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Comparative Seismic Analysis of RCC, Steel & Steel-Concrete Composite Frame

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ABSTRACT: Steel-Concrete composite constructions are nowadays very popular owing to their advantages over conventional Concrete and Steel constructions. Concrete structures are bulky and impart more seismic weight and less deflection whereas Steel structures impart more deflections and ductility to the structure, which is beneficial in resisting earthquake forces. Composite Construction combines the better properties of both steel and concrete along with lesser cost, speedy construction, fire protection etc. Hence the aim of the present study is to compare seismic performance of a 3D (G+7) storey RCC, Steel and Composite building frame situated in earthquake zone V. All frames are designed for same gravity loadings. The RCC slab is used in all three cases. Beam and column sections are made of either RCC, Steel or Steel-concrete composite sections. Equivalent static method and Response Spectrum method are used for seismic analysis. SAP 2000 software is used and results are compared. Cost effectiveness based on material cost for all types of building frames is determined. Comparative study concludes that the composite frames are best suited among all the three types of constructions in terms of material cost benefit added with better seismic behavior.

KEYWORDS: Composite Beam, Equivalent static method, Response spectrum method, SAP 2000, RCC

I. INTRODUCTION

In India most of the building structures fall under the category of low rise buildings. So, for these structures reinforced concrete members are used widely because the construction becomes quite convenient and economical in nature. But since the population in cities is growing exponentially and the land is limited, there is a need of vertical growth of buildings in these cities. So, for the fulfillment of this purpose a large number of medium to high rise buildings are coming up these days. For these high rise buildings it has been found out that use of composite members in construction is more effective and economic than using reinforced concrete members. The popularity of steel-concrete composite construction in cities can be owed to its advantage over the conventional reinforced concrete construction. Reinforced concrete frames are used in low rise buildings because loading is nominal. But in medium and high rise buildings, the conventional reinforced concrete construction cannot be adopted as there is increased dead load along with span restrictions, less stiffness and framework which is quite vulnerable to hazards.

In construction industry in India use of steel is very less as compared to other developing nations like China, Brazil etc. Seeing the development in India, there is a dire need to explore more in the field of construction and devise new improved techniques to use Steel as a construction material wherever it is economical to use it. Steel concrete composite frames use more steel and prove to be an economic approach to solving the problems faced in medium to high rise building structures.

1.1 Composite Structures

When a steel component, like an I-section beam, is attached to a concrete component such that there is a transfer of forces and moments between them, such as a bridge or a floor slab, then a composite member is formed. In such a composite T-beam, as shown in Figure 1.1, the comparatively high strength of the concrete in compression complements the high strength of the steel in tension. Here it is very important to note that both the materials are used to fullest of their capabilities and give an efficient and economical construction which is an added advantage.

