International Journal of Advance Research in Science and Engineering
Volume No. 11, Issue No. 01, January 2022
www.ijarse.com
IJARSE
ISSN 2319 - 8354

Progressive Collapse Analysis of High Rise Building Using Linear Static Procedure

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ABSTRACT

The various loads that a structure is subjected due to unforeseen events cause it to lose its robustness. A greater insight into the lack of robustness in a structure is gained through the vulnerability of a structure to disproportionate collapse. Although the topic of Disproportionate Collapse gained importance ever since the Ronan Point Apartment incident (1968), the methods of Alternate Load Paths and Segmentation still appear to be a challenge for the designer. Although Indirect Methods of analysis include the provisions from various international standards like the DoD, ACI, GSA and ASCE, not much provisions are made in the Indian Standards for the consideration of Disproportionate Collapse. Thus, direct methods of analysis are to be employed. This project aims at studying the behaviour of a structure under disproportionate collapse. Out of the various methods of analysis available for disproportionate collapse, the Linear Static method of analysis by creating an Alternate Load Path by the method of Notional Element Removal is employed in this study. 10, 15 and 20 story building frames are modeled in ETABS and the availability of alternate load paths after the removal of critical columns is checked and the sections are revised so as to make sure the frame bridges the transfer of vertical forces despite the loss of column.

Keywords *- Alternate Load Path, Disproportionate Collapse, Robustness, Linear static, Notional element Removal.*

1. INTRODUCTION

On the morning of May 16, 1968, a minor gas explosion blew out the exterior walls of apartment of the Ronan Point apartment tower (Figure 1). This triggered a progression of failures, resulting in the collapse of the southeast corner of the tower. This collapse revived the intellectual debate on structural collapse, and spurred a significant amount of research into disproportionate collapse and robustness of structures. As a result of this event, and the consequent report of the Commission of inquiry, a number of countries implemented provisions to minimize the potential for disproportionate collapse. Following the terrorist attacks on the Murrah Federal Office Building, in 1995, and the World Trade Centre, in 2001, interest in this subject appears to have reached a peak. These events have highlighted the increased threat of terrorism worldwide and the need to consider hazards (explosions or detonations) that may not have been viewed as significant in the past.

A disproportionate collapse is one which is judged (by some measure defined by the observer) to be

International Journal of Advance Research in Science and Engineering
Volume No. 11, Issue No. 01, January 2022
www.ijarse.com
IJARSE
ISSN 2319 - 8354

disproportionate to the initial cause. This is merely a judgment made on observations of the consequences of the damage which results from the initiating events and does not describe the characteristics of the structural behaviour. A collapse maybe progressive in nature but not necessarily disproportionate in its extents, for example if arrested after it progresses through a number of structural bays. Vice versa, a collapse may be disproportionate but not necessarily progressive, for example, the collapse is limited in its extents to a single structural bay but the structural bays are large.

Progressive Collapse is generally acknowledged to be an undesirable form of failure, to be avoided at all cost. For the past several decades, prevention of progressive collapse has been one of the unchallenged demands in structural engineering. But, in fact, virtually all collapses could be regarded as progressive in one way or another; a building's

Fig. 1 Ronan Point Building after Collapse

susceptibility to progressive collapse should be of particular concern only if the collapse is also disproportionate. Indeed, the engineering imperative should be not the prevention of progressive collapse but the prevention of disproportionate collapse (be it progressive or not). The terms progressive collapse and disproportionate collapse have been used interchangeably in this thesis, both referring to a progressive collapse that might also turn out to be disproportionate.

2. PROGRESSIVE COLLAPSE

Progressive collapse can be defined as collapse of all or a large part of a structure precipitated by failure or damage of a relatively small part of it. The General Services Administration (GSA, 2003) offers a somewhat more specific description of the phenomenon: "Progressive collapse is a situation where local failure of a primary structural component leads to the collapse of adjoining members which, in turn, leads to additional collapse."

Local failure is always caused by an accidental action. An accidental action can be expressed as a design situation involving exceptional conditions of the structure or its exposure to explosion, impact or local

International Journal of Advance Research in Science and Engineering
Volume No. 11, Issue No. 01, January 2022
www.ijarse.com
IJARSE
ISSN 2319 - 8354

failure. Examples of accidental actions are gas explosions, vehicle impact or bomb attacks, but can also be the result of design and construction errors. In case of an accidental action, the sudden unexpected load is typically concentrated on one or two key elements in a structure. Hereby it is possible that a structural element has its load pattern or boundary conditions changed such that it will be loaded beyond its static or dynamic capacity. Because of these changes, progressive collapse can occur.

