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A Comparative Study on the Effect of Infill Walls on RCC Frame Structures

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Abstract: *In-filled frame structures are commonly used in buildings, even in those located in seismically active regions. Present IS-codes and others unfortunately, do not have adequate guidance for treating the modeling, analysis and design of in-filled frame structures. In this study all theories (techniques for modeling the infill-frame interface) are described and then one method has been applied to study the seismic response of in-filled frame structures. In this study infill walls are modeled as an equivalent diagonal strut while analysis. Work has been carried out for 20 storey infill structure in which the bottom storey height is varied and different combinations of infill wall are analyzed. All these models have been compared with bare frame structure. On the basis of this work results has been obtained. The results show that the influence of infill on the structural performance is significant. The structural responses such as fundamental period, roof displacement, inter-storey drift ratio, stresses and member forces of the bottom storey column generally reduce, with incorporation of infill wall. These results will be useful in the seismic design and understanding of in-filled frame structures.*

Keywords: *Continuum model, Diagonal strut model, Dynamic Analysis, In-filled frame, Static Analysis*

I. Introduction & Problem identification

A large number of reinforced concrete and steel buildings are constructed with masonry infills. Masonry infills are often used to fill the voids between the vertical and horizontal resisting elements of the building frames with the assumption that these infills will not take part in resisting any kind of load either axial or lateral; hence its significance in the analysis of frame is generally neglected. Moreover, non-availability of realistic and simple analytical models of infill becomes another hurdle for its consideration in analysis. In fact, an infill wall enhances considerably the strength and rigidity of the structure. It has been recognized that frames with infills have more strength and rigidity in comparison to the bare frames and their ignorance has become the cause of failure of many of the multi-storied buildings.

Recent studies have shown that the use of masonry infill panel has a significant effect not only on the strength and stiffness but also on the energy dissipation mechanism of the overall structure. Neglecting the effects of masonry infill can lead to inadequate assessment of structural damage of infill frame structures subjected to intense ground motions.

The use of a masonry infill to brace a frame combines some of the desirable structural characteristics of each, while overcoming some of their deficiencies. As the effect of brick infills on frames, the high in-plane rigidity of the masonry wall significantly stiffens the structure, otherwise the frame becomes relatively flexible. On the other side, the ductile frame contains the brittle masonry, after cracking, up to loads and displacements much larger than it could achieve without the frame. The result is, therefore a relatively stiff and tough bracing system. The wall braces the frame partly by its in-plane shear resistance and partly by its behaviour as a diagonal bracing strut in the frame. When the frame is subjected to horizontal loading, it deforms with the columns and beams, bent in double-curvature [Hossain & Khan (2005)].

The “perpendicular” tensile stresses are caused by the divergence of the compressive stress trajectories on opposite sides of the leading diagonal as they approach the middle region of the infill. The diagonal cracking is initiated at and spreads from the middle of the infill, where the tensile stresses are a maximum, tending to stop near the compression corners, where the tension is suppressed [Hossain & Khan (2005)].

The nature of the forces in the frame can be understood by referring to an analogous braced frame. The windward column or the column facing earthquake load first, is in tension and the leeward column or the other side of the building facing earthquake load last, is in compression. Since the infill bears on the frame not as a concentrated force exactly at the corners, but over short lengths of the beam and column adjacent to each compression corner, the frame members are subjected also to transverse shear and a small amount of bending. Consequently, the frame members or their connections are liable to fail by axial force or shear, and especially by tension at the base of the windward column [Hossain & Khan (2005)].

1.1 Structural Effect due to In-filled Frames

The infill walls have a considerable strength and stiffness and they have significant effect on the seismic response of the structural system. There is a general agreement among the researchers that in-filled frames have greater strength as compared to frames without infill walls. The presence of the infill walls in the frame increases its lateral stiffness. The dynamic characteristics also changes due to the change in stiffness and mass of the structural system. However, the effect of the infill walls on the building response under seismic loading is very complex and math intensive.

If the masonry infills are properly distributed throughout the structure and properly considered in the design, then they usually have a beneficial effect on the seismic response of the structure. It resists effect of earthquake shaking and results reducing in the deformation of the structure. On the other hand, negative effects can be caused by irregular positioning of the infills in plan, and especially in elevation. A soft-storey collapse is typical for in-filled structures in which the infills are missing in one, e.g. the bottom storey.

