# Performance Based Analysis of Open Ground Storey

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***Abstract:***

*Soft storey is one of the main reasons for building damage during an earthquake and has been mentioned in all investigation report. Soft storey due to increase storey height is well known subject. Change in amount infill walls between stories also results in soft story. These are usually not considered as a part of load bearing system. This study investigates the soft storey behavior due to increase in storey height, of infill's at ground floor storey by means of linear static and nonlinear static analysis for midrise reinforced concrete building displacement capacity at immediate occupancy, life safety and collapse prevision, performance level and storey drift demands. Soft storey behavior due to change in infill's amount is evaluated in view of the displacement capacities, drift demand and structural behavior.*

**Keywords –** *Soft storey; linear analysis; Seismic zones; Equivalent diagonal strut.*

## I. INTRODUCTION

Due to increasing population since the past few years car parking space for residential apartments in populated cities is a matter of major concern. Hence the trend has been to utilize the ground storey of the building itself for parking. These types of buildings having no infill masonry walls in ground storey, but infilled in all upper storeys, are called Open Ground Storey (OGS) buildings.

There is significant advantage of these category of buildings functionally but from a seismic performance point of view such buildings are considered to have increased vulnerability. From the past earthquakes it was evident that the major type of failure that occurred in OGS buildings included snapping of lateral ties, crushing of core concrete, buckling of longitudinal reinforcement bars etc. Due to the presence of infill walls in the entire upper storey except for the ground storey makes the upper storeys much stiffer than the open ground storey. Thus, the upper storeys move almost together as a single block, and most of the horizontal displacement of the building occurs in the soft ground storey itself. In other words, this type of buildings sway back and forth like inverted pendulum during earthquake shaking, and hence the columns in the ground storey columns and beams are heavily stressed. Therefore it is required that the ground storey columns must have sufficient strength and adequate ductility. The vulnerability of this type of building is attributed to the sudden lowering of lateral stiffness and strength in ground storey, compared to upper storeys with infill walls.

The OGS framed building behaves differently as compared to a bare framed building (without any infill) or a fully infilled framed building under lateral load. A bare frame is much less stiff than a fully infilled frame. When this frame is fully infilled, truss action is introduced. A fully infilled frame shows less inter-storey drift, although it attracts higher base shear (due to increased stiffness). A fully infilled frame Inclusion of stiffness and strength of infill walls in the OGS building frame decreases the fundamental time period compared to a bare frame and consequently increases the base shear demand and the design forces in the ground storey beams and columns. This increased design forces in the ground storey beams and columns of the OGS buildings are not captured in the conventional bare frame analysis.

## II. EQUIVALENT DIAGONAL STRUT METHOD

In this method the infill is modeled as equivalent diagonal strut, having same thickness as infill but its effective width may depend upon number of factors. Table 1shows empirical expressions available for width of strut on the basis of studies conducted by various investigators.

**TABLE 1SHOWS EMPIRICAL EXPRESSIONS**

| Investigator | Formula |
|---|---|
| Stafford smith and Hendry (1963) | $w = 1/2\sqrt{(\alpha_h^2 + \alpha_L^2)}$ |
| Holmes (1963) | $w = d/3$ |
| Smith and Carter (1969) | $w = 0.58\left(\frac{l}{h}\right)^{-0.445} (\lambda H)^{0.335d\left(\frac{l}{h}\right)^{0.064}}$ |
| Mainstone, R.J. (1971) | $w = 0.175(\lambda_h H)^{-0.4} d$ |
| Bazan and Meli, R (1982) | $w = (0.35 + 0.22\beta)h$ |
| Liauw and Kwan (1984) | $W = \frac{0.95h\cos\theta}{\sqrt{\lambda H}}$ |
| Paulay, T and Priestly (1991) | $w = 0.25d$ |
| Angle, R (1994) | $w = d/8$ |

Where, W= effective width of strut
β= (Ec Ac)/ (Gm Am) is a dimensionless parameter
λ= contact length parameter
Ei = Modulus of elasticity of infill material
Ef = Modulus of elasticity of frame material
Ic= Moment of inertia of column
t = thickness of infill Fig 2.1 shows the variable h, d and ɵ

***A. Stafford smith and Hendry***

$W = \frac{1}{2} \text{ x } \sqrt{\alpha h^2 + \alpha l^2}$
$E_f$ = 25000 N/m2
Em = 25000 N/m2
t = 150mm

$Ic = \frac{bd^3}{12} = \frac{0.6 \times 0.6^3}{12} = 0.0108\text{m}^4$

$Ib = \frac{bd^3}{12} = \frac{0.2 \times 0.6^3}{12} = 0.0036\text{m}^4$

$\alpha h = \frac{\pi}{2}\left[\frac{Ef \times Ic \times h}{2 \times Em \times t \times \sin 2\theta}\right]^{\frac{1}{4}}$

