

# Seismic Performance Evaluation of Setback Building with Open Ground Storey

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## Abstract

This study investigates the performance of the setback building with open ground storey using nonlinear static pushover analysis. Such type of building possess vertical geometric and mass irregularity as well as stiffness irregularity. In this paper, plan irregular setback building with open ground storey resting on plain and sloping ground which makes the building so weak to survive during earthquake. An attempt has made to alleviate effects of these irregularities during earthquake by replacing OGS columns by Reinforced concrete filled steel tube columns. RCFST columns increases the stiffness of the OGS which offset the soft storey effect as well as reduce storey displacement, drift and torsional response significantly. From hinges results, it can be observed that performance of the building is improved significantly.

**Keyword-** Setback Building, Soft Storey, Pushover Analysis, Irregularity, RCFST Column, ETABS Etc.

## I. INTRODUCTION

Modernization in urban architecture lead to construction of Setback buildings for better aesthetics and functionality. These buildings are often constructed on sloping ground of hill station to extract the natural beauty of mountains. Open ground storey buildings are very common in India and many other countries. OGS buildings had shown very poor performance during past earthquake especially in Himalayan region. Setback building with OGS possess vertical geometric and mass irregularity as well as stiffness irregularity. These buildings are often irregular in plan which also creates plan irregularity. Buildings with combination of irregularity rests on sloping ground suffer devastating damage during earthquake. It is very necessary to understand the behaviour of these buildings and take suitable measure for collapse prevention.

Seismic fragility of OGS frames found higher than the fully infilled and bare frames because columns in ground storey had lack adequate ductility, stiffness, and strength required to resist high storey shear.[1] Existence of a soft storey at a specified level highly magnifies storey drift at that level.[2] Many preventive techniques are found to reduce the soft storey effect such as provision of extra columns at alternate bays and Lateral buttresses in open ground storey[3] Provision of eccentric bracings in OGS had shown lower drift in open ground storey and probability of collapse.[4] Reinforced concrete filled steel tube columns are used as mitigation measures of soft storey effect of regular shape setback building with OGS configuration[5]. Indian seismic code suggested several preventive measure from soft storey effect which is given in cl.7.10 of IS 1893:2016 (Part-I). In this clause, provision of RC structural wall (commonly known as Shear wall) and bracings in selected bays are suggested as preventive measures from soft storey effect. But RC structural walls and bracings may reduce the functional efficiency if it is provided on periphery of the building. In present study, attempt has made to mitigate the effects caused by various irregularity during earthquake using RCFST columns provided in open ground storey.

## II. OBJECTIVE OF STUDY

Large amount of residential building stock of India consists of some kind of irregularities. Thus, it is very important to investigate open ground storey setback G+4 buildings with RCFST columns as mitigation measures using nonlinear static pushover analysis in ETABS v17. Various parameters under study are Base shear and Displacement at performance point, Safety ratio, Ductility ratio, Location of hinges and Pushover curve. This study will help the society by providing safe and efficient solution to problems in buildings and ensuring the safety of inhabitants during earthquake.

### III. METHODOLOGY

#### A. Details of Building Models

Eight different models are prepared namely T and L shaped G+4 RC Setback building model resting on plain and sloping ground with two different configuration such as open ground storey (OGS) and model with RCFST columns in OGS. Notations of various models are shown in Table 1

Models on Plain ground		Models on Sloping ground	
T shape building with OGS	TP1	T shape building with OGS	TS1
T shape building with RCFSTC	TP2	T shape building with RCFSTC	TS2
L shape building with OGS	LP1	T shape building with OGS	LS1
L shape building with RCFSTC	LP2	T shape building with RCFSTC	LS2

Table 1: Notation of Various Models

Slope angle is kept as 45 degree with horizontal. Setback is provided on fourth and fifth storey. Infill walls are provided in the building in all the storeys except ground storey. Square shaped columns are used to avoid the effects of orientation of columns in this study. Infill walls are modelled as equivalent diagonal strut using macro modelling approach because it is easy to model and analysis process becomes faster with good accuracy.[5] Base of each columns is restrained all degrees of freedom, i.e. fixed support condition. Rigid diaphragm is applied to make all the structural elements act as a single unit. Each bay length is taken 3m. storey height is 3m. Plan of buildings are shown in Figure 1.