However, a first-storey mechanism and subsequent collapse can also occur in the case of RC frame buildings with a regular distribution of masonry infills if the global ductility of the bare frame and the local ductility of the structural elements are low, if the masonry infills are weak and brittle, and if the ground motion is strong compared to the design strength.

Aim and objective of study

A study is undertaken which will involve the finite element analysis of the behaviour of High-Rise reinforced concrete (R.C.) frame with brick masonry infill. Again when a sudden change in stiffness takes place along the building height, the storey at which this drastic change of stiffness occurs is called a soft storey.
According to IS 1893 (Part 1):2002 a soft storey is the one in which the lateral stiffness is less than 70% of that in the storey above or less than 80% of the average stiffness of the three stores above.
The infill components increase the lateral stiffness and serve as a transfer medium of horizontal inertia forces. From this conception the floors that have no infill component has less stiffness regarding other floors. The major objectives of the research work are as follows:

- To find out the influence of masonry infill wall panel in Reinforced Concrete framed Structures in terms of deformation.
- To study the behaviour of frame with brick masonry infill by modeling masonry infill as a diagonal strut. The STAAD Pro V8i is to be used for the development of the model.
- The present study is aimed at findings out the effects of soft storey on frame structures due to horizontal loading.

It is noted that the inclusion of masonry walls as structural elements is not common yet, mainly due to the lack of suitable theory to represent the masonry infill. The present work aims at contributing to enlarge our knowledge on this subject and to assess the reliability of the results obtained by simplified methods.

II. Method of Analysis

- In this study, the masonry in-filled RC frame buildings with the representative configurations were designed using the computer program STAAD Pro V8i. The design earthquake loading for the RC framed buildings and the structural response were computed using the response spectrum method for equivalent static and dynamic force-based 3D analysis in accordance with the Indian Standard IS-code of practice for earthquake-resistant design IS: 1893–2002 _Indian seismic design code last revised in 2002. Assuming that the structural system of the buildings is a Special moment-resisting RC frame (SMRF), the response reduction factor that accounts for the structure was specified as 5.0.
- Two types of structures are examined:

1) Bare frame; 2) In-filled Frames (with single strut approach and with double strut approach)

In the Bare frame analysis, the structural contribution of the masonry infill panels was ignored in the structural analysis for code-based design of the RC frame members. However, the fundamental period of the masonry in-filled RC frame building for obtaining the design earthquake loads was calculated using the formulation specified by the Indian seismic design code for framed buildings with brick infills that results in a shorter natural period and, thus, higher seismic base shear to account for the lateral stiffness of the masonry infills. The dead weight of the masonry infill panels was assumed to act as a uniformly distributed load on the supporting beams.

In the in-filled frame analysis, the structural contribution of the masonry infill panels was taken as equivalent strut approach as specified by the Stafford Smith (1966) and further defined by the Hendry (1988). Figure shows a typical multi-bay multistory masonry in-filled RC frame in a representative masonry in-filled RC frame building structure. Both cases (single strut approach and double strut approach) are represents in the figure. In this study, there are 20 stories, three bays in one direction and four bays in the other direction designed in accordance with the revised Indian seismic design code. The storey height is 3.0 m and the bay length is 6.0 m.

- Staad input for the load generation facility consists of two parts:

1) Definition of the load system(s).
2) Generation of primary load cases using previously defined load system(s).

Primary load case consist dead load, live load, earthquake load, wind load etc. Dead loads are loads from self-weight of beam, slab, column, brick load, floor finish, slab filling etc. Live loads assumed to be produced by the intended use or occupancy of building, including the weight of movable partitions, distributed, concentrated loads, loads due to impact and vibration, and dust load etc.

Load Combinations

According to IS-456:2000 as per table 18 the load combination (0.9*DL + 1.5*EL) is to be considered when stability against overturning or stress reversal is critical [I.S.-456: (2000)]
So as per the code specifications, in this report only the load combination (0.9*DL + 1.5*EL) is used for the analyzing purpose.

Problem Statement

The following practically relevant distributions of masonry infill panels along the elevation of a planar masonry in-filled RC frame were identified for the linear static and dynamic analysis under the influence 4th zone earthquake ground motions:

1. Bare frame considering the dead weight of the masonry infill panels, a hypothetical case based on assumptions consistent with the prevalent design practice
2. Completely in-filled frame;
3. In-filled frame without infill panels in the first ground storey “soft/weak storey” at ground level corresponding to building supported on stilt columns;

The analytical investigation was performed for the following three geometries of RC frames:

1. Twenty-storey_ (ground+19) and storey height is 3.
2. Twenty-storey_ (ground+19) and storey height for ground floor is 4.5 m and other storey height is 3m.
3. Twenty-storey_ (ground+19) and storey height for ground floor is 6 m and other storey height is 3m.

