STUDY OF PROGRESSIVE COLLAPSE ANALYSIS OF A STRUCTURE BY LINEAR STATIC METHOD USING ETAB

SOMESH K H [1]. Prof. Dr. VAHINI [2]

Post Graduate student, Department of Civil Engineering, Government engineering college Haveri, Karnataka, India.

Head and Prof. Department of Civil Engineering, Government engineering college Haveri, Karnataka, India

ABSTRACT

Progressive collapse is one of the most devastating types of building failures, most often leading to costly damages and possible loss of life. To study the effect of failure of columns on the entire structure, Plan irregularity and mass irregularity of building is considered. The progressive collapse analysis and modelling of the building is done using ETAB. Linear static analysis is performed to understand progressive collapse. In the present study the demand capacity ratio (DCR) of reinforced concrete structure of plan irregularity and mass irregularity of building are evaluated as per U.S. General Services Administration (GSA) guidelines. The structure is in “L” and “Y” shape and consists of 12 storeys size as 5m in both X and Y direction. Height of floor is taken as 3m. Many Cases considered by removing columns at different location of the building for study. We got the result as The Y shape structures are more stable than L shape structure.

INTRODUCTION

General Information

The buildings are first designed and then planned for final forces or stresses resistance. but if the load acting on the entire shape or a structural element exceeds the limiting cost of this operational load or strain, the shape fails or any failure of structural element takes region. whilst load exceeds the operational loads, constructing or any detail like beams and column fails its outcomes effects inside the failure of adjoining factors or higher storey participants results in failure of whole shape. This pattern of non-stop failure of structural contributors' reasons failure of entire shape. This phenomenon is called revolutionary fall apart or revolutionary failure. In short it is able to be defined because the collection of motion in which nearby failure becomes worldwide failure.

Progressive-Collapse was first identified in London in the year 1968 took place in the Ronan point storey building. The abrupt gas burst at 18th floor brings about the failure of corner columns from top storey to bottom storey. The other more examples of Progressive Collapse are, attack on World trade center in 2001, collapse of Alfred P Murrah Federal building at Oklahoma City and Hotel New World at Singapore in 1986.

The progressive collapse analysis will be carried by taking out one vertical member (column) or two or more columns. Progressive failure occurs due to extreme loading of normal loads and abnormal loads. Some of the abnormal loads causing progressive collapse are listed as, loads due to gas explosion, vehicle impact loads, loads due to over pressure of wind, Blast loads, Earthquake loads etc.

There are two methods to do the Progressive-Collapse, they are:

Direct method and Alternate load path method.

Direct method: In this method, the precision of work is of very high level but it can be achieved at great expense as the entire structure is modeled first including each and every detail of structural element and member, then air and other explosive characteristics should be modeled by each detail which needs lots of key elements. Special procedure, process and highly qualified software tools are required to study and find out behavior of the building under failure.

The alternate path method: This method was advised by G.S.A and DOD guidelines. In this guideline, a load carrying structural element is taken out at required locations and damage pattern is examined. The main purpose is to make sure whether the adjoining members have enough capacity to take additional extra load and reallocate them suitably or not.

Objectives

To provide step by step explanation of linear static method for the analysis of progressive collapse is the main intension of this project, using commercially available structural analysis software tool such as ETABS.

The potential for progressive collapse of a building will be assessed with plan irregularity and mass irregularity by linear static method.

To understand the process (course of action) of progressive collapse of a plan and mass irregularity building.

To understand the series of failure of members under progressive collapse of a plan and mass irregularity building.

METHODS FOR CALCULATION

Linear Static Analysis

- This method is suitable for the materials which are having same dimensions and same elastic behavior, it means linearly elastic.
- Linear static analysis is simple method mostly used because it is easy to understand.
- The drawback is amplification factors, inertia and damping forces are not considered, so this method of analysis is appropriate only for examining plain or simple structures whose performance is expected.
- Load combination used in this method for Progressive Collapse after column removal the load applied 2[DL + 0.25LL]
- The results outcomes are depend on DCR value which is less than 2 for regular structure and 1.5 for irregular structures.