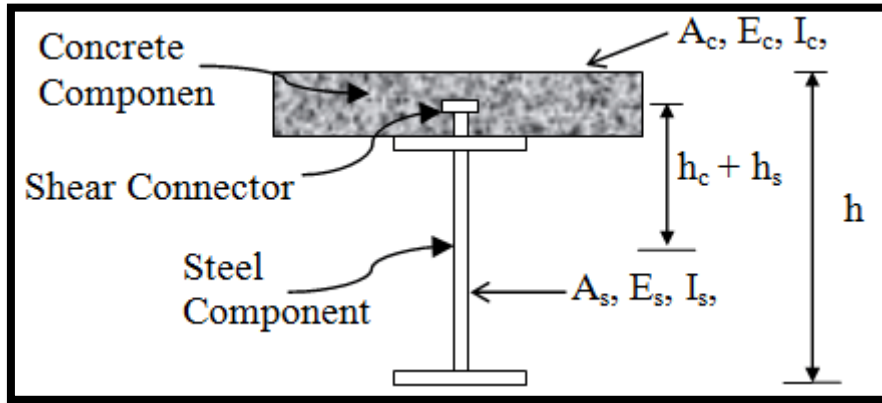


Figure 1.1 Cross Section of a typical composite member

• **Composite Steel-Concrete beam:-** A concrete beam is formed when a concrete slab which is casted in-situ conditions is placed over an I-section or steel beam. Under the influence of loading both these elements tend to behave in an independent way and there is a relative slippage between them. If there is a proper connection such that there is no relative slip between them, then an I-section steel beam with a concrete slab will behave like a monolithic beam. The figure is shown in the figure 1.2. In our present study, the beam is composite of concrete and steel and behaves like a monolithic beam. Concrete is very weak in tension and relatively stronger in tension whereas steel is prone to buckling under the influence of compression. Hence, both of them are provided in a composite such they use their attributes to their maximum advantage. A composite beam can also be made by making connections between a steel I-section with a precast reinforced concrete slab. Keeping the load and the span of the beam constant, we get a more economic cross section for the composite beam than for the non-composite tradition beam. Composite beams have lesser values of deflection than the steel beams owing to its larger value of stiffness. Moreover, steel beam sections are also used in buildings prone to fire as they increase resistance to fire and corrosion.

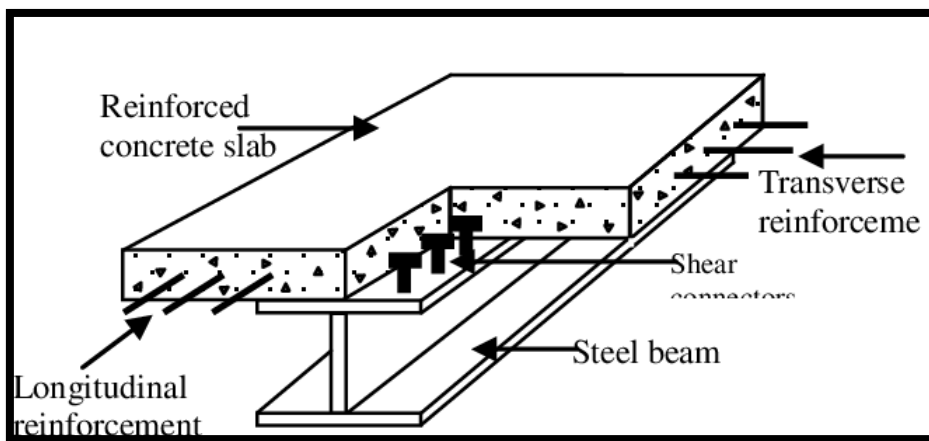


Figure 1.2 Composite beam

• **Steel-Concrete Composite Columns:-** A steel-concrete composite column is a compression member comprising of a concrete filled tubular section of hot-rolled steel or a concrete encased hot-rolled steel section. Figure 1.3(a) and figure 1.3(b) show concrete filled and concrete encased column sections respectively. In a composite column, both the concrete and the steel interact together by friction and bond. Therefore, they resist external loading. Generally, in the composite construction, the initial construction loads are beared and supported by bare steel columns. Concrete is filled on later inside the tubular steel sections or is later casted around the I section. The combination of both steel and concrete is in such a way that both of the materials use their attributes in the most effective way. Due to the lighter weight and higher strength of steel, smaller and lighter foundations can be used. The concrete which is casted around the steel sections at later stages in construction helps in limiting away the lateral deflections, sway and bucking of the

column. It is very convenient and efficient to erect very high rise buildings if we use steel-concrete composite frames along with composite decks and beams. The time taken for erection is also less due to which speedy construction is achieved along better results.