2.1 Methods of preventing Disproportionate Collapse

The design of structures made with the consideration of Progressive Collapse includes various structural and non- structural aspects. The various methods of design adopted for progressive collapse are dealt in detail in the upcoming chapters. There are, in general, three alternative approaches for designing structures to reduce their susceptibility to disproportionate collapse:

a) Redundancy or alternate load paths

b) Local resistance

c) Interconnection or continuity

This thesis considers one of the various methods of design available for progressive collapse – the Alternate Load Path Method by Linear Static Analysis, which is based on increasing the redundancy of the structure.

3. CODES AVAILABLE FOR PROGRESSIVE COLLAPSE

There are currently four primary United States codes addressing progressive collapse in the design of buildings and as for the United Kingdom, two. The various codes to progressive collapse resistance are mentioned below

a) ASCE 7 “Minimum Design Loads for Buildings and Other Structures” (2002)
b) ACI “Building Code Requirements for Reinforced Concrete” (2005)
c) General Service Administration (GSA) “Progressive Collapse Analysis and Design Guidelines” (2003)
d) Unified Facilities Criteria (UFC 4-023-03) “Design of Buildings to Resist Progressive Collapse” (2005)
e) Eurocode 1 - Actions on structures - Part 1-7: General actions – Accidental actions (2006)
f) The UK Building Regulation (2010)

4. LINEAR STATIC ANALYSIS

The simplest form of the notional element removal method involves performing a linear static analysis on the damaged structure. This involves applying the fully factored gravity loads to the damaged structure in a single step. Dynamic effects can be indirectly considered by assuming an equivalent static load based on a constant amplification factor, typically taken equal to 2.0 (GSA 2003, DoD 2009). The response of a structure to redistributed loads following the sudden loss of a critical load-carrying member is dynamic and nonlinear. However, as in seismic design, one simple approach is to use an equivalent static elastic analysis if buildings have relatively simple layouts and do not fall in the following categories:

a) Buildings that utilize a combination of frames and walls in the structural systems,

b) Buildings with vertical discontinuities in columns and walls, which utilize transfer girders,

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www.ijarse.com
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c) Buildings that have a large variance in structural bay size,

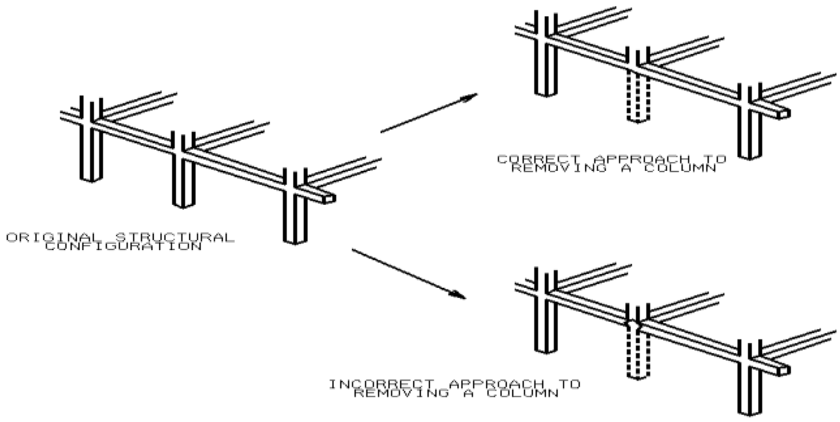
d) Buildings that have plan irregularities, and

e) Buildings that have closely spaced columns, which can lead to uncertainty in the application of a simplified analysis.

4.1 Linear Static Analysis Procedure

According to the UFC 4-023-03, the method of analysis adopted in this study is the linear static analysis. This method follows the general LRFD philosophy by employing a modified version of the ASCE 7 load factor combination for extraordinary events and resistance factors to define design strengths. Three analysis procedures are employed: Linear Static (LSP), Nonlinear Static (NSP) and Nonlinear Dynamic (NDP). These procedures follow the general approach in ASCE 41 with modifications to accommodate the particular issues associated with progressive collapse.

For both external and internal column removal, for the purposes of AP analysis, beam-to-beam continuity is assumed to be maintained across a removed column as shown in Fig. 2.



