International Journal of Applied Engineering and Technology ISSN: 2277-212X (Online)
An Open Access, Online International Journal Available at http://www.cibtech.org/jet.htm
2016 Vol. 6 (3) July-September, pp.31-40/Sharma and Neeraj
Research Article

EXPLORING DIVERGENCE AND DEVIATIONS OF SEISMIC RESPONSE OF RC FRAME BUILDINGS ON STILTS

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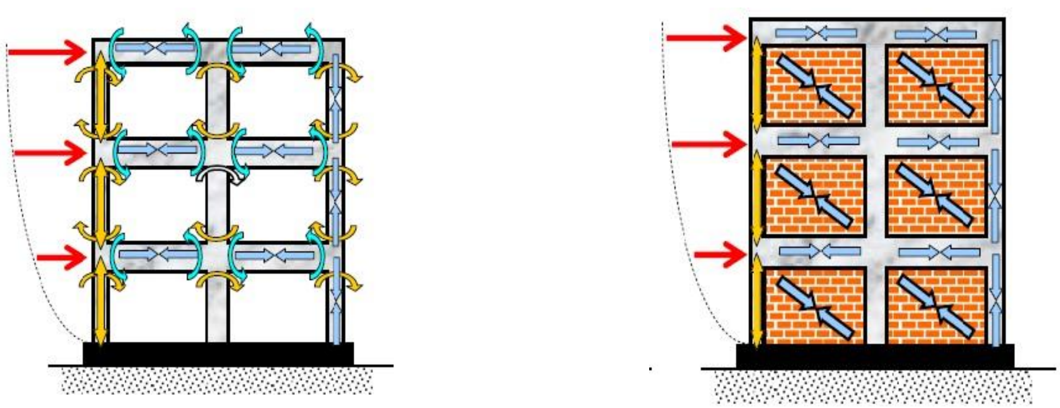
ABSTRACT
For the past few years, the increase in urbanization has made the vehicle parking as a serious issue. Therefore, the ground storey of the building is used for parking, is termed as Stilt Building. The performance of these RC stilt buildings are considered to be very poor due to the absence of infill wall in ground storey while presence of infill walls in upper storey. The presence of infill wall affects the overall behavior of the structure when subjected to seismic forces. When the infill walls are supposed to interact with their respective frames, a very large amount of changes in lateral strength and stiffness of the structures takes place. The present paper is an attempt to study the variations in lateral strength and stiffness of the RC stilt buildings when designed and analyzed for different zones III, IV and V. The study includes the analysis of RC frames buildings when designed as bare, stilt and infill frames with SAP2000 Non-Linear software by pushover analysis method.

Keywords: *Stilt Building, Infill Walls, Lateral Strength and Stiffness*

INTRODUCTION
The reinforced concrete (RC) moment resisting frames are quite popular as compared to structural steel frames in developing countries like India due to low cost of material and labors. Mainly, the vertical spaces created by adjoining RC beams and columns are filled by masonry walls either to protect the inside of structure from rain, snow, wind, etc. or to divide inside spaces according to functional requirements.
In general, the infill panels are considered as non-structural elements. Due to which, their stiffness and strengths are neglected in the design and analysis of structures. However, their mass is taken into account for calculation of load. It is also considered that the Infills alter the building behavior from (Figure 1 (a)) to predominant truss action (Figure 1 (b)) (Murty *et al.*, 2002).



(a) Bare Frame: Predominant Frame Action

(b) Infilled Frame: Predominant Truss Action

Figure 1: Contrasting Structural Behavior of Buildings without and with Unreinforced Masonry Infill Walls (Murty *et al.*, 2002)

From many past earthquake experiences, it is clear that the seismic performance of frames undergoes very severe ill effects due to non-uniform distribution of infills. The uneven distribution of infills in plan may leads to the strength and stiffness irregularity in plan which may be followed by the formation of torsional moments in the building whereas, if the infills are not uniformly distributed in elevation, it can result in vertical irregularity.

Infills panels are not homogeneous as these are made of brick and mortar. Hence, their behavior mainly depends upon brick and mortar both. Moreover, the problem in infills modeling is the uncertainties related to the properties of masonry and mortar. However, a large numbers of analytical and experimental studies have been carried out to understand the influence of infills on lateral strength and stiffness of framed structures.

Stilt Buildings

In multi-storey buildings, ground storey does not contain any partition walls between them, while infill walls are present in upper storeys. Such buildings are known as "Soft storey buildings" or "buildings on stilts" or "stilt building" or "open ground storey buildings" (Murty, 2004). Such types of buildings consist of mainly three types of irregularities namely mass, strength and stiffness irregularity (Figure 2) (Al-Ali *et al.*, 1997).

