if removed, would result in the building collapsing or causing the greatest amount of damage .
3-The main factor considered for study is the demand capacity ratio (DCR) for beams and columns to find the ability of structure to resist the progressive collapse.

3.SCOPE OF STUDY

1-This study is restricted to eight storey RC building with plan area of 708 m^2 and total height of 30 m .
2-Only linear static analysis is performed using ETABS-20 .[11] ,
3-The column and beam sizes are maintained uniform for the frame .
4-The beam and column are modeled with member element and the base of the structure is considered as fixed.

4.METHODOLOGY:

The present objective of this work is to study the behavior of conventional RC-framed buildings subjected to column loss. The parametric studies comprise DCR values of beams and columns. For these cases, a model has been created for conventional RC framed buildings with one column removed at different positions in four cases, then 2 columns removed together in case number five, reanalyzed with ETABS-20.

All the properties of Building are mentioned below :

Size of Beam in all Direction: 40*60 cm, Size of column: 60*60cm, Thickness of Slab: 20 cm, exterior brick wall thickness: 25 cm, typical story height 3.6 m, Bottom story height 4.8 m. The dimensions of plan were as shown in **Fig1**.

Superimposed dead load is taken as 1.5 kN/m2 and other permanent loads such as partition and floor finishing load are taken as 1 kN/m2. Live loads are adopted according to Iraqi code (301-2015) [12] for the administrative building which is 4 kN/m2 and 1 kN/m2 for roof.

lateral loads are calculated for the design of the reference structures according to ACI (318-14). Seismic loads are calculated using equivalent lateral force by Iraqi code for seismic(303-2017).

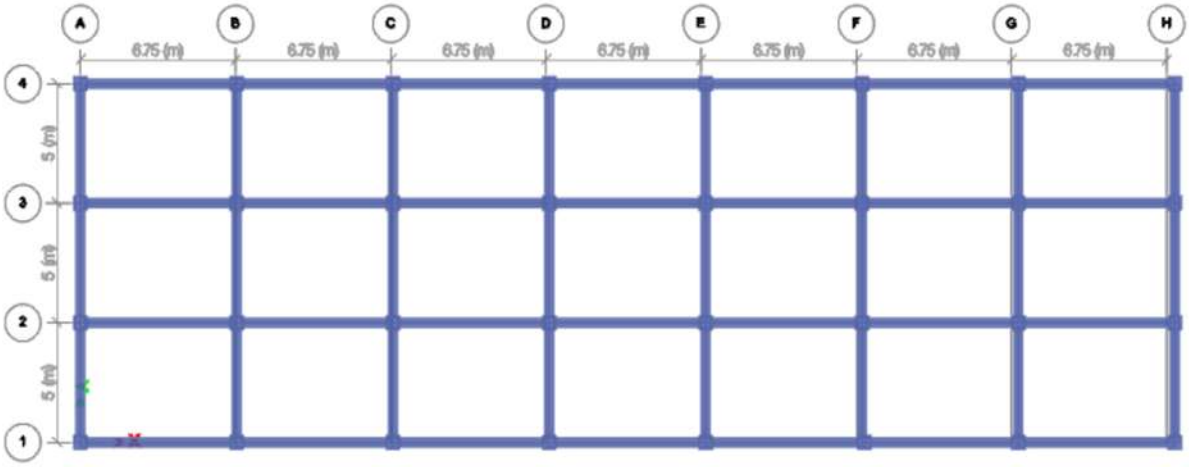

Figure 1. Structure layout.

4.1 MATERIAL PROPERTIES

The materials that were utilized for the analysis are detailed in **Table1.**

Table 1 Material properties.

Material	Property	Original Design
Concrete	Compressive strength f_c'	27.5 MPa
	Young modulus E_C	24647 MPa
	Shear Modulus G	10269.58
	Poisson's ratio	0.2
Steel	Yield Strength steel f_y	413 MPa
	Young modulus E_S	200,000 MPa

4.2DESIGN OF RC BUILDING

The RC building is designed for seismic loads. Seismic loads are calculated using equivalent lateral force by Iraqi code for seismic (303-2017). The details of beams and columns reinforcement is shown in **Fig. 2** and **Fig.3**.

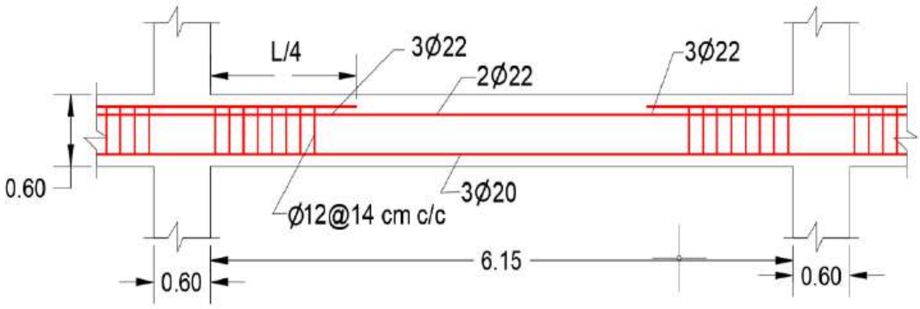

Figure 2. Details of beams reinforcement.

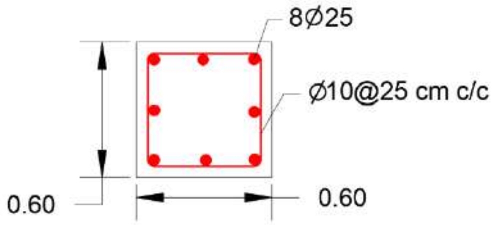

Figure 3. Details of columns reinforcement.

5.ANALYSIS OF PROGRESSIVE COLLAPSE

In the current study, the method developed by the General Services Administration (GSA) is used to evaluate the resistance of reinforced concrete framed structures to the progressive collapse of their support system. The direct design alternate path method and the use of static linear analysis are both approaches that are recommended by the GSA method. The use of the static linear approach is typically restricted to buildings with a low to medium height (Ten stories or less). ETABS 20 is utilized throughout the process of conducting the analysis.

5.1LOAD COMBINATIONS

The structure should be analyzed using the following load combinations applied to the whole structure together with an instantaneous loss of primary vertical support.

2(DL + 0.25LL) for static analysis ,

where :

DL: dead load,

LL: live load.

