International Journal of Civil and Structural Engineering Research ISSN 2348-7607 (Online)
Vol. 3, Issue 1, pp: (360-367), Month: April 2015 - September 2015, Available at: www.researchpublish.com

Comparison of Seismic Behaviour of a Typical Multi-Storey Structure With Composite Columns and Steel Columns

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Abstract: **The present work seeks to investigate the seismic behaviour of a typical ordinary moment resisting framed structure with composite columns and conventional Steel columns and examine the key design issues involved. The present study deals with seismic behaviour of a typical (G+12) storied framed structure assessed through equivalent static method of analysis as per IS: 1893-2002 for moderate seismic zone III using ETABS software package. The analyses are performed on a suite of 2 types of ordinary moment resisting framed 3D space models with different column types – Steel, and CFST. The analysis is carried out and the results are compared in terms of critical earthquake response parameters such as base shear, storey drifts, roof displacements, and storey overturning moments.**

Keywords: **seismic behaviour, composite columns and steel columns, Multi-storey structure.**

I. INTRODUCTION

The buildings in India are constructed with RCC and the adoption of steel structures is generally confined to industrial buildings and of late multi-storey buildings, which have acquired prominence by adopting composite structural elements. However, in recent times, the composite columns are gaining popularity for use in multi-storey buildings by virtue of their excellent static and earthquake resistant properties such as lower mass, high strength, rigidity and stiffness, significantly high toughness and ductility, large energy dissipation capacity. Besides these advantages, easy site erection and installation capability can lead to reduction in labour and foundation costs compared to RCC columns and have excellent buckling resistance, reduced maintenance and fireproofing cost compared to steel columns. Also, the composite systems are lighter in weight (about 20 to 40% lighter than concrete construction). Thus, the composite system is a more complete structural system than simple reinforced concrete or steel elements. When adopting a composite section, the amount of structural steel, reinforcing steel and concrete area, and the geometry as well as the position of the three materials represent relevant design parameters. Indeed, a number of different combinations are possible thus leading to a flexible design. Due to these reasons composite members are gaining importance for the making of sky-scrapers, infrastructure growth and especially for high rise structures of seismic regions in the world.

A steel-concrete composite column is a compression member, comprising either a concrete encased hot-rolled steel section or a concrete filled tubular section of hot-rolled steel and is generally used as a load-bearing member in a composite framed structure. The load carrying capacity of composite columns is more than that of the bare reinforced column and the structural steel column included in the system.

II. OBJECTIVES OF THE STUDY

The main objectives of the present study are:

Comparison of seismic behaviour of two types of multi-storey framed structures consisting of:

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a) Steel frame with RC slab

b) Steel beam, RC slab and Concrete Filled Steel Tube (CFST) Composite columns.

Economic Analysis of the two alternative structures.

III. SCOPE OF THE STUDY

The scope of the present study is envisaged to the following criteria:

(1) Type of structure - (G +12) framed multi-storey structure

(2) Hot rolled steel beams of grade Fe 250 are to be used

(3) Reinforcing steel of grade Fe 500 is to be used

(4) Concrete of grade M 30 is to be used

(5) The structure is assumed to be located on hard soil/rock strata

(6) The building frame is assumed to be Ordinary Moment Resisting Frame (OMRF)

(7) The connections at the joints are assumed to be simple moment resisting

(8) Only seismic analysis by equivalent lateral force method is to be clarified as per IS 1893:2002 codal provisions

(9) Analysis is to be carried out for the one possible location of the structure in: zone III

(10) For the design of composite columns, the design provisions of Eurocode (EC4) are adopted in the absence of specific recommendations and guidelines for composite columns in the Indian Standards

(11) Steel columns are designed as per IS 800:2007 codal provisions

(12) The Two alternative structures are compared with the following structural performance parameters: Base shear, storey drifts, storey overturning moments and roof displacements.