Fig, 2 Removal of Column from Alternate Path Model (UFC 4-023-03)

4.2 Location of Column Removal

As a minimum, remove external columns near the middle of the short side, near the middle of the long side, and at the corner of the building. Also remove columns at locations where the plan geometry of the structure changes significantly, such as abrupt decrease in bay size or re-entrant corners, or, at locations where adjacent columns are lightly loaded, the bays have different tributary sizes, and members frame in at different orientations or elevations. Engineering judgment is to be used to identify these critical column locations. If any other column is within a distance of 30% of the largest dimension of the associated bay from the column removal location, it must be removed simultaneously.

For each plan location defined for element removal, perform AP analyses for:

a) First story above grade

b) Story directly below roof

c) Story at mid-height

d) Story above the location of a column splice or change in column size

For example, if a corner column is specified as the removed element location in a ten story

International Journal of Advance Research in Science and Engineering
Volume No. 11, Issue No. 01, January 2022
www.ijarse.com
IJARSE
ISSN 2319 - 8354

building with a column splice at the third story, one AP analysis is performed for removal of the ground story corner column; another AP analysis is performed for the removal of the corner column at the tenth story; another AP analysis is performed for the fifth story corner column (mid-height story) and one AP analysis is performed for the fourth story corner column (story above the column splice). The location of external column removal as suggested by UFC is given in Fig.3.

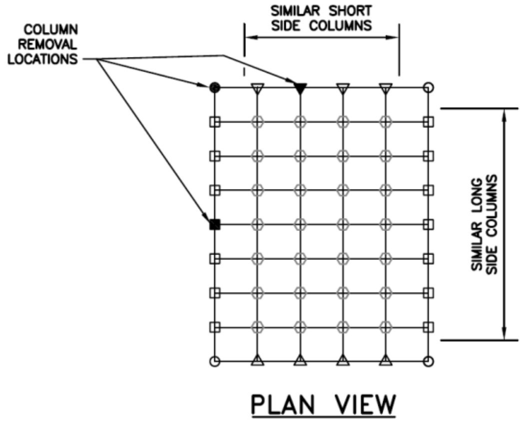


Fig. 3 Locations of External Column Removal (UFC 4-023-03)

If any other column is within a distance of 30% of the largest dimension of the associated bay from the column removal location, it must be simultaneously removed as well. The locations of internal column removal as suggested by UFC is shown in Fig. 4.

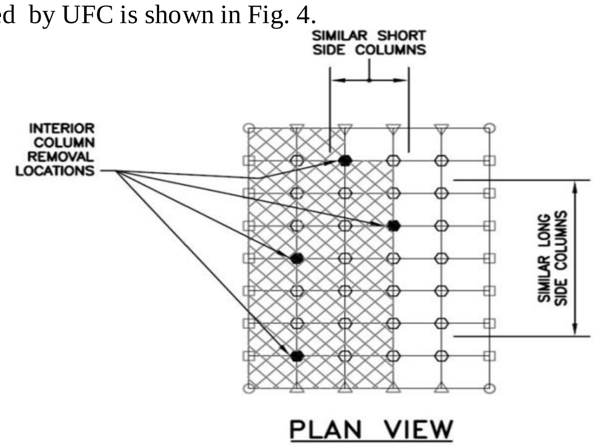


Fig. 4 Location of Internal Column Removal (UFC 4-023-03)

The use of the LSP is limited to structures that meet the following requirements for irregularities and Demand- Capacity Ratios (DCRs). If there are no structural irregularities as defined below in Section 4.3.2, a linear static procedure may be performed and it is not necessary to calculate the DCRs. If the structure is irregular, a linear static procedure may be performed if all of the component DCRs determined are less than or equal to 2.0. If the structure is irregular and one or more of the DCRs exceed 2.0, then a linear static procedure cannot be used.

4.4 Load case for Force-Controlled actions

To calculate the force-controlled actions, simultaneously the following combination of gravity loads are applied

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a. 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.

GLF = ΩLF [1.2 DL + (0.5 LL or 0.2 S)]

b. Gravity Loads for Floor Areas Away From Removed Column or Wall:

Apply the following gravity load combination to those bays not loaded with GLD

GLF = 1.2 DL + (0.5 LL or 0.2 S)

where GLF = Increased gravity loads for force-controlled actions for Linear Static analysis

G = Gravity Loads

DL = Dead load including facade loads (lb/ft^2 or kN/m^2)

LL = Live load including live load reduction (lb/ft^2 or kN/m^2)

S = Snow load (lb/ft^2 or kN/m^2)

ΩLF = Load increase factor for calculating force- controlled actions for Linear Static analysis; For an RC Framed Structure, ΩLF is given as 2.0 as per UFC

5. METHODOLOGY

Building frames of a regular plan were modeled for 10, 15, and 20 storeys in ETABS. The models were made for conventional analysis case and for notional element removal.