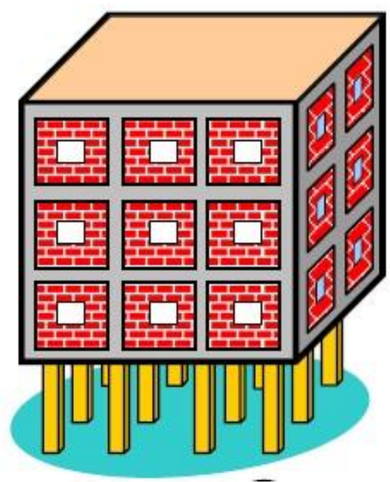


Figure 2: Soft Storey Building (Murty, 2004)

Infilled RC frames are commonly analyzed and designed as bare frames. However, their actual behavior of bare frames is entirely different from that of the bare frames. In stilt buildings, ground storey is bare and upper storeys are infilled with masonry. Therefore, it is of interest to analyze and compare deformation profile, hinge formation sequence, strength, stiffness, etc. of the same frame, modeling it as a bare frame, fully infilled frame, and as stilt frame.

The Indian seismic code classifies a soft storey as one in which the 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. The storey lateral strength is the total strength of all the seismic force resisting elements sharing the storey shear in the considered direction (IS: 1893-2002, 2002).

Research Objectives

The chief objective of the present study is to describe the strength and stiffness of the various reinforced concrete (RC) buildings on stilts when designed under three dimensions. Eventually, the present study is an attempt to identify the strength and stiffness of the numerous RC buildings and explore the suitability of the stilt frames under seismic behavior, when designed for different loading conditions. Moreover, it also covers the following aspects:

- To identify the more significant frame among 'bare', 'infill' and 'stilt' frames and their susceptibility towards failure of the frames.

- To study the effect on strength, stiffness and deformation capacity due to presence of infills
- To study the curve profile between base shear and roof displacement and its influence on the frames stability.
- To study the influence of strength and stiffness take place due to absence of infills?

MATERIALS AND METHODS

Methodology

In this study, two three-dimensional typical residential buildings have been considered and named as frame-A and frame-B respectively. The panel dimensions for frame-A are (4 m X 4 m) and has 4 stories. The height of storey is kept as 3.0 m (Figure 3). On the other hand, frame-B having panel dimensions of (3.5 m X 3.5 m) has 6 stories. The bottom storey height is kept as 4.0 m while the height of upper storey is kept as 3.0 m (Figure 4). Both the frames will be analyzed under SAP2000 Non-Linear software.

