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EFFECT OF SOFT-STOREY ON MULTISTORY BUILDING AND INFLUENCE OF RETROFITTING

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Abstract - *Masonry infill walls significantly contribute to the seismic demand imposed on RC buildings. However, in general, infill walls are considered as non-structural elements in seismic design and assessment of buildings. Non-uniform distribution of infill wall leads to concentration of damage at lower stiffness area which creates soft storey effect. The soft storey creates a major weak point in an earthquake. In this paper, we study the effect of geometric position of the soft storey in the elevation of the building and how retrofit using different steel bracings could be used to reduce this effect. We study parameters like end fixity of a building, height of a building, the position of soft storey, and stiffness distribution that affects the behaviour of a building during an earthquake. Models of multi-story buildings with different configurations are created in E-tabs software. Nonlinear Static Pushover analysis is employed for the seismic evaluation of buildings. The results obtained after the seismic analysis are compared to study the effect of the different retrofitting techniques. Soft storey at the bottom height is found to be more critical. Using X bracing is found to be more effective in reducing the soft storey effect.*

Key Words: E-tabs, Infill walls, Pushover Analysis, Steel bracings, Soft Storey.

1.INTRODUCTION

Infill wall is not considered as a structural element in the traditional construction process and is assumed not to carry any forces. It considers beams and columns as structural elements and designs according to them. This assumption causes a large gap between the building that is considered in analysis and design, and that finally constructed. This study will consider the effect of stiffness in the seismic behaviour of a building and how the mode shape of the building changes. A soft storey is a storey whose lateral stiffness is less than that of the storey above. It usually occurs due to the irregular distribution of infill walls. It can form at any level of the building to meet the required needs and purposes. During an earthquake, the soft storey creates a weak point in the building and can cause structural damage to the buildings. Also, there are lot of buildings in which the effect of soft storey is not considered while designing. Hence the retrofitting of these buildings is necessary, especially in earthquake prone areas. In this study, we compare different retrofitting techniques and try to select the most efficient technique.

Adrian Fredrick C. Dya and Andres Winston C. Oretaa in 2015 published "Seismic vulnerability assessment of soft story irregular buildings using pushover analysis" in which they explain how the building with the soft story is more susceptible to damage. The main reason for this is the localization of seismic forces in the soft story. They studied the various methods for retrofitting the existing soft story building and the best technique is selected. André Furtado, Hugo Rodrigues, Humberto Varum and Aníbal Costa in 2015 published "Evaluation of different strengthening techniques' efficiency for a soft storey building" in which a comparison of different strengthening techniques for a building governed by a soft story mechanism is done. Out of the four different techniques namely RC column jacketing, the addition of shear walls with and without shear links, steel bracing and RC shear walls, they concluded that the steel bracings were more effective in the elimination of the soft storey mechanism. P.G Asteris, S.T Antoniou, D.S Sophaianopoulos and C.Z., Chrysostomou explain two methods for modelling infill walls, micro-modelling and macro-modelling in "Mathematical Macro-modelling of Infilled Frames". In the paper, they explain different macro modelling techniques. They concluded that a single strut is chosen to model the infill wall in E-tabs software. K.H Abdelkarem, F.K Abdel Sayed, M.H Ahmed and N. Al-Mekhlafy in 2013 published "Equivalent Strut Width for Modelling R.C Infilled Frames" in which they explain how to model infill using equivalent strut method. They found out the best equation to calculate equivalent width. They concluded that the single-strut model is better to be used because it can be accepted as correct and due to its simplicity. S.A Ahamad and K.V Pratap in 2020 published "Dynamic analysis of G + 20 multi storied building by using shear walls in various locations for different seismic zones by using E-tabs" in which they studied the usage of shear walls at different locations in a G+20 multi storied building and to study the nature of the structure exposed to the earthquake by response spectrum analysis in E-tabs software. E-tabs software was selected for the modelling and seismic analysis of the different multi-storied buildings. H. Moghaddam and I. Hajirasouliha in 2006 published "An investigation on the accuracy of pushover analysis for estimating the seismic deformation of braced steel frames" in which they explain the potentialities of the pushover analysis to estimate the seismic deformation demands of concentrically braced steel frames. They concluded that the ability of non-linear static procedures to predict the maximum roof displacement caused by the design ground motion is emphasized for concentrically braced steel frames. Helmut Krawinkler and G. D. P. K. Seneviratna in 1998 published "Pros and cons analysis of seismic evaluation" in which they assessed the accuracy of pushover analysis, identified conditions under which the pushover will provide adequate information. They concluded that pushover analysis will provide insight into structural aspects that control performance during severe earthquakes.