Assumptions

a) The material of concrete is assumed to be homogeneous and linearly elastic.

b) The buildings are assumed to be fixed at base.

c) Member sizes are carried out based on the worst combination of loads.

d) Structures are analyzed under linear, equivalent static analysis for gravity loads.

e) Strong column – weak beam concept of design is considered; i.e., failure of the beam is permitted and failure of column is prohibited.

f) The governing criteria of design is strength and not serviceability.

g) Deflections, drifts and other structural responses of the frames are not considered.

h) Force-controlled load combinations are used for design and deformation-controlled load combinations are ignored.

i) Dynamic effects in design are indirectly incorporated by means of a load increase factor suggested as 2.0 as per the American Guidelines for RC Frames.

j) Clear length of columns available between two beams are removed.

k) Only a regular building plan is considered. The building possesses no irregularities specified in Section 4.3.2.

5.1Description of the building

Reinforced concrete building frames are considered in this parametric study. These frames are modeled for three different elevations – 30m, 45m and 60m above the grade with 10, 15 and 20 storeys respectively. The

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Volume No. 11, Issue No. 01, January 2022
www.ijarse.com
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building plan is symmetric about both the axes. The frames are made up of bays of constant span of 5m along the transverse direction and alternating 6m and 5m spans in the longitudinal direction. The building plan is shown in Fig. 5

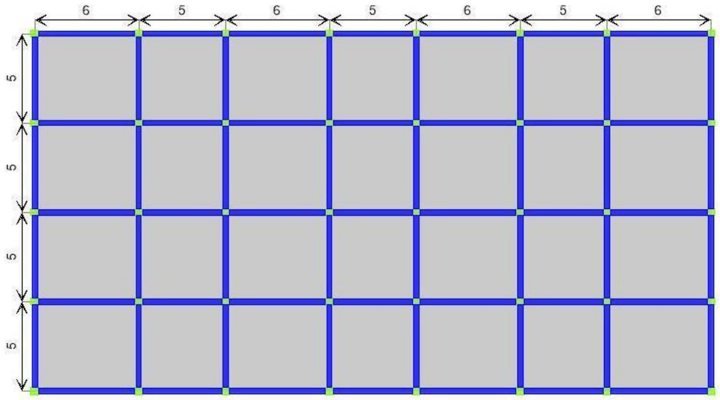

Fig. 5 Beam Column Layout

5.2 Locations of Column Removal

Columns for notional element removal were removed from the various locations specified by the UFC. They are –

a) Corner b) Middle of Long Side c) Middle of Short Side d) Interior Middle
e) Interior Columns near the Edge

The analysis is then performed for four different storey locations –

a) First story above grade b) Story directly below roof c) Story at mid-height
d) Story above the location of a column splice or change in column size

Thus the various exterior and interior columns chosen for removal are shown in Figures 6 and 7. These columns are removed from the various storey levels separately and separate analysis is carried out for each of the models. These cases used in this study were indicated as GF for first story above grade case, ROOF for story directly below the roof, MID for story at mid height.

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www.ijarse.com
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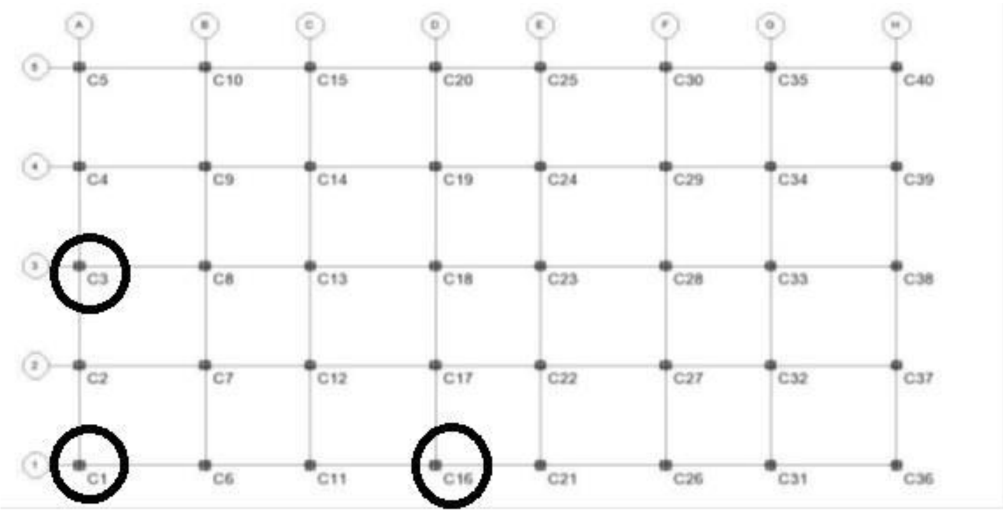