Steps in Brief for Software

- At first model is prepared. It is either regular or irregular structure.
- Loads are defined in load patterns i.e. DL, LL, FF, Parapet Load, EQX and EQY.
- The loads combinations are prepared by the loads defined as per IS code and perform analysis for required load combination.
- Before column removal, the load combination applied is (DL + 0.25LL) and after removal of the column, the load combination is 2(DL + 0.25LL).
- Then frames results are taken from the load combinations.
- Ultimate capacity of the member is evaluated based on standard code.
- Find out DCR of the member.

Methodology for the Present Study

In this study, the performances of reinforced concrete framed irregular buildings at different seismic zones against progressive collapse are considered. The building with plan and mass irregularity is investigated for different earthquake zones as per guidelines of GSA. The demand capacity ratio of beams and columns are considered in the critical region or failure portion of the building under each column removal case. Providing extent & category of progressive collapse in various seismic zones provides more vital knowledge about the structure against progressive collapse resistance, by implementing some of the measures to the design. So as to ensure safety against progressive collapse of the structure additional abnormal loadings must be considered.

The objective of GSA guidelines is to help in assessing the risk of progressive collapse analysis for any seismic zone. The following cases can be analyzed.

Case1: Analysis of column removed building at ground floor located at the middle of exterior side of building.
Case2: Analysis of column removed building at ground floor located at middle of interior side of the building.
Case3: Analysis of corner column removed building at ground floor located at any portion of the building.
Case 4: Analysis of any interior column removed building at ground floor located at any portion of the building.
Permissible Criteria for Progressive Collapse: The GSA guidelines tells about the use of the DCR value which is defined as the ratio of the load or force acting on the structural member like column, beam etc., after the removal of a column to the member capacity to the ultimate capacity of that member. This determines the failure of structural components by the linear static analysis method.

$$DCR = W_{al} / W_{ul}$$

Where, W_{al} = load or force acting on the structural member like column, beam etc., after the removal of a column to the member capacity (AL, SF and BM)
W_{ul} = ultimate capacity of that member that the member can withstand the load.

- DCR value should be less than 2 for typical structural configurations.
- DCR value should be less than 1.5 for a typical structural configuration.

Problem Description

To learn the concept of progressive failure different columns are removed at various locations and variation of Bending-moment, Axial-load and interaction ratio is observed from floor to floor.

The structure is in “L” and “Y” shape and consists of 12 storeys size as 5m in both X and Y direction. Height of floor is taken as 3m.

Sizes of Beams are maintained constant in all storeys but the column sizes are reduced with the increase in floor and hence structure can be considered to have irregular geometry. The loading is taken as per G.S.A recommendation that is [DL + 0.25LL] for before removal case and 2[DL + 0.25 LL] for after removal case. The design has been done as per IS: 456 code using ETABS software.

Building details are as follows

1) Material information

   Concrete used is of M30 grade (fck- 30 N/mm^2)

   Reinforcement steel is of Fe 500 grade (fy – 500 N/mm^2)

2) Slab thickness – 150 mm
3) Wall thickness – 300 mm
4) Beam Size:

   L shape – 300 X 450 mm Y shape – 300 X 500 mm

5) Column dimension:

L shape: 300mm X 750mm – 1^{st} to 4^{th} storey

300mm X 600mm – 5^{th} to 8^{th} storey

300mm X 450mm – 9^{th} to 12^{th} storey

Y shape: 300mm X 800mm – 1^{st} to 4^{th} storey

300mm X 600mm – 5^{th} to 8^{th} storey

300mm X 450mm – 9^{th} to 12^{th} storey

6) Load Consideration:

- Dead load = Self weight of the members
- Live load = 3 kN/m^2
- Floor finish =1.5 kN/m^2
- Wall load = 13.8 kN/m
- Parapet load = 3.75 kN/m

At first the model is prepared as per required configuration; the materials, frame section and slab sections are defined. The beam and columns are taken as rectangular sections and slab has been defined as membrane type with 150 mm thickness. Live and floor finish loads are assigned as U.D.L on floors and wall load is taken as U.D.L type on beams. After assigning fixed support to column base the structure is modeled, analyzed and designed for required load condition as per IS: 456.

