

Comparative analysis of Seismic Behaviour of Multi-storey Composite Steel and Conventional Reinforced Concrete Framed Structures

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Abstract—In high rise structures there are many members that are monolithically connected to each other and if yielding takes place in any one of them, then a redistribution of forces takes place. Therefore Seismic analysis is very necessary whenever high rise buildings are to be erected, most especially in areas that are prone to earthquake. In this study a comparative analysis of seismic behaviour of Multi-storey Composite and Conventional RCC Frame Structures at various heights has been carried out and observed that; RCC structure has higher response as compare to the composite structure.

Index Terms— Earthquake, Composite, Conventional, Frame, Steel, Reinforced Concrete, Structure, Multi-storey

1.0 Introduction:

In the present world, high rise buildings are becoming a usual practice in the infra structural development due to the progressive population increment in the cities and limitation of land. This brings up the idea of vertical development (i.e the constructions of high rise buildings) so as to accommodate the entire population. The conventional reinforced concrete is the most common practice in the constructions of low rise and medium rise buildings but in high rise buildings it is consider being uneconomical and bound to risk of failure due to high weight [6]. But with the development of design methods and experimental researches for CFST columns and composite beams, the steel-concrete composite frame has been widely used in multi-story and high-rise buildings. The composite structure has the advantages of fabrication in factories; assemble construction, short construction period, high bearing force and good ductility [9]. When earthquakes occur, a building undergoes dynamic motion. This is because the building is subjected to inertia forces that act in opposite direction to the acceleration of earthquake excitations. These inertia forces, called seismic loads, are usually dealt with by assuming forces external to the building. Since earthquake motions vary with time and inertia forces vary with time and direction, seismic loads are not constant in terms of time and space. In designing buildings, the maximum story shear force is considered to be the most influential; therefore seismic loads are the static loads to give the maximum story shear force for each story, i.e. equivalent static seismic loads. Time histories of earthquake motions are also used to

analyze high-rise buildings, and their elements and contents for seismic design. The earthquake motions for dynamic design are called design earthquake motions. In the previous recommendations, only the equivalent static seismic loads were considered to be seismic loads. In this study, not only equivalent static seismic loads but also design earthquake motions as time histories are included in seismic loads considered in the wider sense. In ISO/TC98 which deals with “bases for design of structures”, the term “action” is used instead of “load” and action includes not only load as external force but various influences that may cause deformations to the structures [2].

2.1 earthquakes and its response analysis

Earthquake is the vibration of earth produced by rapid release of energy from within itself. This extra energy may be stored in earth and released at intervals due to many different phenomena, some of which are as under: Plate tectonics, volcanic eruptions, Atomic explosions, Collision of massive meteorites with the surface of earth. It causes shaking of the ground. So a building resting on it will experience motion at its base. From Newton’s First Law of Motion, even though the base of the building moves with the ground, the roof has a part in influencing tendency to stay in its original position. But since the walls and columns are connected to it, they drag the roof along with them. This is much like the situation that you are faced with when the bus you are standing in suddenly starts; your feet move with the bus, but your upper body tends to stay back making you fall backwards. This tendency to continue to remain in the previous position is known as inertia. In the building, since the walls or columns are flexible, the motion of the roof is different from that of the ground [4]

Earthquake response analysis of structures is the art of simulating the behaviour of a structure subjected to an earthquake ground motion based on dynamics and mathematical modelling of the structure. The correct

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analysis will depend upon the proper modelling of the behaviour of material, elements, connection and structure. Earthquake load acting on a structure depends on epicentre distance and depth of hypocentre below earth surface and the energy released during an earthquake. For easier understanding, it can be said that the line of action joining hypocentre to the centre of mass of structure indicates direction of load vector. The most determinant effect on a structure is generally caused by lateral component of earth quake load. As compared to gravity load effect, earthquake load effects on buildings are quite variable and increase rapidly as the height of building increases. For gravity loads, structure is designed by considering area supported by a column and spans of beam; whereas for earthquake loads, design is a function of total mass, height. It is likely that low and midrise structures, having good structural form can carry most of earthquake loads. The strength requirement is a dominant factor in the design of structure. As height increases the rigidity (i.e. the resistant to lateral deflection) and stability (i.e. resistant to overturning moments) of structure gets affected, and it becomes necessary to design the structure preferably for lateral forces, moments, story drift and total horizontal deflection at topmost story level. Pure rigid frame system or frame action obtained by the interaction of slabs, beam and column is not adequate. The frame alone fails to provide the required lateral stiffness for buildings taller than 15 to 20 (50m to 60m) stories. It is because of the shear taking component of deflection produced by the bending of columns and slab causes the building to deflect excessively. There are two ways to satisfy these requirements. First is to increase the size of members beyond and above the strength requirements and second is to change the form of structure into more rigid and stable to confine deformation. First approach has its own limits, whereas second one is more elegant which increases rigidity and stability of the structure and also confine the deformation requirement. In earthquake engineering, the structure is designed for critical force condition among the load combination [7],[8]