IV. MODELLING AND ANALYSIS

a) Description of the building:

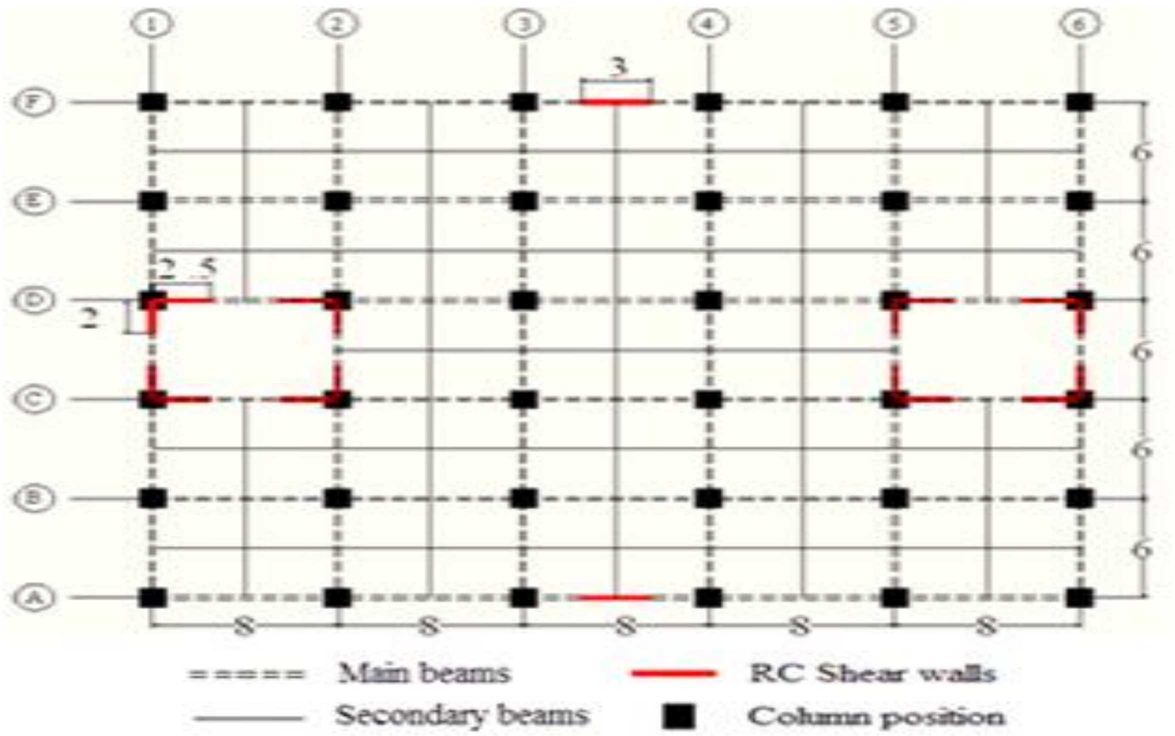
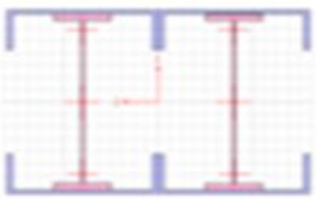
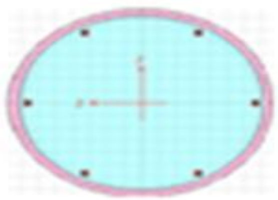


Figure 1: Typical beam-column grid with shear walls (Dimensions in m)

A typical multi-storey i.e., (G+12) framed structure situated in moderate earthquake zone III (Z=0.16) and very severe earthquake zone V (Z=0.36) located on a hard soil strata is chosen for the study. It essentially consists of RC slab (125 mm thick) of size 8 m X 6 m resting on main steel girders (ISMB 500) and further supported by secondary steel joists (ISMB 250), which in turn are supported by main steel girders. This slab and beam structural system is supported on Steel/Infilled columns and is integrally connected using stud type shear connectors designed to ensure full interaction. RC shear walls (250 mm thick) are provided at the middle of the peripheral edges of the building, which also function as the lift core walls. A perimeter moment frame provides both additional lateral resistance and gravity support for the concrete slab-on-steel beam floor.