#### B. Material and Section Properties

Unit weight of concrete: 25 kN/m<sup>3</sup>, Unit weight of Infill walls: 21.2068 kN/m<sup>3</sup>, characteristic strength of concrete: 30 MPa, characteristic strength of steel: 415 MPa, compressive strength of masonry walls: 4.1 MPa, modulus of elasticity of masonry walls: 2300 MPa, characteristic strength of steel tube: 345 Mpa.

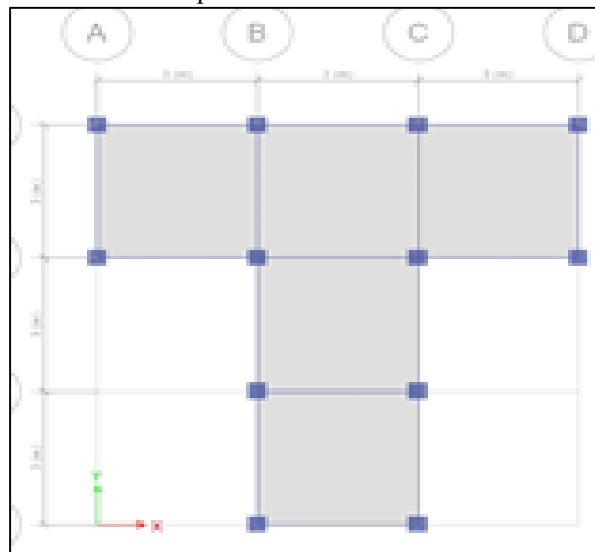


Fig. 1: Plan of building models

#### C. Seismic Design Data and Various Loads

Zone factor (Z): 0.36, soil type: medium soil, damping ratio: 5%, frame type: special moment-resisting frame (SMRF), Response reduction factor (R): 5, and importance factor (I): 1. The types of load considered during the design are dead loads of beams, columns, slab, wall weight (WL), live load of 3 kN/m<sup>2</sup> at floors and 1.5 kN/m<sup>2</sup> at roof, mass source (1.0DL+1.0 WL+0.25 LL).

### IV. ANALYSIS METHODS

All models are analysed using nonlinear static pushover analysis in ETABS v17. In this study, buildings possess various irregularities so it is necessary to analyse it using nonlinear analysis. Pushover analysis is more practical and provide better estimate of seismic performance of the structures. In Infill wall modelling, double equivalent diagonal struts are modelled such that tension is not developed as they are designed as compression members.

#### A. Equivalent Static Analysis

For equivalent static force analysis, natural period of building is calculated as described in IS 1893:2016 (Part-I). Design seismic base shear calculations and its distribution along height is also done as per code.[6] Seismic weight is calculated using full dead load and 25% of live load. Design was carried out as per default load combination provided by ETABS software.

### B. Pushover Analysis

The pushover analysis consists of application of gravity load and specific lateral load pattern. Two load cases are used in which first nonlinear static load case for gravity load under load control and start from zero initial condition. In second nonlinear static load case monotonically increasing lateral load pattern under displacement control specified to start from final condition of first load case. Here lateral load pattern applied is obtained from Equivalent static analysis. P-delta effects also considered during pushover analysis. Section property modifiers are assigned to beam and column. The value for reduction factor for MI for beam element is taken as 0.35 and for column element it is taken as 0.7. Section modifiers are assigned to beams and columns to take care of cracked section while carrying out pushover analysis. [7]

### C. Modelling of Plastic Hinges

The pushover analysis is carried out by using default hinges provided in ETABS as per ASCE 41-13. M3 hinges for beam and PM2M3 hinges for columns are provided. Auto Fibre PM2M3 hinges are provided in RCFST columns. Where M3= rotational hinge about major/stronger axis, M2= rotational hinge about minor axis, P= compression hinge.

