Analysis of an Irregular (L-shaped) Flat Slab Building (G+11) using Nonlinear Static Theory for Progressive Collapse

[1]Shilpa S, [2]Vishwajith Kadri

[1]Assistant Professor, [2]M. tech Student
Department of Civil Engineering
Srinivas University Institute of Engineering and Technology
Mukka, Mangalore, Karnataka state, India.

***Abstract*- Structures can Experience Progressive Collapse, a Catastrophic Phenomenon caused by both natural and man-made risks. Conventional RC frame buildings are now often utilized in Construction. Compared to traditional RC frame Construction, a Flat slab Structure has numerous advantages. The study applies a non-linear static analysis approach known as Pushover Analysis to the Progressive Collapse Analysis of a Flat slab building. This kind of study applies an existing lateral load pattern to a computer model of a structure. Pushover Analysis is carried out and the ETABS software is used to simulate the (G+11) structure.**

***Index Terms*- Flat slab, Pushover Analysis, Earthquake Loads, Progressive Collapse, ETABS.**

I. INTRODUCTION

Buildings are frequently designed to support loads from the wind, earthquakes, and dead, and live things. Despite this, the structure is secure for both those loads alone and in combination. Nevertheless, if a load-bearing structural member is damaged or fails, the structure can collapse. Structural parts can sustain damage from both man-made and natural disasters, such as unanticipated gas explosions, car crashes resulting from mishaps, bomb explosions caused by acts of terrorism, etc. When a structural component fails, the members close to that column are put under increased strain. When that strain reaches its breaking point, those members will also fail, causing a gradual collapse. Progressive collapse can produce large proportions. Progressive Collapse can cause a considerable number of incorrect triggers, which reduces a structure's capacity to support weights before the building collapses entirely.

Progressive collapse is described as "the spreading of an initial local failure from element to element, ultimately leading to the collapse of an entire structure or a disproportionately large part of it." The column loss scenario is more likely to cause progressive collapse than an earthquake since the failure of one component often causes the entire building, or a significant portion of it, to collapse. Nowadays, reinforced concrete (RC) frame constructions are favoured over flat slab structures because of several advantages. In flat slab constructions, columns are fixed directly to slabs without the need for beams, simplifying shuttering operations, optimizing available space, and reducing construction time.

II. AIM AND OBJECTIVE OF WORK

- **Aim**

The aim of this project is to investigate the behavior of flat slab structures after a sudden column loss event. The extent of damage, and the influence of dynamic effects and nonlinear capacity will be examined to consider their roles in assessing the potential for progressive failures. Different structural configurations will also be investigated.

- **Objective**

1. Create a numerical model using GSA principles to analyze a reinforced concrete flat slab structure for a gradual collapse caused by the removal of one column at a time from several key points.
2. To determine whether the structure complies with regulations on punching shear safety.
3. Analyze the responses of the intact structure and the structure with a crucial column removed by GSA recommendations.
4. To compare storey displacement, storey shear, and storey stiffness at the first storey of a G+11 story building between the undamaged structure and various column removal instances.
5. To use pushover analysis to investigate the structure's hinge creation mechanism.

III. LITERATURE REVIEW

Divya et.al (2014),[1]: This study examines the critical failure and collapse analysis of flat slab, shear wall or reinforced concrete frame buildings. By GSA rules, the analysis was completed by removing the column and shear wall at the designated points. They have employed Etabs software to do linear static analysis. Demand capacity ratios for each of the crucial portions have been discovered, and the structure has been examined for progressive collapse. The findings show that the addition of shear walls increases structural stiffness and resistance to progressive collapse brought on by the loss of a load-bearing structural element. They concluded that structures, shear walls or not, are prone to collapsing when a column and shear wall are lost.

Modi et.al (2016),[2]: Pushover analysis was studied to establish and contrast the various approaches utilizing predetermined acceptance criteria. Pushover analyses have been performed for the structures in compliance with ATC40 and FEMA356 regulations. They compared the outcomes, such as base shear and storey drift, among others. They came to the conclusion that the building's performance declines as the number of stories rises. Additionally, research has indicated that when storey height grows, the time and displacement of buildings will also increase.