The sizes of the columns are fixed based on preliminary design and axial load capacity. Table 1 shows different column sections, which are modelled in the "Section Designer" form of Etabs for the purpose of analysis.

TABLE 1 Different column sections adopted in (G+12) framed structure

 Structural steel	 Concrete-infilled steel
2 ISMB 450 with ISMC 400 on both top and bottom flanges	480 mm dia. and 16 mm thick hollow steel ring with concrete infill

b) Methodology of the present work:

Equivalent static load method is used for the present study where, the efficiency and potential utility of the composite columns are compared with conventional steel columns for a typical multi-storey framed structure.

Equivalent Static Lateral Force Method:

The response of a structure to earthquake-induced forces is a dynamic phenomenon. Consequently, a realistic assessment of the design forces can be obtained only through a dynamic analysis of the building models. Although this has long been recognized, dynamic analysis is used only infrequently in routine design because such an analysis is both complicated and time-consuming. A major complication arises from the fact that most structures are designed with the expectation that they would be strained into the inelastic range when subjected to the design earthquake.

The present work follows equivalent static method of analysis. The concept employed in *equivalent static lateral force* procedures is to place static loads on a structure with magnitudes and direction that closely approximate the effects of dynamic loading caused by earthquakes. Concentrated lateral forces due to dynamic loading tend to occur at floor and ceiling/roof levels in buildings, where concentration of mass is the highest. Furthermore, concentrated lateral forces tend to be larger at higher elevations in a structure. Thus, the greatest lateral displacements and the largest lateral forces often occur at the top level of a structure (particularly for tall buildings). These effects are modeled in equivalent static lateral force procedures by placing a force at each story level in a structure.

The design lateral force shall first be computed for the building as a whole. This design lateral force shall then be distributed to the various floor levels. The overall design seismic force thus obtained at each floor level shall then be distributed to individual lateral load resisting elements depending on the floor diaphragm action.

V. ANALYSIS OF RESULTS AND DISCUSSION

After analyzing the two alternative structures located in seismic zone III by equivalent static lateral force method conforming to IS 1893:2002 using Etabs, the results are extracted and compared in terms of critical earthquake response parameters such as base shear, maximum storey drifts, roof displacements, storey overturning moments.

a) Design Seismic Base Shear:

Seismic forces accumulate downward in a building. Seismic forces in the building are greatest at the base of the building. The seismic force at base of the building is called the *base shear*. Earthquakes often damage buildings at this level. In a multi-storey building all vibration modes of the building contribute to the base shear as shown below.