### D. Performance Levels

In Figure 2 five points labelled A, B, C, D and E define force–deformation behaviour of a plastic hinge. The values assigned to each of these points vary depending on type of element, material properties, longitudinal and transverse steel content, and axial load level on the element.[8] These are immediate occupancy (IO), life safety (LS) and collapse prevention (CP). IO defines the beginning of the behaviour beyond elasticity; LS defines the limit of the behaviour beyond elasticity that the section is capable of safely ensuring the strength; and CP defines the limit of the behaviour before collapsing.[9]

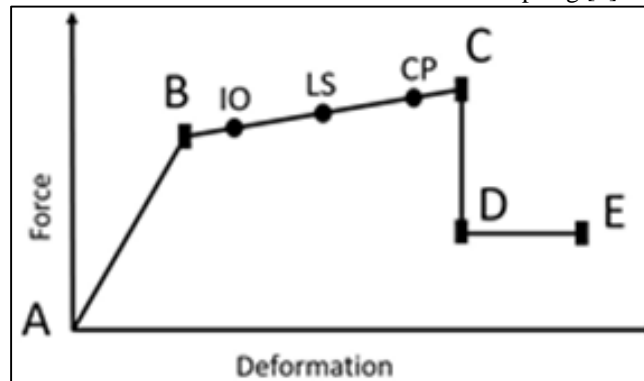


Fig. 2: Force - deformation relationship of a typical plastic hinge (FEMA-356)

## V. RESULTS AND DISCUSSION

After analysing eight different models using pushover analysis. Following results are obtained which are discussed in this section.

### A. Base Shear and Displacement at Performance Point

Model	Base Shear at Performance point (kN)	Displacement at PP. (mm)	Design Base shear (kN)	Safety ratio (SR)
TP1	703.32	13.96	469.94	1.49
TP2	1001.20	6.99	491.84	2.03
LP1	905.28	18.72	451.9	2.00
LP2	1445.37	11.64	473.8	3.05
TS1	549.51	9.88	313.73	1.75
TS2	1233.15	4.64	350.70	3.52
LS1	619.02	11.90	293.41	2.11
LS2	1056.98	5.48	322.64	3.27

Table 2: Base Shear and Displacement at PP and Safety Ratio

Performance point is obtained from intersection of demand curve and capacity curve. Base shear and roof displacement values at performance point are shown in Table 2. Here, displacements are found more in case of LP1 & LS1 than TP1 & TS1. Moreover displacement in TS1 & LS1 are found less which shows that setback step-back type of configuration may be suitable for the building on sloping ground.[10] It is observed that displacements of models with RCFST columns found very less.

### B. Safety Ratio

When safety ratio is more than unity, the structure is said to be safe. Safety ratio is a ratio of Base shear for demand earthquake and design base shear. This parameter is very important to be considered in seismic design. Table 2 shows safety ratio for different models.

From Table 2, it is observed that models are safe as safety ratio is more than unity. Increase in safety ratio is less in case of models resting on plain ground compared to sloping ground after replacing OGS columns by RCFST columns. Safety ratio is more for models on sloping ground than models plain ground.

### C. Ductility Ratio

Ductility ratio is a ratio of displacement corresponding to maximum base shear and displacement at yield point on pushover graph. This ratio gives the idea of ductility of the building with and without provision of RCFST columns in OGS. Ductility ratio is calculated and shown in Table 3. From Table 3, it can be stated that ductility ratio is found more for models on slope than those rest on plain ground. T shape model on plain ground shows increase in ductility ratio but L shape shows opposite behaviour. T shape models on slope shows decrease in ductility ratio whereas L shape shows a little increase in ductility.

### D. Number of Plastic Hinges, its Location and Performance Levels

Plastic hinge pattern shows damage distribution of structural elements in each story. For model TP1, one hinges are formed in ground storey columns between LS to CP performance levels and no hinges are formed beyond CP level.

Model	$\Delta_{max}$ (mm)	$\Delta_y$ (mm)	Ductility ratio (DR)
TP1	41.10	10.78	3.81
TP2	25.73	5.81	4.42
LP1	44.81	18.45	2.42
LP2	24.68	11.47	2.15
TS1	34.95	7.61	4.59
TS2	18.83	4.29	4.38
LS1	35.63	11.60	3.07
LS2	17.23	5.45	3.16

Table 3: Ductility Ratio

Two hinges are formed in OGS columns in LS-CP level whereas six hinges are formed in OGS which are beyond CP level. Which shows the greater probability of damage in OGS columns in TS1. For LP1 & LS1 two hinges are formed falling beyond CP levels. After replacing OGS columns by RCFST columns, No plastic hinges are formed. In LS2 & TS2 models hinges are formed at upper first floor on uphill side of slope and which crosses CP levels. Thus, it is recommended that those columns are also replaced by smaller section of RCFST columns.

