Comparative Analysis of Moment Resisting Frames of Steel and Composite Materials

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Abstract - *The Reinforced concrete (RC) frame buildings are the most common type of construction in urban India which is 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 teams of stiffness and stability. In the present investigation, a moment resisting frame of steel composite material structure are compared in terms of storey displacement, storey drift, and storey shear, deflection of the beam, axial load, and Base shear. In present work, four models of G+10 & four models of G+20 RCC building and Steel-composite structure is modeled and analyzed under the seismic effect. The structure is designed as the Earthquake resisting structure and is analyzed as per IS 1893: 2002 for zone II & IV. The two G+10 & G+20 frame is analyzed as SMRF frame (Special Moment Resisting Frame) and another two G+10 & 20 frames are analyzed as OMRF (Ordinary Moment Resisting Frame) response reduction factors. For the analysis of structure CSI-ETABS 2016 V16.2.0 software is used. From the findings of seismic & wind analysis it is found that displacement & shear is more compared to Steel composite but within permissible limits.*

Applications*: Steel Composite structures are found to be the best mode of construction for high-rise building while comparing with the conventional R.C.C structures as they serve well for various parameters like deflection, base shear, cost of fabrication and lesser dead weight.*

Key Words: *Moment Resisting frame, Steel frame structure, Composite material structural systems, deflection, drift, displacement & base shear.*

1. INTRODUCTION

Reinforced concrete structures are in greater demands in construction. 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 R.C.C masonry buildings from earthquake structural engineers are forced to look for the alternative method of construction. A Moment resisting Composite steel-concrete system can provide economical structural systems with high durability, rapid erection and superior seismic performance characteristics with large openings without bracings. Steel-composite system of construction proved to be the most economical solution to necessarily meet the engineering design requirements of stiffness and strength.

1.1 Moment-resisting frames

Moment-resisting frames are rectilinear assemblages of beams and columns, with the beams rigidly connected to shear, amount of reinforcement etc. Moment frames have been widely used for seismic resisting systems due to their superior deformation and energy dissipation capacities. A moment frame consists of beams and columns, which are rigidly connected. The components of a moment frame should resist both gravity and lateral load. Lateral forces are distributed according to the flexural rigidity of each component. The type of moment frame should be selected according to levels of seismic risk or seismic design category. Seismic risk levels can be classified into low, moderate and high according to seismic zones concrete moment frames into three types: Ordinary Moment Resisting Concrete Frame (OMRCF) and Special Moment Resisting Concrete Frame (SMRCF). Criteria for earthquake resistant design of structures is given in IS 1893 (Part 1), 2002. Part 1 gives details about general provisions and buildings. Bureau of Indian Standards (BIS) classifies RC frame buildings into two categories, OMRF and SMRF with response reduction factors 3 and 5 respectively. If the structure were to remain elastic during its response to the Design Basis Earthquake (DBE) shaking, then it shall be reduced to obtain the design lateral force response. Reduction Factor (R) is the factor by which the actual base shears would be generated.

1. Ordinary Moment-Resisting Frame (OMRF): It is a moment-resisting frame not meeting special detailing requirement for ductile behavior. They are expected to withstand limited inelastic deformations in their members and connections as a result of lateral forces. OMRFs are typically used in low-seismic regions.

2. Special Moment-Resisting Frame (SMRF): It is a moment-resisting frame specially detailed to provide ductile behavior and comply with the requirements given in IS 4326 or IS 13920 or SP6.SMRFs are expected to withstand significant inelastic deformation in their members and connections as a result of lateral forces. SMFs are typically used in mid/high-seismic regions.

1.2 Composite Materials:

A composite member is defined as consisting of a rolled or a built-up structural steel shape that is either filled with concrete encased in reinforced concrete or structurally connected to a reinforced concrete slab. Composite members have constructed such that the structural steel shape and the concrete act together to resist axial compression and bending. The primary structural components used in composite construction consists of the following elements.