5.2ANALYSIS CASES

1.Instantaneous loss of a column on ground floor level located at middle of long side of building

2.Instantaneous loss of a column on ground floor level located at corner of building.

3.Instantaneous loss of a column on ground floor level located at interior of building.

6.EVALUATION OF DEMAND CAPACITY RATIOS AND ANALYSIS RESULTS

6.1REMOVAL OF COLUMN NEAR MIDDLE OF LONG SIDE (CASE 1E)

In this case the column near middle of long side has been removed, as shown in **Fig. 4** and re-analysis the structure. The maximum bending moments from first iteration of the progressive collapse analysis at grid 1 and grid D are shown in **Fig.5** it noticed that the maximum bending moment for beams that connected with the removed column It has become larger compared to the other beams of the building .

Results from the first iteration of the progressive collapse analysis are shown in Table 2 and 3. Both of these tables show maximum bending moments in the beams along grid lines 1 and D. Also shown on these tables are the DCRS, calculated by dividing the moment demands indicated in **Fig.5** by the design moment strengths.

Fig .6 and **Fig.7**show the maximum shear demands and the corresponding DCR values after the first iteration along grid lines 1 and D respectively.

Column axial load shown in **Fig.8** and **Fig.9** the columns are checked after each analysis run. All columns had DCR values well below the maximum of 2.0. For brevity, the column check is only illustrated at the end of the analysis, and not at each stage.

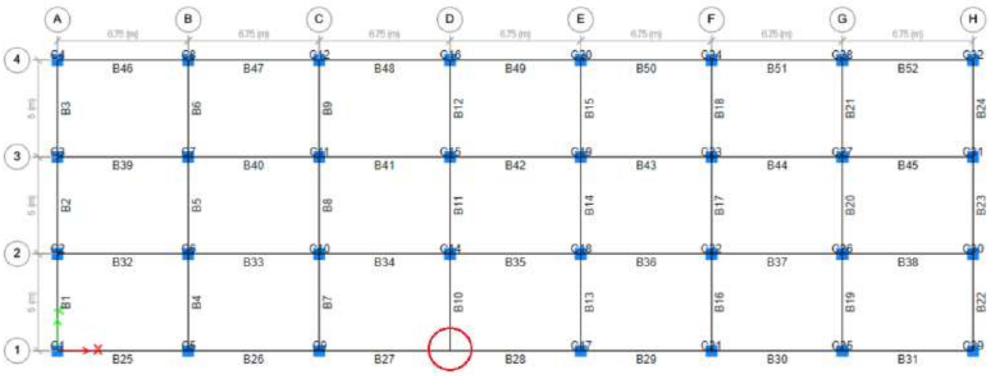

Figure 4.Removal of Column in the long side.

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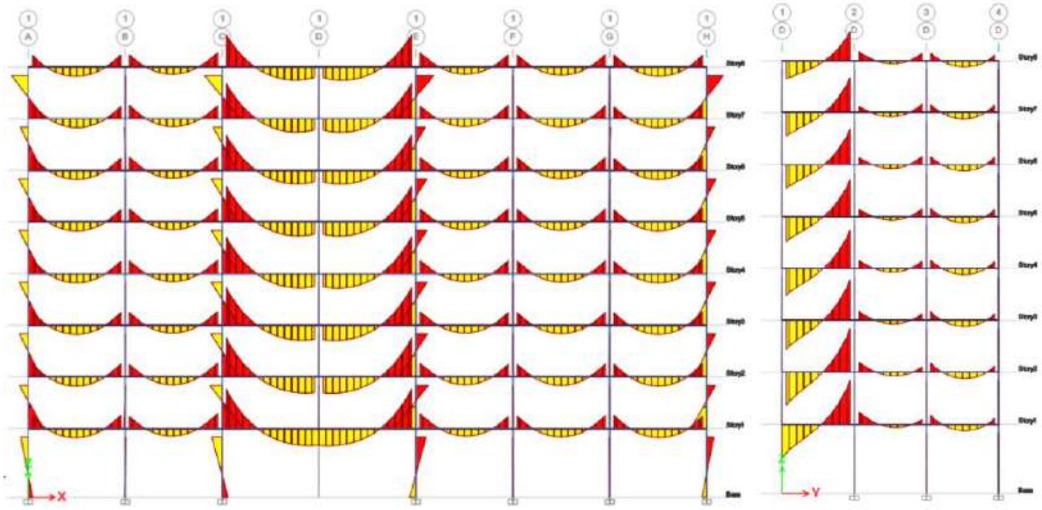

Figure 5.Beam bending moment from first iteration of analysis at elevation 1 and elevation D.

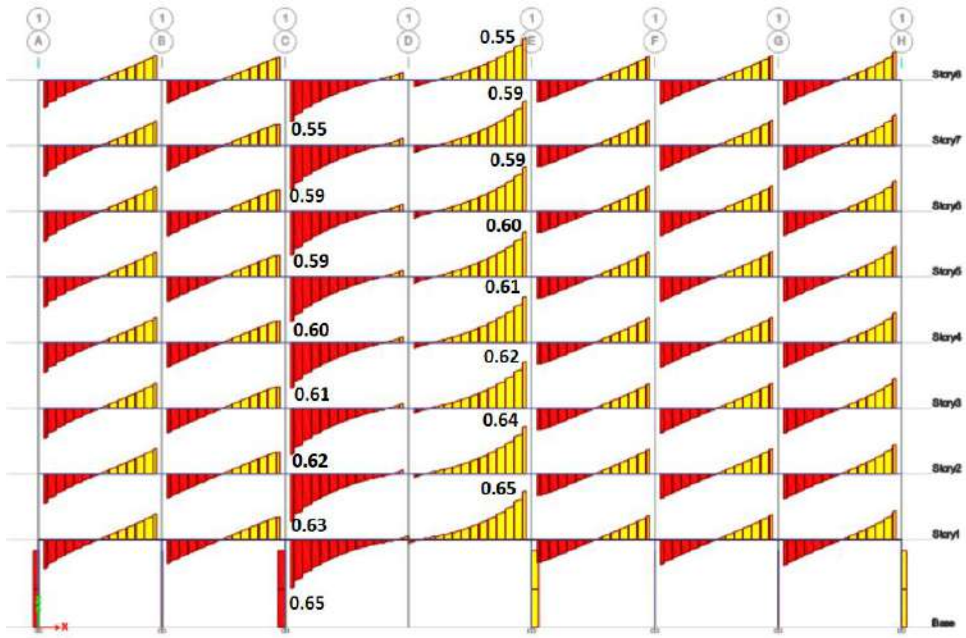

Figure 6.DCR value for beam shear at Grid Line 1.

