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Vertical Irregularities on Reinforced Concrete Frame Buildings

Nishant Kumar[1], Megha Gupta[2], Sunil Saharan[3]
[1,2,3] *Department of Civil Engineering, Sharda University,*

Abstract— Many Multi-storey buildings require open taller first storey for parking of vehicles, retail stores, bank branches, restaurant owing to lack of horizontal space and high cost. Due to this, the first storey has lesser strength and stiffness as compared to upper storeys which are stiffened by presence of walls (either masonry or RC). Such buildings are often called soft storey buildings. Buildings with soft first storey, the upper storeys being stiff, undergo smaller inter-storey drifts. However, the inter-storey drift in the soft first storey is large. This paper highlights the effect of presence of soft storeys in the building by study of an example building with different models and incorporating various retrofitting techniques to reduce the effect of soft storeys. Introduction of shear wall represents a structurally efficient solution to stiffen the RC frame.

Keywords— Soft Storeys, Vertical Irregularities, IS 1893, Retrofitting.

I. Introduction

Earthquake is one of the nature's greatest hazards to property and human lives. It poses a unique engineering design problem. An intense earthquake constitutes severe loading to which most civil engineering structures may possibly be subjected. The number of earthquakes reported worldwide, are usually followed by enormous death and injury. Not only life but also economy that are threatened from this disaster. The approach of engineering design is to design the structures in such a way that it can survive under the most severe earthquakes, during their service lives to minimize the loss of life and the possibility of damage.

Buildings are designed primarily to serve the needs of an intended occupancy. The design approach adopted in IS 1893 (Part 1): 2002 Clause 6.1.3 is:

- To ensure that the structure possess at least minimum strength to withstand minor earthquake without damage;
- To resist moderate earthquake without significant structural damage, though some non-structural damage may occur;
- To withstand a major earthquake without collapse.

According to IS 1893 (Part 1): 2002, a soft storey is a storey whose lateral stiffness is less than 70 percent of that in storey above or less than 80 percent of the average lateral stiffness of the three storeys above.

Introduction of masonry infill, shear wall and steel bracings represents a structurally efficient solution to stiffen a structural system because the main function of these is to increase the stiffness of the system. In modern buildings, shear walls are commonly used as a vertical structural element for resisting the lateral loads that may be induced by the effect of wind and earthquakes.

The objective of this study is to compare different methods of retrofitting the building to reduce the effect of soft storey and to find the most efficient retrofitting technique. The RC frame studied is retrofitted by the following techniques:

1. Brick Infill in the soft ground storey
2. RC Wall in the soft ground storey
3. Steel Bracings in the soft ground storey

II. ANALYSIS OF INFILL FRAMES

One of the most common approximation of infill walls is on the basis of equivalent diagonal strut i.e. the system is modelled as a braced frame and infill walls as web element (Drydale, et. al., 1994) [1]. The geometric and material properties of the equivalent diagonal strut are required for conventional braced frame analysis to determine the increased stiffness of the infill frame. The geometric properties are of equivalent width and thickness of the strut. Originally proposed by Polyakov (1956) [2] and subsequently developed by many investigators, the width of strut depends on the length of contact between the wall and the columns, α_h and between the wall and the beams, α_L as shown in the figure.

Stafford Smith (1962 & 1966) [3,4] developed the formulations for α_h and α_L on the basis of beam on elastic foundation. The following equations are proposed to determine α_h and α_L, which depend on the relative stiffness of the frame and infill, and on the geometry of the panel.

$$\alpha_h = \frac{\pi}{2}\sqrt[4]{\frac{4\,E_f\,I_c\,h}{E_m\,t\sin 2\theta}}$$

$$\alpha_L = \Pi\sqrt[4]{\frac{4\,E_f\,I_b\,L}{E_m\,t\sin 2\theta}}$$

where,

E_m and E_f = Elastic modulus of the masonry wall and frame material, respectively

t, h, L = Thickness, height and length of infill wall, respectively

I_c, I_b = Moment of inertia of the column and the beam of the frame, respectively