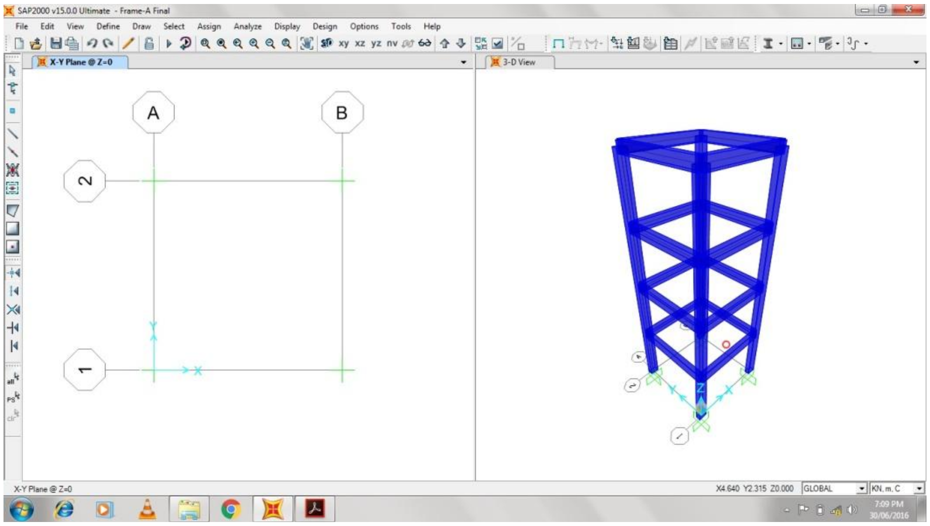


Figure 3: SAP Model of Frame –A

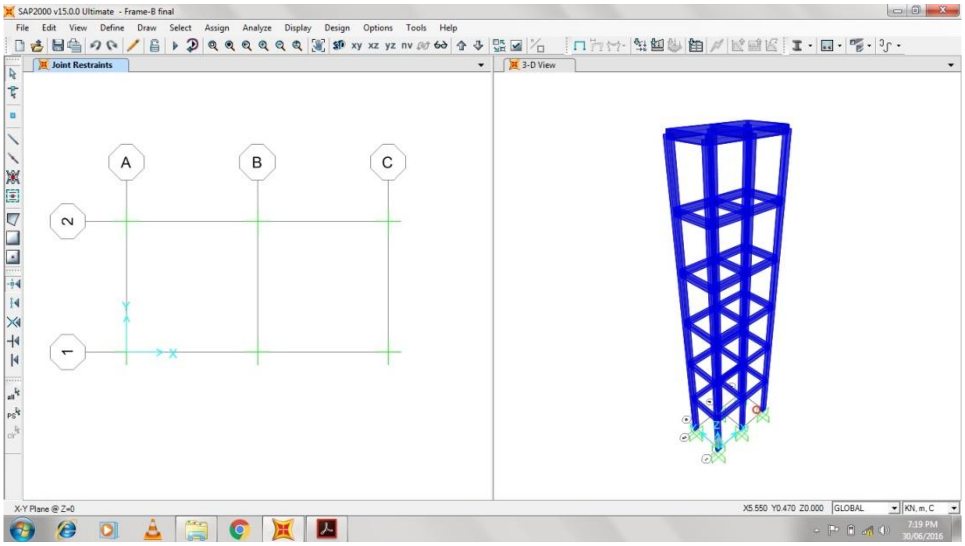


Figure 4: SAP Model of Frame –B

The thickness of infill wall is 230 mm in both frames. Dead load of infill walls is applied on the beams in the form of uniformly distributed load at which it rests. However, during the calculations of seismic weight, half of dead load of infill is lumped at the floor below and half at the floor above. Self-weight of columns and beams are calculated from unit weight of concrete and their cross-sections areas. The vertical distribution of design base shear as per IS:1893-2002 and their values are given in Table 1 and 2.

Table 1: Base Shear Distribution in Frame-A

Floor	Earthquake Force (kN)		
	Zone III	**Zone IV**	**Zone V**
Fourth	30.5	45.8	68.7
Third	19.84	29.76	44.64
Second	8.83	13.24	19.85
First	2.22	3.33	5
V_B	**61.39**	**92.13**	**138.19**

Table 2: Base Shear Distribution in Frame-B

Floor	Earthquake Force (kN)		
	Zone III	**Zone IV**	**Zone V**
Sixth	46.41	92.81	141.53
Fifth	30.64	61.28	93.45
Fourth	19.61	39.25	59.81
Third	11.03	20.06	36.64
Second	4.91	9.81	14.96
First	1.23	2.46	3.74
V_B	**113.83**	**225.67**	**350.13**

Analysis of the Frames

As per IS:1893-2002, the various load combinations that are considered for the analysis are as follows:

$$1.5(DL + IL)$$
$$1.2\ (DL + IL \pm EL)$$
$$1.5(DL \pm EL)$$
$$0.9DL \pm 1.5EL$$

In the above equations, DL is the self-weight of columns, beams, slabs, infills and floor finishing; and IL is imposed load.

Design Cases

The design of both the frames is done as per IS:456-2000 limit state procedures. The frames are detailed as per IS:456-2000 when designed for gravity loads only.

On the other hand, the detailing of frames is done as per IS:13920-1993 for all the cases in which seismic loads are considered. Frame-A serves larger area and its seismic weight is 1550 kN while frame-B has 5700 kN. The approximate fundamental natural periods of frame-A and frame-B calculated as per IS:1893-2002 are 0.41 s and 0.55 s respectively.

GRAV: In this case, frames have been designed for only gravity loads (DL and IL), and no earthquake load has been considered. This case is to simulate non-seismically designed older buildings in order to envisage seismic performance of such buildings. Therefore, it is analyzed for only one combination, i.e., $1.5(DL + IL)$ and detailed as per IS:456-2000.

EQ3: In this case, the frames have been designed for DL, IL, and EL for zone III. Detailing is done as per IS:13920-1993.
EQ4: In this case, the frames have been designed for DL, IL, and EL for zone IV. Detailing is done as per IS:13920-1993.
EQ5: In this case, the frames have been designed for DL, IL, and EL for zone V. Detailing is done as per IS:13920-1993.

RESULTS AND DISCUSSION

The two RC frames are designed for different seismic zones and pushover analysis is performed for bar, stilt and infill frame as per the procedure described in the previous chapter. The base shear versus roof displacement, termed as pushover curve, is obtained for all these cases. The effect of infill walls, modeled as single diagonal strut, on the seismic response of the frame is studied through different response qualities particularly lateral strength, lateral stiffness (hereafter referred as strength and stiffness respectively) and ductility. Strength of frame is expressed as a percentage of corresponding seismic weights (%W) (Table 3) while roof displacement is expressed in terms of percentage of the respective frame height (%H) (Table 4). The ductility of both frames is tabulated in table 5.