TABLE 2 Variations of Base Shear in Seismic Zone III

Column Types	Base Shear	
	EQX	EQY
Steel	5460	5460
Infilled	4260	4260

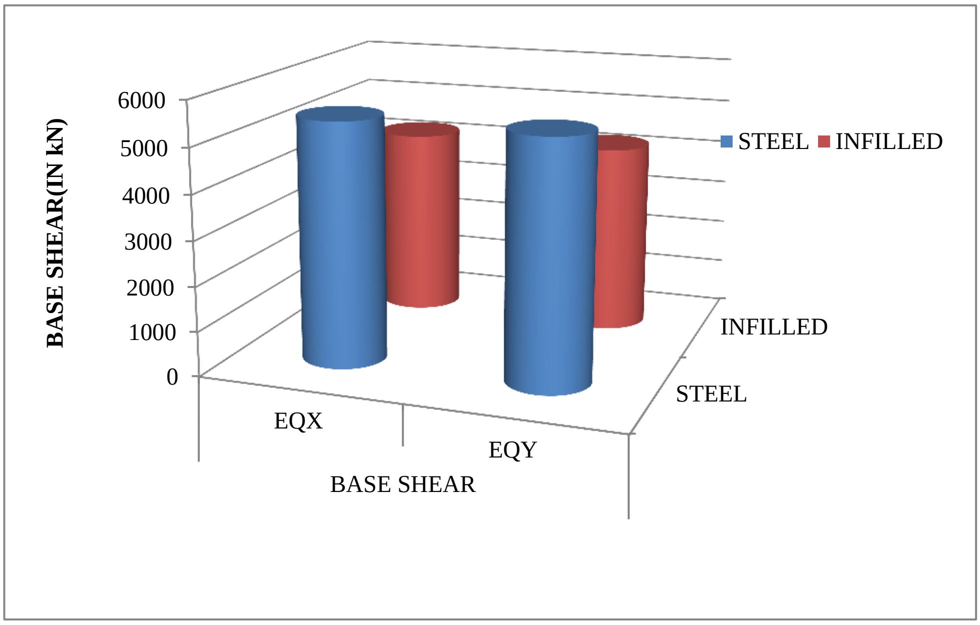


Fig 2: Base shear variation in Zone III.

From figure above it is evident that, when compared to steel (5.5 MN) columns, the composite columns are found to experience the least magnitude of base shear (4.3 MN) and 22% reduction in base shear can be attributed to the reduction in mass of the composite columns, which in turn reduces the mass of the structure.

b) Storey overturning moment:

Storey overturning moments are calculated by multiplying seismic lateral forces with the storey height. In the present case, a considerable reduction of overturning moments is noticed for composite columns, where the columns are short.

TABLE 3 Variations of Storey overturning moment in Seismic Zone III

Column Types	Storey Overturning Moments	
	EQX	EQY
Steel	220	220
Infilled	171	171

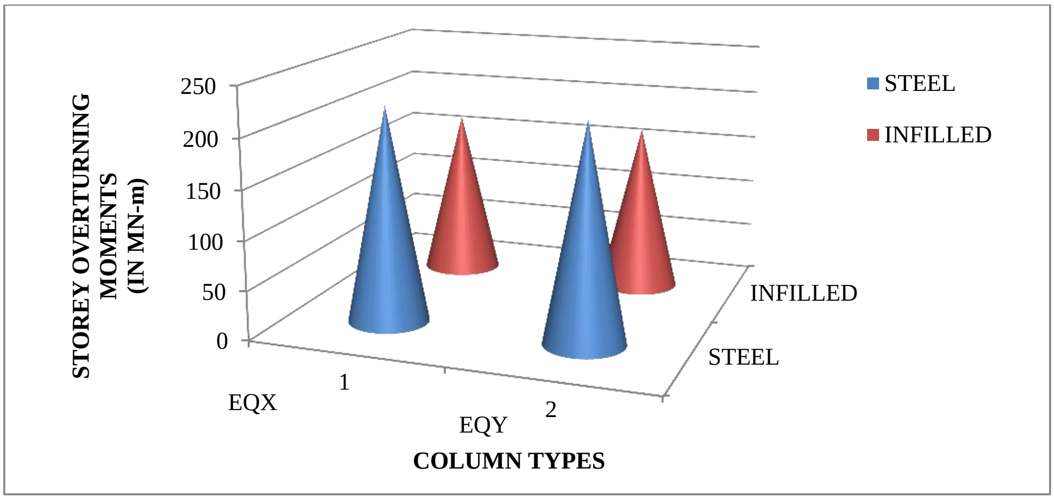


Fig 3: Storey overturning moment's variation in seismic Zone III

From figure above, it is evident that, when compared to steel (220 MN-m) columns, the composite columns, especially the infilled columns are found to experience the least magnitude of overturning moment (171 MN-m). The 22% reduction in overturning moment is observed with respect to steel columns. This variation apparently shows that the structure with composite short columns has greater stability against buckling as well as overturning at base level and thus providing continuous load path for the upcoming forces to the foundation.

c. Storey Drift:

Storey drift is generally defined as the lateral displacement of one floor relative to the floor below. The inter-storey drift criterion is the global collapse parameter that is utilized to evaluate the force reduction factors reflecting the average margin of safety exhibited by each frame under the effect of ground motions. Total building drift is the absolute displacement of any point relative to the base. Building separations or joints must be provided to permit adjoining buildings to respond independently to earthquake ground motion. For seismic loads, the maximum story drift is found from ETABS and is compared to the allowable story drift given in IS 1893:2002. It was determined that all floor levels met the serviceability requirements for seismic forces.