$\theta = \tan^{-1}(\frac{h}{l})$

Hendry (1998) proposed the following equation to determine the equivalent or effective strut width *w*, where the strut is assumed to be subjected to uniform compressive stress,

$$w = \frac{1}{2}\sqrt{\alpha_h^2 + \alpha_L^2}$$

Stiffness of Infill (Masonry) = $\frac{A\,E_m\,\cos^2\theta}{l_d}$

where,

A = Area of equivalent strut = w × t

l_d = Length of equivalent strut = $\sqrt{h^2 + L^2}$

Stiffness of Shear Wall (fixed) = $\frac{\mathbf{E_c\,t}}{\frac{h}{L}\left[\left(\frac{h^2}{L}\right)+3\right]}$

where,

E_c = Modulus of Elasticity of concrete

t = thickness of shear wall

h = height of shear wall

L = length of shear wall

III. PROBLEM FORMULATION

A (G+4) storeyed two-bay RC frame with open ground storey and brick infill top storeys is considered with the storey heights as 3m and 3.5m for the top and the ground storeys respectively. The bay width is taken as 5m. The frame is assumed to be fixed against translation in all directions and rotation about all axes at the bottom nodes. The design lateral force on the infill frame was estimated using the Indian Seismic Code [IS: 1893, 2002] [6]. The frame was modelled in STAAD-PRO 2004 and storey drifts were calculated. The stiffness of each floor was calculated using the above explained theory. Details of the frame are given in Table 1.

Table 1

Sr. No	Particulars	Details/Values
1	Type of Building	Residential
2	Number of Storeys	G + 4
3	Spacing of Frame in x Direction	5m
4	Spacing of Frame in z direction	5m
5	Number of bays in x direction	2
6	Number of bays in y direction	1
7	Storey Height	3m
8	Ground Storey Height	3.5m
9	Column Size	250 × 300 mm
10	Beam Size	250 × 300 mm
11	Infill Wall thickness	150 mm
12	Shear Wall thickness	150 mm
13	Grade of Concrete	M20
14	Zone	4
15	Size of Steel bracing	2 ∟ 150 × 75 × 10 mm

Various building models are:

1. Model 1: Frame with ground storey as soft storey, Fig 1.
2. Model 2: Frame with brick infill of 150 mm at ground storey, Fig 2.
3. Model 3: Frame with shear wall of 150 mm at ground storey, Fig 3.
4. Model 4: Frame with steel bracing at ground storey, Fig 4.


Fig 1

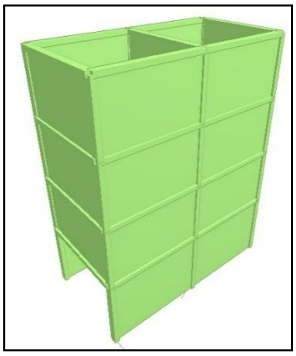
Fig 2

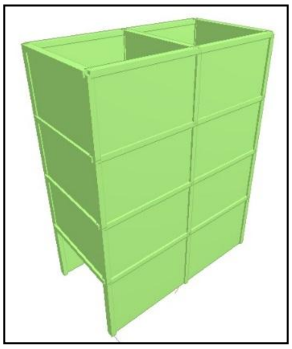
Fig 3

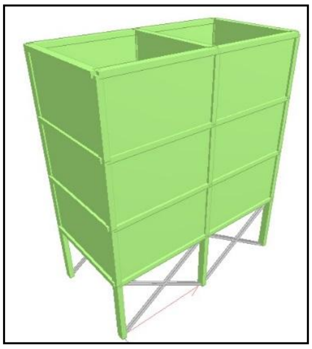
Fig 4

IV. RESULTS

The stiffness calculation of ground storey and storey above for the various building models are given below in Table 2.

TABLE 2

MODEL	STIFFNESS (in kN/m)	
	GROUND STOREY	STOREY ABOVE
MODEL 1	10,560	425,970
MODEL 2	332,380	425,970
MODEL 3	1,768,560	425,970
MODEL 4	390,020	425,970

Comparison of base shear for different building models are given in Table 3 below along with Fig. 5.:

TABLE 3

Building Model	Base Shear (kN)
Model 1	41.89
Model 2	45.34
Model 3	47.18
Model 4	38.38