Table 3: Lateral Strength (%W) of Frame-A and Frame-B

Design Case	Frame-A			Frame-B		
	Bare	**Stilt**	**Infill**	**Bare**	**Stilt**	**Infill**
GRAV	6.9	15.2	21.3	9.1	14.9	49
EQ3	10.7	19	24.3	14	18.4	51.9
EQ4	15.3	22.7	27.9	16.9	18.7	53.2
EQ5	36.1	37.5	42.7	35.2	35.5	68.7

Table 4: Maximum Roof Displacement (%H) of Frame-A and Frame-B

Design Case	Frame-A			Frame-B		
	Bare	**Stilt**	**Infill**	**Bare**	**Stilt**	**Infill**
GRAV	1.73	0.95	1.05	1.16	0.64	0.67
EQ3	3.38	2.09	2.1	1.96	1.47	1.12
EQ4	2.88	1.99	1.99	1.33	1.45	1.11
EQ5	2.79	2.07	2.07	1.36	1.05	1.25

Table 5: Ductility of Frame-A and Frame-B

Design Case	Frame-A			Frame-B		
	Bare	**Stilt**	**Infill**	**Bare**	**Stilt**	**Infill**
GRAV	4.9	5.1	7.9	4.8	4.4	4
EQ3	9.7	11.7	14.6	8.8	10.6	7.3
EQ4	9	15.7	19.8	5.7	12.1	7.3
EQ5	5.5	8.6	10	5.5	7.6	7.9

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Design Cases GRAV

Strength increment due to infills in stilt frame-A and frame-B are 8.3%W and 5.8%W, respectively, i.e., strength of stilt frame-A and frame-B are 2.2 and 1.6 times the strength of the corresponding bare frames. On the other hand, strength contribution of infills in infill frame-A and frame-B are 14.5%W and 39.9%W, i.e., 3.1 and 5.4 times that of respective bare frames. Contribution of infills towards the total strength of stilt and infill frame-A are 55% and 68% respectively, whereas contribution of infills in stilt and infill frame-B are 39% and 81%. This shows that RC frame is weak as compared to the infill panel. Strength enhancement in stilt frame-B due to infill is not as significant as in frame-A (Figure 5 and Figure 6). Ductility is increased due to presence of infill in frame-A, though this increment in stilt frame is negligible. Conversely, ductility is decreased 8 to 17% in frame-B due to infills.