R.Jeyanthi, et. al. (2017),[3]: After analyzing a single RCC building model, they came to the conclusion that there is only a minimal chance of progressive collapse in the event that the corner column is removed. In comparison to the beams that are not near the damaged column joint, the beams that are next to the removed column have the greatest bending moment.

Ruchika Mishra, et. al. (2017),[4]: They only looked at one structure, demand capacity ratios for various column removals, and linear static analysis. They advised contrasting the outcomes of various metrics both before and after the progressive building.

Eshwar Kuncham, et. al. (2019),[5]: Using three cases for linear static and dynamic analysis, they examined three two-dimensional models with varying storeys and came to the conclusion that removing the corner column would be more vulnerable than removing the middle column. According to pushdown analysis, removing the corner column in a four-story building causes a partial failure, but removing the middle column causes the entire structure to fail.

IV. INTRODUCTION TO PUSHOVER ANALYSIS

Pushover analysis is a non-linear static analysis in which the structure is subjected to increasing lateral loads and gravity loads until either the target displacement is reached or the structure collapses. It is used to derive a pushover, or so-called capacity curve, such as Base shear Vs. displacement, from which the structure's deformation capacity and behaviour beyond its elastic state can be determined.

- **METHODS OF PUSHOVER ANALYSIS**

Generally, pushover analysis is classified into two types

i. Force-controlled: The building is subjected to lateral loads during force-controlled analysis, and the displacements are calculated. This approach assumes that the building can handle the load being applied since its size is known. Loads are applied using this manner in descending sequence, starting at zero and increasing in magnitude.

ii. Displacement controlled: In this approach, forces in the lateral direction are identified after a goal displacement has been specified at the outset. It is broken down into many phases and then administered gradually.

V. METHODOLOGY

In this work, a nonlinear analysis utilizing Etabs-2016 is used to simulate an irregular structure made up of a G+11 story reinforced concrete flat slab with an L-shaped end beam. According to GSA rules, nonlinear analysis is performed by deleting one column at a time from external, internal, and corner locations. Since the structure is made of a flat slab and an end beam, we must check for punching shear failure. Etabs is used to assess the model and provides a punching shear ratio; this ratio must be within 1. If it surpasses 1, the column's punching shear fails. According to FEMA 356 rules, all structural components are given plastic hinges to move the building into the plastic zone in order to do the pushover analysis, a nonlinear analysis, in each scenario when a column is removed. Following model analysis, a pushover curve with base shear and roof displacement is shown, and the efficiency of each member is evaluated.

- **Nonlinear Static analysis (Pushover) procedure**

Plastic analysis is nothing more than nonlinear analysis. The stress-strain curve is no longer linear because the materials that are loaded act nonlinearly, or tend to yield. The following are the many stages taken throughout the analysis.

Step 1: The building is modelled first, and GSA-recommended loads are put into the structure without removing any columns (undamaged structure).

Step 2: To move the structure into a plastic zone, plastic hinges are attached to each of the structure's columns.
Step 3: Target displacement is provided together with defined load situations for pushover analysis in both directions.
Step 4: After the structure has been studied, a force deformation curve and the hinge states for associated columns are derived.
Similarly, the building is modeled for different column removal cases as per guidelines and loads are applied as follows G_N=2(1.2*Dead load + 0.5*Live load or 0.2*Snow load) for the floors adjacent to a removed column. For all other floors, GN=1.2*Dead load + 0.5*Live load or 0.2*Snow load Where G_N is increased gravity loads for nonlinear analysis.

- **Description about the building**

Grade of concrete = 30 N/mm^2
Grade of steel = 500 N/mm^2
Slab panel = 5m x 5m
Thickness of slab = 150mm
Thickness of drop panel = 225 mm
Floor to floor height = 3m
Live load =3 kN/m^2
Floor Finish load =1.5 kN/m^2
Location: Bangalore
Seismic zone: II Soil type: Medium
Response reduction factor: 3 (table 7 of IS 1893:2002) Importance factor: 1 (As per the clause of 6.4.2 of IS 1893:2002)
Fundamental time period (T_a): as per the IS 1893:2002.
Column sizes and % of steel:

COLUMN SIZE	LOCATION	FLOORS	% STEEL
500 X 500	Exterior	0 to 05	3.830
600 X 600	interior	0 to 05	3.790
500 X 500	Exterior	06 to 09	2.940
600 X 600	interior	06 to 09	3.120
500 X 500	Exterior	10 to 11	2.000
600 X 600	interior	10 to 11	2.310

