

**PUSHOVER ANALYSIS OF PLAN IRREGULAR RC BUILDINGS WITH  
SOFT STORY USING SPECIAL SHAPED COLUMNS**<sup>1</sup>Anju Nayas, <sup>2</sup>Minu Antony<sup>1</sup>Civil Engineering Department, Saintgits College of Engineering, Kottayam, India<sup>2</sup>Assistant Professor, Civil Engineering Department, Saintgits College of Engineering, Kottayam, India

**Abstract**— Irregular buildings constitute a major portion of the modern urban infrastructure. The group of people involved in constructing the building facilities, including owner, architect, structural engineer, contractor and local authorities, come up with the overall planning, selection of structural system, and its configuration. This may lead to building structures with irregularities in their mass, stiffness and strength along the height of building. When such buildings are located in a seismically active area, the structural engineer's role becomes more challenging. The analysis of the seismic response of irregular buildings is complex due to nonlinear and inelastic response and more difficult than that of regular buildings. Therefore, the structural engineer needs to have a complete understanding of the seismic response of irregular structures. The effect of shape of column and orientation of column will have a major influence on the structure when the structure is subjected to a lateral load such as earthquake load .

The objective of this study is to carry out nonlinear static analysis of plan irregular RC frame with vertical irregularity in the form of soft story using special shaped columns. This study also finds out which plan irregular building is the most effective in resisting lateral loads. The software used for modelling and analysis is ETABS 2015.

**Index terms**—Special columns, Base shear, Soft story, ETABS 2015

**I. INTRODUCTION**

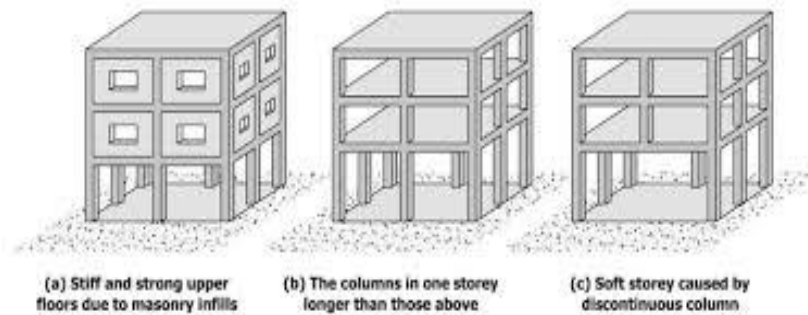
Earthquakes are the most unpredictable and devastating of all natural disasters, which are very difficult to save over engineering properties and life. Hence in order to overcome these issues we need to identify the seismic performance of the built environment through the development of various analytical procedures, which ensure the structures to withstand frequent minor earthquakes and produce enough caution whenever subjected to major earthquakes, so that can save as many lives as possible. There are several guidelines all over the world which has been repeatedly updating on this topic. The behavior of a building during an earthquake depends on several factors, stiffness, and adequate lateral strength, and ductility, simple and regular configurations. The buildings with regular geometry and uniformly distributed mass and stiffness in plan as well as in elevation suffer much less damage when compared to buildings with irregular configurations. But nowadays the need and demand of the latest generation and growing population has made the architects and engineers inevitable towards planning of irregular configurations. Hence earthquake engineering has developed the key issues in evaluating the role of building configurations. One such development is the provision of special columns in buildings. Some special shapes of columns are L-shaped, Tee- shaped and cross (+) shaped which are not commonly used but gives more indoor space than commonly used shapes of column. Special shaped columns avoid prominent corners in a room which increases the usable floor area.

**Research Significance**

The plan irregularity can be defined as per IS 1893-2002, that plan configurations of a structure and its lateral force resisting system contain re-entrant corners, where both projections of the structure beyond the re-entrant corner are greater than 15 percent of its plan dimension in the given direction. Buildings with large re-entrant corners, (i.e., plan shapes such as L, V, +, Y, etc.) show poor performance during seismic events. Each wing of such a building tends to vibrate as per its own dynamic characteristics, causing a stress concentration at the junctions of the wings. So these buildings are unsafe in seismically active areas. This study aims to create awareness about these issues in earthquake resistant design of multi-storied buildings.