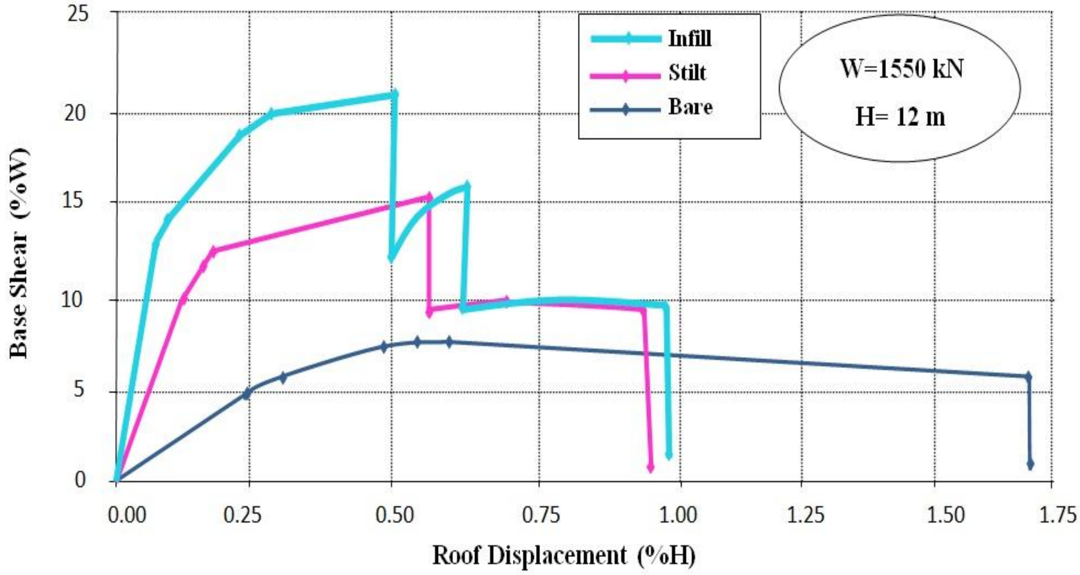

Figure 5: Pushover Curve of Frame-A for Design Case GRAV

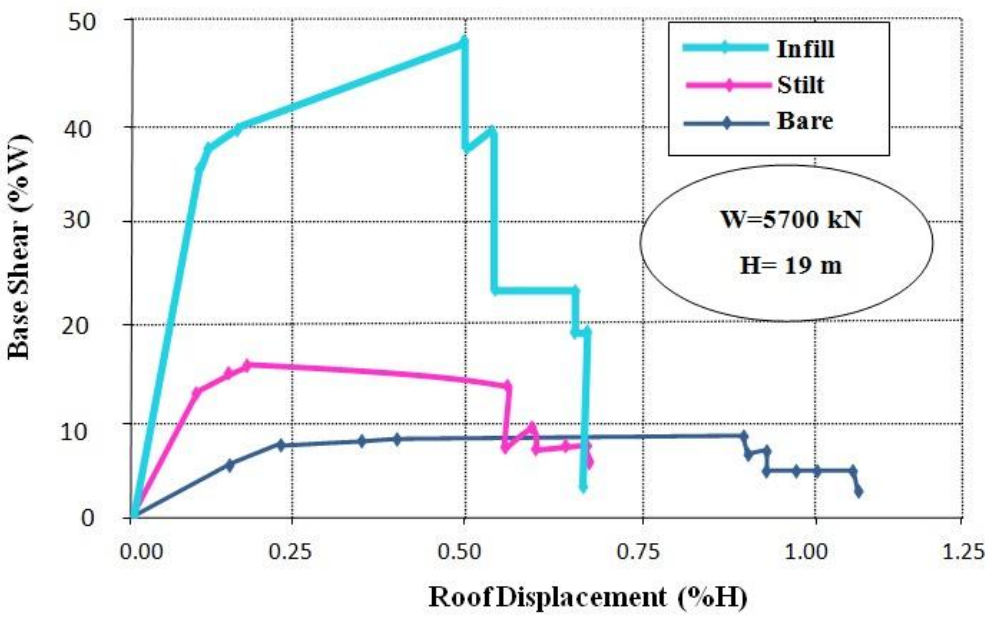

Figure 6: Pushover Curve of Frame-B for Design Case GRAV

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Design Case EQ3

Strength increment due to infills in stilt frame-A and frame-B are 8.4%W and 4.4%W, respectively i.e., strength of stilt frame-A and frame-B are 1.8 and 1.3 times the corresponding bare frame strengths. On the other hand, strength contribution of infills in infill frame-A and frame-B are 13.7%W and 37.9%W i.e., 2.3 and 3.7 times respective bare frames. Contribution of infills in the total strength of stilt and infill frame-A are 44% and 56% respectively, whereas infills contribution in stilt and infill frame-B are 24% and 73%. Deformation capacity of infill and stilt frames considerably decreases due to presence of infill which is apparent form figure 7 and 8. Deformation capacity of stilt and infill frame-A is 62% of bare frame. While deformation capacities of stilt and infill frame-B are 74% and 56% of bare frame. Ductility is increases about 20% due to infill in both stilt frames. Ductility is increased about 50% in infill frame-A, whereas 18% decrease in infill frame-B owing to infills.