The D-C Ratio values of beam and column are checked for Bending-moment, axial force and P-M-M ratio for every removal of column case. Only one of the columns is removed at a time and checked for required results in adjacent column and beams. Totally 3 columns are removed and results are checked for every floor.

Cases considered for study

Case 1- Shorter side removal of Middle base column.

Case 2- Removal of Corner base column.

Case 3- Removal of Interior base column.

Case 4- Removal of Center base column.

CALCULATIONS

Data:

Breadth of the Beam, b = 300 mm Depth of the Beam, D = 450 mm

Acting bending moment on beam of storey 1 (M_u) – 481.8536 kN-m

Characteristic strength of concrete, f_{ck} = 30 N/mm^2

Characteristic strength of steel, f_y = 500 N/mm^2

Cover given to beam, d' = 25mm

Effective depth of beam, d = (450 – 25) = 425 m

Limiting moment calculation:

As per IS 456 the limiting moment depends on grade of steel used.

In the present case the steel used is Fe 500 grade and hence the limiting moment is given by $M_{ulim} = 0.133 f_{ck} b d^2$

M_{ulim} = 0.133 X 30 X 300 X 425^2

= 216.2081 kN-m

D-C Ratio:

D-C Ratio = (Acting force / Ultimate force)

= 481.8536 / 216.2081

= 2.22 > 2.0 Hence not safe.

P-M-M Ratio Calculations

Column considered is C15 of storey 2 Data:

Breadth, b = 300 mm Depth, D = 750 mm Cover given, d'' = 40 mm

A.L. P_u = 116.9969 kN

Bi-axial moment: M_x = 12.5755 kN-m and M_y = 345.8659 kN-m;

f_{ck} = 30 N/mm^2 and f_y = 500 N/mm^2

Calculation:

Rebar percentage = 1.19%

Area of reinforcement = 1.19*300*750/100 = 2677.5 mm^2 Let us provide 6 bars of 25mm

Area of reinforcement provided = 2945.24 mm^2

Provided Rebar percentage = 1.31 %

To find Mu:

$M_u = 1.15 \text{ X } \sqrt{(M^2 + M^2)}$

$M_u = 1.15 \text{ X } \sqrt{(12.5755^2 + 345.8659^2)}$

=398 kN-m

To find Mux1:

p/f_{ck} = 0.12 ; d'' /D = 0.05

$P_u/f_{ck}bD$ = (116.9969 / 30 X 300 X 750) = 0.0173

From Chart 47 of SP-16 $M_{ux1} / f_{ck}bD^2$ = 0.24

M_{ux1} = 0.24 X 30 X 300 X 750^2 = 1215 kN-m

To find Muy1:

p/f_{ck} = 0.12 ; d''/b = 0.13

From chart 48 and 49 of SP-16, we need to interpolate the value for d''/b=0.130, $M_{uy1} / f_{ck}db^2$ = 0.22

M_{uy1} =0.22 X 30 X 750 X 300^2 = 445.5 kN-m

Calculation of Puz:

$P_{uz} = 0.45 f_{ck} A_c + 0.75 fy\ A_{sc}$

P_{uz} = 0.45 X 30 X 216602 + 0.75 X 415 X 8398 P_{uz} = 5538 kN

To find αn:

P_u/P_{uz} = 0.0211 lies between 0.2-0.8 Therefore αn = 1.02

Interaction ratio:

$(M_{ux}/M_{ux1})^{\alpha n} + (M_{uy}/M_{uy1})^{\alpha n} < 1.0$

$(12.5755/1215)^{1.02} + (345.8659/445.5)^{1.02} = 0.78 <$ 1.00 Hence safe.