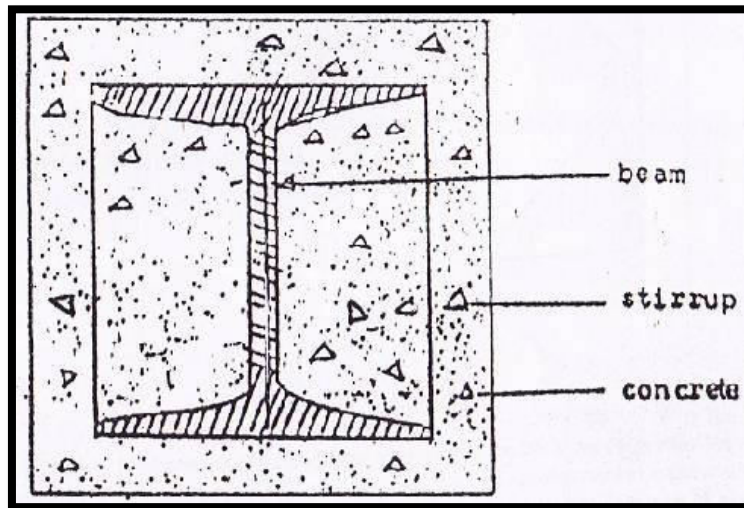


Figure 1.3.a Concrete encased steel column

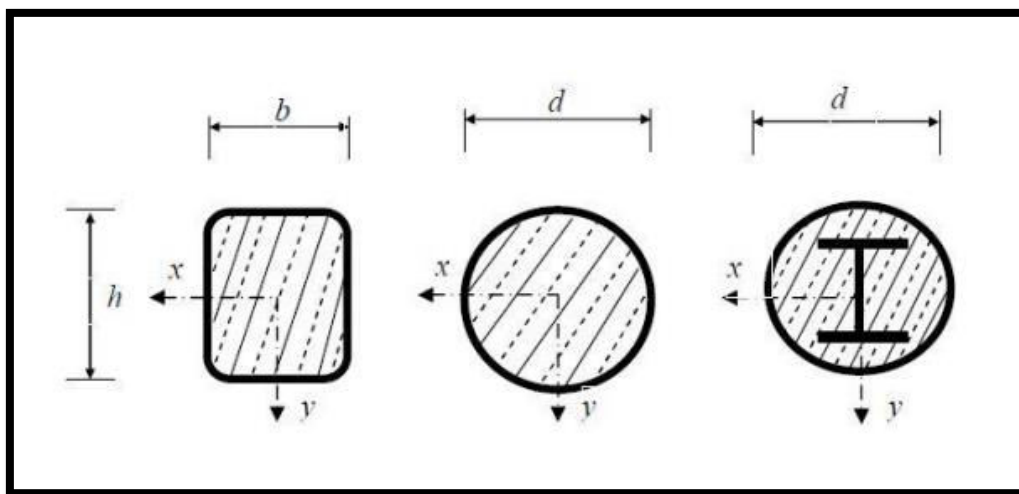


Figure 1.3.b Steel encased concrete column sections

The aim of the present study is to compare performance of a 3D (G+7) story RCC, Steel and composite building frame situated in earthquake zone V. All frames are designed for same gravity loadings. The RCC slab is used in all three cases. Beam and column sections are made of either RCC, Steel or Steel-concrete composite sections. Equivalent static method and Response Spectrum method are used for seismic analysis. SAP 2000 software is used and results are compared. Cost effectiveness based on quantity of materials of all types are determined.

II. LITERATURE REVIEW

D.R. Panchal & Dr. S.C. Patodi evaluated the seismic performance of multistoried building for which they have considered Steel-Concrete Composite and R.C.C. For their analysis the methods that they used were Equivalent static method and Linear Dynamic Response Spectrum Analysis. The results thus obtained were analyzed and compared with each other.



Jingbo Liu, Yangbing Liu, Heng Liu proposed a performance based fragility analysis based method in which the uncertainty due to variability in ground motion and structures are considered. By the proposed method of fragility analysis they performed analysis of a 15 storeyed building having composite beam and concrete filled square steel tube column.