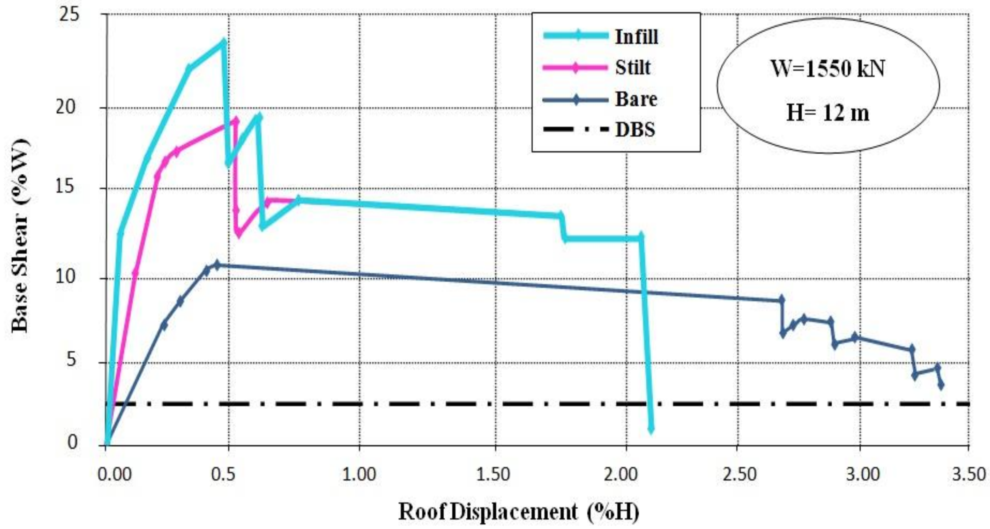

Figure 7: Pushover Curve of Frame-A for Design Case EQ3

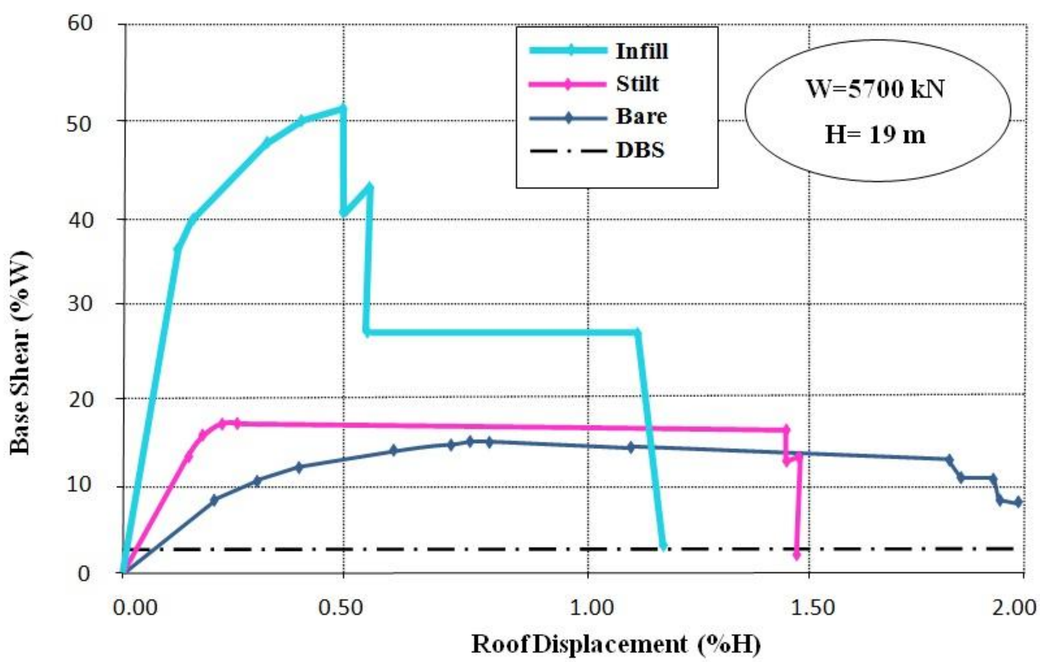

Figure 8: Pushover Curve of Frame-B for Design Case EQ3

Design Case EQ4

Strength increment due to infills in stilt frame-A and frame-B are 7.4%W and 1.8%W, respectively i.e. strength of stilt frame-A and frame-B are 1.5 and 1.1 times the corresponding bare frame strengths. On the other hand, strength contribution of infills in infill frame-A and frame-B are 12.5%W and 36.3%W i.e. 1.8 and 3.1 times respective bare frames. Contribution of infills in total strength of stilt and infill frame-A are 10% and 45% respectively. While infills contribution in stilt and infill frame-B are 39% and 68%. Deformation capacity of stilt and infill frame-A is 69% of bare frame. However, deformation capacity of stilt frame-B is slightly more than that of bare frame, whereas deformation capacity of infill frame-B is slightly more than that of bare frame.