Load verification

1. Floor Finish:

(10 x 30 x 1.5x12) + (10 x 20 x 1.5x 12) = 9000 kN

2. Live Load:

(10 x 30 x 3x 12) + (10 x 20 x 3 x 12) = 18000 kN

3. Dead Load:

Beam: (0.3 x 0.45 x 25 x 260 x 12) = 10530 kN

Slab: (0.15 x 25 x 20 x 25x 12) = 22500 kN

For Column

L(m)	B(m)	H(m)	Density (kN/m^3)	Floor (no)	number	
0.4	0.4	2.55	25	4	3	= 4844.36 kN
0.6	0.6	2.55	25	4	3	
0.75	0.75	2.55	25	4	3	
0.3	0.75	2.55	25	4	30	
0.3	0.60	2.55	25	4	30	
0.3	0.40	2.55	25	4	30	

Total dead load obtained is 37874.36 kN -------------------- (3)

Parapet wall: (3.75 x 110) = 412.5 kN ----------------- (4)

Wall load on 12^{th} floor: (0.3 x 2.55 x 20 x 11 x 260) = 43758 kN The values got from these calculations:

SL.NO	LOAD TYPE	VALUE (kN)
1	DEAD LOAD	37874.36
2	LIVE LOAD	18000
3	FLOOR FINISH	9000
4	WALL LOAD	43758

Y Shape Irregularity

Data:

Breadth of the Beam, b = 300 mm Depth of the Beam, D = 500 mm

Acting bending moment on beam of storey 1, M_u = 470.2379 kN-m Characteristic strength of concrete, f_{ck} = 30 N/mm^2

Characteristic strength of steel, f_y = 500 N/mm^2

Cover given to beam, d' = 25mm

Effective depth of beam, d = (500 – 25) = 475 mm

Limiting moment calculation:

As per IS 456 the limiting moment depends on grade of steel used.

In the present case the steel used is Fe 500 grade and hence the limiting moment is given by M_{ulim} = $0.133 f_{ck} bd^2$

M_{ulim} = 0.133 X 30 X 300 X 475^2

= 270.073 kN-m

D-C Ratio:

D-C Ratio = (Acting force / Ultimate force)

= 470.2379 / 270.073

= 1.74 > 1.5 Hence not safe.

P-M-M Ratio Calculation

Column considered is C15 of storey 2 Data:

Breadth, b = 300 mm Depth, D = 800 mm Cover given, d'' = 40 mm

Axial-load, P_u = 195.9904 kN

Bi-axial moment: M_x = 3.9198 kN-m and M_y = 385.1279 kN-m; f_{ck} = 30 N/mm2 and f_y = 500 N/mm^2

Calculation:

Rebar percentage = 1.07%

Area of reinforcement = 1.07*300*800/100 = 2568 mm^2 Let us provide 6 bars of 25mm

Area of reinforcement provided = 2945 mm^2

Provided Rebar percentage = 1.22 %

To find Mu:

$M_u = 1.15 \text{ X } \sqrt{(M_{ux}^2 + M_{uy}^2)}$

$M_u = 1.15 \text{ X } \sqrt{(3.9198^2 + 385.1279^2)}$

= 442.92 kN-m

To find Mux1:

p/f_{ck} = 0.12 ; d'' /D = 0.05

$P_u/f_{ck}bD$ = (195.9904 / 30 X 300 X 800) = 0.027

From Chart 47 of SP-16 $M_{ux1} / f_{ck}bD^2$ = 0.14

M_{ux1} = 0.14 X 30 X 300 X 800^2 = 806.4 kN-m

To find Muy1:

p/f_{ck} = 0.12 ; d''/b = 0.13

From chart 48 and 49 of SP-16, we need to interpolate the value for d''/b=0.130, $M_{uy1} / f_{ck}db^2$ = 0.12

M_{uy1} = 0.22 X 30 X 800 X 300^2 = 475.2 kN-m

Calculation of Puz:

$P_{uz} = 0.45 f_{ck} A_c + 0.75 f_y A_{sc}$

P_{uz} = 0.45 X 30 X 237055 + 0.75 X 500 X 2945 P_{uz} = 4304.617 kN

To find αn:

P_u/P_{uz} = 0.04 lies between 0.2-0.8 Therefore αn = 1.02

Interaction ratio:

$(M_{ux}/M_{ux1})^{\alpha n} + (M_{uy}/M_{uy1})^{\alpha n} < 1.0$

$(3.9198/806.4)^{1.02} + (385.1279/475.2)^{1.02} = 0.81 < 1.00$ Hence safe.