1. Composite deck slab: The composite floor system is built up of steel beams, metal decking, and concrete. The arrangement of composite floor systems are rolled or built-up steel beam joined to a formed steel deck and concrete slab. The composite floor system provides stability to the overall building system by providing a rigid horizontal diaphragm, while distributing wind and seismic shears to the lateral load-resisting systems. Slab thicknesses are generally in the range 100 mm to 250 mm for shallow decking, and in the range 280 mm to 320 mm for deep decking.

2. Composite Beam: A concrete beam is formed when a concrete slab which is cast in-situ conditions is placed over an I-section or steel beam. 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.

3. Composite Column: Comprising either of a concrete-encased hot rolled steel section or a concrete filled hollow section of hot rolled steel having a steel-concrete composite column is a compression member. It is normally used for composite framed structure as a load bearing member. Concrete is filled inside the tubular steel sections or is later casted around the I section. The concrete casted around the steel sections at later stages in construction helps in restricting away the lateral deflections, sway and bucking of the column. It is very useful and efficient to erect very high rise buildings if we use steel-concrete composite frames with composite decks and beams. The time taken for erection is also less hence speedy construction is achieved.

4. Shear Connector: Shear connections are essential for steel concrete construction as they integrate the compression capacity of the supported concrete slab with supporting steel beams/girders to improve the load carrying capacity as well as overall rigidity. Though steel to concrete bond may help shear transfer between the two to a certain extent, yet it is neglected as per the codes because of its uncertainty. All codes, therefore, specify positive connectors at the interface of steel and concrete.

1.3 Objectives/Aim of investigation

1. To estimate the seismic demands developed and to facilitate the conceptual design process.

2. The investigation is specifically towards the improving the seismic behavior of Steel composite moment resisting frame structures, & also intended to be for the development and implementation performance-based seismic engineering.

3. To understand the behavior and to predict the response of typical composite moment resisting frame structures.

4. To evaluate the maximum storey displacement, the range of inter-story drift & storey shear in steel composite moment resisting frame structures under earthquake Zone II & IV.

5. To obtain the response of G+10 & G+20 model structures by analyzing multistoried frames of steel and composite structure having OMRF and SMRF conditions.

6. To make a comparative study on the deflections, time period, storey drift, Seismic response and wind analysis for the various zones.

2. METHODOLOGY AND ANALYSIS

In this study, the G+10 & G+20 RCC structure and Steel-Composite structure is analyzed. The structure is designed as Earthquake resisting structure and are analyzed as per IS 1893: 2002.In present work four models of G+10 & four models of G+20 RCC building and Steel-composite structure is modeled and analyzed under the seismic effect. The two G+10 & G+20 frame is analyzed as SMRF frame (Special Moment Resisting Frame) and another two G+10 & 20 frame is analyzed as OMRF (Ordinary Moment Resisting Frame). Each model has 3.6 meter ground floor. The basic plan area of model is 36 x 25 meter.

The floor to floor height of building is 3 meter. Column spacing is 6 meter in X and 5 meters Y- direction each bays. The total height of structure is 33.6 meters for G+10 & 63.6 meters for G+20 structure. For the analysis of structure CSI-ETABS (extended 3d analysis of building system) software is used. The structure is first modeled in software and scrutinized for any duplicate nodes or member. The beam and column parameters are provided to the structure. All the column base is assigned as fixed support. The earthquake loads on the structure is assigned as per IS 1893: 2002 guidelines.

The Zone of earthquake is II & IV. At last both the frames are analyzed and results are interpreted and compared with each other. The frames with different Response reduction factor (R) is analyzed separately and results of max. Bending moment of beams of each floors, axial forces on column, Drift in X and Z direction and lateral force distribution on each floor is compared with another frame results.

IS 1893: 2002 gives the guidelines for Earthquake

Resistance design. As per Clause 6. 4. 2, the design horizontal seismic Coefficient (Ah)

Ah $=Z/2*I/R*Sa/g$

Where,

Z = Zone factor

I = Importance Factor

R = Response Reduction factor

Sa/g = Average Response acceleration coefficient

As per IS 1893:2002 the zone of the earthquake in India is divided into four zones as follows, (Clause 6. 4. 2, Table 2, Pg. 16)

Table 1. Earthquake zone & intensity

ZONE	II	III	IV	V
INTENSITY	0.10	0.16	0.24	0.36

1. STRUCTURE IMPORTANCE FACTOR: The importance factor (I) is mention in clause 6.4.2 and values are tabulated in table no. 6 of IS 1893:2002 for important service and community building such as school, hospitals etc. as 1.5 & all other buildings as 1.