In this study, we mainly focus on 1) Analysis of a building with soft storey subjected to static and dynamic lateral loads. 2) To evaluate the effect of soft storey at different levels. 3) To compare the effect of bare frame, infilled frame, and hybrid frame. 4) To evaluate the influence of the height of the building. 5) retrofitting methods in reducing the lateral deflection in the building. 6) To study the effect of the end condition on the mode shape of the building.

2. METHODOLOGY

2.1 Infill Wall

Infill wall is the supporting wall that closes the perimeter of a building constructed within a three-dimensional framework structure. It is modelled using the equivalent diagonal strut method as it is very easy and suitable for large RC structures. The basic parameter which affects the strength and stiffness is its equivalent width w_{ds}, which is calculated as

$$w_{ds} = 0.175\ \alpha_h^{-.4}\ L_{ds}$$

$$\alpha_h = h\ (\sqrt[4]{(E_m t \sin 2\theta)/4E_f I_c h})$$

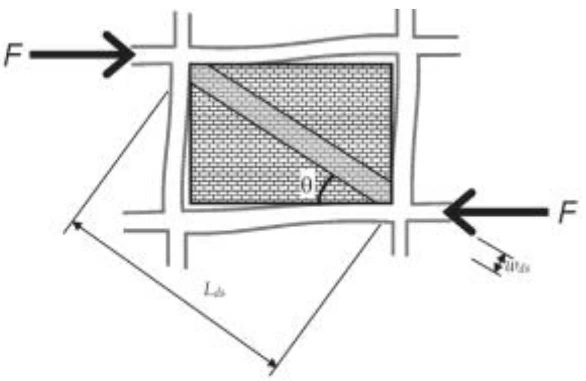


Fig -1: Equivalent diagonal strut of URM infill walls

where E_m and E_f are moduli of elasticity of the materials of the URM infill and RC moment resisting frame, I_c the moment of inertia of the adjoining column, t the thickness of the infill wall, and θ the angle of the diagonal strut with the horizontal.

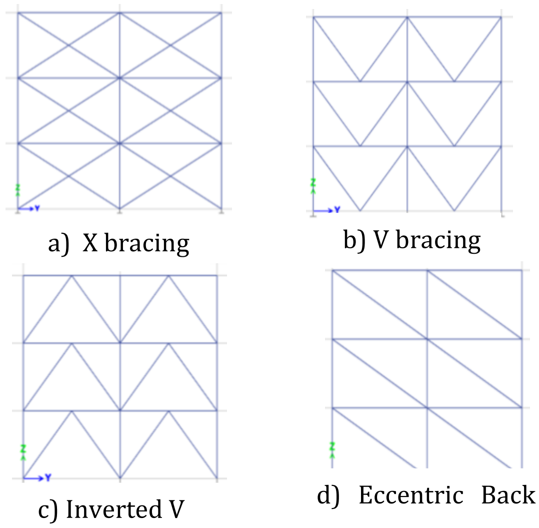
2.2 Pushover Analysis

Pushover Analysis is a static non-linear analysis. It helps to demonstrate how progressive failure takes place in buildings and find out the final mode of failure. It estimates the strength capacity of a building from its elastic state to ultimate strength. It exhibits the weak areas in the structure by providing hinges. Hinges are locations where cross diagonal cracks are expected during an earthquake. They are expected to found at either end of the beam or column. In our analysis, we use the displacement coefficient method where the building is pushed to target displacement. Target displacement is the maximum displacement experienced by the building during the design earthquake. According to FEMA 356, the target displacement δt, at each floor level shall be calculated by equation

$$\delta_t = C_0 C_1 C_2 C_3 S_a \frac{T_e^2}{4\pi^2} g$$

2.3 Bracings

Concentrically Braced Frames (CBFs) resist the lateral force through a vertical concentric truss system. They are efficient in resisting lateral forces as they provide strength and stiffness. In this study, we use different types of concentric bracing systems for the retrofit of soft story. We compare X, V, inverted V and Eccentric back bracing system. The reduction capacity of each bracing system to reduce the effect of soft storey is compared. The bracing section used is ISWB600.