Load verification

1. Floor Finish:

   (25 x 10 x 3 x 1.5 x12) + (0.5 x 10 x 8.66 x 1.5x 12)

   = 14279.4 kN

2. Live Load:

   (25 x 10 x 3 x 3 x 12) + (0.5 x 10 x 8.66 x 3 x 12) = 28558.8 kN

3. Dead Load:

   Beam: (0.3 x 0.5 x 25 x 400.98 x 12) = 18044.1 kN

   Slab: (0.15 x 25 x 798.3 x 12) = 35698.5 kN

Column:

L(m)	B(m)	H(m)	Density (kN/m^3)	Floor (no)	number	
0.4	0.4	2.5	25	4	4	= 7562.5 kN
0.6	0.6	2.5	25	4	4	
0.75	0.75	2.5	25	4	4	
0.3	0.80	2.5	25	4	48	
0.3	0.60	2.5	25	4	48	
0.3	0.40	2.5	25	4	48	

Total dead load obtained is 61305.1 kN

Parapet wall: (3.75 x 180) = 675 kN

Wall load on floor: (0.3 x 2.55 x 11 x 400.98 x 20) = 67484.93 kN

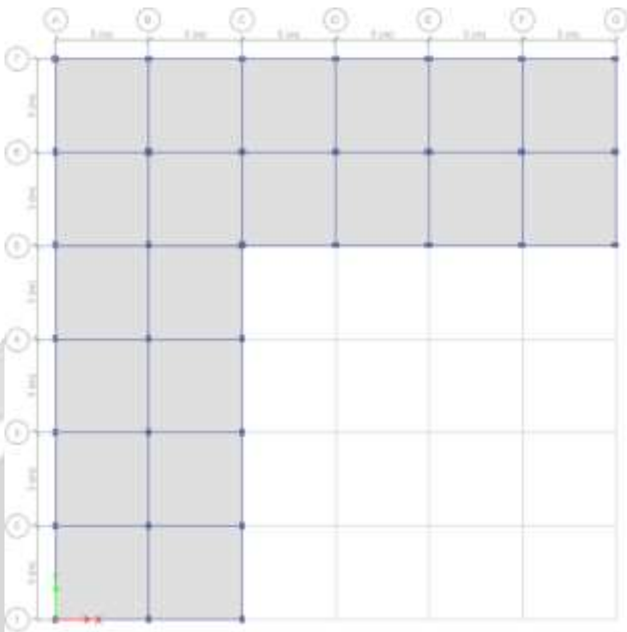
The values got from these calculations are:

SL.NO	LOAD TYPE	VALUE (KN)
1	DEAD LOAD	37874.36
2	LIVE LOAD	18000
3	FLOOR FINISH	9000
4	WALL LOAD	43758
5	PARAPET LOAD	412.5