$\alpha h = \frac{\pi}{2}\left[\frac{25000 \times 0.0108 \times 3.6}{2 \times 25000 \times 0.150 \times \sin 2 \times 31}\right]^{\frac{1}{4}}$

$\alpha h = 0.69\text{m}$

$\alpha l = \pi\left[\frac{Ef \times Ib \times l}{Em \times t \times \sin 2\theta}\right]^{\frac{1}{4}}$

$\alpha l = \pi\left[\frac{25000 \times 0.0036 \times 6}{25000 \times 0.150 \times \sin 2 \times 31}\right]^{\frac{1}{4}}$

$\alpha l = 0.84\text{m}$

$W = \frac{1}{2} \text{ x } \sqrt{0.69 \times 0.69 + 0.84 \times 0.84}$

W = 0.54m

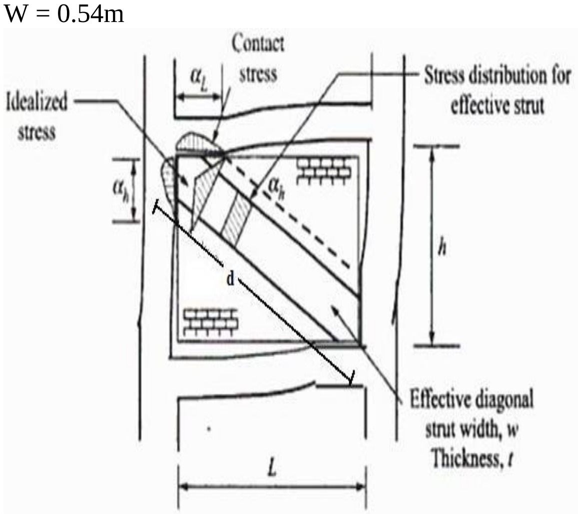


**Fig 1 Equivalent Diagonal Strut**

## III. IDEALIZATION OF STRUCTURE

To study the Seismic behavior of building structure while considering the effect of open ground storey, building frame is modeled as 3D space frame using standard two nodded frame element with two longitudinal degrees of freedom and one rotational degree of freedom at each node. At the interface of infill and frame, the infill element and the frame element are given same nodes.

The idealized form of a typical 5 bay x 2 bay 4 storey building frame with infill wall modeled as represented schematically in **Fig. 2** the present study also considers bare frame to see how correctly the influence of open ground storey on Seismic behavior can be predicted.

A 5 bay x 2 bay building frames with 4 storey's on isolated footing have been considered. The height of each storey is taken as 3.1 m. Thickness for roof and floor is taken as 120 mm and their corresponding dead load is directly applied on the beam. The brick infill with thickness 230 mm. All the above dimensions were arrived on the basis of the design following the respective Indian code for design of reinforced concrete structure. However, these design data are believed to be practicable and hence, do not affect the generality of the conclusion.

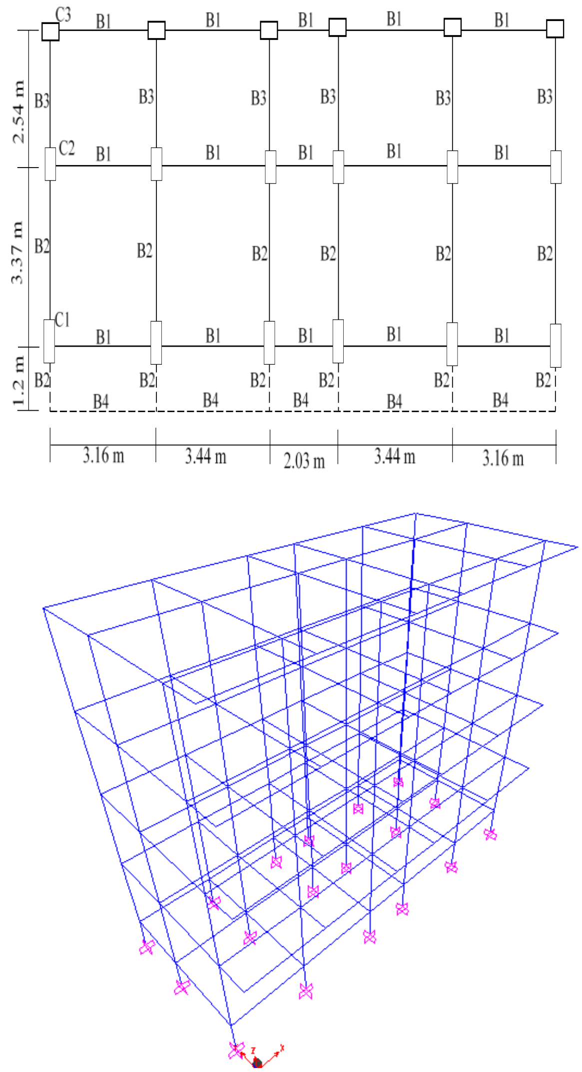


**Fig. 2 Plan and Elevation of Building**

### *A. Analysis of Typical Building*

The plan layout and elevation of G+3 storey building is shown in **Fig 3**. The building considered is analyzed for all seismic zones.