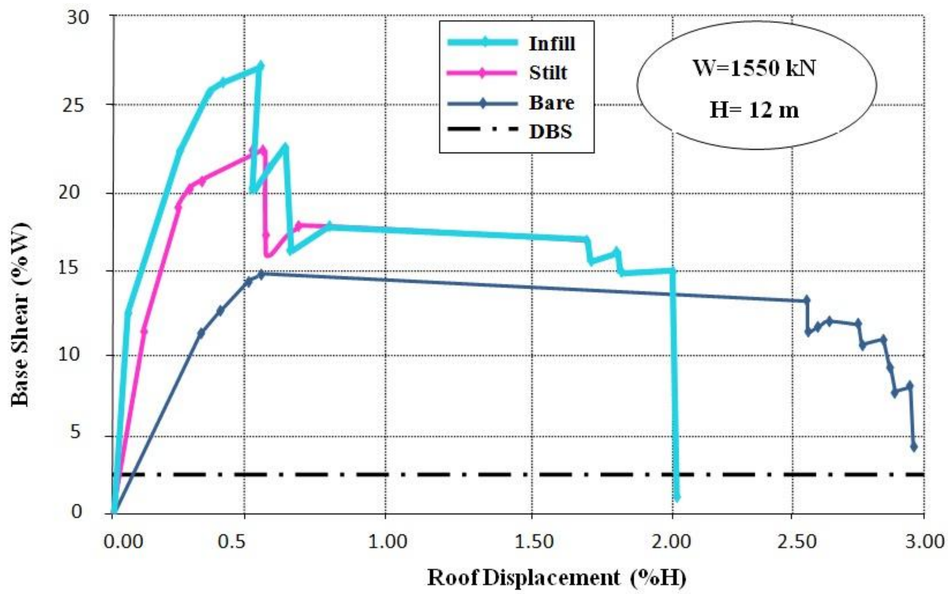

Figure 9: Pushover Curve of Frame-A for Design Case EQ4

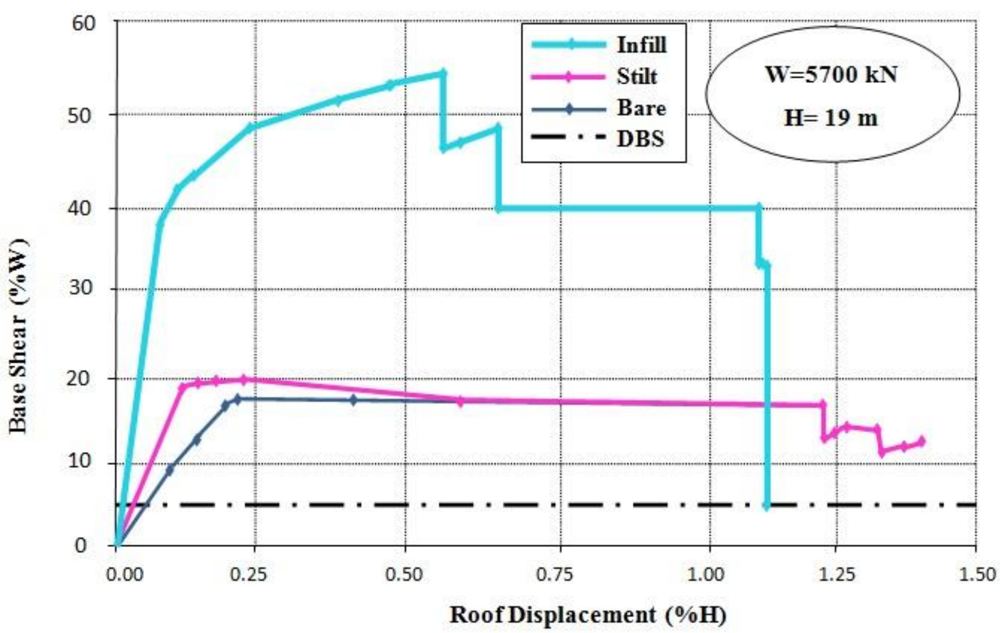

Figure 10: Pushover Curve of Frame-B for Design Case EQ4

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Design Case EQ5

Strength increment due to infills in stilt frame-A and frame-B are 1.5%W and 0.3%W respectively. On the other hand, strength contribution of infills in infill frame-A and frame-B are 6.6%W and 33.5%W i.e. 1.2 and 2.0 times the respective bare frames. Contribution of infills in total strength of stilt and infill frame-A are 4% and 16%, respectively, whereas infills contribution in stilt and infill frame-B are 1% and 49%. This shows that contribution of infills in the strength of stilt frame is negligible as frame is quite strong compare to infills. Deformation capacity of infill and stilt frames considerably decreases due to presence of infill which apparent from figure 11 and 12. Ductility increases about 60-80% due to presence of infill in frame-A, whereas in frame-B, ductility increases about 40%.