a) X bracing b) V bracing c) Inverted V d) Eccentric Back

Fig -2: Different types of Steel bracings

3. MODELLING

Models with 10,20,30 storey with different configurations are created using E-tabs software. Each model has 4 bays in the X and Y direction. Bay width of the building is 5 m and the height of each story is 3 m. The end condition of each model is fixed.

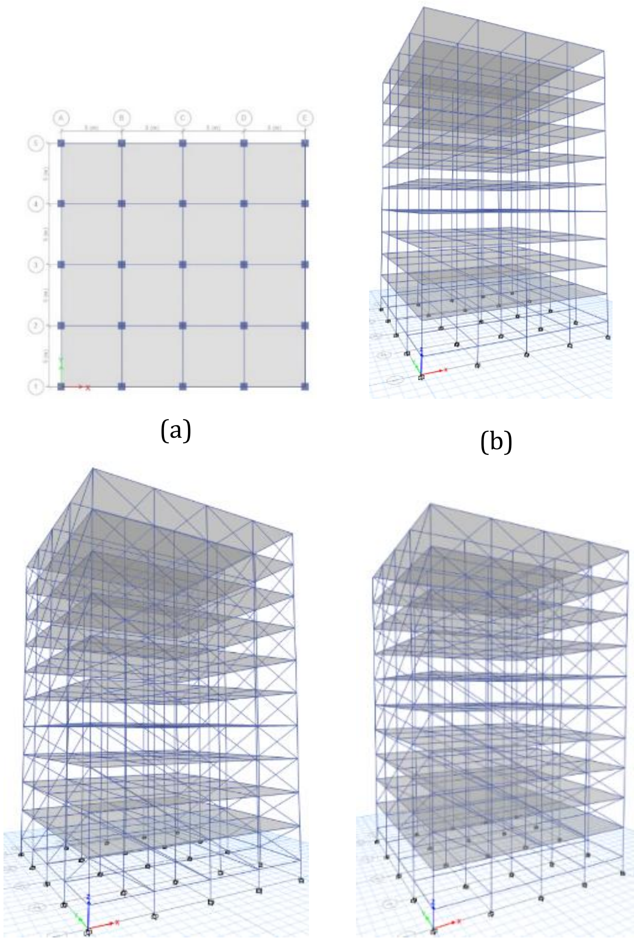
M30 grade of concrete and Fe 415 grade of Steel is used for slabs, columns and beams of the building. Fe 250 is used for the bracing sections.

Beam dimension of 10,20,30 storey is 300*400mm. Column dimension is 600*600mm. The thickness of the slab is taken as 150mm. Masonry diagonal strut has a dimension of 230*710mm.

The values of Zone Factor (Z), Importance factor(I), Response Reduction Factor (R) are taken as 0.36, 1 and 3 respectively. The soil is of type 2.

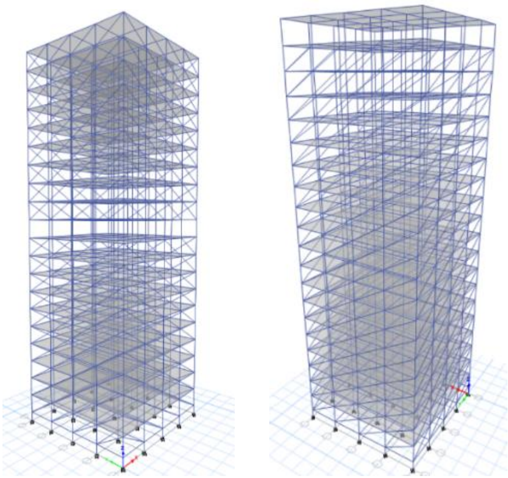
The Shell loads (on Slabs) acting in the Gravity direction are Dead=2kN/m² and Live=3kN/m². The Frame loads applied uniformly on the beams as wall load =14.5kN/m. The Seismic loads EQ-x and EQ-y are given in Load patterns directly using Code IS1893:2016.