2. Response Reduction Factor (R): The Response Reduction Factor (R) as Per IS1893:2002 Clause 6. 4. 2, Table No.7 of IS 1893:2002 for OMRF as 3 & SMRF as 5.

2.1 Building Structural Details

Figure 1 shows six bays along X axis & five bays each with 6m & 5M respectively with a storey height of 3m.Total 8 models of G+10 & G+20 frames of RCC and Steel composite structure is analyzed for the reduction factor OMRF & SMRF type. Loading cases for both the type of structure is assumed to be same. All building structures are modeled and analyzed using CSI ETABS 2016 V16.2.0 software.

The method used in this study is response spectrum analysis. Seismic load corresponding to seismic zone II & IV of IS 1893:2002 are considered for the analysis. The properties of material and geometric properties are shown below.

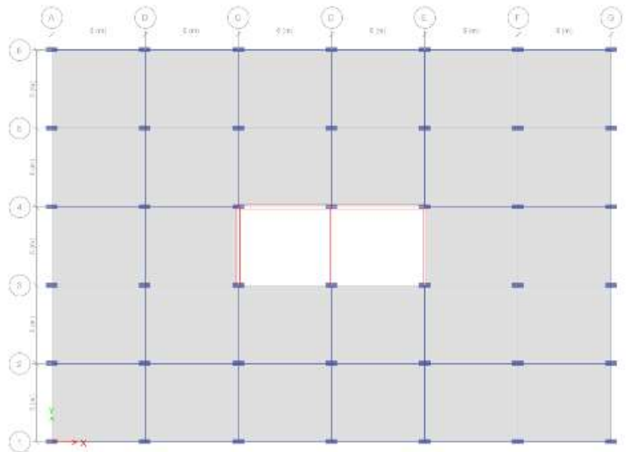

Figure 1.Plan of the RCC & Steel Composite structure.

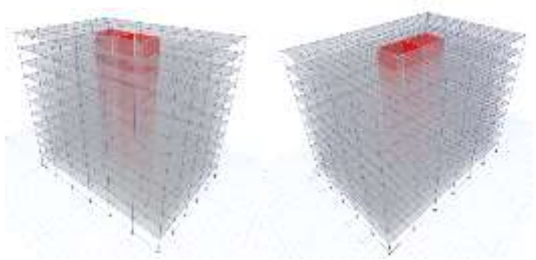

Figure 2.Model of the RCC & Steel Composite G+10 structure.

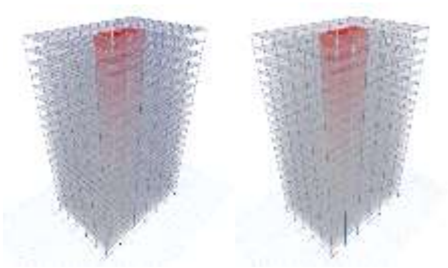

Figure 3.Plan of the RCC & Steel Composite G+20 structure.

Table 2. Data for Analysis of RCC and Composite Structure

Particulars	RCC Structure	Steel- Composite Structure
Plan Dimension	36x25 m	36x25 m
Total height of the building	G+10 33.6m G+20 63.6m	G+10 33.6m G+20 63.6m
Height of each storey	3 m	3 m
Depth of foundation	3 m	3 m
Size of beams main	230x600mm	ISHB 225-1

