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Seismic Analysis of RCC, Steel and Steel Concrete Composite Frame

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Abstract: In India, reinforced concrete structures are in greater demands in construction because the construction becomes quite convenient and economical in nature. The use of Steel in the construction industry is very low in India compared to many developing countries. From the recent researches it is evident that nowadays, the composite sections using Steel encased with Concrete are economic, cost and time effective solution in major civil structures such as bridges and high-rise buildings. In the past, for the design of a building, the choice was normally between a concrete structure and a masonry structure. In a recent trend, the composite mode of construction has gained several advantages in comparison with the conventional system construction. Due to the failure of many multi-storied and low-rise RCC masonry buildings from earthquake structural engineers are forced to look for the alternative method of construction.

Steel-Concrete composite constructions are nowadays very popular owing to their advantages over conventional concrete and steel constructions. Hence the aim of the present study is to compare seismic performance of a 3D (G+8) 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. ETABS 2015 software is used and results are compared based on fundamental time period, displacements, base shear and storey drift. Comparative study based on seismic analysis concludes that, RCC construction is best suited for low rise buildings among all the three types of constructions.
Keywords: Low rise buildings, seismic analysis, Steel concrete composite construction, RCC, Response spectrum method.

I. INTRODUCTION

Most of the building structures in India 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 fulfilment 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 concretes 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.

Construction industry of India use very less steel as compared to other developing nations like China, Brazil etc. Seeing the development in India, there is a serious 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. As we know, the building subjected to several types of forces in the lifetime such as Static forces due to dead load, live load and dynamic forces due to the earthquake and high-velocity wind. The rapid growth of urban population and limited land space have considerably influenced the developments of high-rise structures. Lateral loads are an important consideration as the building height increase. It is necessary to choose a structural system in such a way that it can resist lateral loads effectively. It is required to understand the behavior of structural systems in terms of stiffness and stability. Hence in the present investigation, comparative study of seismic analysis of RCC, steel and steel composite frame structure were performed and the effective type of building which performs better in earthquake excitations can be suggested.

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II. METHOD OF ANALYSIS

In present study a (G+8) storied structure for RCC, Steel and composite structure is considered and Response spectrum method of analysis is used for seismic analysis.

1) *Step 1:* Design of beam and column sections the frame is analyzed with dead and live loads for beams and columns in ETABS 2015 for all three types of structures. The steel beam designed for steel frame is provided in composite frame too.
2) *Step 2:* Each type of frame is analyzed separately by using equivalent static load method and response spectrum method by using ETABS 2015.
3) *Step 3:* The results obtained are compared in terms of base shear, maximum storey displacement, story drifts and fundamental time period etc. and the effective type of building which performs better in earthquake excitations can be suggested.

A. Building Configuration

The building considered here is G+8 storey office building located in seismic zone V. The plan of building is shown in figure 2. The basic planning and the loading conditions are considered same for both RCC, Steel & Steel Composite Concrete Structure. In case of RCC structure, the structural members slab, beam and column are designed as per IS 456:2000 and in case of Steel Concrete Composite Structure, members are designed as per AISC 360-10. Composite beams are designed with structural steel section anchored to the steel deck slab with the help of shear studs and columns are considered made of RCC having structural steel section in its core and reinforcement in the concrete outside. Lateral loads are considered to be carried by the beam column frame as a moment resisting frame.

The explained 3D building model is analyzed using Equivalent Static Method and Response Spectrum Method. The building models are then analyzed by the software ETABS 2015. Different parameters such as maximum storey displacement, storey drift, base shear and fundamental time period are studied for the seismic loads. Seismic codes are unique to a particular region of country. In India, Indian standard criteria for earthquake resistant design of structures IS 1893 (Part-1): 2016 is the main code that provides outline for calculating seismic design force. For the analysis and design, following design data is considered:

TABLE I. DESIGN DATA FOR BUILDINGS

Type of building	Office Building
No of Stories	(G+8)
Type of frame	Moment Resisting Frame
Total height of building	27.5 m
Height of each storey	3.0 m
Foundation Depth	3.5 m
Plan of the building	20 m × 20 m
Floor Diaphragm	Rigid
Grade of Concrete	M25
Grade of reinforcing Steel	Fe500 for main steel Fe415 for distribution steel
Grade of structural steel	Fe345
Seismic Zone factor (Z)	0.36
Soil Type	Medium soil
Importance factor	1.5
Response reduction factor	5
Damping Ratio	0.05
Modal Combination Method	CQC
Directional Combination Type	SRSS
Diaphragm Eccentricity	0.05 for all diaphragm
Frame load on floors	12 kN/m
Frame load on roofs	6 kN/m
Shell load on floors	3 kN/m^2
Shell load on roof	1.5 kN/m^2

TABLE II. SECTIONS USED IN THE STRUCTURE

Member	RCC	Steel	Composite
Beam	300 × 400 mm	ISMB 350	ISWB 450
Column	450 × 700 mm	ISWB 600-1	600 × 600 mm with encased ISMB 350
Slab / Deck	150 mm Slab	200 mm Deck	200 mm Deck

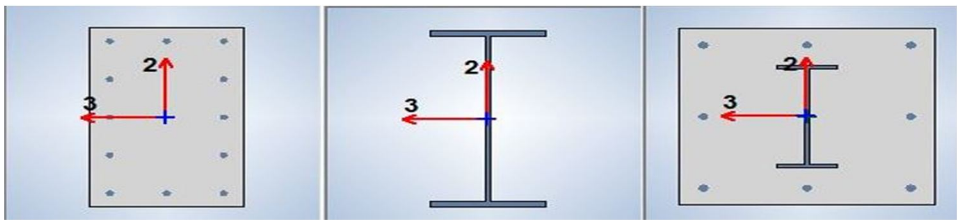

Fig. 1 Sections used in structures

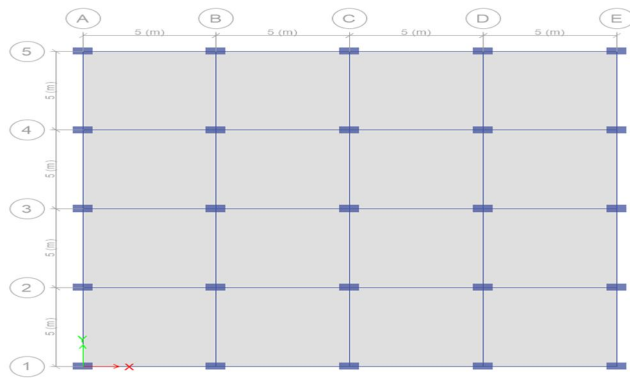

Fig. 2 Plan of considered building configuration

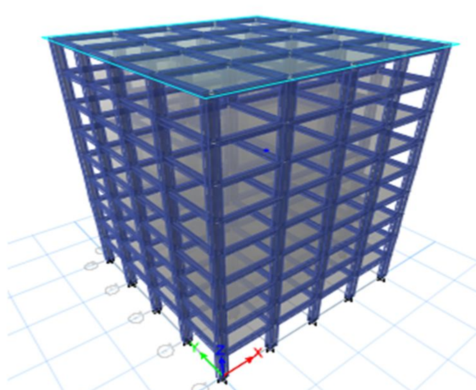
Fig. 3 3D model for RCC building

B. Analysis Methods

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

1) *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: 2016, 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 centre of mass of the structure.

2) *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.

Different methods of combination are as follows:

a) Absolute-peak values are added together
b) Square root of the sum of squares (SRSS)
c) Complete quadratic combination (CQC)

In our present study we have used the SRSS method to combine the modes. The consequence of a response spectrum analysis utilizing the response spectrum from a ground motion is commonly not quite the same as which might be computed from a linear dynamic analysis utilizing the actual earthquake data.

III. RESULTS AND DISCUSSION

The present study is to understand the seismic behavior of RCC, steel and steel concrete composite buildings under the action of earthquake forces. Results are discussed in terms of base shear induced in the columns at foundation level, fundamental time periods, maximum top storey displacements and storey drifts compared within the considered configurations of buildings.