The various configurations include bare frame, fully infilled frame, soft storey at the bottom storey. The 20-storey model is provided with soft storey at the top, middle and bottom storey. Soft storey and bare frame model of 20 storey are modelled and analysed again for hinged end condition. The model with the soft story is retrofitted using different types of bracings



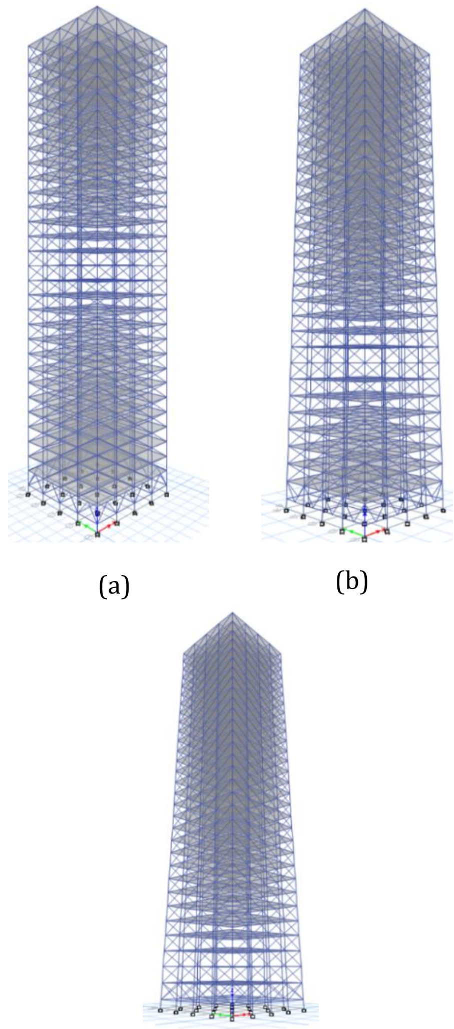
(a) (b) (c) (d)

Fig -3: a) Plan View b) Bare Frame c) Fully Infilled d) Soft Storey Model of 10 storey building



(a) (b)

Fig -4: Soft storey models of 20 storey building at (a)Middle storey (b)Top storey



(a) (b) (c)

Fig -5: Retrofit using a) Inverted V bracing b) V bracing c) X bracing of 30 storey building

4. RESULT ANALYSIS

The results obtained after pushover analysis of the different models are studied. The models are compared using storey displacement and normalized storey displacement. The normalized storey displacement is used to compare the effect on the mode shape of the building irrespective of the number of stories. Different graphs are created to analyse the effect of different parameters.

4.1 Effect of the Degree of Fixity at Member Ends

The effect of column end condition is studied. For this, the bare frame of 20 storey building is used for the comparison. Lack of rotational fixity in the field makes the end condition fixed whereas highly flexible soil makes it hinged. Full rotational fixity at column base restricts the lateral sway at the first storey. The lack of rotational fixity at column base (hinged condition) increases the lateral sway in the lower stories. The effect of the end condition is very drastic at the lower stories. Hence actual field conditions should be considered while designing a building.