Table 1: Column size and Percentage of Steel

VI: ETABS MODELLING

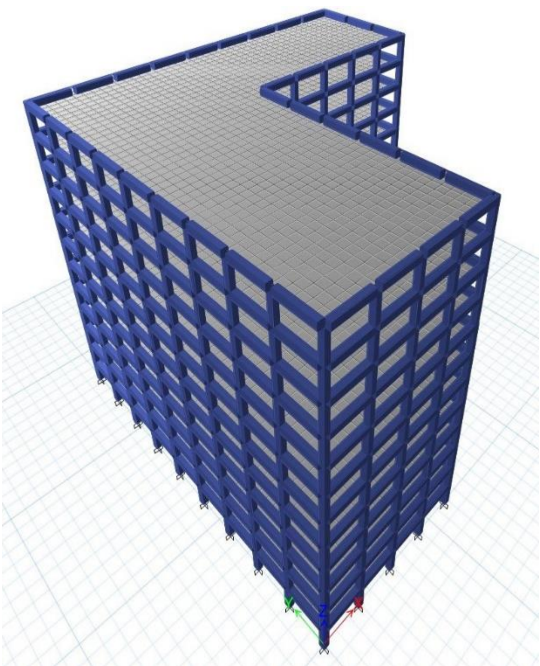


Fig 1: 3D model of the building. Fig2: Plan of the building with column labels.

- In the analysis, Corner column is removed at 6 locations, exterior column removed at 5 locations and interior column are removed at 3 locations.

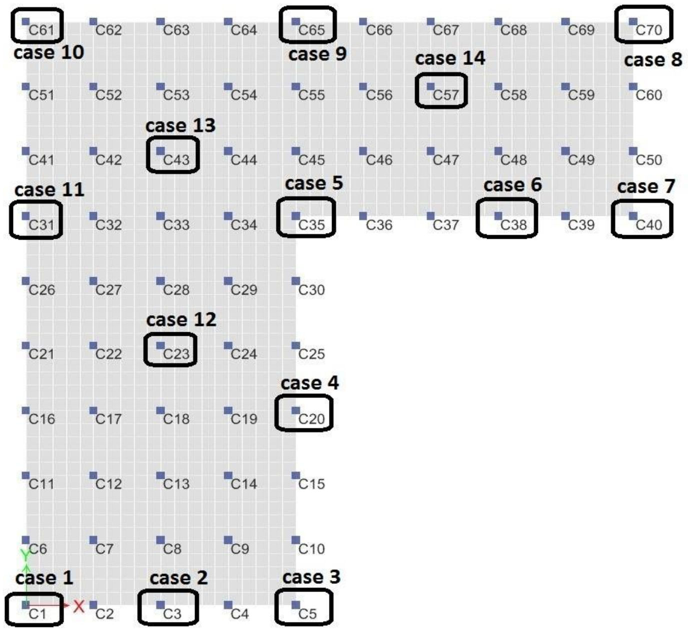


Fig 3: Column removal cases at different locations.