beam Size of beams Secondary composite beam	230x450mm	ISLB 125-1
Size of columns	300x750	ISHB 225-1 CFST element
Thickness of slab Thickness of walls	150mm 250mm	150 mm with 75 mm rib & profiled deck sheeting
Seismic zone Zone factor Importance factor Site type Damping ratio Response reduction factor	II & IV 0.10 & 0.24 1.0 II 5% OMRF 3 SMRF 5	II & IV 0.10 & 0.24 1.0 II 5% OMRF 3 SMRF 5
Wind speed Terrain category	33 & 47 m/s 2	33 & 47 m/s 2
Time period	Program calculated	Program calculated
Floor finish Live load at all floors Density of concrete Density of brick Density of steel Load on walls	1.5 kN/m^2 2 kN/m^2 25 kN/m^3 20 kN/m^3 7850 kg/m^3 12 kN/m^2	1.5 kN/m^2 2 kN/m^2 25 kN/m^3 20 kN/m^3 7850 kg/m^3 12 kN/m^2
Grade of concrete Grade of reinforcing steel Soil condition	M25 & M40 Fe500 hard soil	M25 & M40 Fe500 hard soil

2.2 Analysis

The analysis is carried out using the equivalent static method and then analyzed using Dynamic analysis for both the type of building. By using Extended-three dimensional Analysis of Building Structure (E-TABS) software 2016 V16.2.0, the models of structures were analyzed. The study parameters were Maximum storey displacement, storey drift, storey shear, overturning moment, bending moment, shear force, axial force and cost of the structure. Since the design is related to India, for calculation of seismic loads and parameters, Indian standard of code for earthquake resistant design of structures IS 1893 (PART-1): 2002 and wind loads of IS-875 (PART-3) were referred for values.

3. Results and Discussion

The result for both R.C.C and steel-concrete composite structures the response spectrum analysis was done. Also to code, the loads were calculated and distributed as per the code IS1893:2002, for zone II and IV for OMRF & SMRF structures, The results obtained are compared with various parameters are mentioned below.

3.1 Storey Displacement

Displacement in a composite structure is slightly higher than that of an RCC structure by 28.57% in G+10 and 20% that of G+20, but it is within the permissible limit by H/500 ,where H is storey height for both X & Y direction along longitudinal direction and transverse direction than that in RCC structure.

3.2 Storey Drift

The result shows that the storey drifts for a composite structure are comparatively higher than RCC structure in both G+10 & G+20 structure but it is within the permissible limit by 0.004H, where H is storey height along for the transverse and longitudinal direction of OMRF & SMRF factor.

3.3 Storey Shear

From the analysis, it is noted that the storey shear does not vary much for the composite structure and R.C.C structure in both G+10 and G+20 for OMRF and SMRF conditions.

3.4 Axial force & weight of the structure

From the analysis, it is noted that the Axial force on the column acting on the ground floor in RCC structure is 208.95 KN higher than that of the composite structure in G+10 and 712.55 KN in G+20 respectively. i.e, axial force & weight of the structure is relatively lower in case of the Steel-composite structure.

Table 3: Comparison of various parameters of RCC and steel-composite structure

STOREY	G+10		G+20	
COMPARISION	RCC	STEEL & COMPOSITE	RCC	STEEL & COMPOSITE
MAX STOREY DISPLACEMENT (mm)	0.015	0.021	0.012	0.015
MAX STOREY DRIFT	0.0000 01	0.000001	2.67E-07	3.23E-07
STOREY SHEAR (KN)	0.3212	0.0209	0.1231	0.0235
OVERTURNING MOMENT(KN-m)	7.4266	2.2424	4.9706	1.0094

3.5 Maximum shear force in beams

From the analysis, it is noted that in RCC structure the shear force is maximum when compared to both G+10 and G+20 storey with respect to the steel-composite structure by 13.76KN & 16.63KN respectively.

3.6 Maximum bending moments in beams

From the analysis, it is noted that in RCC structure the bending moment is maximum when compared to both G+10 and G+20 storey with respect to the steel-composite structure by 18.10KN & 16.79KN respectively.