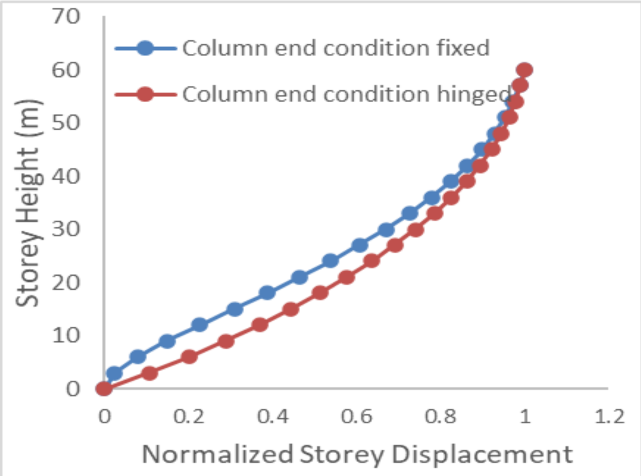
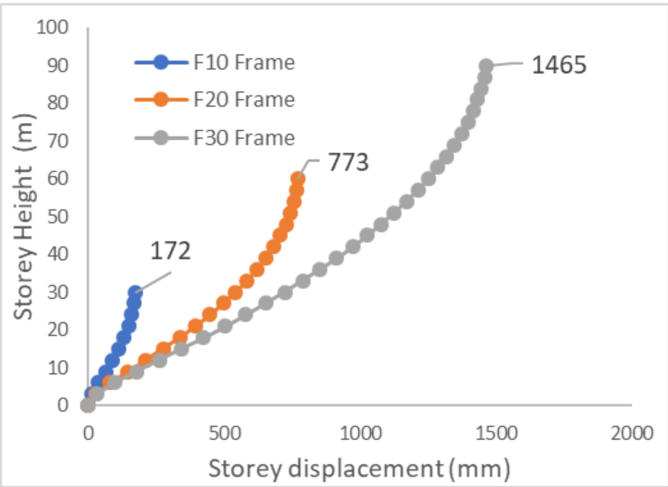


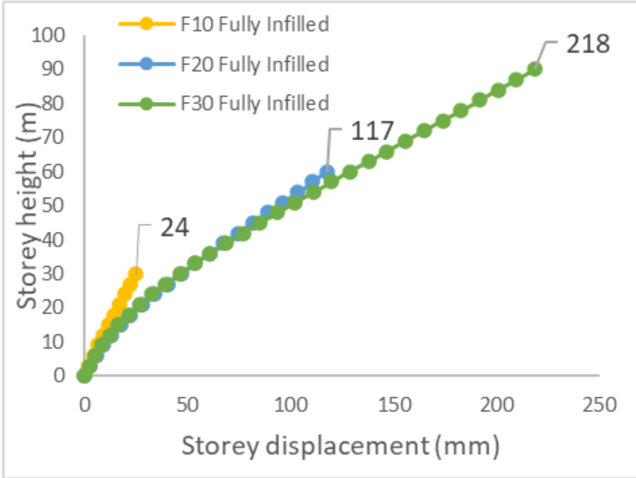
Chart -1: Comparison between Fixed and Hinged column base condition

4.2 Effect of the storey height

From the graph of the bare frame, it is clear that the maximum storey displacement increases with an increase in storey height. while considering the effect of infill, the maximum storey displacement increases with an increase in storey height but it has reduced drastically. Mode shape changes from bending to shear when considering the effect of infill walls and it is due to the change in stiffness.



(a)

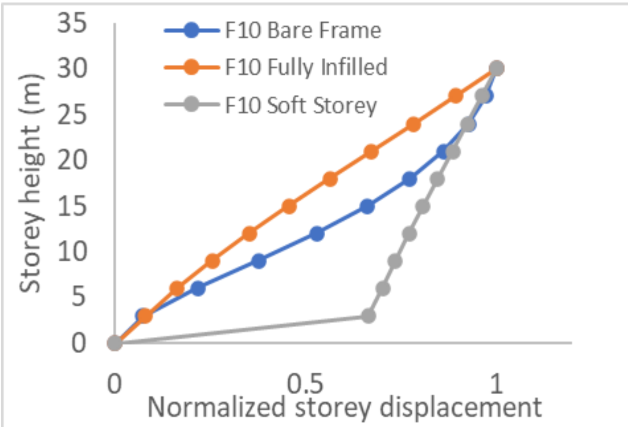


(b)