Shashikala.Koppad, Dr.S.V.Itti considered steel-concrete composite with RCC options for analyzing a B+G+15 building which is situated in earthquake zone III and earthquake loading is as per the guidelines of IS1893(part-I): 2002. The parameters like bending moment and maximum shear force were coming more for RCC structure than the composite structure. Their work suggested that composite framed structures have many benefits over the traditional RC structures for high rise buildings.

A.S. Elnashai and A.Y. Elghazouli developed a model for analysis of structures subjected to cyclic and dynamic loads. These structures were primarily Steel-Concrete Composites and the model they developed was a non-linear model. The efficiency and accuracy of the developed model is shown through correlation between the experimental results and analytical simulations. The model was used for parametric studies resulting in providing important conclusion for ductility based earthquake-resistant design.

D.R. Panchal and P.M. Marathe used a comparative method of study for RCC, Composite and steel options in a G+30 storey commercial building situated in earthquake Zone IV. For this they used Equivalent static method and used the software ETABS. The comparative study included size, deflections, material consumption of members in RCC and steel sections as compared to Composite sections was also studied closely and based on this study a cost comparison analysis was also performed.

III. PROPOSED METHODOLOGY

3.1 Methodology

Step1:

Design of beam and column sections

The frame is analyzed with dead and live loads for RCC sections for beams and columns in SAP 2000. The maximum forces in columns and beams are determined from output file. The sections are designed manually for these maximum forces as RCC, Steel and Composite sections for the three types of frame separately. The codes IS 456-2000, IS 800-2007 and AISC LRFD 1999 are used for RCC, Steel and Composite column section design. The steel beam designed for steel frame is provided in composite frame too. The RCC beam section provided is 0.3m x 0.4 m.

Step 2:

Analysis

Each type of frame is analyzed separately by using Equivalent Static Load Method and Response Spectrum Method by using SAP 2000. The analysis is conducted for IS 1893(Part 1), 2002 specified combinations of loadings.

Step 3:

Comparison of results

The results obtained are compared in terms of base shear, story deflections, story drifts ,modal participation factor etc. and cost effectiveness with respect to material quantities are determined.

3.2 Design and analysis

The sections are designed for maximum moment.
The sections adopted for analysis are

Table 3.1 SECTIONS USED IN THE STRUCTURES

Section	RCC	Steel	Composite
Column	0.45mx 0.75m Cross section	ISHB 300 H	0.35m x0.35 m with ISHB 250 steel section
Beam Main and secondary	0.3m x 0.4m	ISMB 200 with 125 mm thick concrete slab on top without shear connectors.	ISMB 250 with 125 mm thick concrete slab on top without shear connectors.