VII. ETABS ANALYSIS RESULT

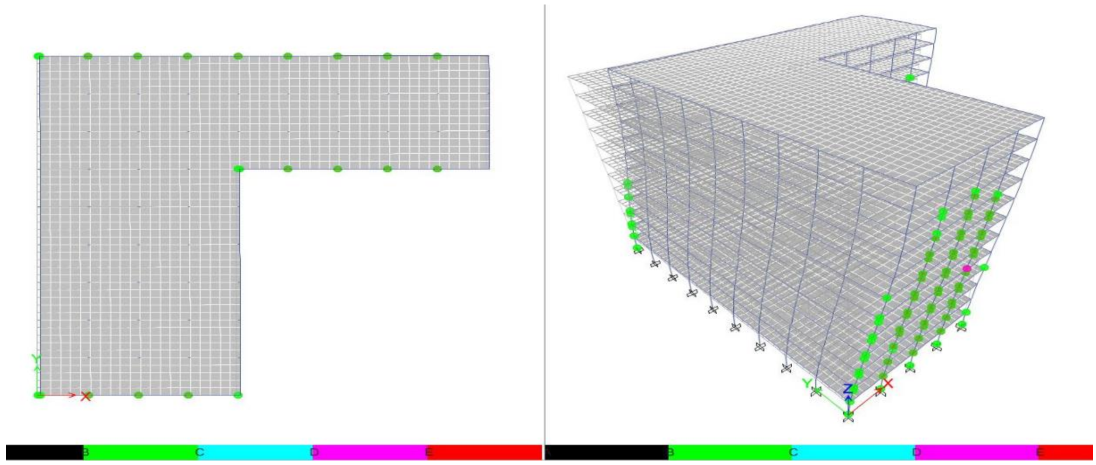
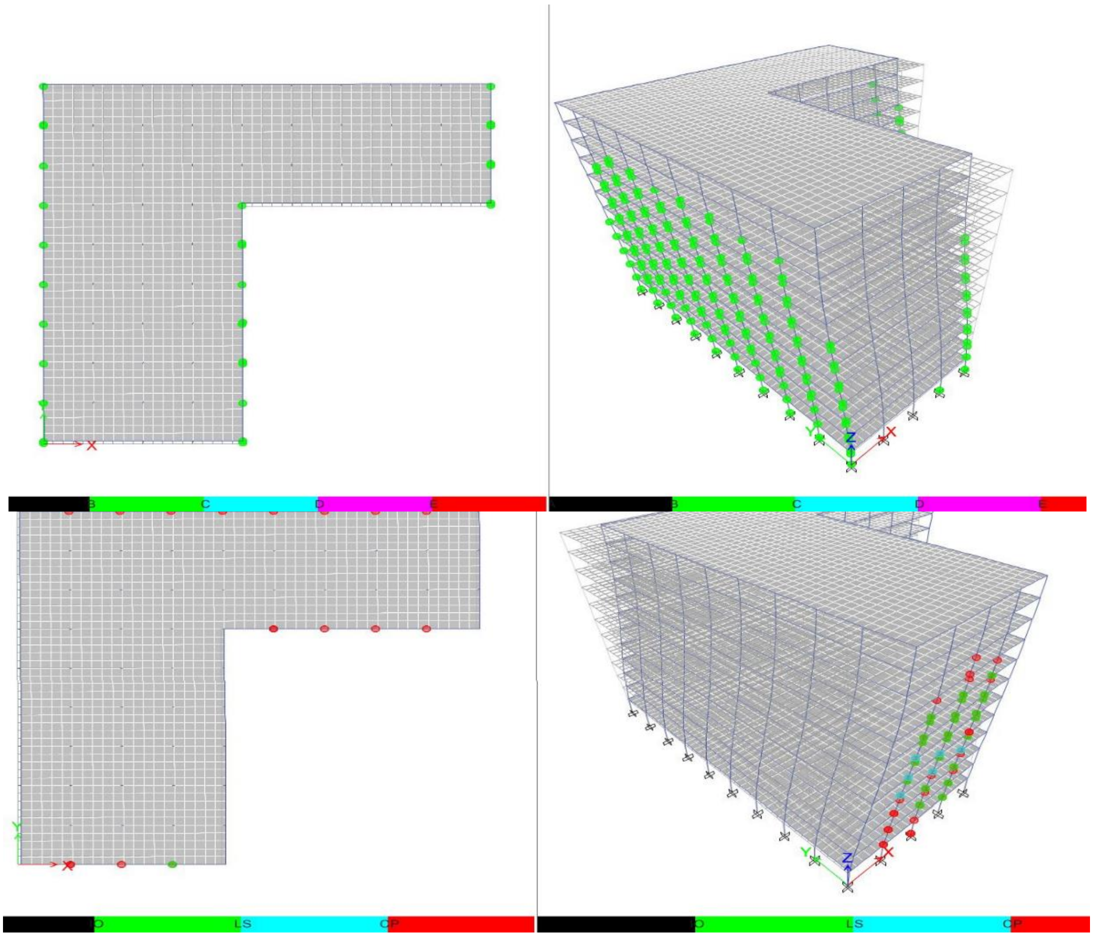


Fig 4: Hinge formations for undamaged structure pushed in X direction.