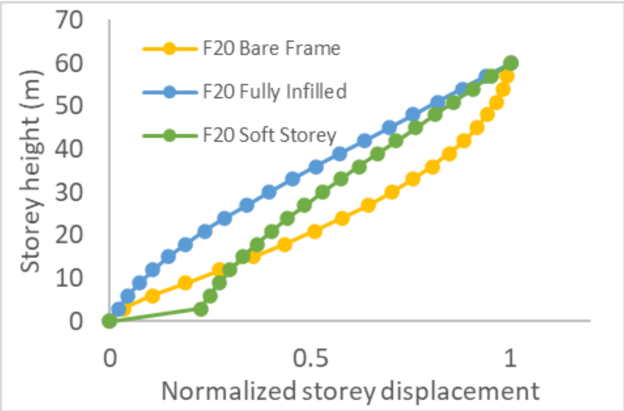
Chart -2: Effect of storey height in the case of a) bare frame b) Fully infilled frame

4.3 Effect of storey height in the case of soft storey

The displacement at the soft storey is very high as compared with other storey and this effect is clear from the graph. This can be noticed only if infill walls are considered in the analysis. If it is not considered, there will be large damage to life and property during an earthquake. Many buildings are not designed for soft storey effect, even though the soft storey may be present in the building. If stiffness is distributed evenly, they considerably reduce deformations and related damage. Hence, the effect of stiffness is important in the study of the seismic performance of a building. The effect of the infill wall should be studied by considering it as a structural member.



(a)



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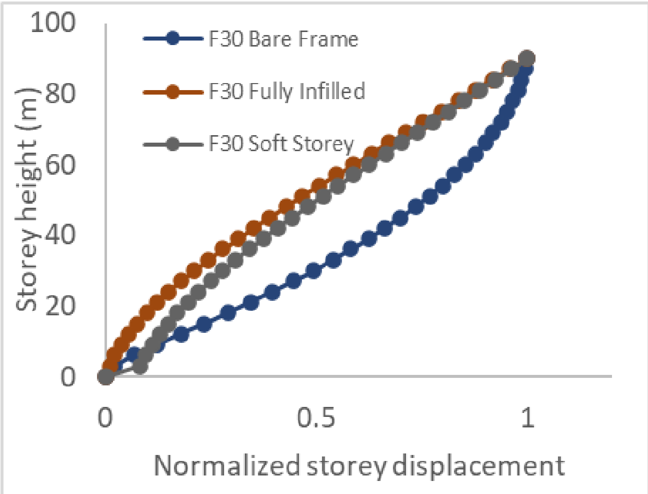


(c)

Chart -3: Comparison between bare frame, infilled frame, and soft storey using Normalized Story Displacement a) 10 storey b) 20 storey c) 30 storey

4.4 Location of the soft storey

In the graph, we can see that the soft storey at the top storey doesn't create any soft storey effect. Hence, we can conclude that soft storey at the top storey is much safer when compared with the other two cases. While comparing the other two cases, soft storey at the bottom is more critical when compared with intermediate stories. Providing soft storey at bottom height is more critical. This effect is due to the increase in base shear at the bottom storey. The base shear decreases as we move from the bottom to the top storey of a building.