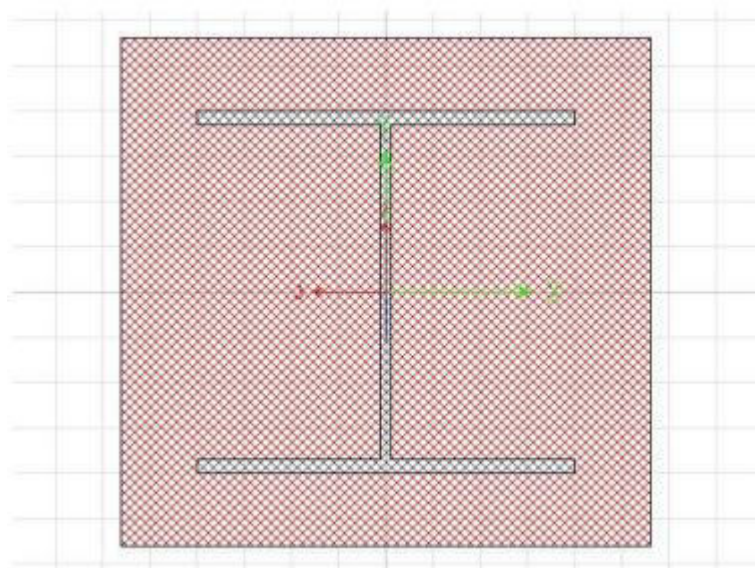


Figure 3.1.a Column Section for Composite frame

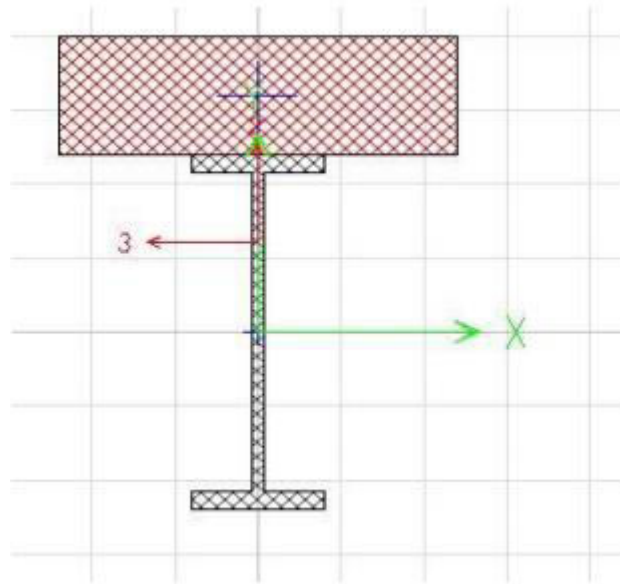


Figure 3.1.b Beam section for Composite frame and steel frame

Analysis-

In the present work the two methods of analysis which have been performed are as follows.

- **Equivalent Static Analysis:** This method is based on the assumption that whole of the seismic mass of the structure vibrates with a single time period. The structure is assumed to be in its fundamental mode of vibration. But this method provides satisfactory results only when the structure is low rise and there is no significant twisting on ground movement. As per the IS 1893: 2002, total design seismic base shear is found by the multiplication of seismic weight of the building and the design horizontal acceleration spectrum value. This force is distributed horizontally in the proportion of mass and it should act at the vertical center of mass of the structure.
- **Response Spectrum Analysis:** Multiple modes of responses can be taken into account using this method of analysis. Except for very complex or simple structure, this approach is required in many building codes. The structure responds in a way that can be defined as a combination of many special modes. These modes are determined by dynamic analysis. For every mode, a response is perused from the design spectrum, in view of the modal frequency and the modal mass, and they are then combined to give an evaluation of the aggregate response of the structure. In this we need to ascertain the force magnitudes in all directions i.e. X, Y & Z and afterwards see the consequences for the building.



IV. RESULTS AND DISCUSSIONS

1. Equivalent Static method

Table 4.1.a Storey Drift due to Equivalent Static Analysis in X-direction

Storey number	Drift of Steel in X-direction	Drift of Composite in X-direction	Drift of RCC in X-direction
0	0	0	0
1	0.228706	0.0634	0.0085
2	0.25166	0.16	0.0185
3	0.2623	0.21	0.026
4	0.2397	0.223	0.028
5	0.2016	0.219	0.032
6	0.19956	0.198	0.027
7	0.170416	0.167	0.02
8	0.132716	0.132	0.0105

Table 4.1.b Storey Drift in Equivalent Static method in Y-direction

Storey number	Drift of Steel in Y-direction	Drift of Composite in Y-direction	Drift of RCC in Y-direction
0	0	0	0
1	0.173725	0.0634	0.0085



2	0.325014	0.16	0.0185
3	0.35656	0.21	0.026
4	0.344811	0.223	0.028
5	0.308372	0.219	0.032
6	0.250333	0.198	0.027
7	0.173608	0.167	0.02
8	0.094878	0.132	0.0105

2. Response Spectrum Analysis:

Table 4.1.c Storey Drift due to Response spectrum(X-direction)