A. Maximum Storey Displacements (mm)

TABLE III. MAXIMUM STOREY DISPLACEMENTS

Story	Elevation (m)	Composite	RCC	Steel
Story9	27.5	28.1	34.4	40.4
Story8	24.5	27.1	32.6	38.4
Story7	21.5	25.4	30.1	35.6
Story6	18.5	22.9	26.8	31.8
Story5	15.5	19.8	22.7	27.1
Story4	12.5	16	18	21.7
Story3	9.5	11.8	12.9	15.7
Story2	6.5	7.3	7.6	9.5
Story1	3.5	2.9	2.9	3.7
Base	0	0	0	0

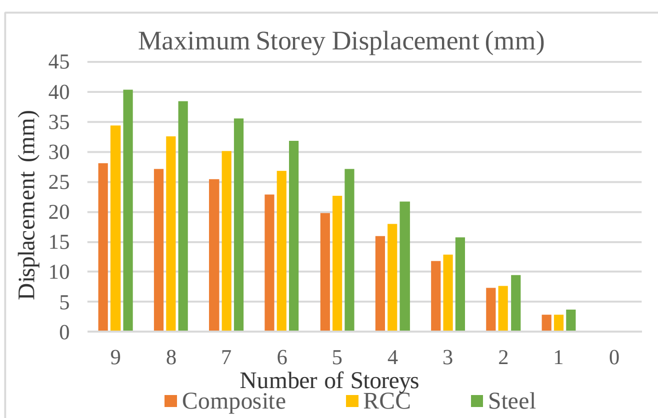

Fig. 4 Graph of Maximum storey displacement vs storey number

From the graph of displacement v/s number of storeys, it is observed that steel concrete composite frame structure has less displacement compared to RCC and Steel building. Percentage reduction in top storey displacement of composite building is 18.31% and 30.4% with compared to RCC and Steel building respectively.

IV. MAXIMUM STOREY DRIFT

TABLE IV. MAXIMUM STOREY DRIFT

Story	Elevation (m)	Composite	RCC	Steel
Story9	27.5	0.000414	0.000709	0.000805
Story8	24.5	0.000663	0.000969	0.001141
Story7	21.5	0.000913	0.001231	0.001457
Story6	18.5	0.001124	0.001453	0.001705
Story5	15.5	0.001298	0.00163	0.001901
Story4	12.5	0.001438	0.001753	0.002048
Story3	9.5	0.001516	0.001776	0.002105
Story2	6.5	0.001441	0.00158	0.001927
Story1	3.5	0.000839	0.000816	0.001058
Base	0	0	0	0

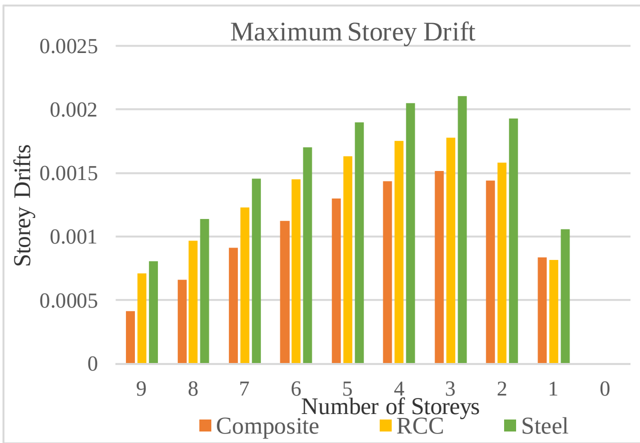

Fig. 5 Graph of Storey drift vs storey number

In the above tables and figures, drift values are presented storey wise for considered building configurations. Composite Structures show storey drift reduction of 41.5% and 48.6% compared to R.C.C structures and steel structures respectively. Steel structures shows maximum drift values compared to other building configurations.