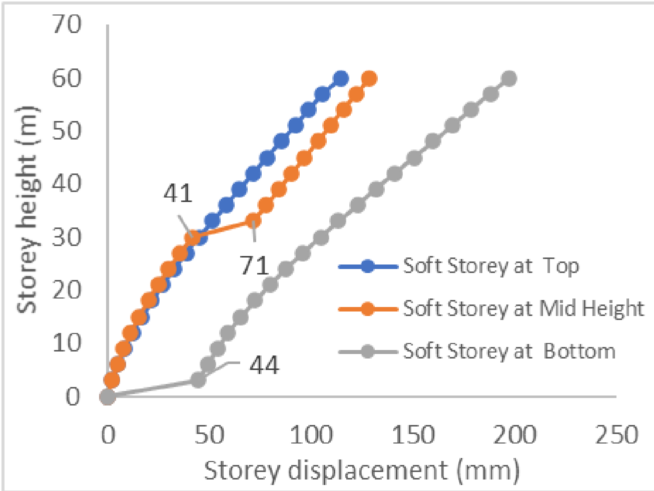
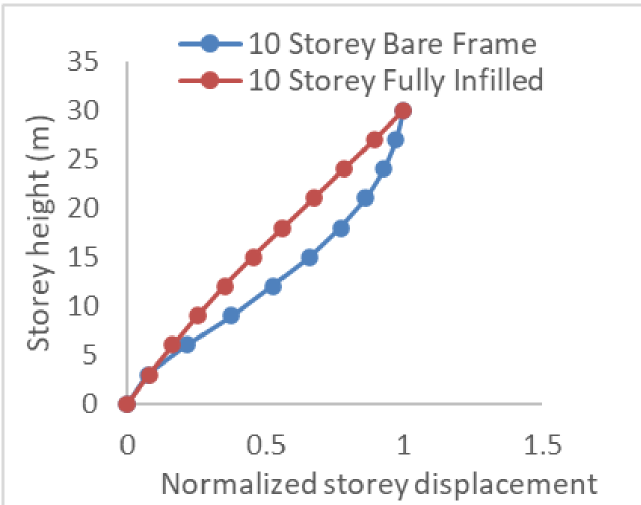


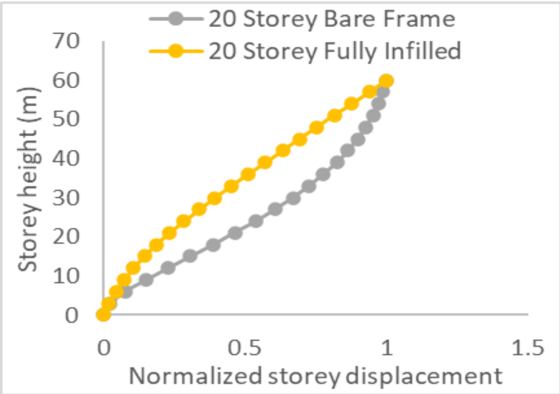
Chart-4: Comparison of soft storey effect at different levels

4.5 Change in bending behaviour with storey height

The bending behaviour of the building is drastically different when considering the infill wall as a structural element and when not considered. When infill walls are not considered in the analysis, the building exhibit bending behaviour which is not the actual case. When infill walls are present, lateral stiffness is constant throughout the building and the behaviour exhibited is entirely different. The infill walls transfer the moments acting in the case of a bare frame to the columns via truss action. This transfer of moments through strut action changes the mode shape of the bare frame from bending to shear in the case of the infilled frame. This change in mode shape can be inferred from fig 7.



(a)



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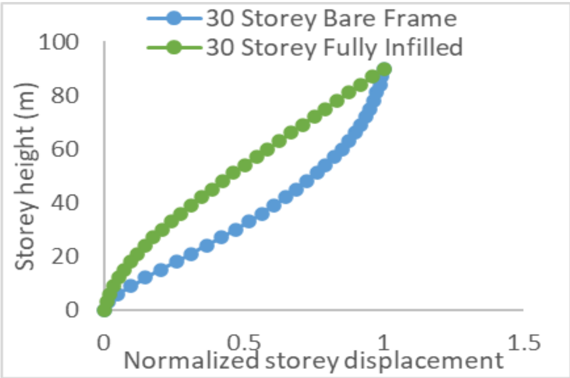

(c)

Chart -5: Comparison between bare and infilled frame of (a) 10 storey (b) 20 storey (c) 30 storey

4.6 Effect of storey height and displacement at soft storey

The displacement at soft story is influenced by the height of the building. The soft storey effect in the 10-storey model is very significant. The stories above the soft storey act as a rigid structure like an inverted pendulum and moves together. In the case of 20 and 30 storey the part above the soft storey is becoming slender and exhibit bending behaviour which reduces the soft storey effect.