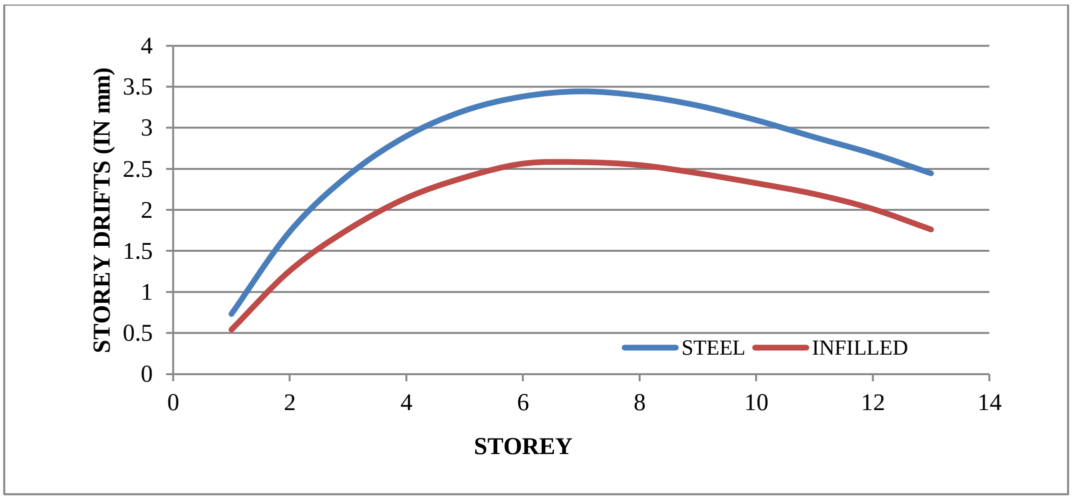


Fig 4: Drift variation at various storey levels of two alternative structures with different column types located in Seismic Zone III