2.2 Framed Structure

Framed structures are structures having the combination of slab, beam and column to resist the lateral and gravity load. These structures are used to overcome the large moment developed due the applied loading. There are many types of frame structures but as for this paper we shall discuss only two types that is; R.C frames structures and composite steel frame structure s.

RC Framed Structures: An RC framed structure is basically an assembly of slabs, beams, columns and foundation inter-connected to each other as a unit. The load transfer, in such a structure takes place from the slabs to the beams, from the beams to the columns and then to the lower columns and finally to the foundation which in turn transfers it to the soil.

However, for a load bearing structure, the loads are directly transferred to the soil through the walls that are designed to specifically carry the loads.

Composite Framed Structures: Composite framed structure consist of steel- concrete combinations, i.e the columns and beams are made of steel work to carry the whole weight of the concrete slab and its loading with the use of shear connector.

2.3 Loadings

Generally, Loading on tall building differs from loading on low rise buildings in its accumulation into much larger structural forces. The collection of gravity loading over a large number of stories in a tall building can produce column loading of an order higher than those in low rise buildings. Wind loading on a tall building not only acts over a larger surface area but also with greater intensity at greater height and with a large moment arm about the base than on a low rise building. Although wind loading on a low rise building has an insignificant influence on the design of structure, wind on a high rise building can have a dominant influence on its structural arrangement and design [7]

In earthquake region, any inertial loads from the shaking of the ground may well exceed the loading due to wind and therefore be dominant in influencing the building's design and cost. The building's dynamic response plays a large part in influencing and in estimating the effective loading on the structure. The following discussion describes some of the most common kinds of loads on multi-storied structures:

2.3.1 Live load:

A load produced by the use and occupancy of the building or other structure that does not include construction or environmental loads, such as wind load, snow load, rain load, earthquake load, flood load. But Wind, flood and earthquake loads are random in nature and it is difficult to predict them. They are estimated based on a probabilistic approach.

2.3.2 Gravity load:

This constitutes the dead loads due to the self-weight of individual elements that make up the structural system as well as the live loads that are acting on the structure when in service. The dead loads are calculated from the member sizes and estimated material densities. Live loads prescribed by codes are empirical and conservative based on experience and accepted practice. A floor should be designed for the most adverse effect of uniformly distributed load and concentrated load as specified in Table-1, but they should not be considered to act simultaneously. All other structural elements such as beams and columns are designed for the corresponding uniformly distributed loads on floors. Reduction in imposed (live) load may be made in designing columns,

load bearing walls etc., if there is no specific load like plant or machinery on the floor.

Table 1.0 Live Load Magnitudes

Occupancy classification	Uniformly distributed load (kN/m ²)	Concentrated load (kN)
Office buildings	2.5	2.7
Offices and staff rooms		
Class rooms	3.0	2.7
Corridors, store rooms and Reading rooms	4.0	4.7
Residential buildings: Apartments	2.0	1.8
Public places such as Restaurants	4.0	2.7
Corridors	3.0	4.5

Reduction in live loads

Except for roof uniform live loads, all other minimum uniformly distributed live loads, may be reduced according to the following provisions. The supporting members of the roof of the multi-storied building is designed for 100% of uniformly distributed load; further reductions of 10% for each successive floor down to a minimum of 50% of uniformly distributed load is done.