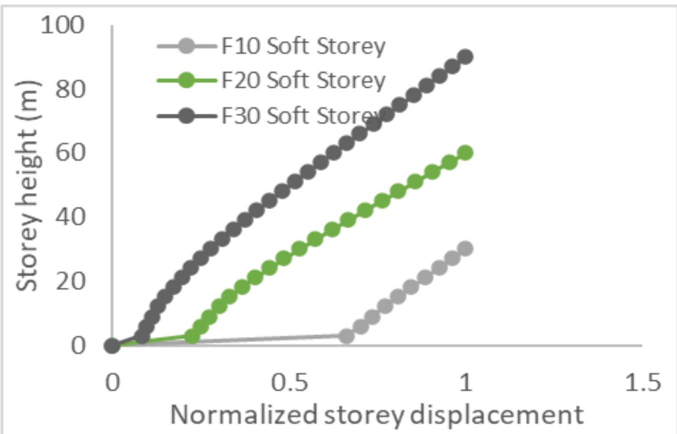

Chart-6: Effect of storey height and displacement at soft storey

4.7 Effect of bracings on the open ground storey

Among 4 different bracing systems, X bracing is found to be more effective in reducing the soft storey effect. For 10, 20, 30 storey buildings, the X bracing shows effective reduction capacity than others. Inverted V bracing is as much effective as X bracing. The average soft storey reduction capacity of X is found to be 80.03%. Inverted V is found to be the second most effective. It has a 78.37% reduction capacity. The highest reduction capacity of X bracing is due to its capacity to form strut action in both X and Y direction.

Table-1: Effect of the different bracing system in G+10 Storey building

Model type	Displacement at soft storey level (mm)	Reduction Capacity %
Soft Storey	37.99	-
X Bracing	10.051	73.5
V Bracing	12.09	68.13
Inverted V bracing	17.695	70.11
Eccentric Back bracing	16.835	53.36

Table-2: Effect of the different bracing system in G+20 Storey building

Model type	Displacement at soft storey level (mm)	Reduction Capacity %
Soft Storey	44.661	-
X Bracing	6.216	86.08
V Bracing	7.548	83.1
Inverted V bracing	6.592	85.23
Eccentric Back bracing	11.68	73.47

Table-3: Effect of the different bracing system in G+30 Storey building

Model type	Displacement at soft storey level (mm)	Reduction Capacity %
Soft Storey	17.847	-
X Bracing	3.472	80.5
V Bracing	4.36	75.6
Inverted V bracing	3.611	79.77
Eccentric Back bracing	7.122	60.11

5. CONCLUSIONS

Based on the results and discussion given in chapter 5 the following conclusions are drawn.

- ❖ The lack of rotational fixity at the column base (hinged condition) increases the lateral sway in the lower stories than in higher storeys. On the other hand, full rotational fixity at column base restricts the lateral sway at the first storey and thus, induces initial flexural behaviour near the base.
- ❖ Providing soft storey at the top storey won't create much soft storey effect. Providing soft storey at the bottom is found to be more critical than providing at the middle of the storey height. This effect is because the base shear is maximum at the base and it decreases as we move from the bottom to top storey.
- ❖ Infill walls can change the seismic response of RC frames very significantly. By introducing the effect of the infill wall, the seismic performance of the building increases drastically. The worst situation is when a soft storey is created. Then the building should be designed to reduce the soft storey effect or the damage concentration will be high at the soft storey. In the case of existing structures, the soft storey should be retrofitted.
- ❖ In the case of the soft storey, the soft storey effect is more drastic in the G+10 storey building, and the effect is decreasing as the number of storey increases. In the case of the soft storey, stories above the soft storey act as a rigid structure (like an inverted pendulum). In the case of higher structures, the part above the soft story becomes more flexible as the slenderness ratio of the building increases, hence less soft story effect.
- ❖ Among 5 different bracing systems, X bracing is found to be more effective in reducing the soft storey effect. For 10, 20, 30 storey buildings, the X bracing shows effective reduction capacity than others. Inverted V bracing is as much effective as X bracing. The average soft storey reduction capacity of X is found to be 80.03%. Inverted V is found to be the second most effective. It has a 78.37% reduction capacity.
- ❖ There is no change in mode shapes of bare frames as storey height increases. The mode shape shows a bending behaviour. But in infilled frames the moments are transferred through the truss action of infill walls, hence the behaviour changes from flexural to shear.

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