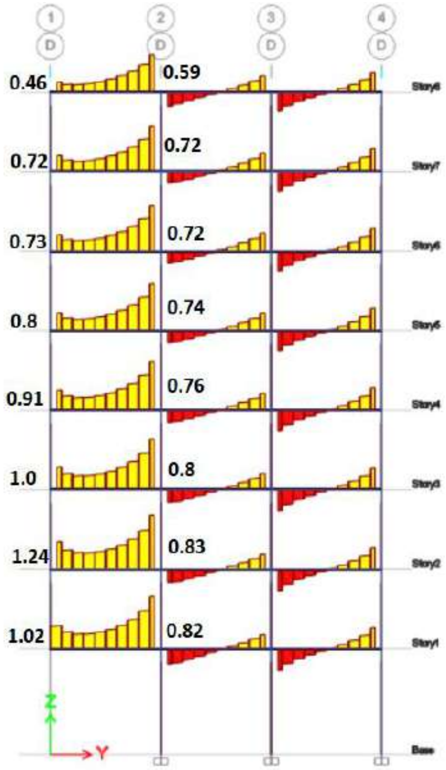

Figure 7. DCR value for beam shear at Grid Line D.

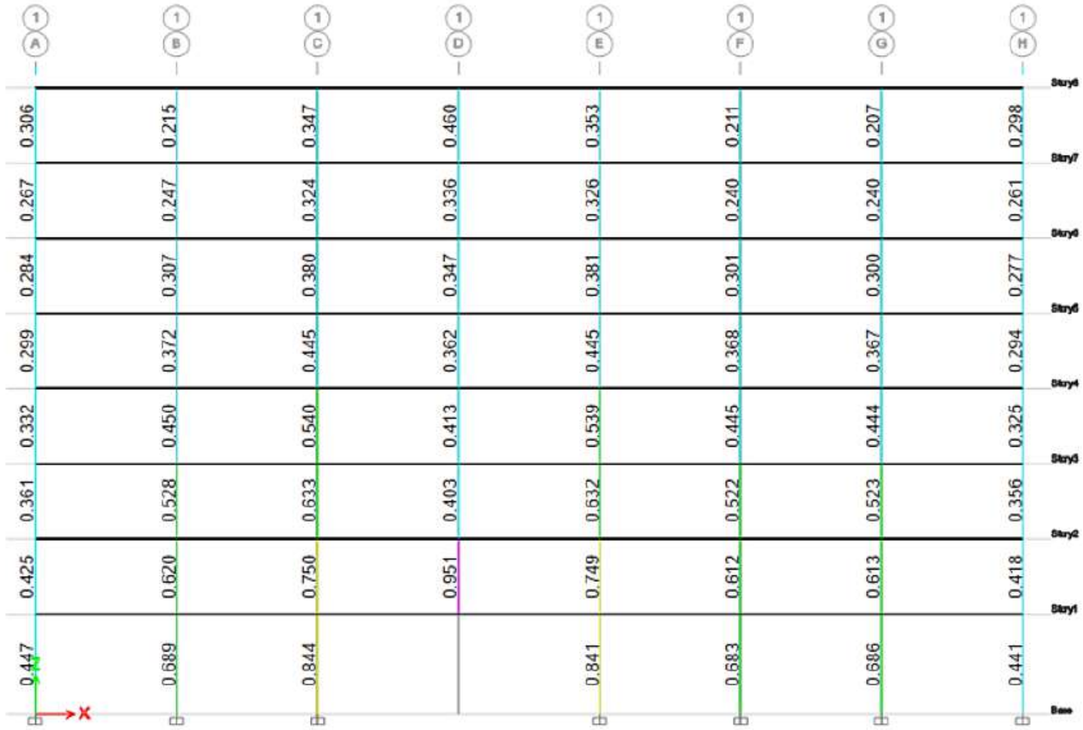

Figure 8. DCR value for Columns subjected to axial load at Grid Line 1.

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Figure 9. DCR value for Columns subjected to axial load at Grid Line D.

Table 2 Flexural DCR for Transverse Beam (Case 1E)

Story	B27 and B28 (Transverse direction Beams)								
	Ultimate Moment Capacity (kN.m)			Moment after removing column (kN.m)			Flexural DCR		
	Support 1	Span	Support 2	Support 1	Span	Support 2	Support 1	Span	Support 2
1	217.3	181.1	217.3	392.47	172.5	394.68	1.81	0.95	1.82
2	217.3	181.1	217.3	386.37	163.18	389.44	1.78	0.90	1.79
3	217.3	181.1	217.3	372.69	152.96	376.09	1.72	0.84	1.73
4	217.3	181.1	217.3	363.7	146.17	366.85	1.67	0.81	1.69
5	217.3	181.1	217.3	356.29	141.96	359.46	1.64	0.78	1.65
6	217.3	181.1	217.3	350.81	138.3	353.18	1.61	0.76	1.63
7	217.3	181.1	217.3	350.11	136.89	350.81	1.61	0.76	1.61
8	217.3	181.1	217.3	320.52	132.04	323.04	1.48	0.73	1.48

Table 3 Flexural DCR for Longitudinal Beam (Case 1E)

.	B10 (Longitudinal Direction Beam)					
	Ultimate Moment Capacity (kN.m)		Moment after removing col (kN.m)		Flexural DCR	
	Support	span	Support	span	Support	span
1	217.3	181.1	435.35	331.1	2.00	1.83
2	217.3	181.1	435.90	328.15	2.00	1.81
3	217.3	181.1	404.27	287.26	1.86	1.59
4	217.3	181.1	382.62	266.07	1.76	1.47
5	217.3	181.1	365.53	247.97	1.68	1.37
6	217.3	181.1	352.23	233.9	1.62	1.29
7	217.3	181.1	350.81	232.81	1.61	1.29
8	217.3	181.1	291.14	180.03	1.34	0.99

6.2 REMOVAL OF COLUMN AT CORNER (CASE 2E)

In this case the corner column has been removed as shown in **Fig.10** and re-analysis the structure. The maximum bending moments from first iteration of the progressive collapse analysis at grid A and grid 1 are shown in **Fig.11**.