V. FUNDAMENTAL TIME PERIOD (S):

TABLE V. FUNDAMENTAL TIME PERIOD

Mode	Composite	RCC	Steel
1	1.384	1.849	3.258
2	1.371	1.648	2.086
3	1.234	1.543	1.905
4	0.432	0.581	1.079
5	0.427	0.489	0.645
6	0.387	0.473	0.639
7	0.234	0.317	0.574
8	0.229	0.249	0.451
9	0.21	0.247	0.349
10	0.149	0.204	0.345
11	0.146	0.154	0.296
12	0.135	0.148	0.287

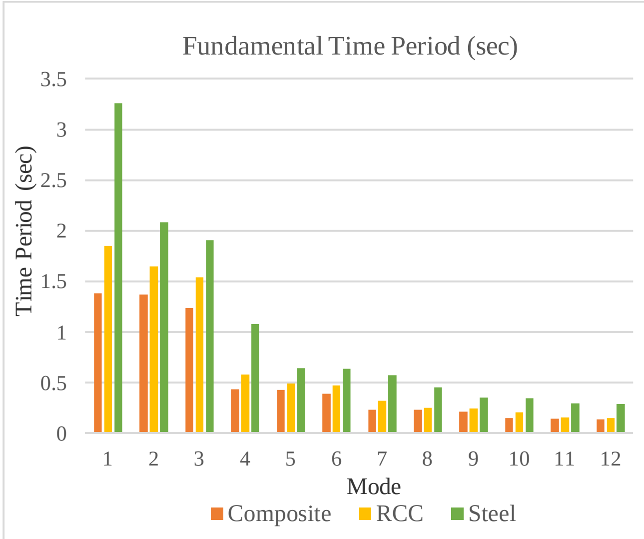

Fig. 6 Graph of Fundamental time period vs Mode Number

The above results show that steel structure shows maximum time period values compared to other building configurations. It implies that it is more flexible to oscillate back and forth when lateral forces act on the building. Also results show that Composite building has lower natural time period which implies that it is less flexible compared to other structures.

VI. MAXIMUM BASE SHEAR (KN)

TABLE VI. MAXIMUM BASE SHEAR

Type of Structure	Maximum Base Shear (kN)
RCC Structure	1364.05
Steel Structure	1000.57
Steel Concrete Composite Structure	1588.87

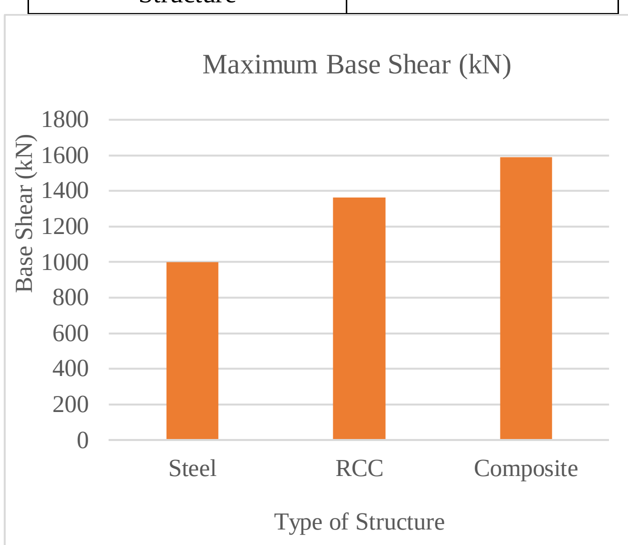

Fig. 7 Graph of Maximum base shear vs Types of structure

Base Shear for Steel concrete composite frame is on higher side compared to other building configuration because weight of composite frame is more than the steel and RCC frame. Base shear values for Steel concrete composite frame is 14.14% and 37% more than RCC and steel frame respectively.

VII. CONCLUSIONS

From the seismic analysis of different building configurations i.e. RCC, steel and steel concrete composite structures the following conclusions can be made:

A. The maximum displacement values are less in composite structures compared to RCC and steel structures hence it concludes that stiffness of composite structure is high compared to other buildings.
B. As the stiffness of composite members is high, the story drifts of composite structures are comparatively less than RCC and steel structures within permissible limits.
C. As the weight of the Steel concrete composite frame is more compared to RCC and Steel frame, it concludes that Steel concrete composite structure has maximum base shear value.
D. As it is already mentioned displacement values are less for composite structures so that time period required is also less for composite structures as compared to RCC and steel structure.