2.3.3. Seismic load:

Seismic motion consists of horizontal and vertical ground motions, with the vertical motion usually having a much smaller magnitude. Further, factor of safety provided against gravity loads usually can accommodate additional forces due to vertical acceleration due to earthquakes. So the horizontal motion of the ground causes the most significant effect on the structure by shaking the foundation back and forth. The mass of building resists this motion by setting up inertia forces throughout the structure. The magnitude of the horizontal shear force "F" depends on the mass of the building M, the acceleration of the ground "a" and the nature of the structure. If a building and the foundation were rigid, it would have the same acceleration as the ground as given by Newton's second law of motion, i.e. $F = M \times a$. However, in practice all buildings are flexible to some degree. For a structure that deforms slightly, thereby absorbing some energy, the force will be less than the product of mass and acceleration. But a very flexible structure will be subject to a much larger force under repetitive ground motion. This shows the magnitude of the lateral force on a building is not only dependent on acceleration of the ground but it will also depend on the type of the structure. As an inertia problem, the dynamic

response of the building plays a large part in influencing and in estimating the effective loading on the structure. The earthquake load is estimated by Seismic co-efficient method or Response spectrum method. The later takes account of dynamic characteristics of structure along with ground motion. For detailed information on evaluating earthquake load, reader is referred to IS: 1893 - 2002 [5] and the chapter on Industrial Buildings.

2.4 General procedure for seismic load estimation and design

2.4.1 Design Spectrum

1. For the purpose of determining seismic forces the country is classified into four seismic zones, that is zone I, II III and IV

2. The design horizontal seismic coefficient A_h for a structure shall be determined by the following expression.

$$A_h = \frac{Z}{2} \frac{I}{R} \frac{S_a}{g} \quad 1$$

Provided that for any structure with $T < 0.1s$, the Value of A_h will not be taken less than $Z/2$ whatever be the value of $1/R$. Where, Z = Zone factor given in Table 2 of IS 1893:2002 [5], is for the Maximum Considered Earthquake (MCE) and service life of structure in a zone. The factor 2 in the denominator of Z is used so as to reduce the Maximum Considered Earthquake (MCE) zone factor to the factor for Design Basis Earthquake (DBE) I = Importance factor depending upon the functional use of the structures, characterized by hazardous consequences of its failure, post - earthquake functional needs, historical value or economic importance (Table 6 of IS 1893:2002) [5] this remains similar to SP22: 1982 R = Response reduction factor, depending on the perceived seismic damage performance of the structure, characterized by ductile or brittle deformations. However the ratio $(\frac{I}{R})$ shall not be greater than 1.0 (Table 7 of IS 1893:2002) this factor was absent in SP22:1982 $\frac{S_a}{g}$ = Average response acceleration coefficient for rock or soil sites as given by Figure 2 of IS 1893:2002 [5] and Table based on appropriate natural periods and damping of the structure.

2.4.2 Distribution of Seismic Force along Height of Building

Dynamic analysis of buildings has indicated that the seismic forces increase from zero at base to maximum at the top. One type of distribution of this force is an inverted triangle, which is used by many designers. This is suitable only for structures in which mass and stiffness in each story is equal, but since it is usually not so the distribution suggested in the Code gives parabolic distribution of seismic forces such that the seismic shears are higher near top stores for the same base shear. The distribution of forces along with the height of the building is given by the formula given in the Code.

$$Q = VB \frac{W_i h_i^2}{\sum_{i=1}^n W_i h_i^2}$$

The code restricts the use of pseudo static method to ordinary or normal structures/ buildings and excludes all special layouts like Plaza type building or building with flexible first story or building on hill slopes. For such buildings, modal method of analysis is recommended.

2.4.3 Fundamental Natural Period.

The approximate fundamental natural period of vibration (T_a) in seconds of a moment resisting frame building without brick infill panels may be estimated by the empirical expression:

$T_a = 0.075 h^{0.75}$ for RC frame building

$= 0.085 h^{0.75}$ for Steel building

Where, h = Height of building in m. This excludes the basement storey, where basement walls are connected with the ground floor deck or fitted between the between building columns. But it includes the basement storey when they are not so connected. The approximate fundamental natural period of vibration (T_a) in seconds of all other buildings including moment resisting frame buildings with brick infill panels may be estimated by the empirical expression:

$$T_a = \frac{0.09h}{\sqrt{d}} \quad 2$$

Where, h = Height of building in m

d = Base dimension of building at the plinth level in m along the considered direction of the lateral force.