**Data**

1) Live Load = 3 kN/m2 at typical floor
2) Earthquake load = As per IS-1893(Part-1)-2002
3) Storey height = 3.1 m
4) Walls = 0.23 m thick
5) Slab thickness = 0.12 m
6) Density of concrete = 25 kN/m3
7) Density of brick = 20 kN/m3

TABLE 2 SECTION PROPERTIES

| **Columns** | **Size (mm)** | **Beams** | **Size (mm)** |
|---|---|---|---|
| C1 | 230 x 450 | B1 | 230 x 350 |
| C2 | 230 x 400 | B2 | 230 x 400 |
| C3 | 230 x 350 | B3 | 230 x 300 |
| | | B4 | 200 x 400 |

TABLE 3 PROPERTIES OF MATERIALS

| **Materials** | **Modulus of elasticity (kN/m$^2$)** | **Poisson's ratio** |
|---|---|---|
| Concrete M25 | 25 x $10^6$ | 0.2 |
| Masonry | 4.5 x $10^6$ | 0.19 |

## IV. PUSHOVER ANALYSIS FOR STRUCTURE (WITHOUT INFILL)

Pushover analysis is carried out for building models. First pushover analysis is done for the gravity loads (DL+LL) incrementally under load control. The lateral pushover analysis (PUSH-X) is followed after the gravity pushover, under displacement control. The building is pushed in lateral directions until the formation of collapse mechanism. The capacity curve (base shear versus roof displacement) is obtained in X-direction and presented in Fig. These figures clearly show that global stiffness of an open ground storey building hardly changes even if the stiffness of the infill walls is ignored. If there is no considerable change in the stiffness elastic base shear demand for the building will also not change considerably if the stiffness of the infill walls is ignored. The variation of pushover curves in X-directions is in agreement with the linear analysis results presented in the previous section with regard to the variation of elastic base shear demand for building models.