As illustrated in **Table 4** and **Table5**, after the re-analysis DCR values for positive bending moment directly over the removed column are less than 2.0. In addition, negative bending moment at the first and second story level (at grid line 2) is 2.1 also the maximum negative bending moment DCR of 2.01 occurs at grid lines A on the third story level. Since the DCR at this location (2.01) is less than 1 % greater than 2.0, it will be assumed that the existing reinforcing steel is satisfactory. In first and second story level that exceeds the allowable DCR at this stage. **Fig.12** and **Fig.13** show the maximum shear demands and the corresponding DCR values after the first iteration along grid lines 1 and A respectively. Column axial load shown in **Fig.14** and **Fig.15** the columns are checked after each analysis run. All columns had DCR values well below the maximum of 2.0. For brevity, the column check is only illustrated at the end of the analysis.

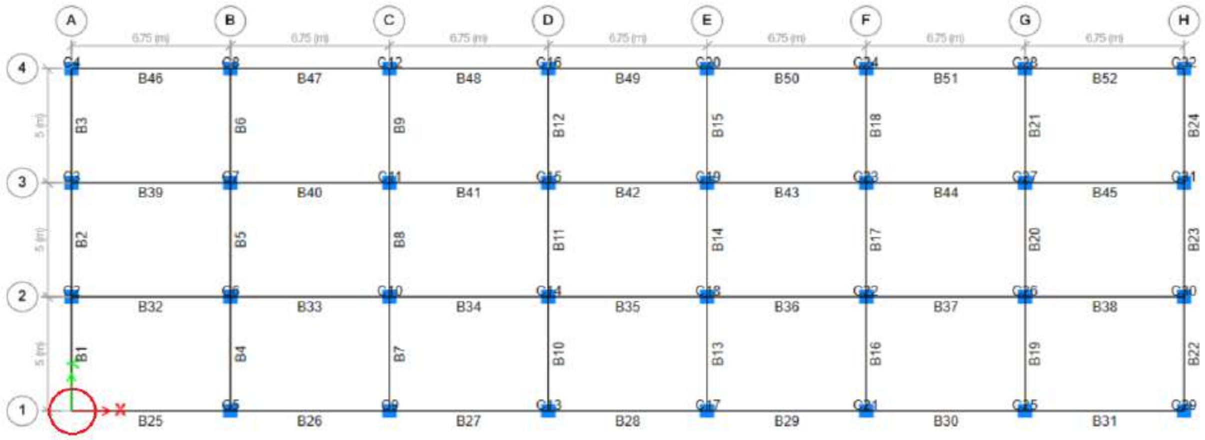

Figure 10. Removal of Column in the corner.

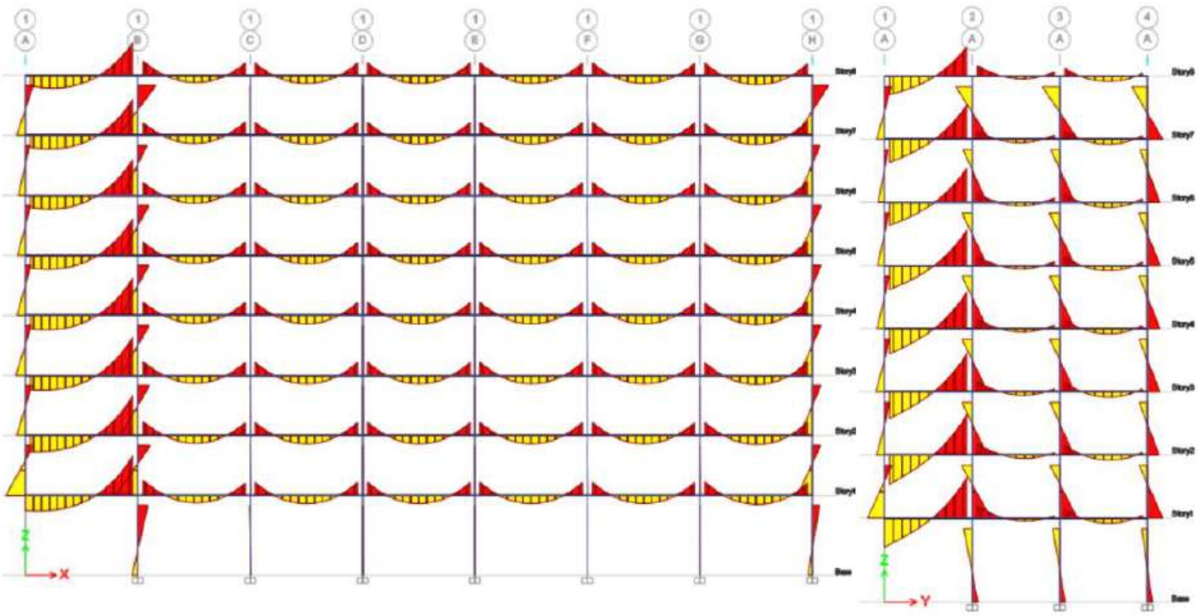

Figure 11. Beam bending moment from first iteration of analysis at Grid 1 and Grid A.