3.0 Modelling of structures

3.1 Analytical Analysis

The main objective of the analysis is to study the different forces acting on a building. The analysis is carried out in STAAD Pro2007 software. Results of conventional R.C.C structure i.e slab beam and column and composite framed i.e slab, steel beam and column for different heights are discussed below.

Conventional R.C.C structure and composite framed structure for different height are modeled and analyzed for the different combinations of static loading and seismic loading. The comparison was made between two structures which are situated in seismic zone.

3.2 Assumptions

The building considered for this study is assumed to be a hospital building situated in zone IV. The building is modeled and compared for Conventional R.C.C structure and composite framed structure for different static loading. The following are the assumptions made:

3.3 Building Description

The building consist of 3 bays in X-direction and 5 bays in Z-direction and the overall heights of the buildings are kept as 19.6 m, 29.2 m, 38.8m from ground, these buildings are of G+5 storey, G+8 storey and G+11 storeys respectively. The height of ground floor to first floor is 3.6m and the subsequent floors are of 3.2m each.

Components properties

The different components of conventional R.C.C structure are as follows:

Columns of the building is of 230mm x 450mm

Beam size of the building is of 230mm x 450mm

Slab thickness of the building is of 150mm

Similarly the different components of composite structures are as follows:

Steel columns of the building is of ISWB 500

Steel beam of the building is of ISHB 450

Slab thickness of the building is of 150mm.

3.4. Description for Loading

The loading on the buildings is considered as per following calculations

1) Dead Loads

i. Wall load with 150mm thickness = $20 \times 3.2 \times 0.15 = 10.26 \text{ kN/m}$

ii. Wall load with 230mm thickness = $20 \times 3.2 \times 0.23 = 15.73 \text{ kN/m}$

iii. Weight of the slab having thickness 0.150m = $25 \times 0.150 = 3.75 \text{ kN/m}^2$

v. Self-weight of building is automatically considered by the STAAD Pro2007 software.

2) Live Loads

The live load of 4.0 kN/m^2 is considered on the floor of the buildings.

The live load of 2.0 kN/m^2 is considered on the roof floor of the buildings.

3) Earthquake Forces Data

Earthquake load for the building has been calculated as per IS-1893-2002:

i. Z for zone IV = 0.24

ii. Response Reduction Factor (RF) = 3

iii. Importance Factor (I) = 1.5

iv. Rock and soil site factor (SS) = 3

v. Type of Structures = 1

For generating the earthquake forces in the analysis, "member weight" has been provided as per appropriate beam load. Software for the analysis generates effective seismic forces as per the various factors defined above.

3.5 Sample Calculations

1. Natural Time Period:

i) For G+5 storey building RCC structure

$T_a = 0.09 (19.6) / \sqrt{11.5} = 0.5202 \text{ sec}$

ii) For G+5 storey building composite structure

$T_a = 0.085 \times 19.6^{0.75} = 0.7918 \text{ sec.}$

2. Design Seismic Base Shear:

i) For G+5 storey conventional building with beam

$V_b = Ah \times W = 2138.804 \text{ KN}$

ii) For G+5 storey composite

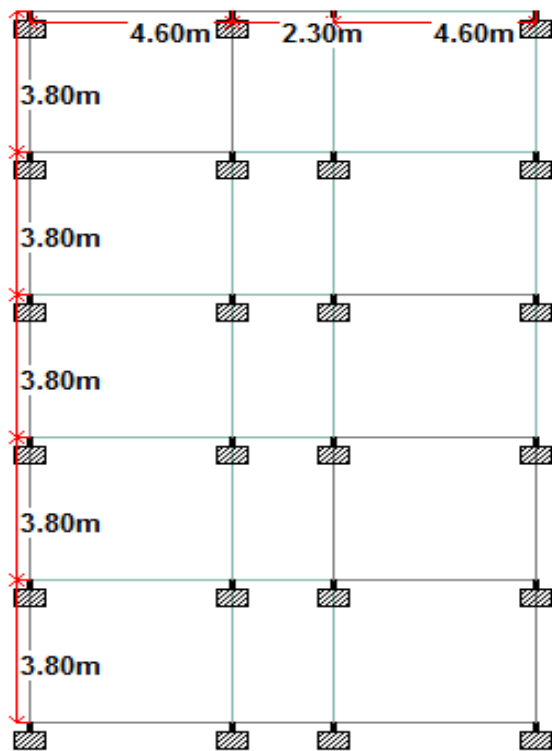


Figure 1.0 Plan of G+5 storeys for conventional RCC and composite steel framed structure