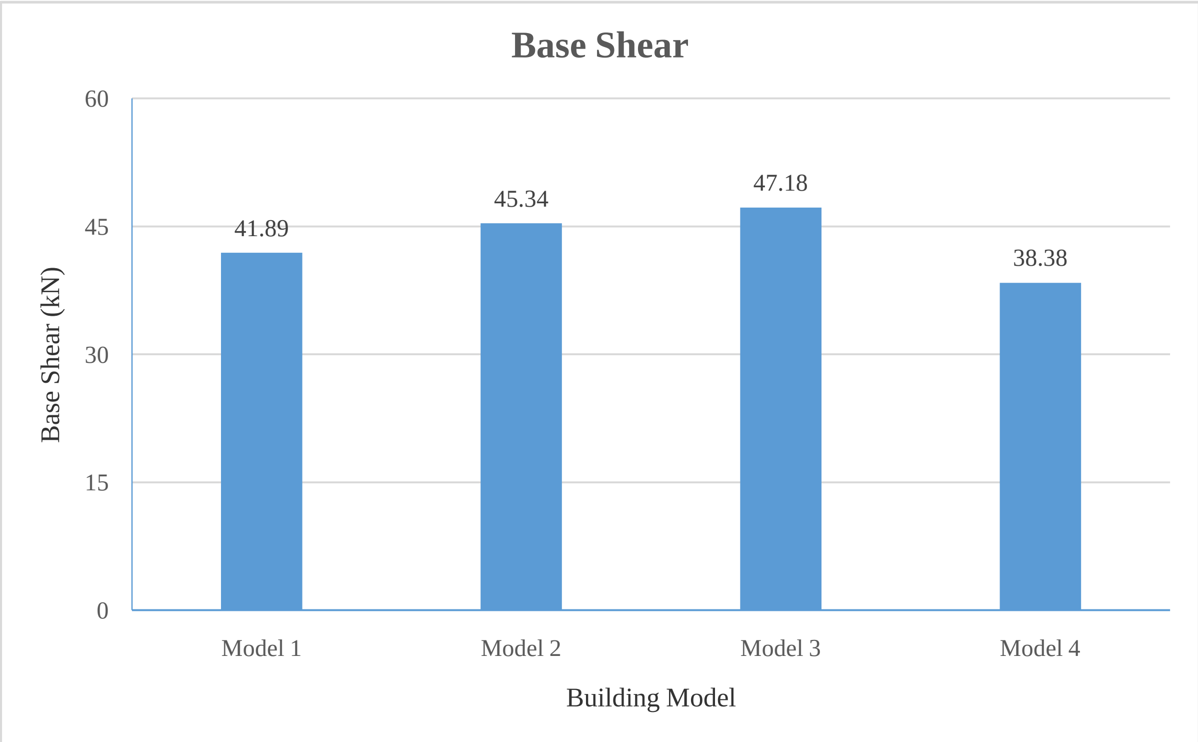

Fig 5: Base shear comparison

Comparison of ground storey stiffness by using different retrofitting techniques is given in Table 4 below along with Fig. 6.

TABLE 4				
STOREY	**STIFFNESS (in kN/m)**			
	Open Storey	**Brick Infill**	**Shear Wall**	**Steel Bracing**
Ground	10,560	332,380	1,768,560	390,020

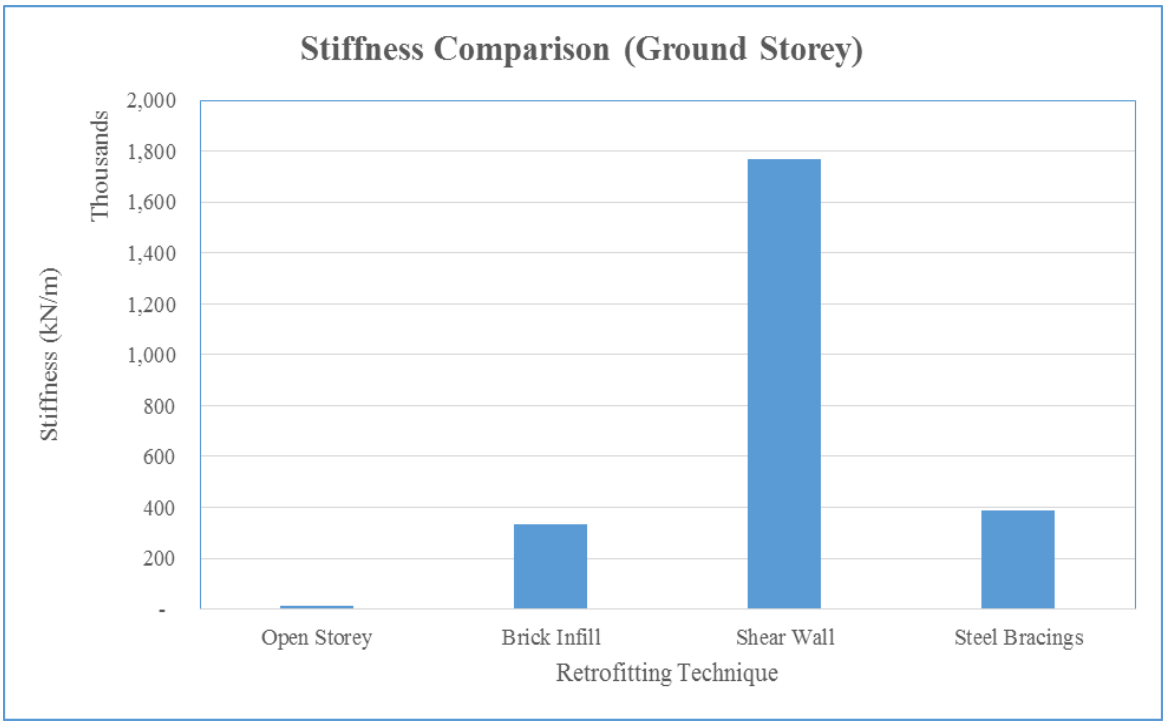

Fig. 6: Stiffness Comparison (Ground Storey)

Storey Drift Comparison: Storey Drift comparison of the RC frame by using different retrofitting techniques is given below in Table 5 and Fig. 7.