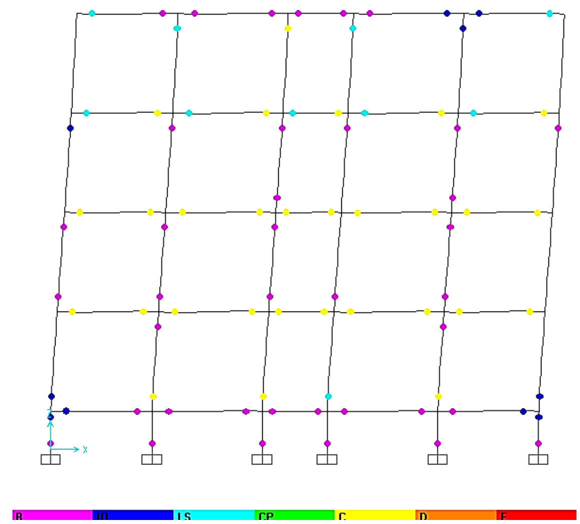

**Fig. 3Modelled without Infill Stiffness**

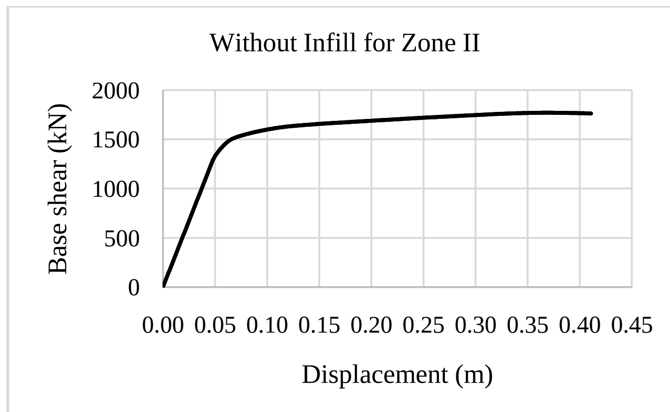


**Fig. 4 Pushover Curve of Structure without Infill for Zone II**

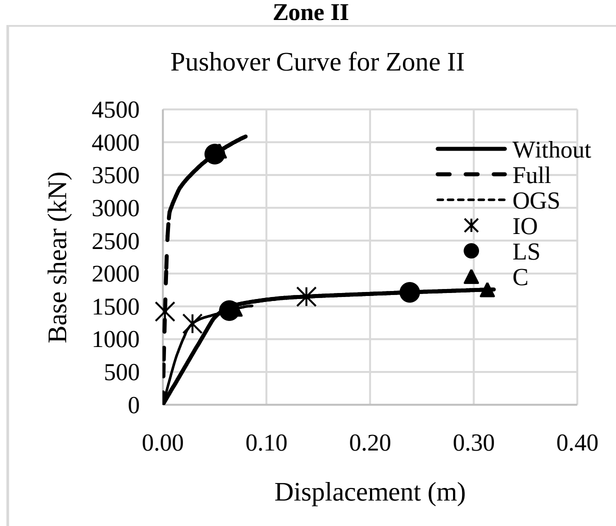


**Fig. 5 Pushover Curve Comparison for Zone II**

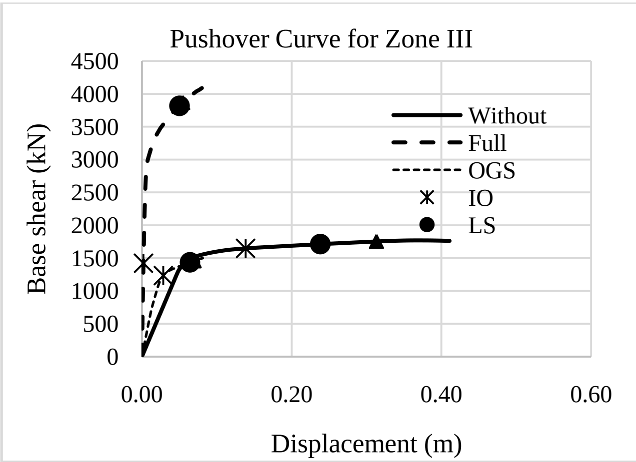


**Fig. 6 Pushover Curve Comparison for Zone III**

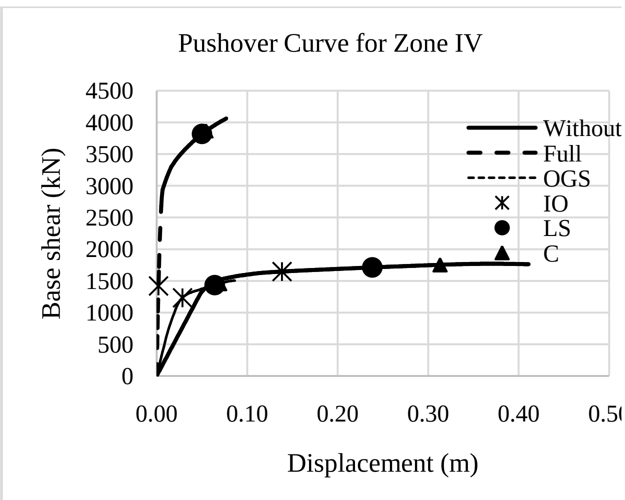


**Fig. 7 Pushover Curve Comparison for Zone IV**

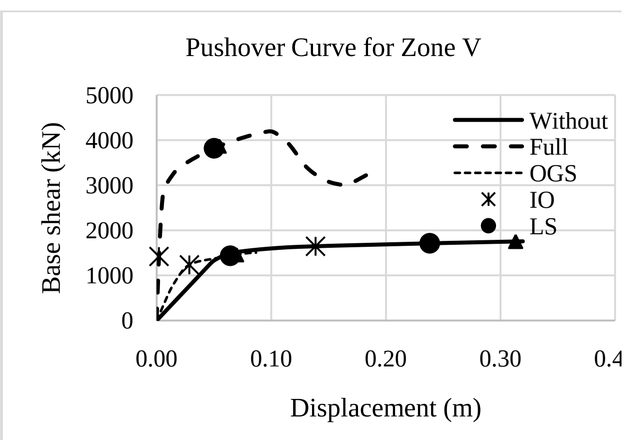


**Fig. 8 Pushover Curve Comparison for Zone V**

## V. CONCLUSIONS

Nonlinear static analyses of building models are carried out to compare the structure with and without infill. To check the deformation of the structure we locate the position of soft storey at ground floor level. Nonlinear static (pushover) analysis is carried out for all the building models considered. First pushover analysis is done for the gravity loads incrementally under load control. The lateral pushover analysis is followed after the gravity pushover, under displacement control for all zones.

Followings are the salient conclusions obtained from the present study

1. Stiffness of the structure is an important factor in case of OGS type building, in the present study infill can improve stiffness of structure but in to some extent, that is not enough to save structure against seismic effect.
2. Problem of OGS buildings cannot be identified properly through elastic analysis as the stiffness of OGS building and Bare-frame building are almost same.
3. Nonlinear analysis reveals that OGS building fails through a ground storey mechanism at a comparatively low base shear and displacement. And the mode of failure is found to be brittle.

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