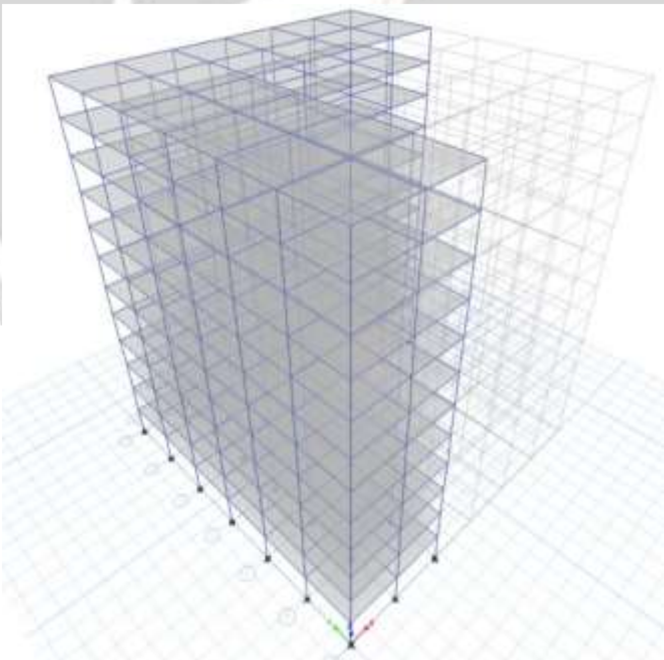
RESULTS

Plan and 3-Dimensional View of the Structure

L Shape Plan Irregularity

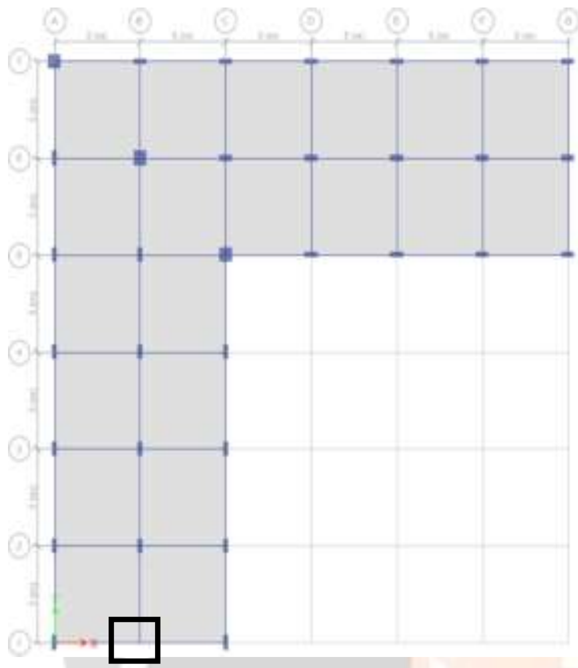


Plan



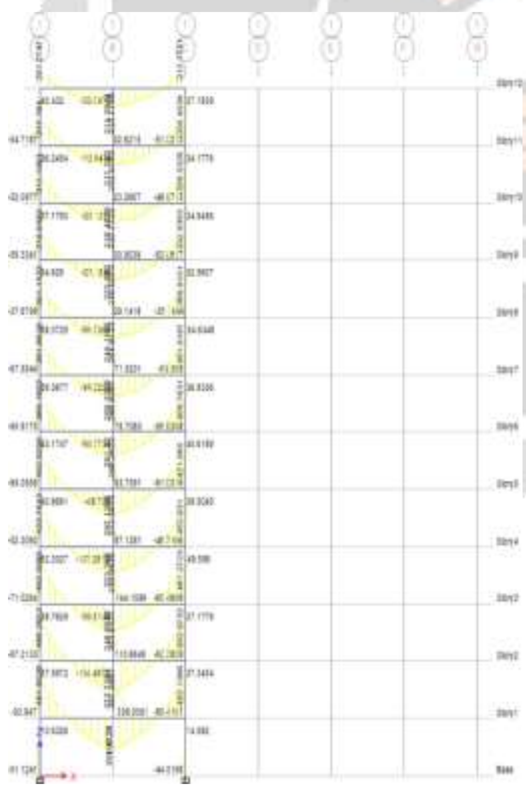
3d Model

Removal of Middle Exterior Column at Storey 1



Plan

Elevation



Bending Moment

Axial Load

CONCLUSION

1. For L shape structure, the DCR value of the columns adjacent to the removal column fails for all the 4 cases.
2. The L shape mass irregularity structure is more susceptible to progressive collapse for both interior and center column removal and less susceptible to corner column removal.
3. The L shape plan irregularity structure is highly susceptible to progressive collapse for center column removal and less susceptible to corner column removal.
4. It is observed that lower storey beams are more critical than upper storey beams.
5. The DCR values of zone 5 are more than zone 2, zone 5 is more susceptible to progressive collapse.
6. For Y shape plan irregularity structure, the DCR values for center and corner column removal case are within the limit. Hence no progressive collapse occurs.
7. For Y shape mass irregularity structure, no progressive collapse occurs when center column is removed.
8. For the Y shape structure under consideration, the DCR value for beam within the limit for above 3-4 floors only, for remaining floors the values are exceeds the limit.
9. In mass irregularity structure, the DCR value is more in 12^{th}, 8^{th} and 4^{th} as the mass loadings are applied at these storeys.
10. For plan irregularity structure, the DCR values are linearly varying from top to bottom floors.
11. The percentage increase in the A.L. in the column after column removal and applying scale factor is more in zone 2
12. Interaction ratio after removal is observed to be reaching the limiting value in few columns. It can be made safe either by increasing the steel or by increasing size of column.
13. The downward deflections of beam in case of center column removal at storey 1 are less when compared to all other cases in Y shape structures and corner column removal at storey 1 are less when compared to all other cases in L shape structures.
14. The structures should be seismically designed so that it sustains the progressive collapse when any of the columns fails.
15. If the beam fails by exceeding the DCR value i.e. greater than 1.5, then beam needs to be redesign to resist progressive collapse. It can be made safe either by increasing the reinforcement or by increasing dimension.
16. The L shape structure is more susceptible to progressive collapse than Y shape structure as most of columns and beams are failed in all the cases and exceed the DCR value limit.