TABLE 4: Variations of Storey drift in Seismic Zone III

Column Type	Storey Drift	
	EQX	EQY
Steel	3.44	3.23
Infilled	2.58	2.52

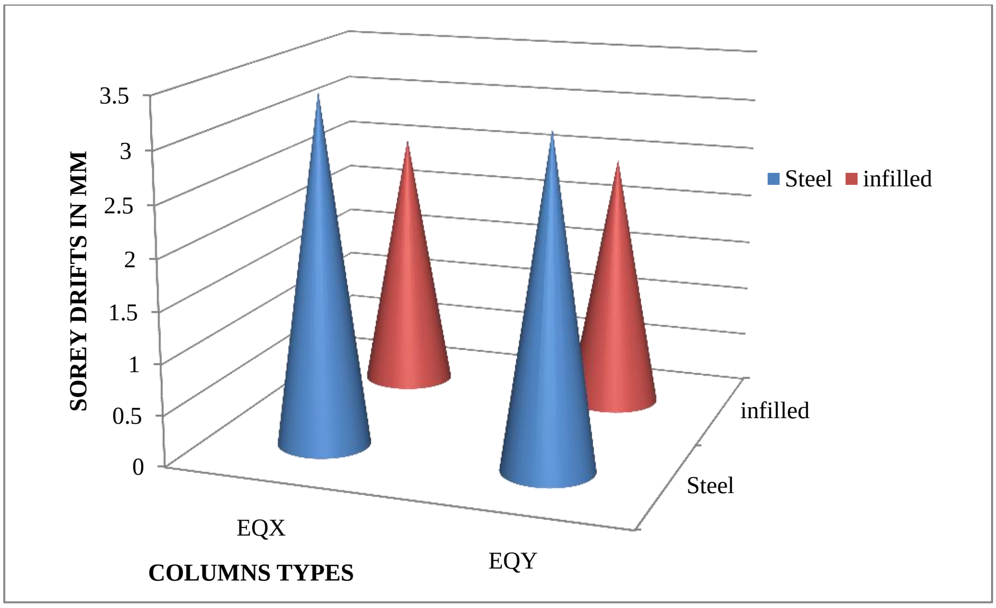


Fig 5: shows storey drift variations in Zone III

From figure above, it is observed that, when compared steel (3.44 mm) columns, the composite columns, especially the infilled columns are found to experience the least magnitude of storey drifts (2.58 mm). The storey drift of 25 % reduction in case of infilled column is observed when compared with the steel columns, which has highest magnitude of storey drift (3.23 to 3.44 mm). The reduction in storey drift is due to reduction in base shear and increase in stiffness of the composite columns.

d. Roof Displacements:

Earthquake-induced motions, even when they are more violent than those induced by wind (as cited by Taranath (2005). evoke a totally different human response—first, because earthquakes occur much less frequently than windstorms, and second, because the duration of motion caused by an earthquake is generally short. Displacements, the extent to which a structural element moves or bends under pressure is the main serviceability concern in the structures. Lateral displacements that occur during earthquakes should be limited to prevent distress in structural members and architectural components.

The value of maximum roof displacement is a direct and efficient measure used to quantify the overall displacement response of a building. However, the value of roof displacement provides no direct information about localized deformation within a structure. If the value of the inter-story displacement for each story is the same as the value of the roof displacement divided by the number of stories, the structure is said to deform uniformly.

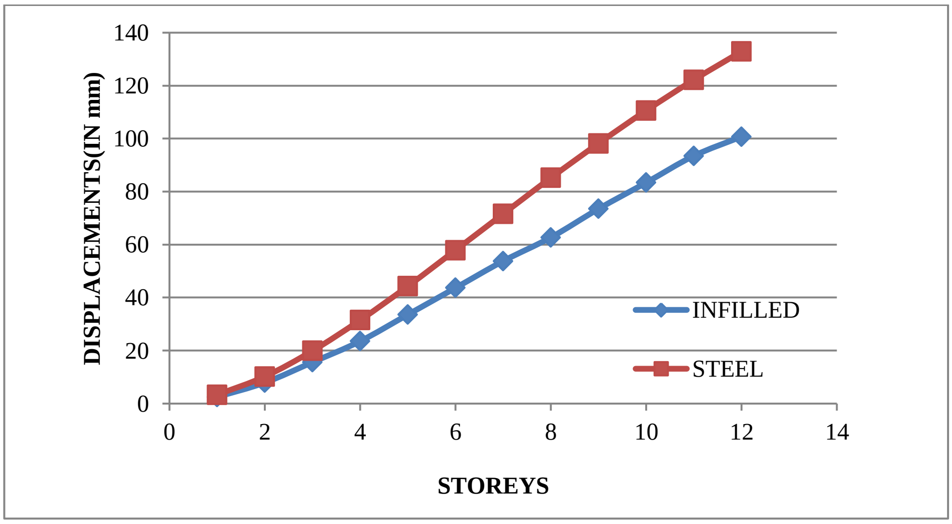


Fig 6: Displacement variation at various storey levels of four alternative structures located in Seismic Zone III.