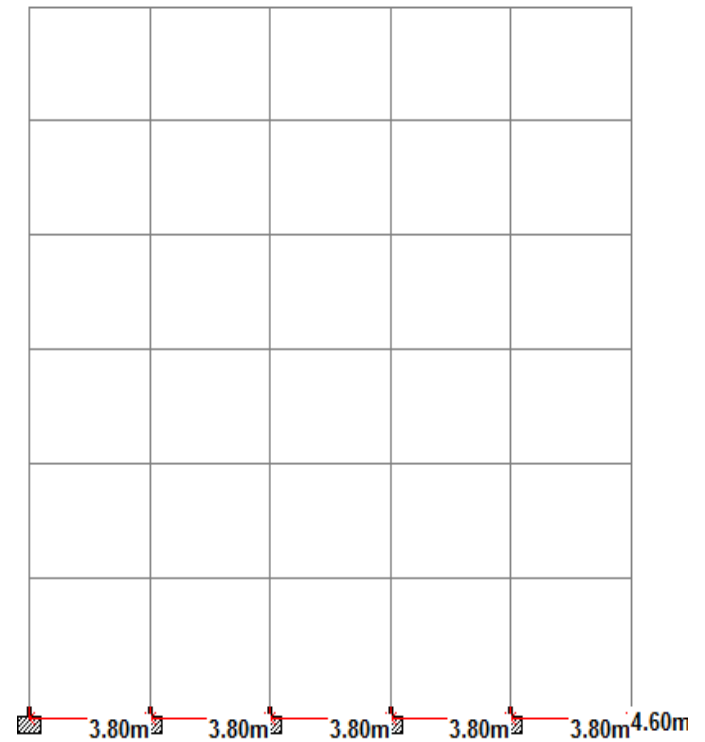


Figure 3.0: Elevation of G+5 storeys for conventional RCC and composite steel framed structure

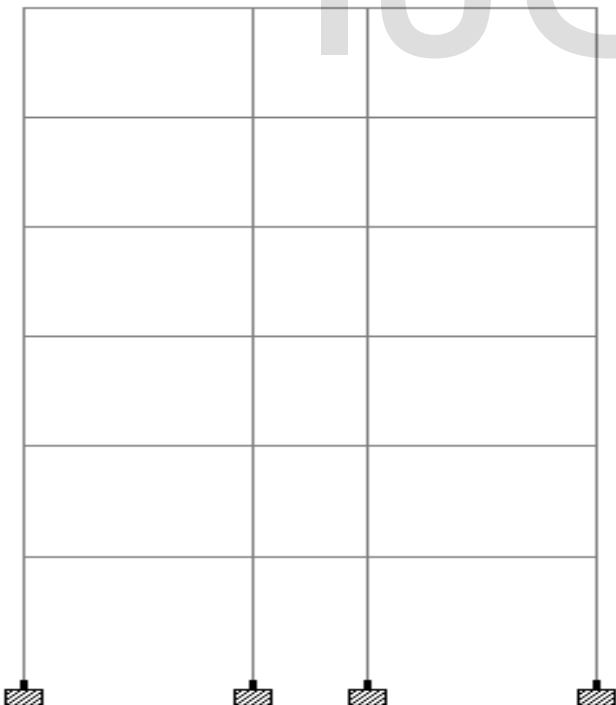


Figure 2.0: Elevation of G+5 storeys for conventional RCC and composite steel frame structure