**STIFFNESS IRREGULARITY (SOFT STORY)**

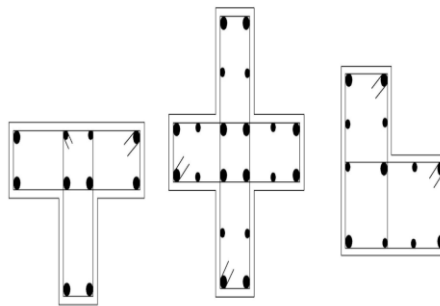
A soft story is one in which the lateral stiffness is less than 70% of that in the story above or less than 80% of the average lateral stiffness of the three stories above. Figure 1 shows soft story.



**Figure 1: Soft story**

#### SPECIAL COLUMNS

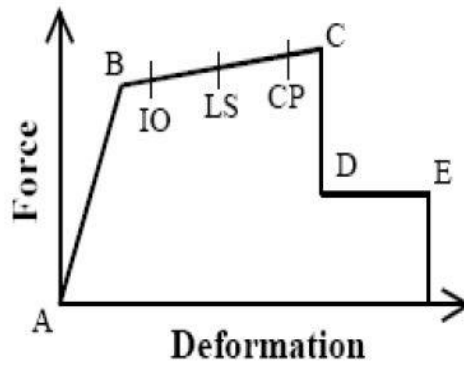
Special-shaped columns are those in which the column section is L-shaped, Tee-shaped or crisscross-shaped as shown in figure 2. In recent years, special-shaped columns won the national attention and love of the owners and engineers because of its equal thickness of columns and wall, excellent architectural appearance and high room rate. In 2006, Ministry of Construction of the People's Republic of China has issued "Technical specification for concrete structures with specially shaped columns" (JGJ149-2006), which has been implemented since August 1, 2006. Accordingly, there have been a lot of research on ordinary reinforced concrete (RC) frame structure with special-shaped column, and this type of the structure has received quite extensive application because of its great architectural functions and pleasing appearance. Therefore special columns can be provided in re-entrant corners of plan irregular buildings.



**Figure 2: Special Columns**

#### NONLINEAR STATIC PUSHOVER ANALYSIS

The guidelines and standards mentioned in the introduction include modelling procedures, acceptance criteria and analysis procedures for pushover analysis. These documents explain the force-deformation criteria for potential locations of lumped inelastic behaviour, represented as plastic hinges used in pushover analysis. As shown in Figure 5 below, five points labelled A, B, C, D, and E are used to define the force deformation behaviour of the plastic hinge, and the three points labelled as IO (Immediate Occupancy), LS (Life Safety) and CP (Collapse Prevention) are used to define the acceptance criteria for the hinge. In these documents, if all the members meet the acceptance criteria for a particular performance level, such as Life Safety, then the entire structure is supposed to achieve the Life Safety level of performance. The values given to each of these points vary depending on the type of member as well as many other parameters, such as the expected type of failure, the level of stresses with respect to the strength, and code compliance. Fig-3: Force-Deformation Relation for Plastic Hinge in Pushover Analysis Both ATC-40 and FEMA 356 documents present similar performance-based engineering methods that rely on nonlinear static analysis procedures for prediction of structural demands. While procedures in both documents involve generation of a "pushover" curve to predict the inelastic force-deformation behaviour of the structure, the technique used to calculate the global inelastic displacement demand for a given seismic ground motion differs. The FEMA 356 document uses the Coefficient Method, whereby displacement demand is calculated by modifying elastic predictions of displacement demand. ASCE-41-13 NSP is an improvement over FEMA 356 which is the displacement coefficient method whereas the ATC-40 Report details the Capacity-Spectrum Method, in which the modal displacement demand is determined from the intersection of a capacity curve, derived from the pushover curve, with a demand curve consisting of a smoothed response spectrum representing the design ground motion, modified to account for hysteretic damping effects.