All the models have four- bay in X-dir. and three-bay in Z-dir. frame with a bay length of 6.0 m in both directions. Assume slab thickness 200 mm, 1.5 kN/m^2 floor finish load and 2 kN/m^2 live load on the slab and 11.6 kN/m uniform load on the beam due to 230 mm masonry wall load. For the in-filled wall mechanism both single strut and double strut approach has studied.
So as per above description, there are total 15 models for investigation purpose:

1. Bare frame for 3.0 m bottom storey height
2. Bare frame for 4.5 m bottom storey height
3. Bare frame for 6.0 m bottom storey height
4. In-filled frame single strut approach for 3.0 m bottom storey height
5. In-filled frame single strut approach for 4.5 m bottom storey height
6. In-filled frame single strut approach for 6.0 m bottom storey height
7. In-filled frame single strut approach with stilt storey for 3.0 m bottom storey height
8. In-filled frame single strut approach with stilt storey for 4.5 m bottom storey height
9. In-filled frame single strut approach with stilt storey for 6.0 m bottom storey height
10. In-filled frame double strut approach for 3.0 m bottom storey height
11. In-filled frame double strut approach for 4.5 m bottom storey height
12. In-filled frame double strut approach for 6.0 m bottom storey height
13. In-filled frame double strut approach with stilt storey for 3.0 m bottom storey height
14. In-filled frame double strut approach with stilt storey for 4.5 m bottom storey height
15. In-filled frame double strut approach with stilt storey for 6.0 m bottom storey height

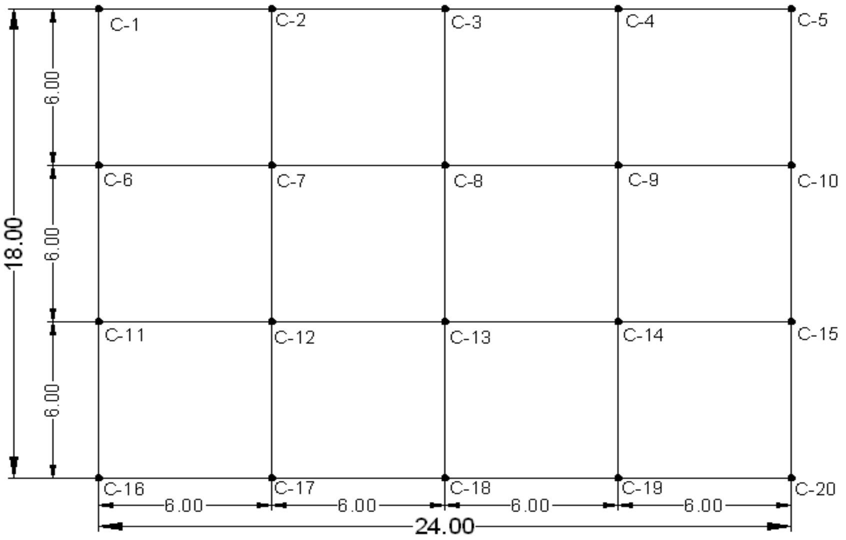
III. Result & Discussion

In this study, a 20 storey building has been taken, whose each storey height is 3m except the ground level storey. Static and Dynamic analysis has been done for bare frame and infilled frame (with stilt and without stilt storey) for ground level storey height of 3.0 m, 4.5 m & 6.0 m.

- Comparision has been done on the basis of Axial Forces, Shear Forces, Bending Moment, Torsion Moment only for the bottom storey in different models and also comparision has been done for deflection of the whole building.

- The load combination (1.5 EQz + 0.9 DL) has been taken for analysis as the X-direction is stronger than Z-direction.

There are 20 columns in the building as shown in Fig.



Typical layout plan of the frame

On the basis of static and dynamic analysis graph has been drawn for Bare Frame, Infilled Wall Single Strut Approach Frame (**IWSSA**), Infilled Wall Single Strut Approach Frame With Stilt (**Stilt IWSSA**), Infilled Wall Double Strut Approach Frame (**IWDSA**) and Infilled Wall Double Strut Approach Frame With Stilt (**Stilt IWDSA**).