Fig. 6 Locations of Exterior Columns Removed

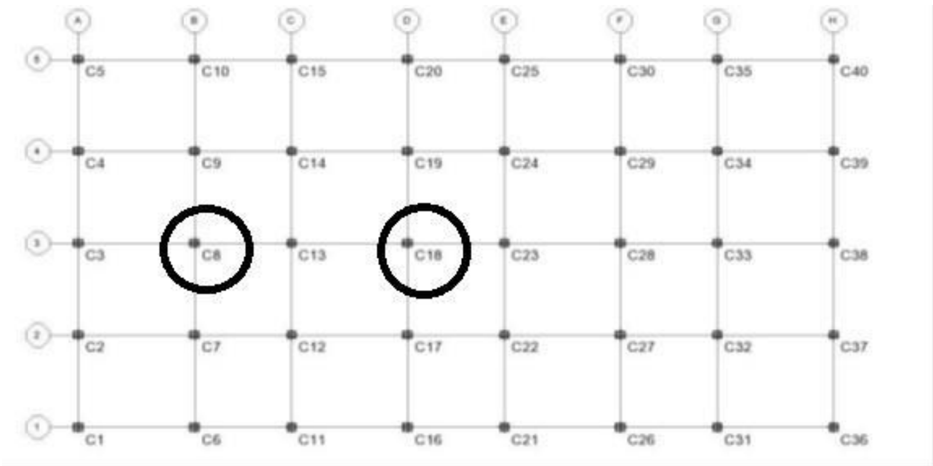

Fig. 7 Locations of Interior Columns Removed

5.3. Loading details

The loadings are same for all floors other than roof. The dead load, live load and super imposed dead loads are considered as per IS 875 part 1 & 2. The super imposed dead load (SIDL) includes false ceiling, services and partition loads. The wall loads are provided on the periphery of the building. The live load and super imposed dead loads are assigned to solid slab along the negative global direction. The live load, SIDL and wall loads are taken as 3 kN/m^2, 2.3 kN/m^2 and 13.8 kN/m for the typical floors and 1.5 kN/m^2, 1.8 kN/m^2 and 4.6 kN/m for the roof respectively.

5.4 Load combinations

The load combinations suggested by the UFC is given in Section 4.3.3. This combination is the base combination for Gravity Loads as per the ASCE 7. Furthermore, it could be observed that the load combination has been considered with Live Load Reduction. Adapting all these into the Indian Context, the base load combination with gravity loads with and without live load reduction was considered and the design was made for the worst case. The Live Load Reduction as suggested by IS 875 Part 2 was taken into account and the following

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cases were considered –

1. Full Live Load Combination - 1.5 DL+1.5 LL for all storey cases
2. Reduced Live Load Combination - 1.5 DL+0.9 LL for 10 storey
   1.5 DL+0.75 LL for 15 and 20 storeys

5.5. D e s i g n parameters

The models were designed for concrete grade M40 and Fe 415 steel. The columns were designed with steel percentage within 4% to avoid congestion of reinforcement and the steel in beams were restricted to 2%. Revised sections for the various cases also used the same grades of materials. Higher story frames like 20 storey models used M50 concrete in the lower few storeys. Also, a Double angle – Bracing System was adopted in the all storey models above the removed column. The braces were modelled with ISA 200
Sections.

6. RESULTS AND DISCUSSIONS

This chapter presents the tables, graphs and various results obtained from the analysis and design of the different cases of building frames. The influence of one column removal over its adjacent columns, increase in axial forces and the Rebar Ratio were determined.

6.1 Influence of removed column on adjacent columns

On analyzing the models with column removal at various locations, the columns adjacent to the removed column showed increased loads and Rebar Ratio. In this phase, the Corner column (C1) has been removed and the axial force and the rebar ratio had been calculated in the adjacent columns of C1. The columns adjacent to the corner column can be seen in Figure 6 – Column C2, C6 for Corner column whose axial force and rebar ratio has been calculated. A Double angle Bracing has been provided above the removed column and the structure is analyzed again and the axial force and the Rebar ratio were determined.