**Fig-3: Force-Deformation Relation for Plastic Hinge in Pushover Analysis**

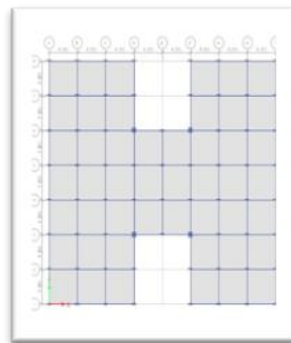
## **II. OBJECTIVES OF PRESENT STUDY**

- To perform nonlinear static analysis of different plan irregular buildings with soft story conforming to IS 1893:2001(Part 2).
- To study and compare base shear capacity of different buildings under consideration.
- To find out the best plan irregular configuration and best column which can resist earthquake forces.

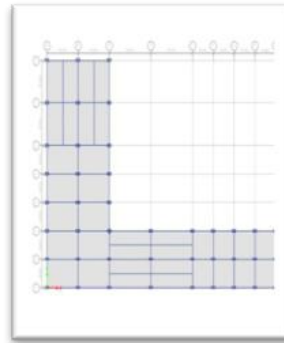
## **III. MODELLING OF BUILDINGS**

The study is carried out on a (G+19) building having different plan irregular configurations. The plan irregularities considered are H, L and Tee shape configurations. The buildings are considered to be located in Zone III as per IS 1893:2002. The building is modeled using the software ETABS 2015. The dimensions of the beams, columns and slabs, the loads applied and other details are summarized in Table1.

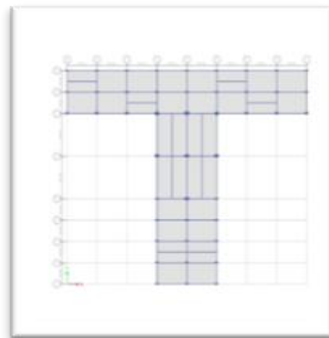
### **CONFIGURATIONS OF PLAN IRREGULARITY CHOSEN**



**Model 1**



**Model 2**



**Model 3**

Table 1:Details and dimensions of building models

|                             |                                                    |
|-----------------------------|----------------------------------------------------|
| Type of structure           | Ordinary moment resisting RC frame                 |
| Grade of concrete           | M40                                                |
| Grade of steel              | Fe 415                                             |
| Plan area                   | 896 m <sup>2</sup>                                 |
| Floor height                | 3 m                                                |
| Bottom story height         | 4m                                                 |
| Beam size                   | 230x600mm<br>230x500mm<br>300x700mm<br>250x700mm   |
| Column size                 | 230x600mm<br>600x900mm<br>450x800mm                |
| Tee shape column            | B=D=750mm<br>t <sub>f</sub> =t <sub>w</sub> =200mm |
| L shape column              | B=D=750mm<br>Thickness-200mm                       |
| Cross shape column          | B=D=750mm<br>t <sub>f</sub> =t <sub>w</sub> =200mm |
| Slab thickness              | 150 mm                                             |
| Live load on floor and roof | 3kN/m <sup>2</sup> and 1.5kN/m <sup>2</sup>        |
| Plan irregularity           | H,L and T                                          |

#### IV. ANALYSIS

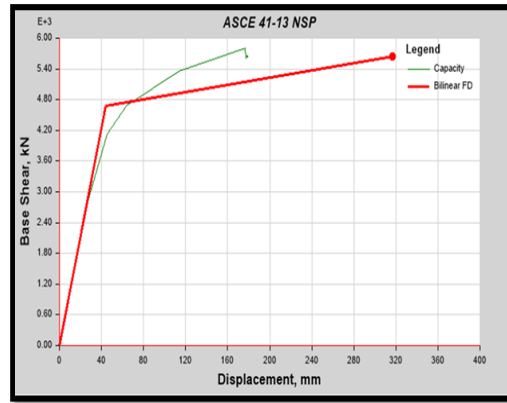
Pushover analysis is carried out on models considering both plan and stiffness irregularity. After assigning the loads to the structure, pushover analysis is done to evaluate the base shear obtained from performance point of pushover curve. After the analysis the behaviour of the buildings are compared in terms of base shear.