As the forces and moments on some columns are same, so graph has been plotted only for those eight columns which have different values such as C-1, C-3, C-6, C-8, C-11, C-13, C-16 & C-18.

- Graphs for the Axial Forces:

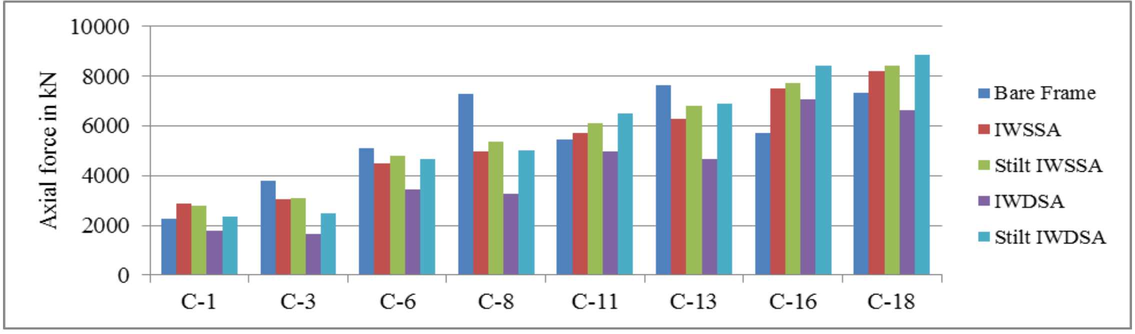


Fig. (a) Axial Forces (Static Analysis) in Columns for 4.5 m bottom storey height

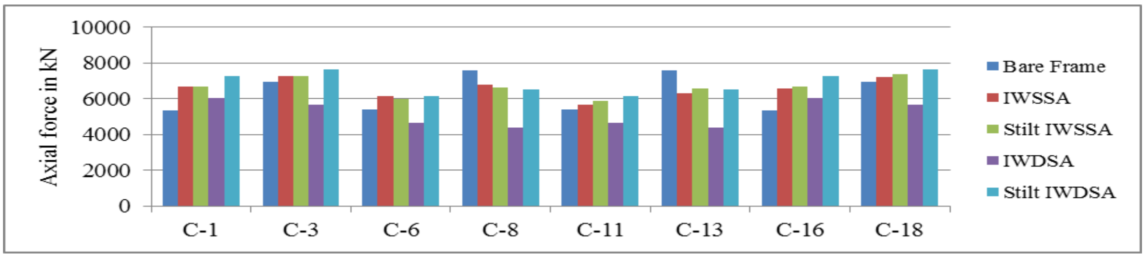


Fig. (b) Axial Forces (Dynamic Analysis) in Columns for 4.5 m bottom storey height

Above figures shows axial forces in different columns. The static analysis graph (a) of each shows that the forces on the infill frame are maximum at the opposite side of the building columns from the direction of earthquake forces applied and the forces on the bare frame are maximum at middle columns(C-8 & C-13). The dynamic analysis graph (b) of each shows that the forces are comparatively equally distributed. The axial forces slightly increase as the bottom story height increases except for infill wall double strut approach (IWDSA) where forces decrease primarily due to proper energy dissipation mechanism.

- Graph for the Shear Forces in Z-Direction (Global Axis):

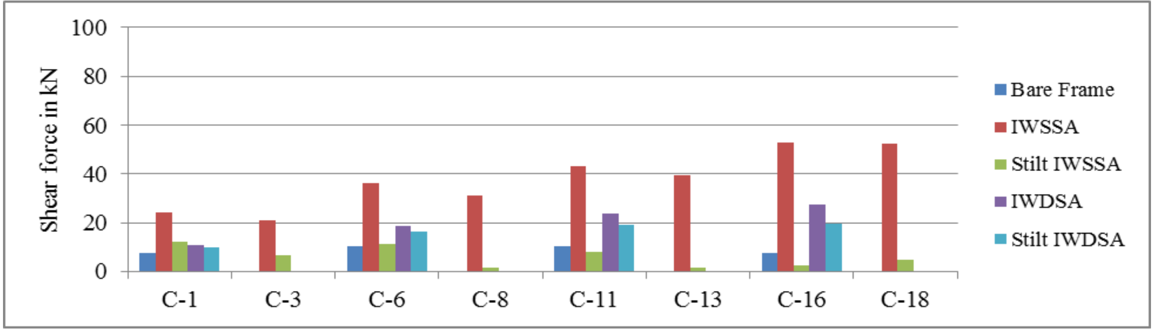


Fig. (a) Shear Forces (Static Analysis) in Columns for 6.0 m bottom storey height