Storey number	Drift of steel X-direction (m)	Drift of Composite in X-direction (m)	Drift of RCC in X-direction
0	0	0	0
1	0.194584	0.06183	0.00999
2	0.212933	0.14469	0.02082
3	0.24291	0.18271	0.026793
4	0.250454	0.19162	0.029301
5	0.219621	0.1818	0.024973
6	0.176447	0.16061	0.022574
7	0.128406	0.13484	0.015001
8	0.087103	0.112562	0.00792



Table 4.1.d Storey Drift due to Response Spectrum (Y-direction)

Storey number	Drift of Steel in Y-direction (m)	Drift of Composite in Y-direction (m)	Drift of RCC in Y-direction(m)
0	0	0	0
1	0.173695	0.070635	0.016823
2	0.2251	0.1625	0.030067
3	0.25015	0.20172	0.033999
4	0.270017	0.207945	0.020062
5	0.253265	0.19353	0.022671
6	0.191607	0.16681	0.020568
7	0.124383	0.1354	0.013956
8	0.064534	0.108515	0.00736

3. Base Shear Calculation

Table 4.2 Base Shear for Different Cases

	Composite	RCC	STEEL
EQx	1305.798KN	2172.7KN	1236.916KN
EQy	1305.798KN	2164.19KN	1236.92KN
RSx	1305.798KN	2179.42KN	1236.969KN
RSy	1305.798KN	2179.42KN	1236.94KN

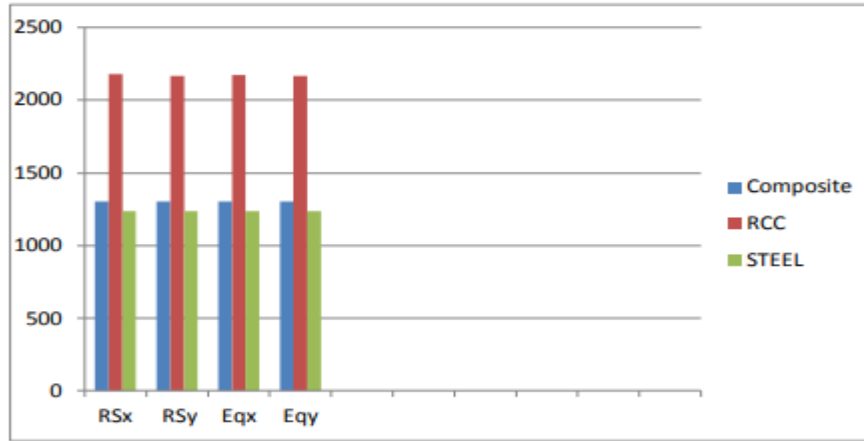
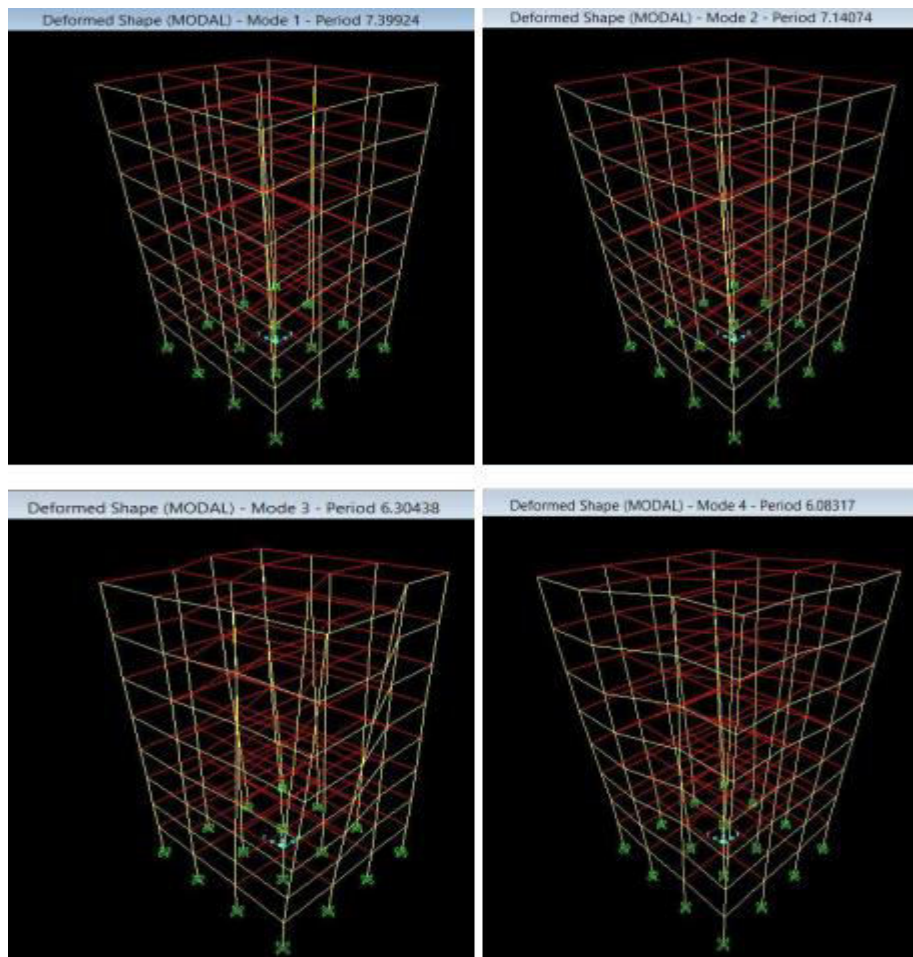