TABLE 5				
STOREY	**STOREY DRIFT (in mm)**			
	Open Ground	**Brick Infill**	**Shear Wall**	**Steel Bracing**
Ground	19.871	0.126	0.084	0.525
First	20.107	0.247	0.198	0.720
Second	20.332	0.362	0.303	0.920
Third	20.541	0.462	0.394	1.106
Fourth	20.743	0.550	0.473	1.282

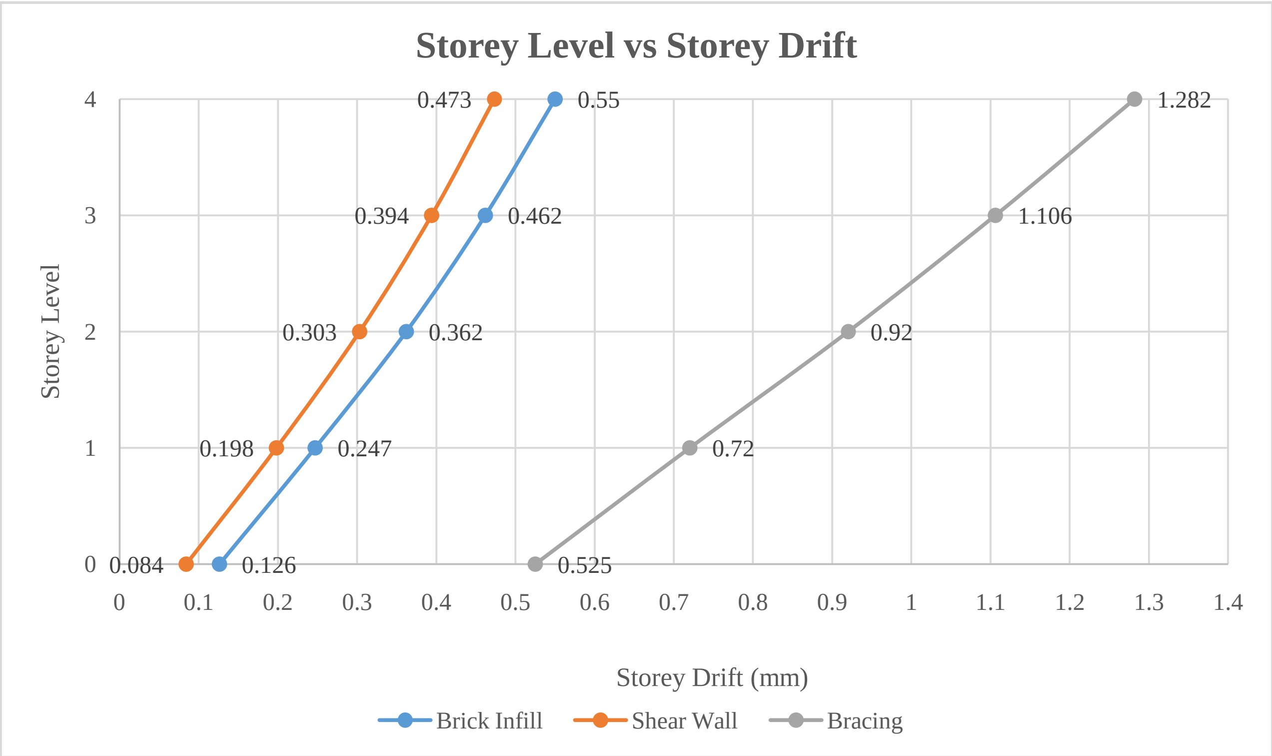

Fig. 7: Comparison Storey Level vs Storey Drift

V. CONCLUSIONS

The salient conclusions of the study are:

1. The displacements in soft storey are very large, thus it is clear that such buildings will perform poorly under strong shaking.
2. Most of the energy developed during Earthquake is dissipated by the columns of the soft stories.
3. The three methods using Brick Infill, Shear Walls and Steel Bracing are effective in reducing the storey drift.
4. Maximum Base Shear is carried by building having Shear Wall in ground storey.
5. For the open ground storey frame, retrofitting by means of introducing RC shear wall in the open ground storey, offers the maximum stiffness.
6. By introducing shear walls to the ground storey, the storey drift reduces by 99.5% as compared to the building with ground storey as soft storey.

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