### E. Pushover Curves

Pushover curves for all eight models are shown in Fig.3. It is observed that capacity of TP1, TS1, LP1 and LS1 has considerably increased by replacing OGS columns with RCFST columns. Models with RCFST columns shows greater base shear for corresponding displacement. So, this point should be taken into account while designing the building.

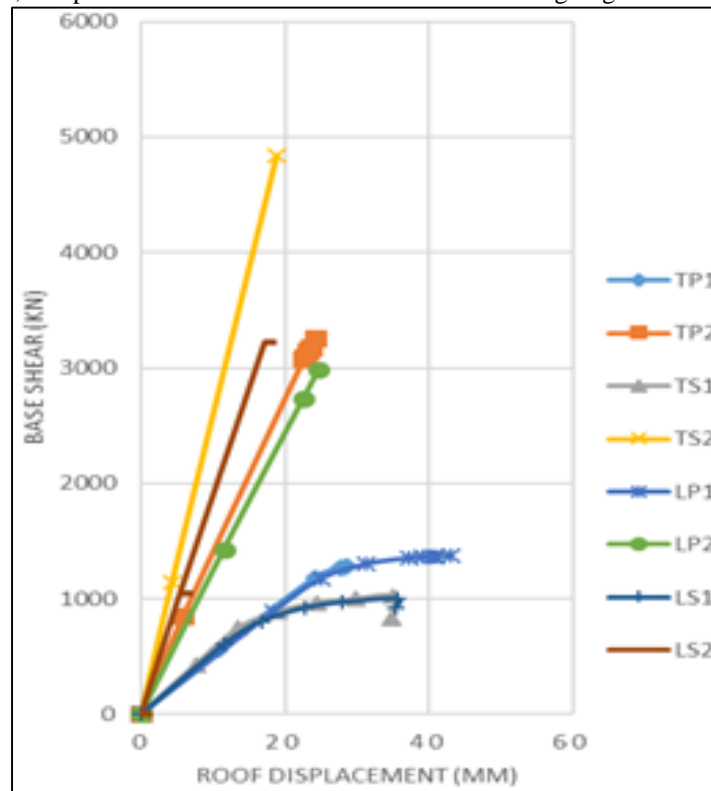


Fig. 3: Pushover curves for different models

## VI. CONCLUSIONS

- From the results discussed, it is concluded that building become safe after replacing OGS columns by RCFST columns.
- After replacing OGS columns by RCFST columns safety ratio is increased by 36% and 52.5% for T and L shape setback building resting on plain ground respectively.
- Moreover safety ratio is increased by 101.1% and 54.9% for T and L shape setback building resting on sloping ground respectively.
- After replacing OGS columns by RCFST columns ductility ratio is increased by 16% and 2.9% for T shape building on plain ground and L shape setback building resting on slope respectively and it is decreased by 11.2% in T shape building on plain ground and 4.6% in L shape setback building resting on sloping ground respectively.
- RCFST columns increase the stiffness and strength of the OGS which helps to improve the performance of the building during earthquake.
- Plastic hinge pattern shows that plastic hinges formed in OGS columns of OGS models do not satisfy the collapse prevention level. Whereas no hinges are formed in OGS columns in RCFST models.
- But models on sloping ground, plastic hinges are formed in upper storey columns of RCFST model on uphill side of slope. So smaller capacity RCFST column can be provided in place of those columns.
- Capacity curves shows that after replacing OGS columns by RCFST columns, capacity of the buildings has increased very much. Thus, capacity of the building can be reduced to achieve economy in design.
- Thus, reinforced concrete filled steel tube columns provided in open ground storey improve the performance of the plan irregular setback building under seismic events.

In future study, Pushover analysis can be carried out by reducing Beam and column sections by 10%, 20% like wise to reduce the capacity without compromising the performance of the building.

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