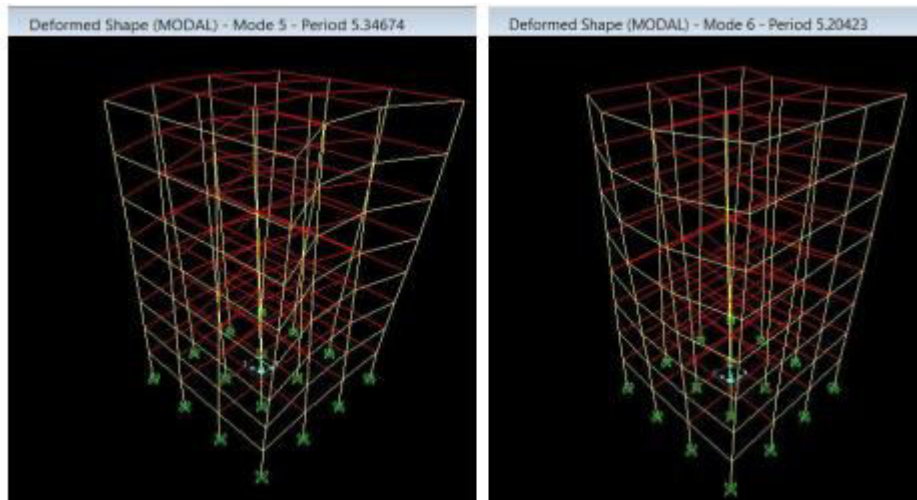
Figure 4.1 Base Shear for Different Cases

Base Shear for RCC frame is maximum because the weight of the RCC frame is more than the steel and the composite frame.

4. Mode Shapes:- Response Spectrum (Composite)

Figure 4.2 The mode shapes for the first 6 modes for the composite building are:





V. CONCLUSION

- Storey drift in Equivalent Static Analysis in X-direction is more for Steel frame as compared to Composite and RCC frames.
- RCC frame has the lowest values of storey drift because of its high stiffness.
- The differences in storey drift for different stories along X and Y direction are owing to orientation of column sections. Moment of inertia of column sections are different in both directions.
- Same storey drift patterns are obtained by using Response Spectrum method validating the results obtained by the Equivalent Static method.
- Base Shear for RCC frame is maximum because the weight of the RCC frame is more than the steel and the composite frame. Base shear gets reduced by 40% for Composite frame and 45% for Steel frame in comparison to the RCC frame.

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