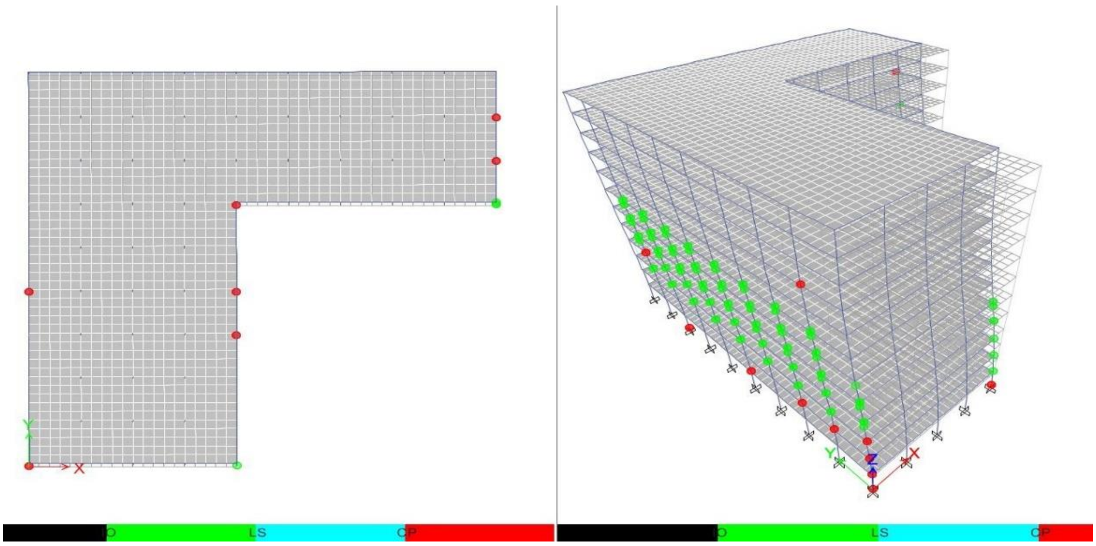


Fig 5: Hinge formations for undamaged structure pushed in Y direction.

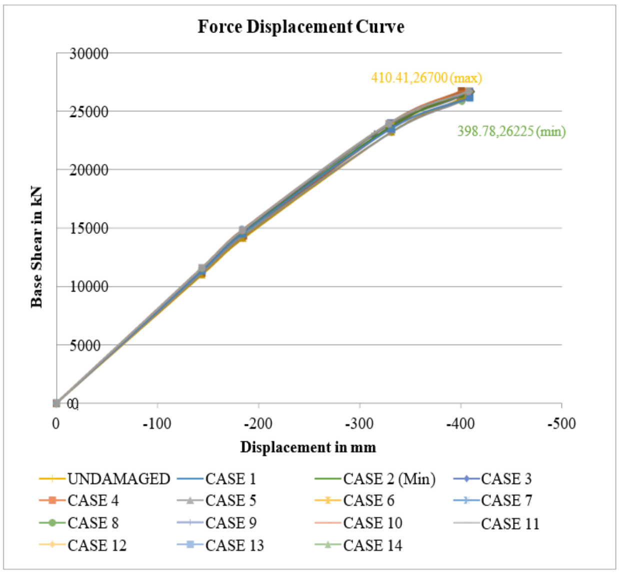


Chart 1: Pushover curve for undamaged and 14 column removal cases, pushed in -X direction

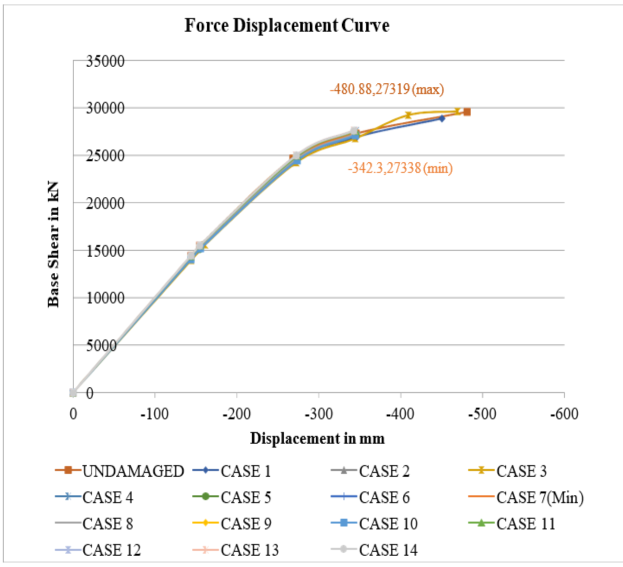


Chart 2: Pushover curve for undamaged and 14 column removal cases, pushed in -Y direction