#### PUSHOVER METHODOLOGY

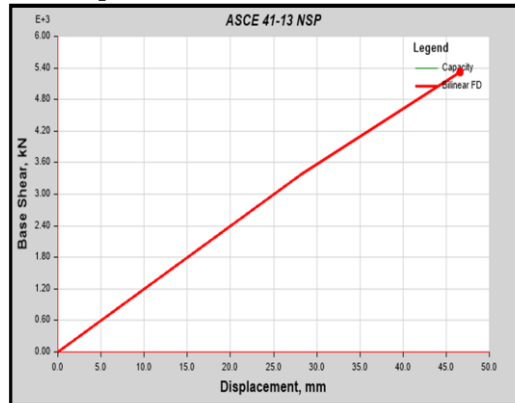
A pushover analysis is performed by subjecting a structure to a monotonically increasing pattern of lateral loads which is representing the inertia forces which would be experienced by the structure when subjected to seismic ground shaking. Under incrementally increasing loads numerous structural elements may yield sequentially. Consequently, at each event, the structure experiences a loss in stiffness. Using this nonlinear static analysis so called pushover analysis, a characteristic non-linear force displacement relationship can be accurately determined. The maximum base shear that the structure can resist is obtained from the performance point. In this paper ASCE-41-13 displacement coefficient method is used. Analysis were done in X direction.

#### V. RESULTS AND DISCUSSIONS.

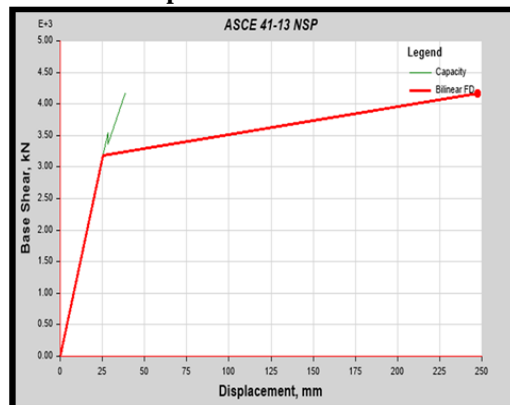
- 1) Pushover analysis of plan irregularity H shape having soft story with special columns are obtained from ETABS 2015 and the pushover curve indicating the performance point are presented below:



**H shape model with cross column**

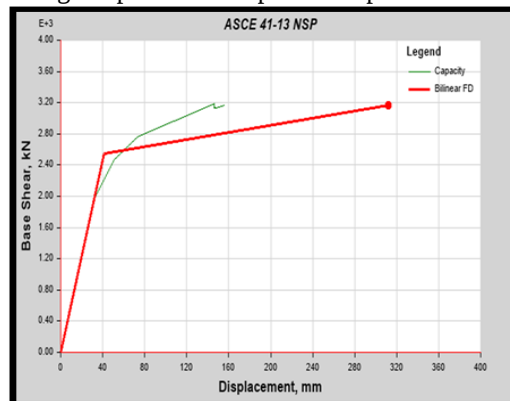


**H shape model with L column**

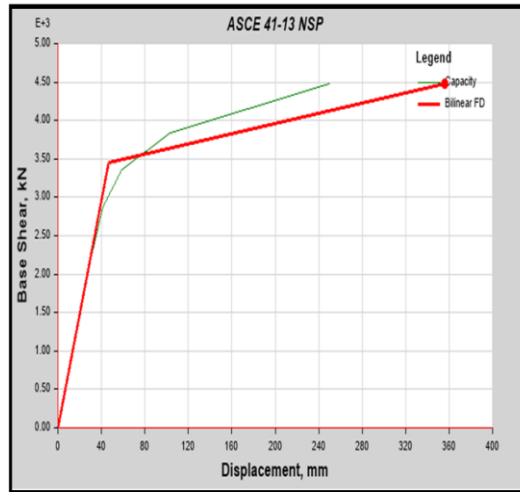


**H shape model with Tee column**

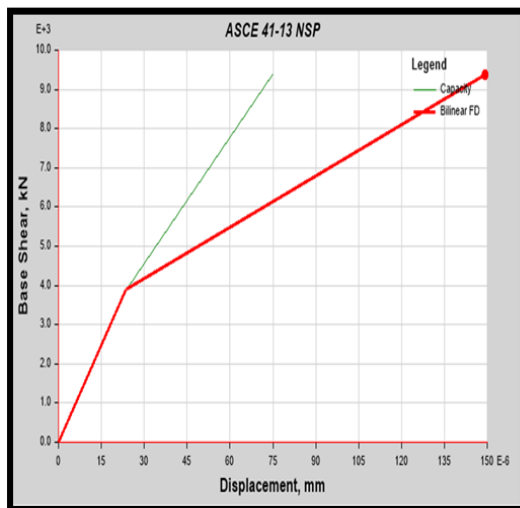
- 2) Pushover analysis of plan irregularity L shape having soft story with special columns are obtained from ETABS 2015 and the pushover curve indicating the performance point are presented below:



**L shape model with cross column**

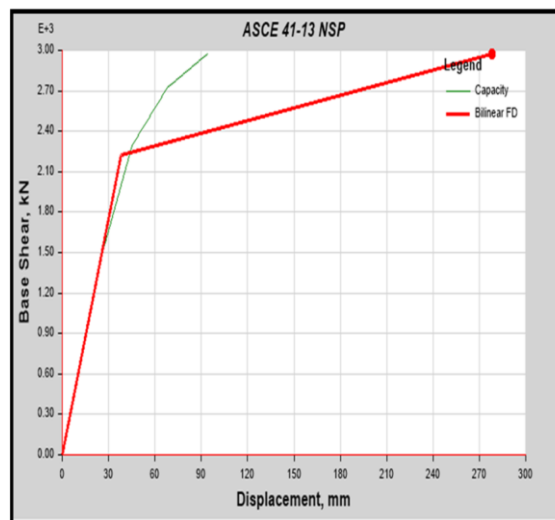


**L shape model with L column**

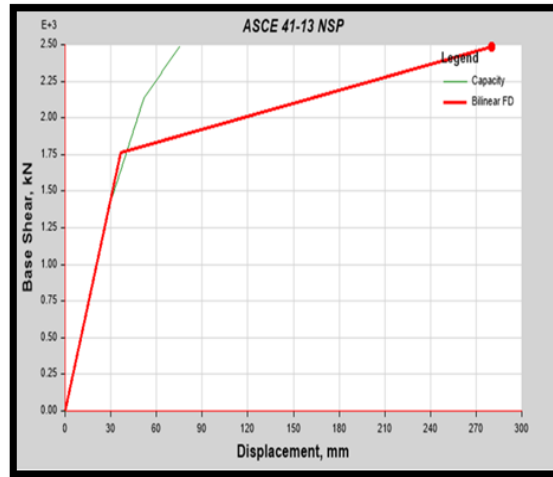


**L shape model with Tee column**

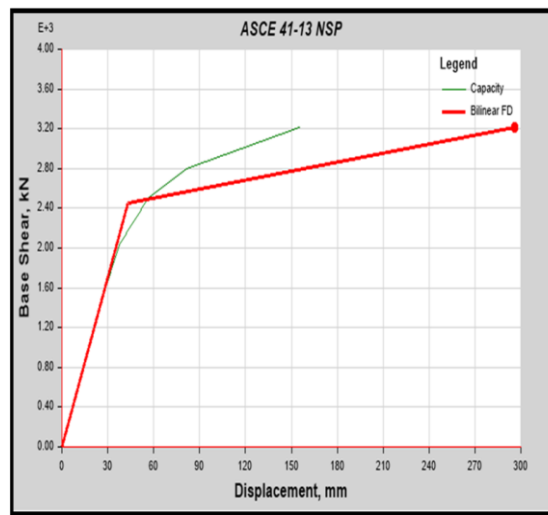
- 3) Pushover analysis of plan irregularity Tee shape having soft story with special columns are obtained from ETABS 2015 and the pushover curve indicating the performance point are presented below:



**Tee shape model with cross column**



**Tee shape model with L column**

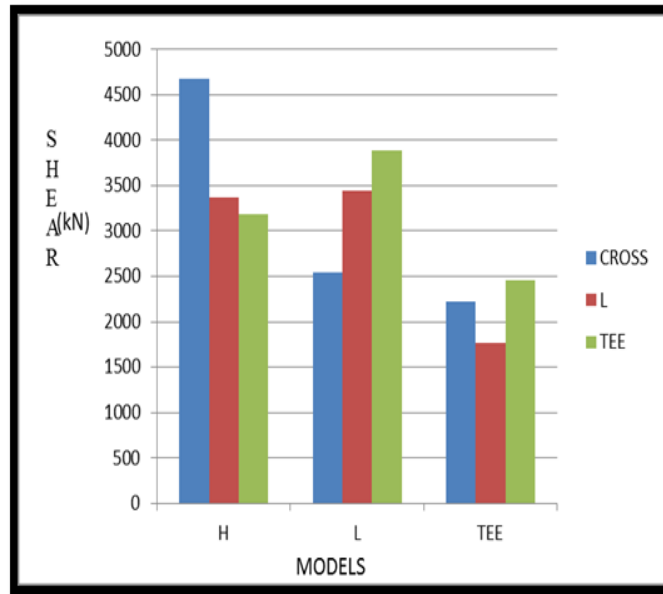


**Tee shape model with Tee column**

Table 2 shows performance point base shears of all models with special shaped columns. Comparison of models were done in terms of base shear in order to determine which model is effective in resisting lateral loads.

Table 2 : Base shear from Performance Point

| PERFORMANCE POINT BASE SHEAR |              |             |
|------------------------------|--------------|-------------|
| H Model                      | Cross Column | 4674.749 kN |
|                              | L column     | 3368.944 kN |
|                              | Tee Column   | 3190.833 kN |
| L Model                      | Cross Column | 2542.854 kN |
|                              | L column     | 3446.990 kN |
|                              | Tee Column   | 3884.389 kN |
| Tee Model                    | Cross Column | 2219.131 kN |
|                              | L column     | 1764.408 kN |
|                              | Tee Column   | 2454.346 kN |



## VI. CONCLUSIONS

The main conclusions obtained from the analysis are summarized below:

1. When earthquake load is applied in X direction the base shear capacity was maximum for H model with cross column, i.e cross column has 27.93% more base shear capacity than L and 31.74% than Tee column.
2. Base shear capacity will be least for Tee shaped building so this shape of structure should be avoided in earthquake prone areas.
3. The base shear capacity of L shaped building is increased by providing Tee shaped column in the re entrant corners , i.e Tee column has 34.53% more base shear capacity than cross column and 11.26% more base shear capacity than L column.

## ACKNOWLEDGMENT

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## REFERENCES

- [1] Sumayya M Kareem, Linda Ann Mathew, " Seismic Analysis of Space Frame with T and Square Shaped Column", *"International Journal of Science and Research (IJSR)" Volume 5 Issue 7, July 2016.*
- [2] Shrutig. Agrawal Dr. P. S. Pajgade "Response of Different Shapes of Columns on RC Buildings with and without Shear walls," *"International Journal of Innovative and Emerging Research in Engineering" Volume 3, Special Issue 1, ICSTSD 2016.*
- [3] Adiya N. Gumble, Dr. Prakash S. Pajgade, "Comparison Between Specially Shaped Columns And Rectangular Columns In R.C. Structure" , *" International Journal of Advance Engineering and Research Development" Volume 2, Issue 5, May -2015.*
- [4] Ami A. Shah, B. A. Shah , "Seismic Evaluation of RC Space Frame With Rectangular and Equivalent Square Column By Pushover Analysis" *International Journal of Research in Engineering and Technology volume: 03 issue: 07, July 2014.*

- [5] Govind M, Kiran K. Shetty, K. Anil Hegde, "Non Linear Static Pushover Analysis of Irregular Space Frame Structure With and Without T Shaped Columns" "*International Journal of Research in Engineering and Technology*" volume: 03 special issue: 03, May 2014.
- [6] Fabio Mazza, "Modelling and nonlinear static analysis of reinforced concrete framed buildings irregular in plan", *Engineering structures* 80(2014) 98-108, [www.elsevier.com](http://www.elsevier.com).
- [7] Pu Yang, Hongxing Liu and ZongmingHaung (2008) "A comparison of seismic behavior between specially shaped column frame structure and rectangular column frame structures. *The 14th World Conference on Earthquake Engineering*, October 12-17, 2008, Beijing, China
- [8] IS 1893 (Part 1): 2002 Indian Standard Criteria for Earthquake Resistant Design of Structures, Part 1 General Provisions and Buildings, (Fifth Revision)