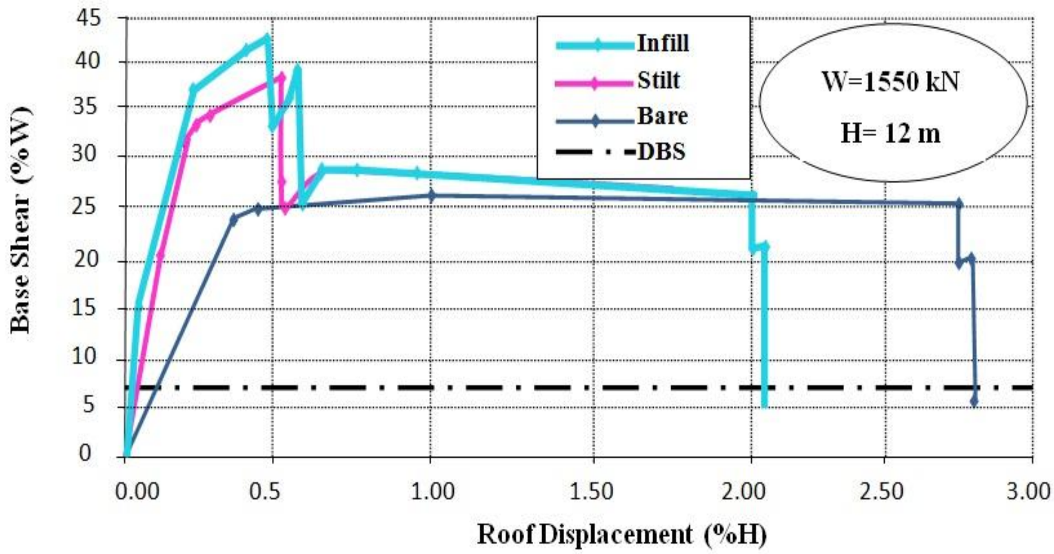

Figure 11: Pushover Curve of Frame-A for Design Case EQ5

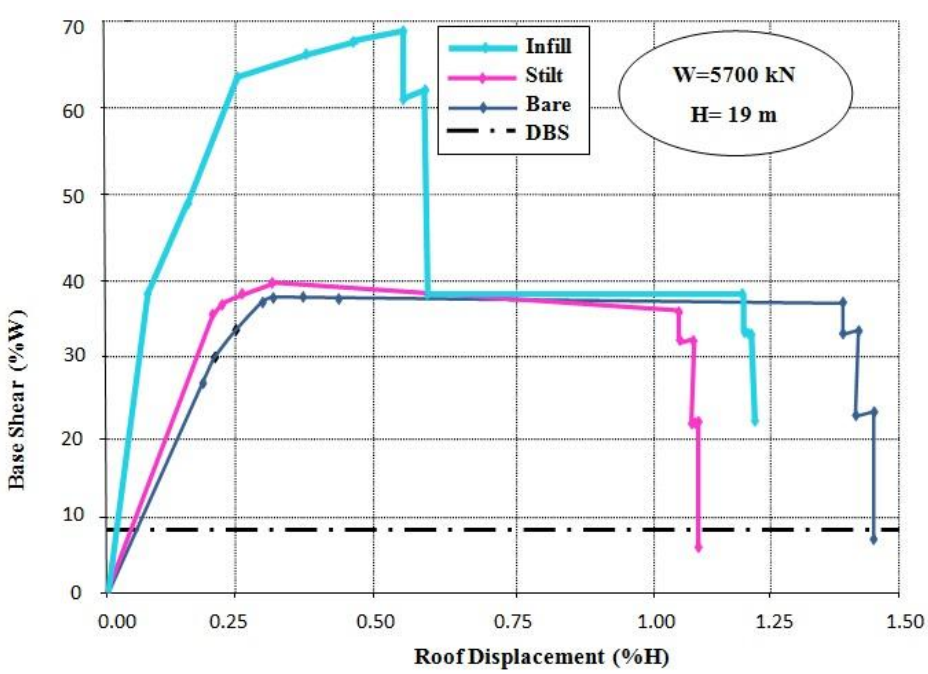

Figure 12: Pushover Curve of Frame-B for Design Case EQ5

Conclusion

The following are the salient conclusion drawn from the present study:

1. Both the stilt frames in all design cases collapse due to failure of ground storey columns. It implies that ground storey columns are more susceptible to failure than first floor beams in stilt frames.
2. Strength and stiffness deficit in ground storey caused by absence of infills is more prominent if ground storey height is more.
3. Deficit in ground storey stiffness is 50-90% due to absence of infills, while overall stiffness deficit is 25-65% and strength deficit is 10-70%.
4. Strength and stiffness deficit in ground storey caused by absence of infills is less prominent in the frames designed for higher seismic zone.
5. Deformation capacity decreased up to 45% due to presence of infills.

Possible Future Work

Observations from previous and present research work on RC frame buildings on stilt show the need for more work understand the seismic behavior of such buildings and find out some rational, simple and economical method of design to avoid formation of weak/soft storey. Following works may be carried out in future:

1. Analyzing and designing of RC infill frame after incorporating infill.
2. Analyzing and designing of RC infill frame with infill wall as shear wall.
3. Opening in infill panels of upper storeys may be considered in future work to simulate the response of buildings with more precision.

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