VIII. ACKNOWLEDGMENT

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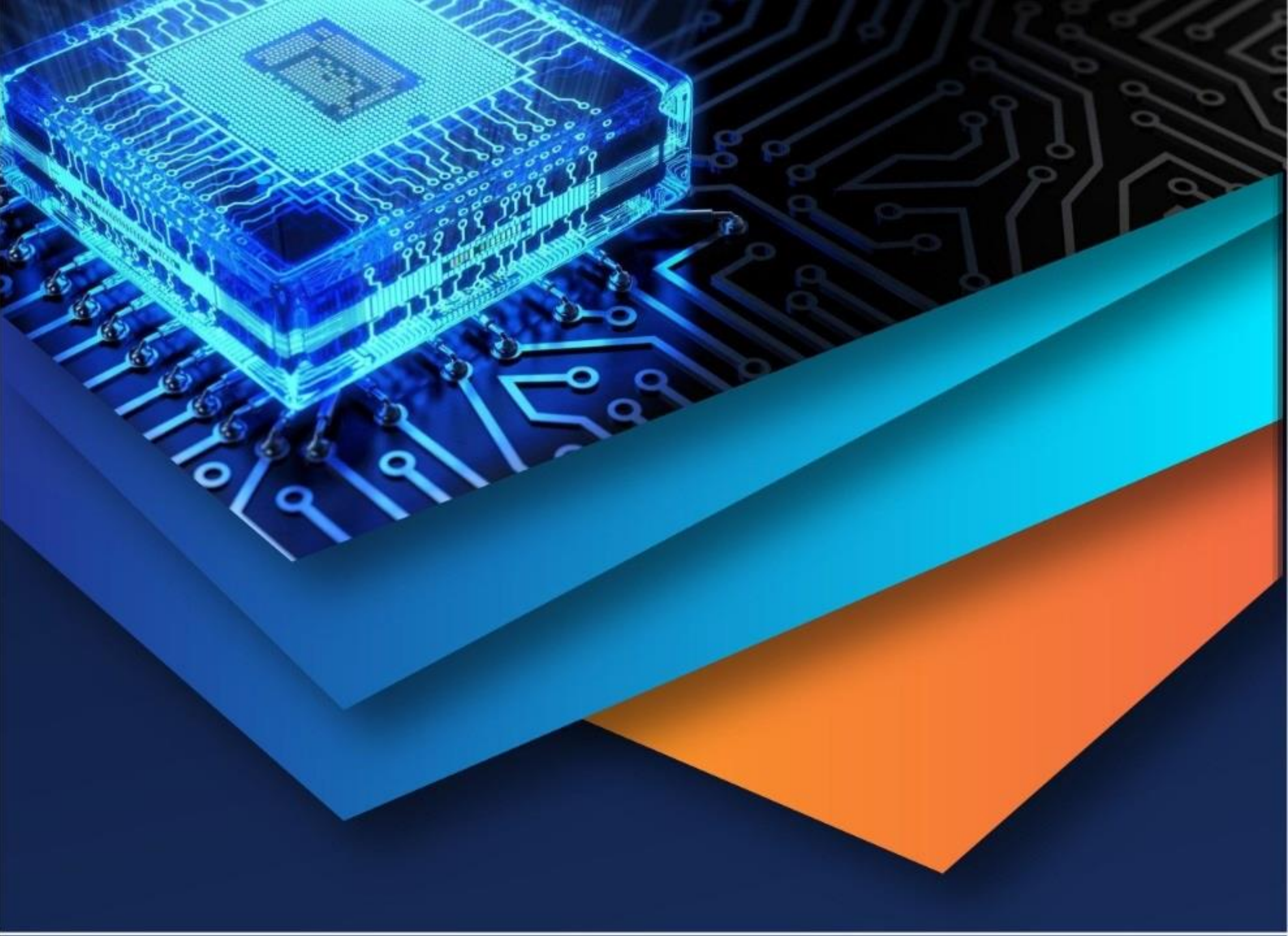

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