TABLE 5 Variations of Roof displacement in Seismic Zone III

Column Type	Roof Displacement	
	EQX	EQY
Steel	143	129
Infilled	105	98

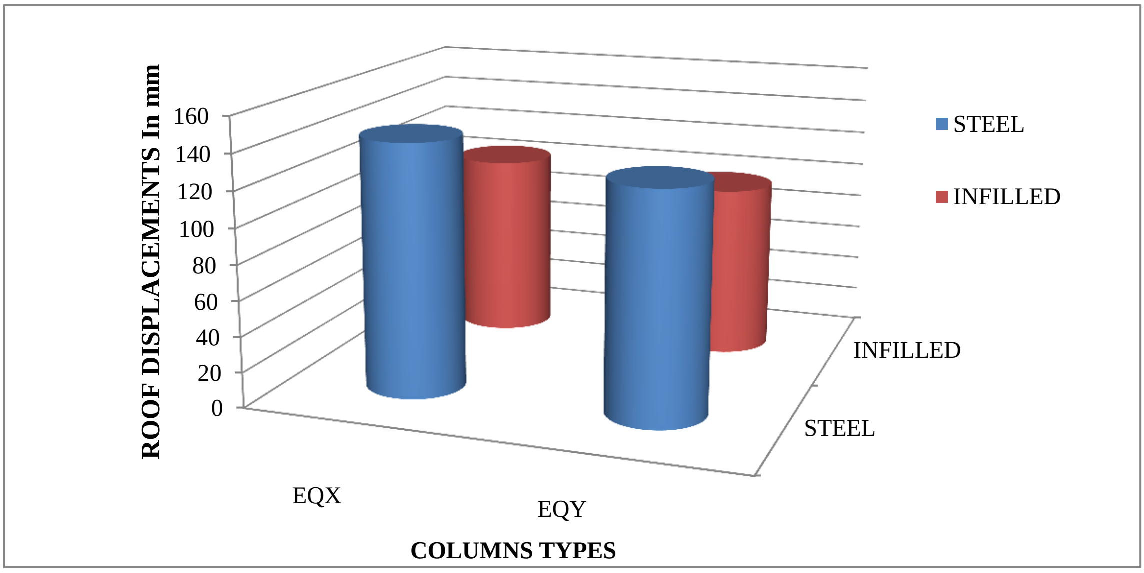


Fig 7: Roof displacements variations in Zone III

From figure above it can be seen that, the least roof displacement occurs in case of infilled columns (98 to 105 mm) compared to steel (143 mm) columns. Roof displacement has been reduced by **26.6%** in case of infilled column when compared with the steel. These variations show that the frame with composite columns have higher lateral stiffness than the steel columns.

VI. CONCLUSIONS

The advantage of superior performance of composite columns under gravity loads have been brought out in several studies. However, the lateral load resistance of composite columns especially against seismic loads has not been investigated so extensively. The present study makes an attempt to bring out the advantages of composite columns against conventional Steel columns in multistorey structures. For this purpose, a typical (G+12) framed multi-storey building with two alternative column schemes vis a vis. Steel and Concrete Filled Steel Tube (CFST) located in seismically active moderate zones III is taken up for evaluation and equivalent static lateral load analysis is carried out using Etabs software. The following conclusions are drawn in respect of various performance parameters.

Lateral Load Resistance:

The seismic performance of the selected multi-storey structure is assessed through various structural response parameters such as base shear, storey overturning moment, storey drift and roof displacement.

a) Seismic Forces under Lateral Loads:

Base shear and storey overturning moment induced by the seismic forces are reduced by **22 to 28%** for composite columns.

These variations indicate that the composite columns have reduced mass/weight thus reducing the entire mass of structure in respect of reduction in base shear and the composite columns have higher global stability and resistance to buckling in respect of reduction in overturning moments.

b) Displacement characteristics:

Lateral deformations such as storey drifts and roof displacements have been checked at various storey levels of all structures with two alternative columns located in zone III.

c) Storey drifts:

When Zone III is considered, the storey drifts are the highest in case of steel, which is well within the permissible limit of 0.004h = 18 mm (as per IS 1893:2002). The composite columns undergo about 25 to 28.5% reduction of lower storey drifts when compared with the steel columns.

d) Roof displacements:

In a similar passion, the roof displacement is highest in case of Steel column. Roof displacement has been reduced by **26.6%** in case of CFST column when compared with the steel. Also, the maximum lateral displacement is the roof displacement value which indicates that the deformation of the entire structure is uniform in two alternative cases. Thus, both parameters demonstrate higher order of both global and local stability indicating that the composite columns are stiffer than conventional Steel columns.

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