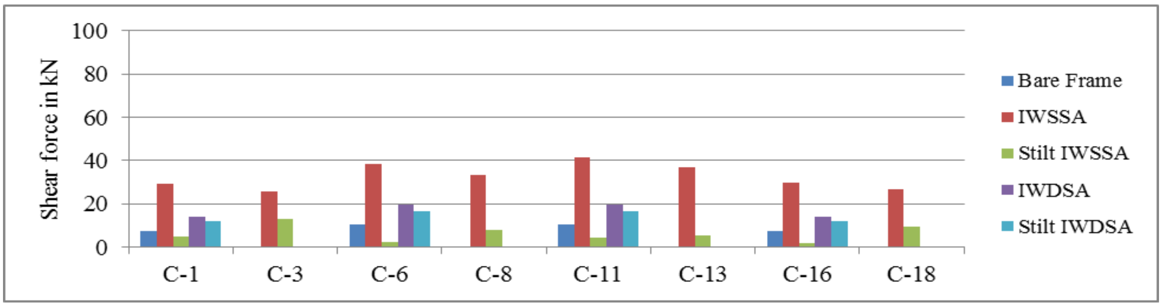


Fig. (b) Shear Forces (Dynamic Analysis) in Columns for 6.0 m bottom storey height

Above Figure shows shear forces in Z-direction of different columns. As shown in above graph shear forces on infill frame are much higher than that observed for bare frame. Generally bare frame analysis is considered for design purposes rather than infill wall mechanism. As a result the columns are designed for lower value of shear force. As per this theory the columns that are designed for lower shear force will fail in shear when earthquake occurs. The analysis here shows that the forces decrease as the bottom storey height increases and the static forces are higher than the dynamic forces.

- For the Shear Forces in X-Direction (Global Axis):

For the shear forces in X-direction for different columns, the phenomenon of the static and dynamic analysis is same but static forces are comparatively higher than dynamic forces. As the bottom storey height increases the shear force decreases. The shear forces on infill frame without stilt are much lesser than the bare frame, so the consideration of infill wall mechanism would be economical for structure. However in the case of stilt, as per the functional requirement, the above graph shows that forces are quite high in comparison of bare frame which may cause the failure of structure in the absence of infill frame mechanisms.

- For the Torsion Moment:

For the torsion moment for different columns, the torsion moment increases with increasing the bottom storey height. In the static analysis torsion moments are lower in bare frame as compared to infill frame. Thus inclusion of infill wall would generate torsional forces in structure. In the dynamic analysis torsion moments are higher in bare frame as compared to infill frame without stilt but much lesser than infill wall with stilt. So the use of infill wall mechanism is quite necessary for the analysis as per the discussion above. The torsion moment is more at outer column of X-direction (C-1, C-5, C-6, C-10, C-11, C-15, C-16 and C-20)

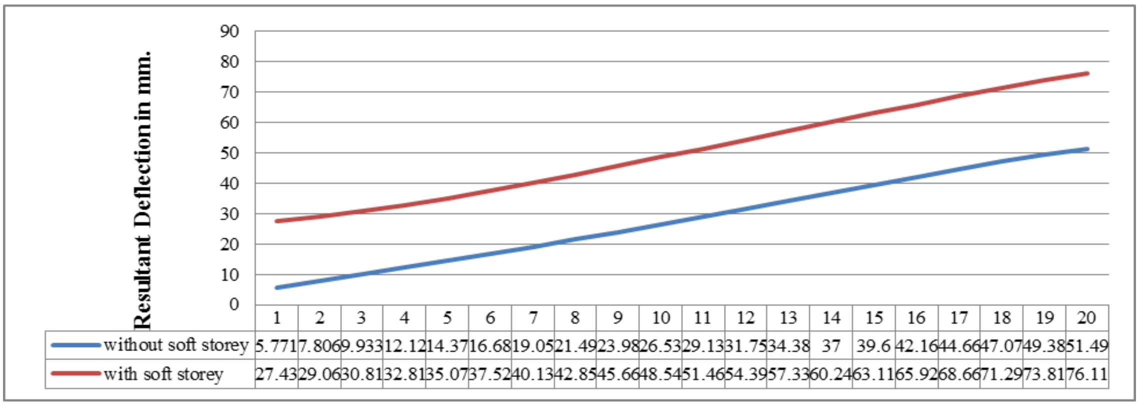
- For the Bending Moment in Z-Direction (Global Axis):