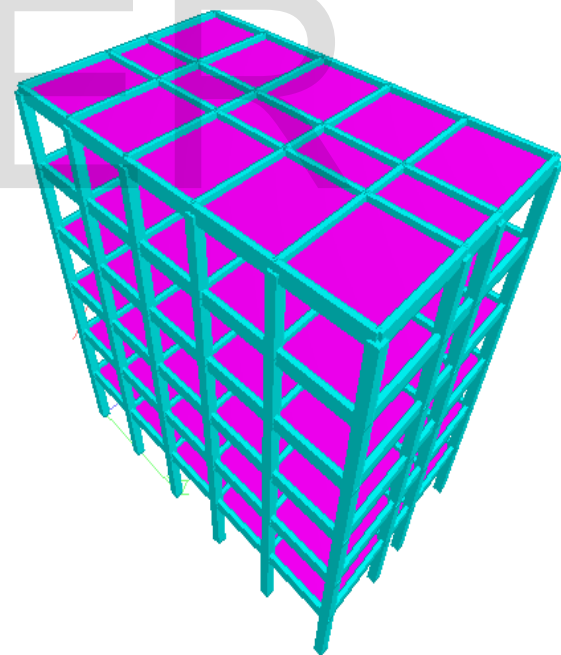


Figure 4.0: 3-D View of G + 5 story conventional RCC framed structure

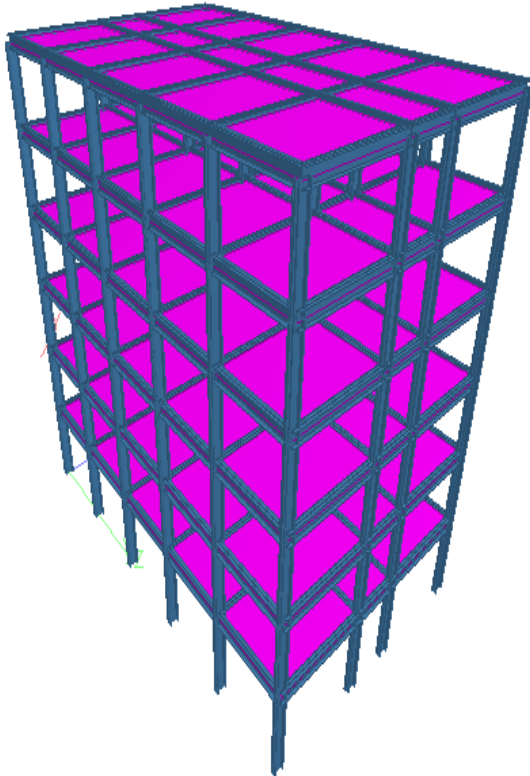


Figure 5.0: 3-D View of G + 5 storeys composite steel framed structure

4.0. Results and discussion

4.1. Natural Time Period:

The time required for a system to complete one cycle of free vibration is the natural period of vibrating system in units of seconds. Table 2 shows the result values of natural time period for different model. Similarly variation of natural time period of different model vs. no. of storey is as shown in Figure 6.

Table 1.0 Result of natural time period for the various models

Height of the building (m)	Number of storeys	Time in seconds (Ta)	
		RCC	Composite
19.6	G+5	0.5202	0.7918
29.2	G+8	0.7750	1.0677
38.8	G+11	1.0297	1.3214

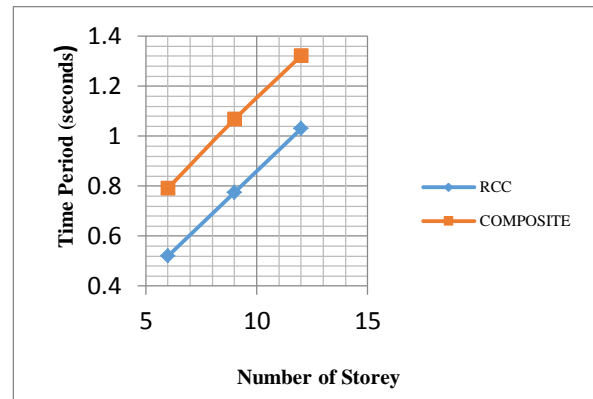


Figure 6.0: Graph of natural time period against number of storeys for various models

4.2 Coefficient of Response Acceleration (S_a/g) for the various Models

It is a factor denoting the acceleration response spectrum of the structure subjected to earthquake ground vibrations, and depends on natural period of vibration and damping of the structure. Table 3.0 below shows the result values of S_a/g for the various models. Similarly Figure 7 shows Graph of Average Response Acceleration (S_a/g) against Number of storeys for various models.