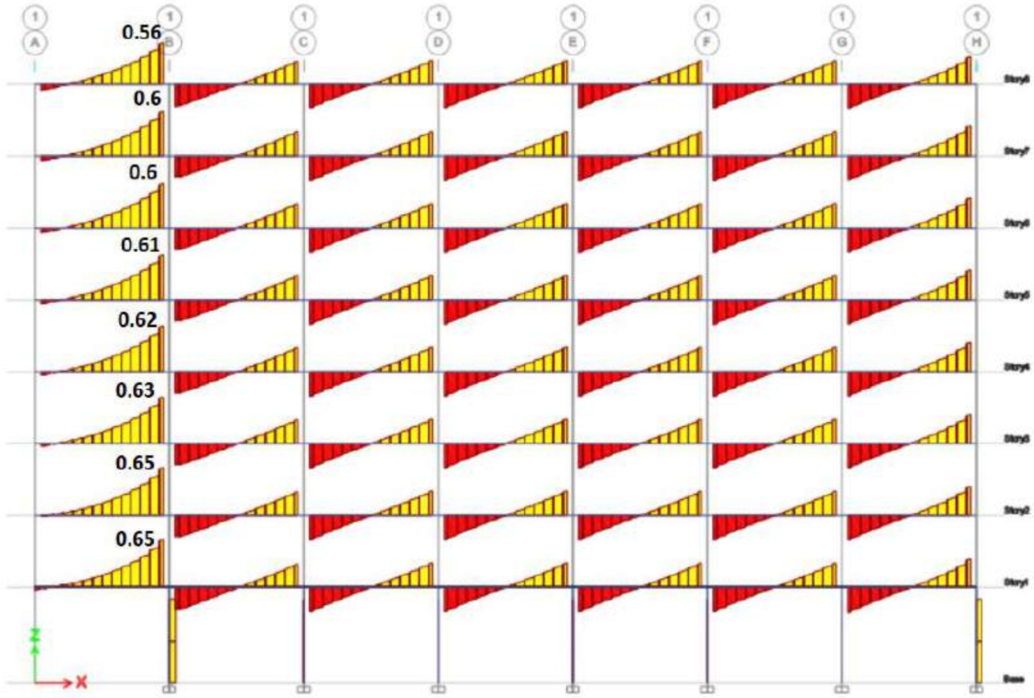

Figure 12. DCR value for beam shear at Grid line 1.

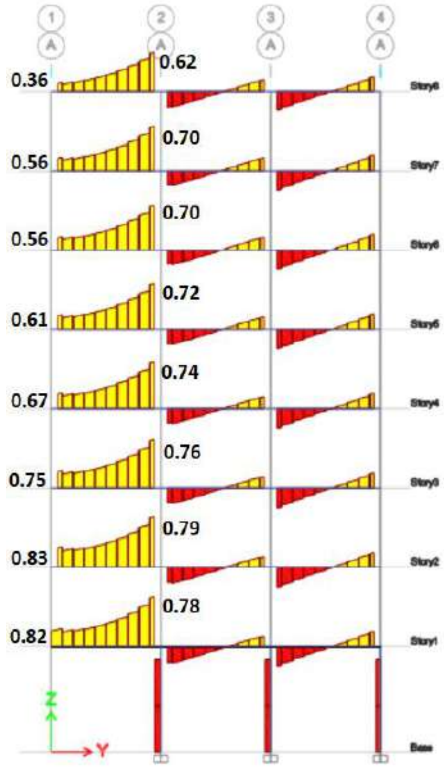

Figure 13. DCR value for beam shear at Grid line A.

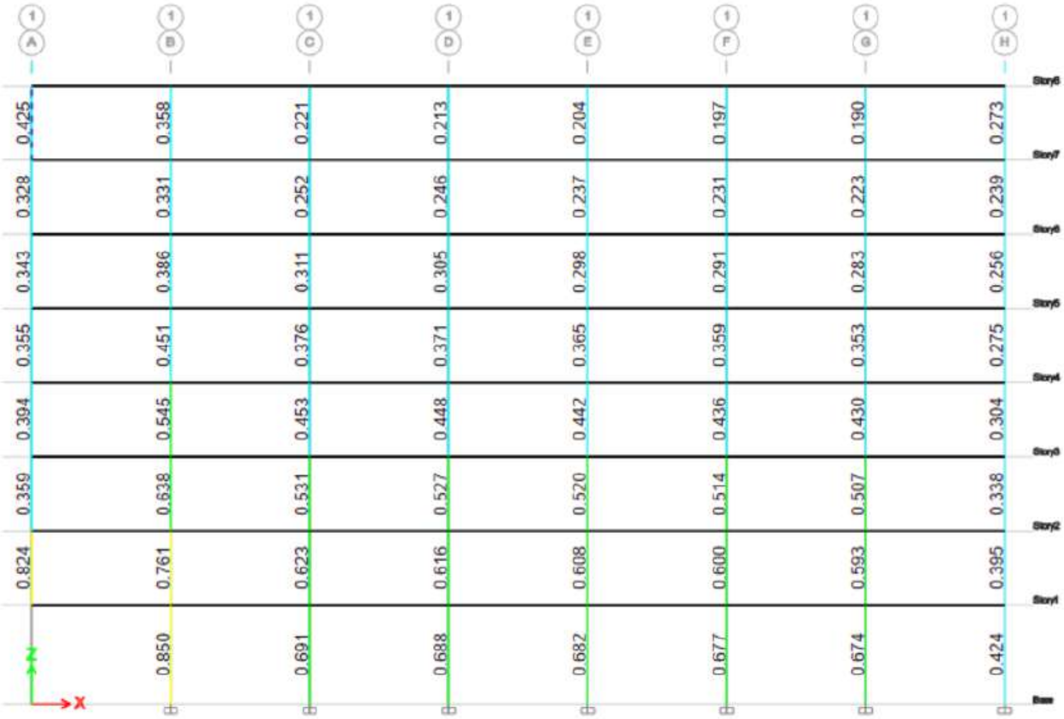

Figure 14.DCR value for Columns subjected to axial load at Grid Line 1.

Figure 15. DCR value for Columns subjected to axial load at Grid Line A.

Table 4 Flexural DCR for Longitudinal Beams (Case 2E)

Story	B1 (Longitudinal direction Beams)					
	Ultimate Moment Capacity (kN.m)		Moment after removing col (kN.m)		Flexural DCR	
	Support	span	Support	span	Support	span
1	217.3	181.1	456.33	336.02	2.1	1.86
2	217.3	181.1	456.33	339.46	2.1	1.87
3	217.3	181.1	437.71	306.01	2.01	1.69
4	217.3	181.1	420.12	289.53	1.93	1.60
5	217.3	181.1	406.2	275.32	1.87	1.52
6	217.3	181.1	394.94	263.9	1.82	1.46
7	217.3	181.1	394.5	204.17	1.82	1.13
8	217.3	181.1	339.69	212.16	1.56	1.17

Table 5 Flexural DCR for Transverse Beams (Case 2E)