6.2 Axial Forces

The increase in axial forces for the columns adjacent to the removed columns was determined from the analysis data obtained. The values of the percentage of increase in axial forces due to one column removal from the various locations and at various storey levels for each of the building frames are tabulated in the following Tables. Tables I to III shows the increase in axial forces of the corner column removal cases and increase in axial force after the provision of Bracing for a
10, 15, 20 storey building frame for the load Combinations.
The values of increase percentage of axial forces for 10 storey building frames for the corner cases of column removal are shown below in Table 1.

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TABLE 1. Percentage variation in Axial Force of 10 Storey Corner Column Removal Case

STOREY	COLUMN	WITHOUT BRACING - % INCREASE IN AXIAL FORCE			BRACING - % INCREASE IN AXIAL FORCE		
		GF	MID	ROOF	GF	MID	ROOF
STOREY 1	C2	29	17	2	3	2	2
STOREY 2	C2	28	19	2	2	3	3
STOREY 3	C2	27	22	2	16	3	3
STOREY 4	C2	26	25	3	15	3	4
STOREY 5	C2	25	30	4	15	4	5
STOREY 6	C2	24	30	5	14	1.5	7
STOREY 7	C2	24	29	7	14	18	10
STOREY 8	C2	24	29	11	14	18	15
STOREY 9	C2	24	29	18	14	19	25
STOREY 10	C2	26	31	36	15	20	53
STOREY 1	C6	22	13	1	2	1	2
STOREY 2	C6	21	14	1	4	1	3
STOREY 3	C6	20	16	2	12	1	3
STOREY 4	C6	19	19	2	12	1	4
STOREY 5	C6	19	22	3	12	1	5
STOREY 6	C6	18	22	4	11	5	7
STOREY 7	C6	18	22	6	11	15	9
STOREY 8	C6	18	22	8	11	15	13
STOREY 9	C6	18	22	14	11	15	23
STOREY 10	C6	20	24	29	12	17	50

From the tables and chart, it can be observed that the column removed from the ground floor showed its influence on the columns upto mid height only. The variations in the increase of axial forces and on provision of double angle bracing over the removed column showed increase in axial force at the different floors for 10 storey corner column removal.

The values of increase percentage of axial forces for 15 storey building frames for the corner cases of column removal are shown below in Table 2.

TABLE 2 Percentage variations in Axial Force of 15 Storey Corner Column Removal Case

STOREY	COLUMN	WITHOUT BRACING - % INCREASE IN AXIAL FORCE			BRACING - % INCREASE IN AXIAL FORCE		
		GF	MID	ROOF	GF	MID	ROOF
STOREY 1	C2	28	14	1	1	1	1
STOREY 2	C2	27	15	1	1	1	1
STOREY 3	C2	25	16	1	12	1	1
STOREY 4	C2	23	19	1	11	1	1
STOREY 5	C2	22	22	2	10	2	1

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STOREY 6	C2	21	25	2	10	2	2
STOREY 7	C2	20	28	2	10	2	3
STOREY 8	C2	19	28	2	9	2	3
STOREY 9	C2	18	26	2	9	14	4
STOREY 10	C2	18	26	3	8	13	6
STOREY 11	C2	17	26	5	8	13	8
STOREY 12	C2	17	25	7	8	13	11
STOREY 13	C2	17	25	10	8	13	17
STOREY 14	C2	17	25	18	8	13	29
STOREY 15	C2	19	27	36	9	14	60
STOREY 1	C6	21	10	1	2	1	1
STOREY 2	C6	20	11	1	3	1	1
STOREY 3	C6	19	12	1	9	1	1
STOREY 4	C6	18	14	1	9	1	1
STOREY 5	C6	17	16	2	8	1	2
STOREY 6	C6	16	18	2	8	2	2
STOREY 7	C6	15	21	2	8	2	3
STOREY 8	C6	14	21	2	8	3	3
STOREY 9	C6	14	20	2	8	11	7
STOREY 10	C6	14	20	3	7	11	9
STOREY 11	C6	13	19	4	7	11	11
STOREY 12	C6	13	19	5	7	11	13
STOREY 13	C6	13	19	8	7	11	16
STOREY 14	C6	13	19	14	7	11	26
STOREY 15	C6	15	21	36	7	12	56

The increase in axial forces for 20 storey frames for the corner case is tabulated for the column removal at ground floor, mid height and below the roof in Table 3.