Table 3.0 Result of Average Response Acceleration for the various models

Height of the building (m)	Number of storeys	Response Acceleration (S_a/g)	
		RCC	Composite
19.6	G+5	2.5000	2.1091
29.2	G+8	2.1548	1.5641
38.8	G+11	1.6218	1.2638

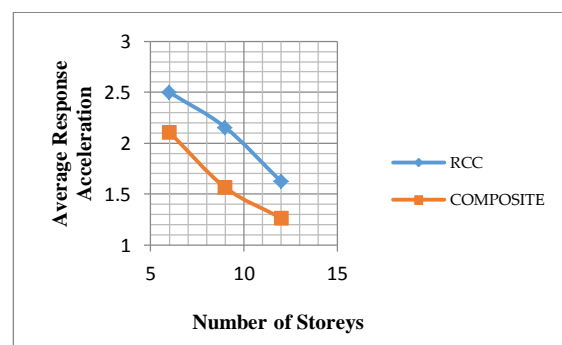


Figure7.0: Graph of Average Response Acceleration against Number of storeys for various models

4.3 Base Shear:

The total design lateral forces or design seismic base shear (V_b) along any principal direction shall be determined by the following expression.

$$V_b = A_h W$$

Table 4.0 shows values of base shear for the different models. Similarly Figure 8 shows Graph of Base Shear against Number of storeys for various models.

Table 4.0 Result of Base Shear for the various models

Height of the building (m)	Number of storeys	Base shear V_b	
		RCC	Composite
19.6	G+5	2138.804	1303.960
29.2	G+8	3230.727	1460.343
38.8	G+11	3604.456	1899.719

4.5 Sway

Sway is the displacement of one level relative to the other level above or below. Table 5.0 show values of sway for the various models. Similarly the Graph of sway against Number of storeys for various models is as shown Figure 9.0

Table 5.0 Result of Sway for the various models

Height of the building (m)	Number of storeys	Sway (cm)	
		RCC	Composite
19.6	G+5	6.763	3.568
29.2	G+8	13.876	5.678
38.8	G+11	22.976	10.132

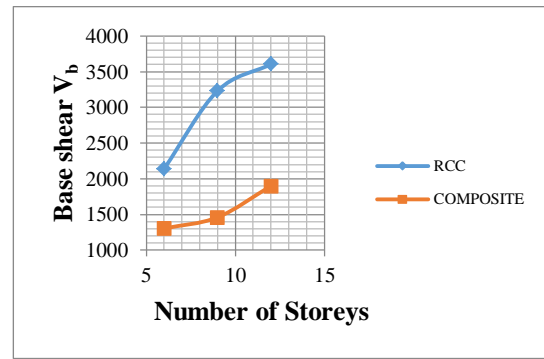


Fig.9 Graph of sway against Number of storeys for various models

5. Conclusion

This paper presents a summary of the study, for conventional R.C.C frame structure and composite steel frame structure for different floor height. The effect of seismic load has been studied for the two types of building with different height. Based on the results obtained, following conclusions have been drawn:

1. The natural time period increases as the height of building (Number of storeys) increases, irrespective of type of building viz. conventional structure and composite structure.
2. In comparison of the conventional R.C. frame to composite steel frame structure s, the time period is more for composite steel frame structure s than conventional building than because composite steel frame structures. This is due the fact that steel is more ductile than concrete.

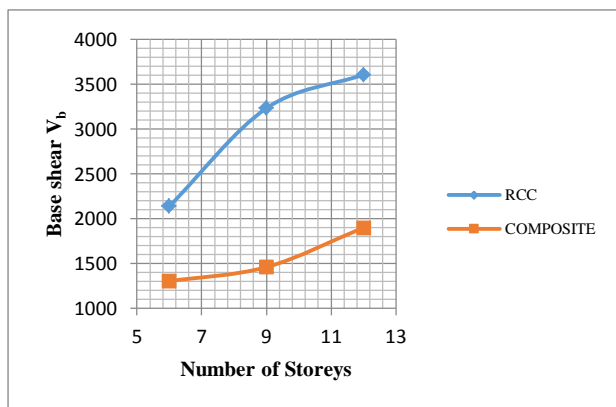


Fig.8 Graph of Base Shear against Number of storeys for various models

3. The average response acceleration coefficient for both conventional RCC frame and composite frame decreases with increase in the height of building, however, this is due to the fact the both structures have similar number members that are stiff.
4. For all the structure, base shear increases as the height increases. This increase in base shear shows similar trend in both structures, the
5. The magnitude of the base shear for composite structure is less than that of the conventional RCC structure this is due less in weight of the composite structure as compare to RCC structure.

With this, it is confirm that, the use of composite steel frame structure in multi-story and high-rise buildings has the advantages of been safe, short construction period, high bearing force and good ductility over reinforced concrete structures.

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