Bending moment in Z-direction of different columns, the phenomena of the static and dynamic analysis are same but static forces are comparatively higher than dynamic forces. As the bottom storey height increases, the bending moment increases. The bending moment on infill frame without stilt are much lesser than the bare frame, so provision of infill wall mechanism would be economical. Whereas for stilt structure, as per the functional requirement, the above graph shows that forces are comparatively high in comparison of bare frame which may cause the failure of structure if infill frame mechanism has not been considered in design.

- For the Bending Moment in X-Direction (Global Axis):

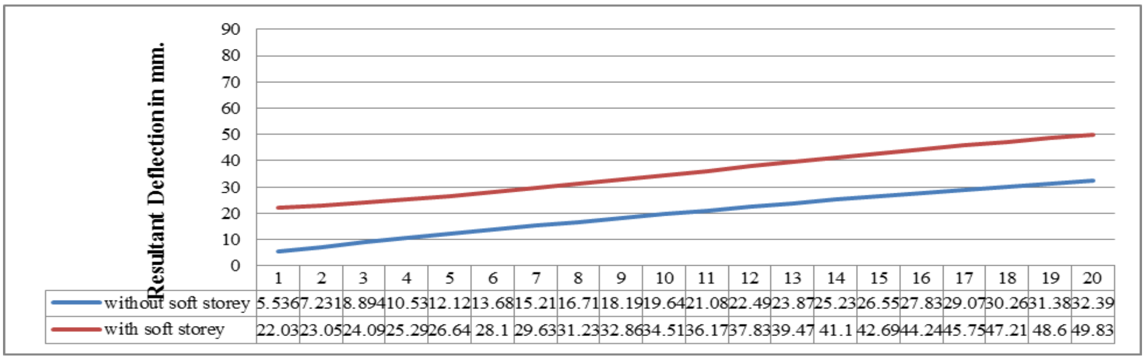
On bare frame, the bending moments are less as compared to the moments of infill frames. In case of 3.0 m bottom storey height, the moment from infills with stilt (as theory of single strut approach) is least compared to other models of infill frame but quite higher than the bare frame as observed from static and dynamic analysis. In 4.5 m and 6.0 m bottom storey height, the moment from infill without stilt (as theory of single strut approach) is greatest as compared to other frames as observed from static and dynamic analysis.

- Deflection graph for the Single Equivalent Strut Approach Theory:



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
without soft storey	5.771	7.806	9.933	12.12	14.37	16.68	19.05	21.49	23.98	26.53	29.13	31.75	34.38	37	39.6	42.16	44.66	47.07	49.38	51.49
with soft storey	27.43	29.06	30.81	32.81	35.07	37.52	40.13	42.85	45.66	48.54	51.46	54.39	57.33	60.24	63.11	65.92	68.66	71.29	73.81	76.11

Fig. (a) Deflection for Static Analysis for 6.0 m bottom storey height



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
without soft storey	5.536	7.231	8.894	10.53	12.12	13.68	15.21	16.71	18.19	19.64	21.08	22.49	23.87	25.23	26.55	27.83	29.07	30.26	31.38	32.39
with soft storey	22.03	23.05	24.09	25.29	26.64	28.1	29.63	31.23	32.86	34.51	36.17	37.83	39.47	41.1	42.69	44.24	45.75	47.21	48.6	49.83

Fig. (b) Deflection for Dynamic Analysis for 6.0 m bottom storey height

Deflection of the building for 3 m bottom storey height with soft storey is slightly higher than without soft storey. Deflection of first floor in the infill with soft storey is 2.28 (Static Analysis) and 2.06 times (Dynamic Analysis) higher than the infill without soft story. The maximum deflection is 53.1 mm (infill with stilt) and 50 mm (infill without stilt) for static analysis. In dynamic analysis maximum deflection is 31.6 mm (infill with stilt) and 31.1 mm (infill without stilt).