Story	B25 (Transverse direction Beams)					
	Ultimate Moment Capacity (kN.m)		Moment after removing col (kN.m)		Flexural DCR	
	Support	Span	Support	Span	Support	Span
1	217.3	181.1	396.81	156.42	1.83	0.86
2	217.3	181.1	397.27	164.18	1.83	0.91
3	217.3	181.1	382.39	150.38	1.76	0.83
4	217.3	181.1	373.24	143.86	1.72	0.79
5	217.3	181.1	365.73	139.65	1.68	0.77
6	217.3	181.1	359.12	136.26	1.65	0.75
7	217.3	181.1	360.81	136.1	1.66	0.75
8	217.3	181.1	328.18	126.89	1.51	0.70

6.3 REMOVAL OF INTERIOR COLUMN (CASE I1)

In this case the interior column has been removed as shown in **Fig.16** and re-analysis the structure. The maximum bending moments from first iteration of the progressive collapse analysis at grid D and grid 2 are shown in **Fig.17.**

Results from the first iteration of the progressive collapse analysis are shown in Table 6 and 7. Both of these tables show maximum bending moments in the beams along grid lines D and 2. Also shown on these tables are the DCRS, calculated by dividing the moment demands indicated in **Fig.17** by the design moment strengths.

Fig.18 and **Fig.19** show the maximum shear demands and the corresponding DCR values after the first iteration along grid lines A and 3 respectively.

Column axial load shown in **Fig.20** and **Fig.21** the columns are checked after each analysis run. All columns had DCR values well below the maximum of 2.0. For brevity, the column check is only illustrated at the end of the analysis, and not at each stage.

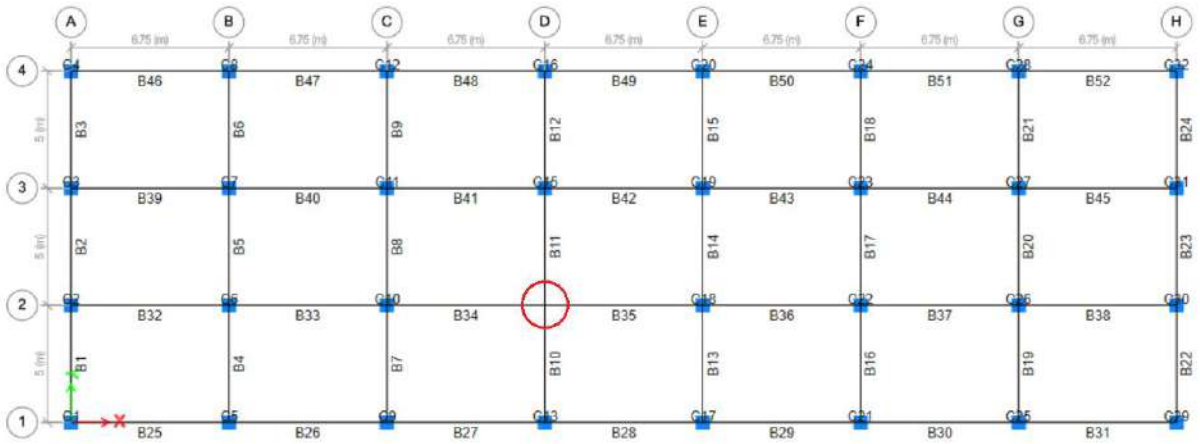

Figure 16. Removal of Column in the interior of building.

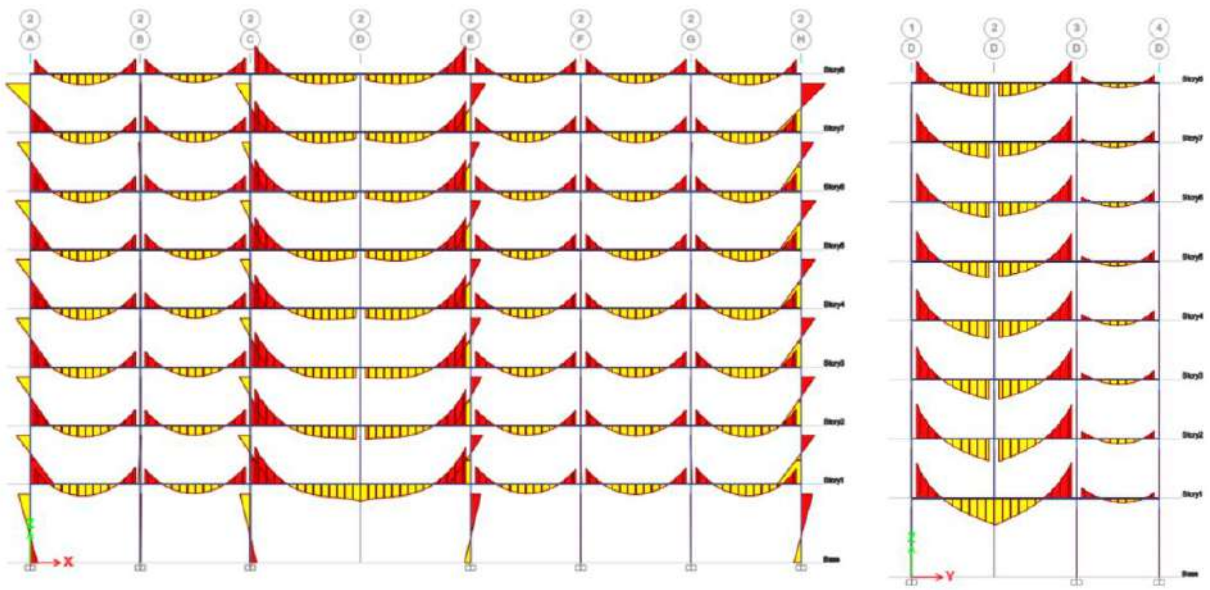

Figure 17. Beam bending moment from first iteration of analysis at Grid 2 and Grid D.