17. The Y shape structures are more stable than L shape structure as in center column removal and corner case no progressive collapse takes place and only bottom storey columns and beams are failing in remaining cases.
18. Ultimately it concluded that the atypical structures are highly critical than typical structures because in typical structure is of uniform geometry and load distribution is uniform.

REFERENCES

1. Anu Thampy, Hanna Paulose, "Assessment of Progressive Collapse Potential in Regular and Irregular RC Structures Using Linear Static Analysis", International Journal of Advance Engineering and Research Development Volume 4, Issue 6, June - 2017.
2. Balasaraswathi.K.M, Ramakrishna.G, "Progressive Collapse Analysis of Asymmetric Reinforced Concrete Building", International Journal for Trends in Engineering & Technology, ISSN: 2349 – 9303, Volume 23, Issue 1 – May 2017.
3. Bhavik, R. Patel and Dr. Bharat J. Shah, "Progressive Collapse Assessment of Reinforced Concrete Frame Structure with and without Considering Actual Soil Condition", International Conference on Re- search and Innovations in Science, Engineering &Technology, Volume 1, 2017.
4. David Stephen, Dennis Lamb, John Forth, Jianqiao Ye, Konstantinos Daniel Tsavdaridis. "An evaluation of modelling approaches and column removal time on progressive collapse of building", Journal of Constructional Steel Research, 2018.
5. Digesh D. Joshi1, Paresh V. Patel and Saumil J. Tank, "Linear and Nonlinear Static Analysis for Assessment of Progressive Collapse Potential of Multistoried Building", ASCE, 2010.
6. Hongyu Wang, Youpo Su, Qingshen Zeng, "Design Methods of Reinforce-concrete Frame Structure to Resist Progressive Collapse in Civil Engineering", Science Direct, 2011.
7. Mrs. Mir Sana Fatema1, Prof. A.A. Hamane, "Progressive Collapse of Reinforced Concrete Building", International Journal of Emerging Trends in Science and Technology, ISSN 2348-9480, volume 3, December 2016.
8. Ms. Monika Kenjale & Prof. Prashant Kulkarni, "Linear and Nonlinear Analysis of Reinforced Concrete Building for Progressive Collapse", Imperial Journal of Interdisciplinary Research (IJIR), ISSN: 2454-1362, Vol-2, Issue-8, 2016.
9. Raghavendra C, Mr. Pradeep A R, "Progressive Collapse Analysis of Reinforced Concrete Framed Structure", International Journal of Civil and Structural Engineering Research, ISSN 2348-7607, Vol. 2, Issue 1, 2014.
10. Rakshith K G, Radhakrishna, "Progressive Collapse Analysis Of Reinforced Concrete Framed Structure", International Journal of Research in Engineering and Technology, ISSN: 2321-7308, Nov-2013.