Deflection of the building for 4.5 m bottom storey height soft storey is higher than without soft storey. Deflection of first floor in the infill with soft storey is 3.5 (Static Analysis) and 2.99 times (Dynamic Analysis) higher than the infill without soft story. The maximum deflection is 61.7 mm (infill with stilt) 50.8 mm (infill without stilt) for static analysis. In dynamic analysis maximum deflection is 38.7 mm (infill with stilt) and 31.7 mm (infill without stilt).

Deflection of the building for 4.5 m bottom storey height with soft storey is higher than without soft storey. Deflection of building with 6.0 m bottom storey height is highest among 3.0 m, 4.5 m and 6.0 m heights. Deflection of first floor in the infill with soft storey is 4.75 (Static Analysis) and 3.97 times (Dynamic Analysis) higher than the infill without soft story. The maximum deflection is 76.1 mm (infill with stilt) 51.4 mm (infill without stilt) for static analysis. In dynamic analysis maximum deflection is 49.8 mm (infill with stilt) and 32.3 mm (infill without stilt).

- Deflection graph for the Double Equivalent Strut Approach Theory:

Deflection of the building for 3 m bottom storey height with soft storey is slightly higher than without soft storey. Deflection of first floor in the infill with soft storey is 3.14 (Static Analysis) and 3.24 times (Dynamic Analysis) higher than the infill without soft story. The maximum deflection is 55.9 mm (infill with stilt) 51.8 mm (infill without stilt) for static analysis. In dynamic analysis maximum deflection is 34.4 mm (infill with stilt) and 33.0 mm (infill without stilt).

Deflection of the building for 4.5 m bottom storey height with soft storey is higher than without soft storey. Deflection of first floor in the infill with soft storey is 6.39 (Static Analysis) and 6.63 times (Dynamic Analysis) higher than the infill without soft story. The maximum deflection is 67.1 mm (infill with stilt) 52.7 mm (infill without stilt) for static analysis. In dynamic analysis maximum deflection is 43.8 mm (infill with stilt) and 33.7 mm (infill without stilt).

Deflection of the building for 4.5 m bottom storey height with soft storey is higher than without soft storey. Deflection of building with 6.0 m bottom storey height is highest among 3.0 m, 4.5 m and 6.0 m heights. Deflection of first floor in the infill with soft storey is 11.27 (Static Analysis) and 11.89 times (Dynamic Analysis) higher than the infill without soft story. The maximum deflection is 84.9 mm (infill with stilt) and

53.1 mm (infill without stilt) for static analysis. In dynamic analysis maximum deflection is 57.9 mm (infill with stilt) and 33.9 mm (infill without stilt).

It is clear from the above discussions and graphs that deflection is much higher in double strut approach infill frame in comparison with single strut approach though both approaches follow a similar pattern.

IV. Conclusion

- Due to infill wall mechanism, the deflection is lower in the infill frames. Deflection from the static analysis is higher than the dynamic analysis. As the bottom storey height increases the value of deflection also increases in different models which are represented by the graphs.
- It can be broadly concluded from the tables and graph that effect of masonry infill is advantageous i.e. masonry infill walls increase global stiffness and strength and reduce the deflection of the structure. On the other hand, effect of infill wall does not show benefits over the torsional moment thus generated and soft-storey effects induced by irregularities.
- The following conclusions may be drawn from the study conducted:
- The proposed diagonal strut analytical procedure can be implemented in the normal course of design. It provides a fairly accurate prediction of structural stiffness, fundamental frequency and time period of masonry in-filled frames.
- Masonry infill frame limits total storey drift when compared to bare frame. As per the graph, inclusion of infill walls cause a decrease in overall deflection and inter storey drifts due to static and dynamic behavior of R/C structures.
- A masonry in-filled structure with a soft first storey is susceptible to failure due to high base shear attracted by the masonry that has to be absorbed by the weaker first storey frame.
- The presence of infill wall leads, in general, to decrease in shear forces on the frame columns. However, in the case of infill frame with a soft ground story, the shear forces acting on columns are considerably higher than those obtained from the analysis of the bare frame.
- The lateral deflection is reduced significantly in the infill frame compared to the deflection of the bare frame.
- Deflection for a soft storey building frame (20 storey with 3 m storey height) at the top level of ground storey is 2-3.3 times greater than that observed in the building without soft storey. Whereas no significant deference is observed in deflection at the top level of the building due to effect of soft storey.
- Deflection, bending and torsion moment, shear and axial forces increase as the bottom storey height is increased and vice-versa.

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This heading is not assigned a number.

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