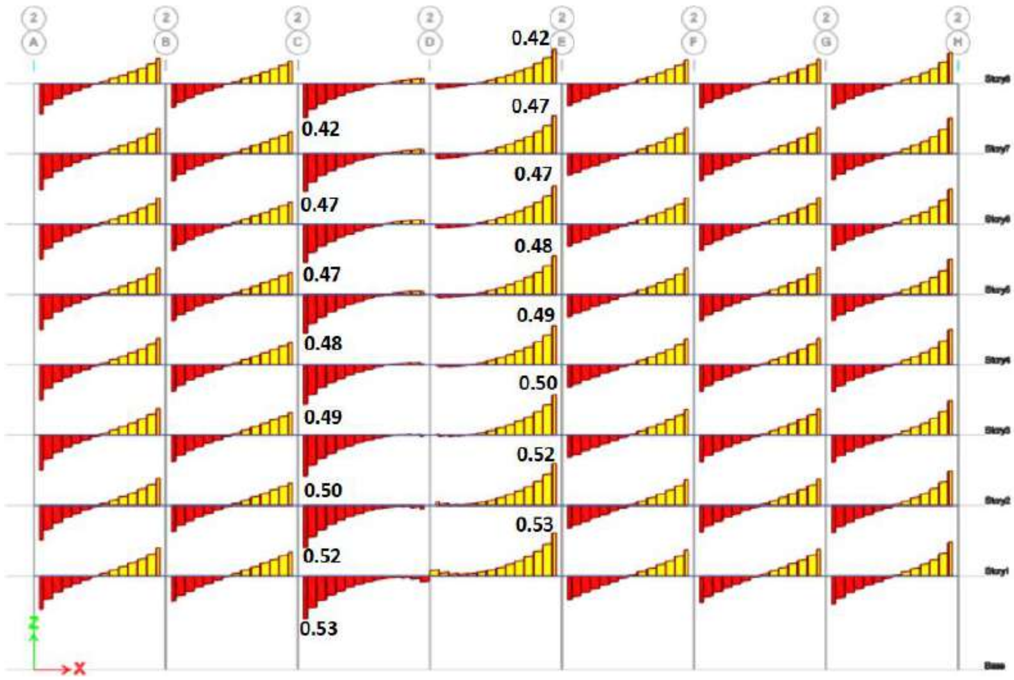

Figure 18. DCR value for beam shear at Grid Line 2.

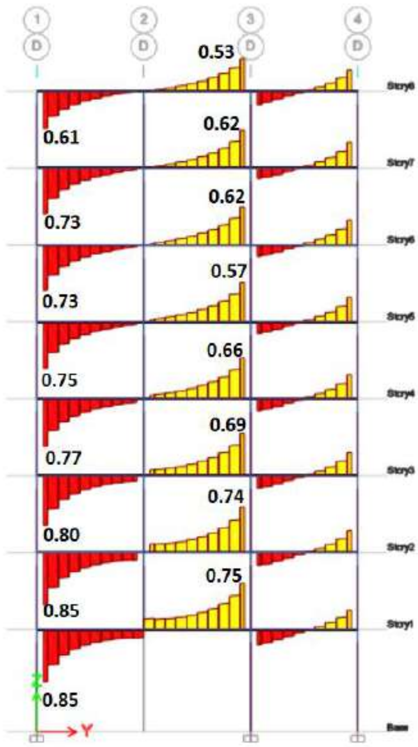

Figure 19. DCR value for beam shear at Grid Line D.

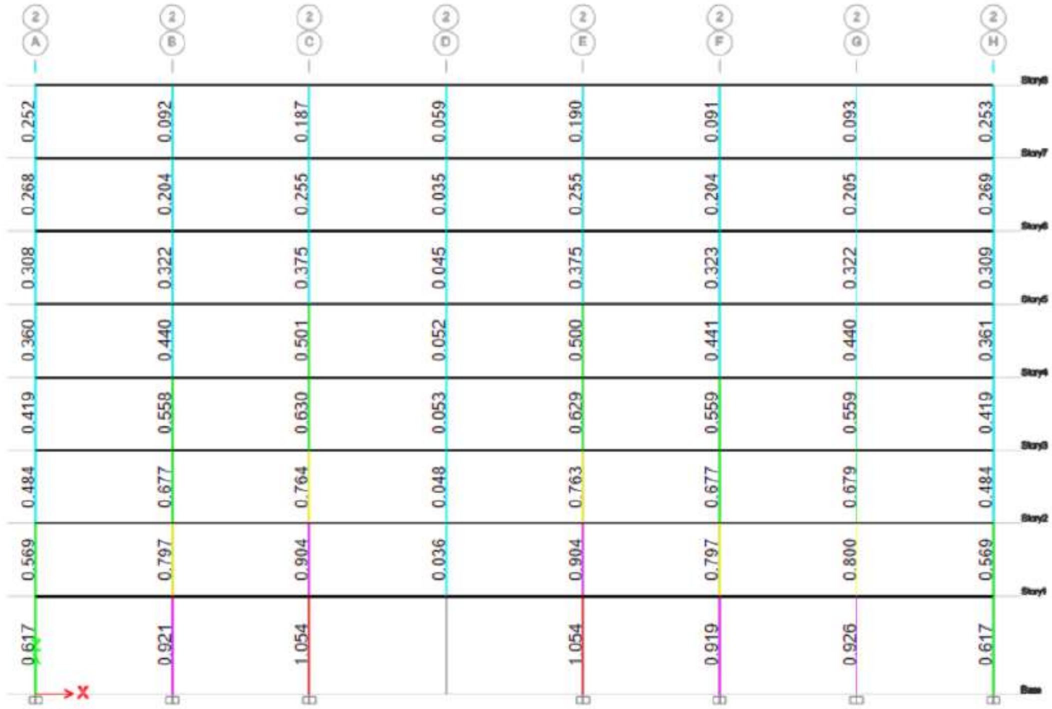

Figure 20. DCR value for Columns subjected to axial load at Grid Line 2.

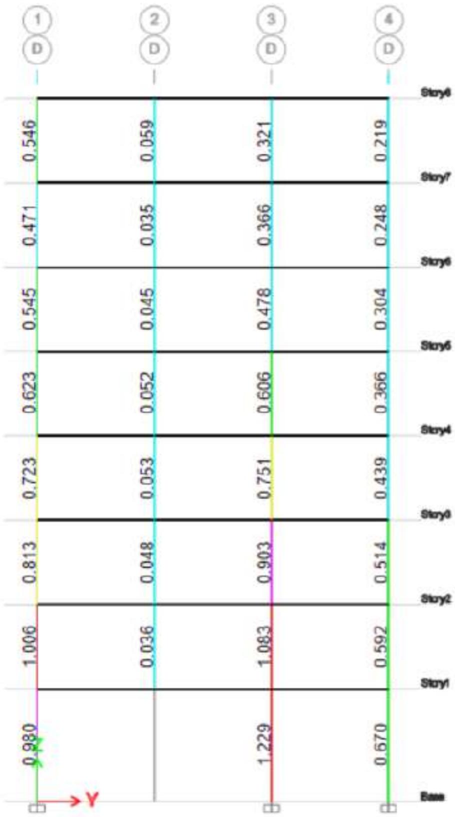

Figure 21. DCR value for Columns subjected to axial load at Grid Line D.