VIII. CONCLUSION

i. During pushover analysis, when the loadings increase iteratively the number of plastic hinges developed increases and finally reaches the collapse stage. With each column removal case, performance level decreases with minimum difference. The maximum displacements increase in each storey with the subsequent column removal case.

ii. For undamaged structure pushed in X direction, Peripheral columns Parallel to X-axis are forming hinges beyond CP. So, these columns need to be strengthened to prevent possible initiation of the progressive collapse.

iii. Column C35, C25, C50, C60 and C20 (Parallel to Y-axis) are get more damaged when the structure is pushed in Y direction. So, to prevent possible commencement of the progressive collapse, the above-mentioned damaged columns need to be strengthened.

iv. In the case of the removal of column, it is observed that when the building is pushed in X direction, case 2 is found to be critical because of least displacement compared to the other cases, whereas when the building is pushed in Y direction, case 7 is found to be critical.

v. When the building is pushed in X direction, for the removal of exterior columns, case 2 is having minimum displacement compared to the other cases because columns are going to be failed earlier in this case and hence case 2 is the critical case. Case 9 happens to be critical for push in Y direction.

vi. Columns are going to get damaged in the removal of interior columns, when the building is pushed in both X and Y directions. Hence case13 prove to be the critical case in both the directions.

vii. Columns are going to get damaged in the removal of corner columns, when the building is pushed in both X and Y directions, case7 seen to be the critical case in both the directions.

viii. From the results it can be observed that the reduction percentage of storey stiffness is maximum in case2 when the earthquake applied in X-direction and case7 has a maximum when the earthquake applied in Y-direction. And also seen that case2 has a maximum displacement in earthquake applied in X-direction and case7 has a maximum displacement in earthquake applied in Y-direction.

ix. From results we can conclude that performance of building is same in +X and –X direction that is case2 critical similarly, case7 is critical in both +Y and –Y.

x. From results we conclude that, when building is pushed in X direction performance is good compared to Y direction. Because of 5 number bays resist in Push-X direction while 4 number of bays to resist in Push-Y direction.

REFERENCES:

1. N,Gururaja B, R Sridhar -Comparative study of progressive collapse analysis of flat slab building with and without shear wall - International Journal of Research in Engineering and Technology ISSN: 2319-1163, volume 5,(2014).
2. Chiral Modi, Jasmin Gadhiya, Aditya Bhatt -Nonlinear static analysis of multi storey building by using SAP2000- International Journal of Advance Engineering and Research Development, ISSN 2348- 4470, Volume 3, Issue 12, December 2016
3. R.Jeyanthi., and S.Mohan kumar,- Progressive Collapse Analysis of a Multistory RCC building using Pushover

Analysis, International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Volume-5, Issue- 03(2017).

4. Ruchika Mishra., and Sima Padamwar - Progressive Collapse analysis on Reinforced Concrete Structures, Indian Journal Science and Research, ISSN: 2250-0138, Volume-14, 323-326 (2017).
5. Eshwar Kuncham., and Venkata Dilip Kumar Pasupuleti - Progressive Collapse Analysis of Two-dimensional Reinforced Concrete Framed Structure, International Journal of Engineering Research & Technology (IJERT), Volume-3, Issue- 02(2019).
6. Bureau of Indian Standards: IS-875, part 1 (1987), for dead loads on buildings and Structures, New Delhi, India.
7. Bureau of Indian Standards: IS-875, part 2 (1987), for live loads on buildings and Structures, New Delhi, India.
8. Bureau of Indian Standards: IS-1893, part 1 (2002), "Criteria for earthquake resistant".
9. Design of structures: Part 1 General provisions and buildings", New Delhi, India.
10. Indian Standard, IS 456-2000 "Code of Practice for Plain and Reinforced Concrete", BIS, New Delhi, India.
11. GSA Alternate Path Analysis and Design Guidelines for Progressive Collapse Resistance October 24, 2013.