TABLE 3 Percentage variations in Axial Force of 20 Storey Corner Column Removal Case

STOREY	COLU MN	WITHOUT BRACING % INCREASE IN AXIAL FORCE			BRACING - % INCREASE IN AXIAL FORCE		
		GF	MID	ROOF	GF	MID	ROOF
STOREY 1	C2	28	9	1	1	1	1
STOREY 2	C2	26	9	1	2	1	1
STOREY 3	C2	24	10	1	8	1	1
STOREY 4	C2	22	12	1	8	1	1
STOREY 5	C2	20	13	1	7	1	1
STOREY 6	C2	19	15	1	7	1	1

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STOREY 7	C2	18	18	1	6	1	1
STOREY 8	C2	17	21	1	6	1	1
STOREY 9	C2	16	24	1	6	1	1
STOREY 10	C2	15	29	1	5	1	1
STOREY 11	C2	14	28	1	5	1	1
STOREY 12	C2	13	27	1	5	10	2
STOREY 13	C2	12	25	1	5	10	3
STOREY 14	C2	12	25	3	4	10	4
STOREY 15	C2	11	24	4	4	9	5
STOREY 16	C2	11	24	4	4	9	7
STOREY 17	C2	11	24	7	4	9	10
STOREY 18	C2	10	24	10	4	9	16
STOREY 19	C2	10	24	18	4	9	26
STOREY 20	C2	12	25	36	4	10	55
STOREY 1	C6	21	7	1	7	1	1
STOREY 2	C6	20	8	1	3	1	1
STOREY 3	C6	18	8	1	6	1	1
STOREY 4	C6	17	9	1	6	1	1
STOREY 5	C6	16	10	1	6	1	1
STOREY 6	C6	5	2	1	5	1	1
STOREY 7	C6	4	3	1	5	1	1
STOREY 8	C6	3	6	1	5	1	1
STOREY 9	C6	3	9	1	4	1	1
STOREY 10	C6	2	12	10	4	1	1
STOREY 11	C6	2	12	10	4	2	2
STOREY 12	C6	1	11	10	4	2	2
STOREY 13	C6	1	10	10	4	8	3
STOREY 14	C6	1	9	10	4	8	4
STOREY 15	C6	1	9	8	3	8	5
STOREY 16	C6	1	9	4	3	7	6
STOREY 17	C6	1	9	1	3	7	9
STOREY 18	C6	1	10	1	3	7	14
STOREY 19	C6	2	11	7	3	7	23
STOREY 20	C6	9	19	28	4	9	52

From the various tables given above, it could be understood that in corner case the ground floor yield the maximum values of increased axial forces, number of columns with high Rebar Ratio. The removal of column from below the roof influenced only the columns in that floor.

The tables shown above indicate that the removal of corner and mid height columns exhibited an influence in the floors whichever was closer to it. The ground floor column removal influenced the first four levels. Apart from the top storey which was dominated by the column removed from below the roof, the other stories were influenced by the mid height column removal from the mid height to the top.

REBAR RATIO

The increase in rebar content of the columns adjacent to the removed columns directly depends upon

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the increase in axial forces. The tables for selective corner case of column removal is shown below in Table 4.

TABLE 4 Rebar Ratios of Columns in Corner Case

STOREY	COLUMN	WITHOUT BRACING - INCREASE IN REBAR RATIO			BRACING –INCREASE IN REBAR RATIO		
		10 STOREY	15 STOREY	20 STOREY	10 TOREY	15 STOREY	20
STOREY 1	C2	3	2	4	0.2	0.1	1
STOREY 1	C6	2	2	3	0.1	0.1	3
STOREY 2	C2	2	3	3	0.1	0.1	3
STOREY 2	C6	2	2	2	0.3	0.1	2
STOREY 3	C2	2	3	2	1.5	0.1	2
STOREY 3	C6	1	2	2	1	0.1	2
STOREY 4	C2	2	2	1	1	0.1	1
STOREY 4	C6	1	1	1	1	0.1	1
STOREY 5	C2	2	2	1	1	0.1	1
STOREY 5	C6	1	1	1	1	0.1	1
STOREY 6	C2	1	1	0	1	0.1	0
STOREY 6	C6	1	1	0	1	0.1	0
STOREY 7	C2	0	1	0	0	0.1	0
STOREY 7	C6	0	1	0	0	0.1	0
STOREY 8	C2	0	0	0	0	0	0
STOREY 8	C6	0	0	0	0	0	0
STOREY 9	C2	0	0	0	0	0	0
STOREY 9	C6	0	0	0	0	0	0
STOREY10	C2	0	0	0	0	0	0
STOREY10	C6	0	0	0	0	0	0
STOREY11	C2		0	0		0	0
STOREY11	C6		0	0		0	0
STOREY12	C2		0	0		0	0
STOREY12	C6		0	0		0	0
STOREY13	C2		0	0		0	0
STOREY13	C6		0	0		0	0
STOREY14	C2		0	0		0	0
STOREY14	C6		0	0		0	0
STOREY15	C2		0	0		0	0
STOREY15	C6		0	0		0	0
STOREY16	C2			0			0
STOREY16	C6			0			0
STOREY17	C2			0			0
STOREY17	C6			0			0
STOREY18	C2			0			0
STOREY18	C6			0			0
STOREY19	C2			0			0
STOREY19	C6			0			0