Table 6 Flexural DCR for Longitudinal Beams (Case 1I)

Story	B10 and B11 (Transverse direction Beams)								
	Ultimate Moment Capacity (kN.m)			Moment after removing col (kN.m)			Flexural DCR		
	Support 1	Span	Support 2	Support 1	Span	Support 2	Support 1	Span	Support 2
1	217.3	181.1	217.3	357.13	274.5	365.83	1.64	1.52	1.68
2	217.3	181.1	217.3	357.52	226.98	349.36	1.65	1.25	1.61
3	217.3	181.1	217.3	331.49	199.69	320.29	1.53	1.10	1.47
4	217.3	181.1	217.3	315.08	181.3	299.42	1.45	1.00	1.38
5	217.3	181.1	217.3	302.03	167.08	283.07	1.39	0.92	1.30
6	217.3	181.1	217.3	290.66	156.34	270.43	1.34	0.86	1.24
7	217.3	181.1	217.3	294.93	152.54	267.44	1.36	0.84	1.23
8	217.3	181.1	217.3	225.53	134.55	227.69	1.04	0.74	1.04

Table 7 Flexural DCR for Transverse Beams (Case 1I)

Story	B34 and B35 (Transverse direction Beams)								
	Ultimate Moment Capacity (kN.m)			Moment after removing col (kN.m)			Flexural DCR		
	Support 1	Span	Support 2	Support 1	Span	Support 2	Support 1	Span	Support 2
1	217.3	181.1	217.3	286.84	129.56	286.94	1.32	0.72	1.32
2	217.3	181.1	217.3	278.05	103.49	278.1	1.28	0.57	1.28
3	217.3	181.1	217.3	264.8	87.85	264.77	1.22	0.49	1.22
4	217.3	181.1	217.3	255.01	84.8	255.02	1.17	0.47	1.17
5	217.3	181.1	217.3	247.35	80.03	247.38	1.14	0.44	1.14
6	217.3	181.1	217.3	241.51	82.25	241.47	1.11	0.45	1.11
7	217.3	181.1	217.3	239.68	81.33	239.85	1.10	0.45	1.10
8	217.3	181.1	217.3	215.41	78.86	215.89	0.99	0.44	0.99

7.CONCLUSIONS

1-In case 1E (the column near the middle of the long side has been removed), the maximum axial DCR value in columns was 1.298 (on the ground floor), while maximum flexural DCR in transverse beams (near the support) was 1.81, and in longitudinal beams near the support for flexural mode was 2.0.

2- In case 2E (the corner column has been removed), the maximum axial DCR value in columns was 0.934 (on the ground floor), while maximum flexural DCR in transverse beams (near the support) was 1.83, and in longitudinal beams (near the support) was 2.1.

3- In case 1I (the interior column has been removed), the maximum axial DCR value in columns was 1.229 (on the ground floor), while maximum flexural DCR in transverse beams (near the support) was 1.32, and in longitudinal beams (near the support) was 1.68.

4-Removing one of three critical columns on the ground floor according to analysis results in a 2(DL+0.25LL) load combination did not lead to progressive collapse, but case 2E was the nearest for progressive collapse. The DCR value was ≥(2.0).

5- In the example of the current study, the DCR value of progressive collapse for shear occurs when the removal one of three critical columns on the ground floor according to analysis results in a 2(DL+0.25LL) load combination was small and didn't exceed (2.0). That is because the beam section dimensions were large and the stirrups spacing was small. Enhance the shear capacity in the detailing stage for corner bays; avoid the collapse in the shear mode for corner column removal.

6- Increase the beam sizes only in first; second and third floor stories up to 100% area of concrete and keeping other floor beams without changing size also prevent the progressive collapse propagation.

REFERNCES

1- Vlassis, A. G., Izzuddin, B. A., Elghazouli, A. Y., &Nethercot, D. A. (2008). Progressive collapse of multi-storey buildings due to sudden column loss—Part II: Application. *Engineering Structures*, *30*(5), 1424-1438.
2- Adam, J. M., Parisi, F., Sagaseta, J., & Lu, X. (2018). Research and practice on progressive collapse and robustness of building structures in the 21st century. *Engineering Structures*, *173*, 122-149.
3- Feng, D. C., Xie, S. C., Xu, J., &Qian, K. (2020). Robustness quantification of reinforced concrete structures subjected to progressive collapse via the probability density evolution method. Engineering Structures, 202, 109877.
4- Kiakojouri, F., Sheidaii, M. R., De Biagi, V., &Chiaia, B. (2021, February). Progressive collapse of structures: A discussion on annotated nomenclature. In *Structures* (Vol. 29, pp. 1417-1423). Elsevier.
5- Naghshbandi, R. (2015). Mitigation Methods of Progressive Collapse for a 10-storey Reinforced Concrete Structure (Doctoral dissertation, UniversitiTeknologi Malaysia).
6- Adam, J. M., Parisi, F., Sagaseta, J., & Lu, X. (2018). Research and practice on progressive collapse and robustness of building structures in the 21st century. *Engineering Structures*, *173*, 122-149.

7- GSA, 2003, "Progressive collapse analysis and design guidelines for new federal office buildings and major modernization projects", U.S. General Services Administration USGSA, Washington, D.C.

8- ASCE-07, 2005, Minimum Design Loads for Buildings and Other Structures. American Society of Civil Engineers, ASCE 7-05, Reston, VA, USA.

9- ACI 318-14,"Building Code Requirements for Structural Concrete and Commentary", American Concrete Institute, 2014.

10- Ministry of Construction and Housing-Central Organization for Standarazation and Quality Control. (2017) "Seismic Code - Iraqi Building Code 303," Ministry of Construction and Housing-Federal Government, Baghdad. 2017.

11- Computers and Structures Inc. (2020), ETABS Integrated Building Design Software. Berkeley, California, USA

12- "Iraqi Standards IQ.301 (2015), Iraqi Code for Forces and Loadings, Iraqi Ministry of Building and Construction, Baghdad, Iraq. (DRAFT)."