International Journal of Advance Research in Science and Engineering
Volume No. 11, Issue No. 01, January 2022
www.ijarse.com
IJARSE
ISSN 2319 - 8354

STOREY20	C2			0			0
STOREY20	C6			0			0

From the above table, it is observed that the storeys up to mid height shows variation in Rebar Ratio and the remaining stories does not have much influence on the Rebar Ratio.

7. CONCLUSION

From the various results and discussions made in Chapter 6, the following conclusions could be drawn –

The linear static method is a threat independent analysis method that is also the simplest of the Alternate Load Path methods available. It gives conservative results and also considers only an equivalent dynamic load by means of a load increment factor. The effect of the corner column removal in ground floor is more compared to the mid and roof floor. Use of bracings for frames helped increase the lateral stiffness of the frames to resist collapse and it helps increase in redundancy.

The columns removed from ground floor alone showed high impact and the provision of Double Angle Bracing helps to decrease the axial force and hence it helps to resist progressive collapse and increase in redundancy. Thus the use of alternate load path method of analysis can be encouraged in cases of buildings of high importance, high elevations and high risk factor associated in terms of accidental loads.

REFERENCES

[1] American Society of Civil Engineers (ASCE), Minimum Design Loads for Buildings and Other Structures, ASCE-7, 2005.

[2] P.Couwenberg, Progressive Collapse of Reinforced Concrete Structures, Document No A-2013.56, 2013.

[3] GSA (2003), Progressive collapse analysis and design guidelines for new federal office buildings and major Modernization projects, U.S: General Services Administration.

[4] Hongyu Wang,Youpo Su, Qingshen Zeng, Design methods of Reinforced-Concrete Frame Structure to Resist Progressive Collapse in Civil Engineering, International Conference on Risk and Engineering Management (REM), 2011, 48–54.

[5] Kai Qian, A.M.ASCE; and Bing Li, Performance of Three-Dimensional Reinforced Concrete Beam-Column Substructures under Loss of a Corner Column Scenario, Journal of Structural Engineering ASCE, 139, 2013, 584- 594.

[6] S.Marjanishvili, Progressive analysis procedure for progressive collapse, Journal of Performance of Constructed Facilities, 18(2), 2004, 79-85.

[7] Michel Byfield, Wjesundhara Mudalige, Colin Morison, Euan Stoddart, A Review of Progressive Collapse Research and Regulations, Proceedings of the Institution of Civil Engineers, 167, 2013.

[8] National Institute of Standards and Technology (NIST) Best practices for reducing the potential for progressive collapse in buildings, NISTIR 7396, Gaithersburg, Md, 2007.

[9] F. Nateghi-A and N. Parsaeifard, Studying the Effect of Initial Damage on Failure Probability of One Story Steel Buildings, Iranica Journal of Energy & Environment, 4 (3), 2013, 258-264.

[10] U.Starossek, Progressive collapse of structures, (Thomas Telford, London, 2009)

[11] U.Starossek, Disproportionate collapse, A pragmatic approach, Proc. Inst. Civ. Eng., Struct. Build., 160, 2017, 317–325.

International Journal of Advance Research in Science and Engineering
Volume No. 11, Issue No. 01, January 2022
www.ijarse.com
IJARSE
ISSN 2319 - 8354

[12] UFC 4-023-03, Design of Structures to Resist Progressive Collapse Unified facilities criteria, 2005.

[13] Uwe Starossek, Progressive Collapse of Structures: Nomenclature and Procedures, Structural Engineering International, 2, 2006.