Table 4: Comparison of shear, bending & axial parameters of RCC and steel-composite structure

STOREY	G+10		G+20		REDUCTION
COMPARISION	RCC	STEEL & COMPOSITE	RCC	STEEL & COMPOSITE	
MAX SHEAR FORCE ON BEAM (KN)	63.3236	49.5562	59.3608	42.7303	13.76 KN & 16.6305 KN
MAX BENDING MOMENT (KN-m)	58.7715	40.6698	50.1081	33.3155	18.1017 KN-m & 16.7926 KN-m
MAX AXIAL FORCE ON COLUMN (KN)	2901.223	2692.272	4835.162	4122.604	208.951 KN & 712.558 KN
WEIGHT OF THE STRUCTURE (KN)	59292.99	47847.59	112977	74701.38	11445.4 KN & 38275.62 KN

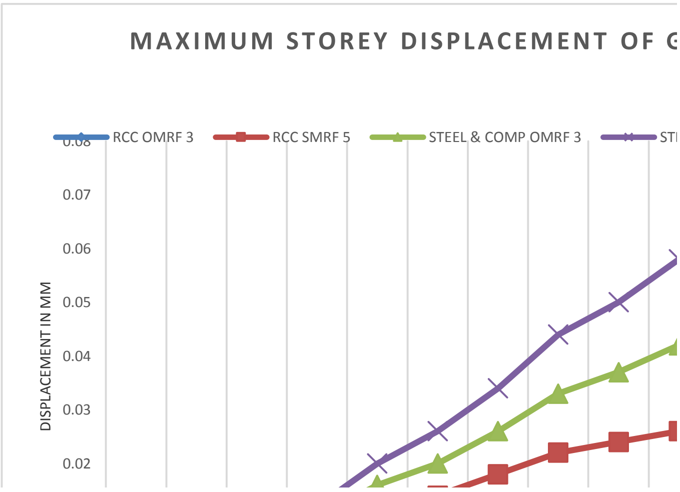

Chart-1: Maximum storey displacement of RCC and steel-composite structure G+10 storey.

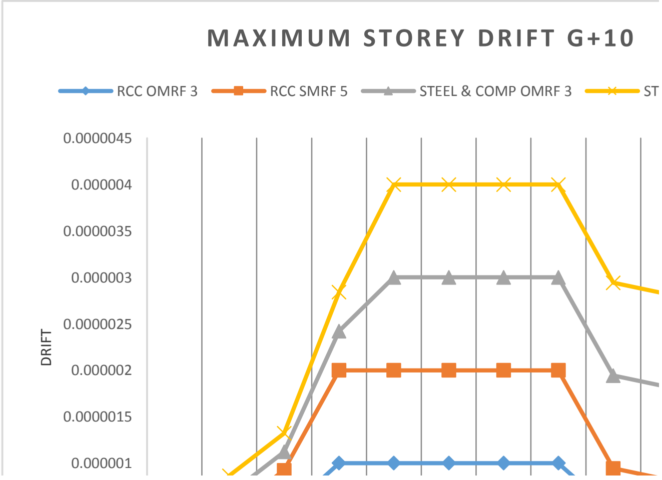

Chart-2: Storey drift of RCC and steel-composite structure G+10 storey.

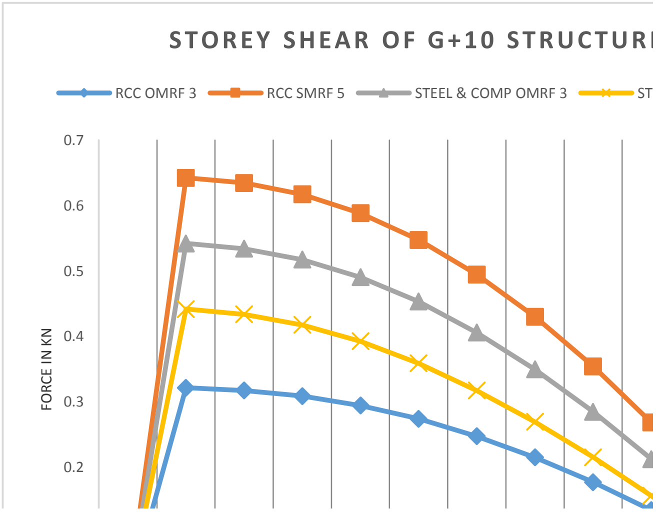

Chart-3: Storey shear of RCC and steel-composite structure G+10 storey.

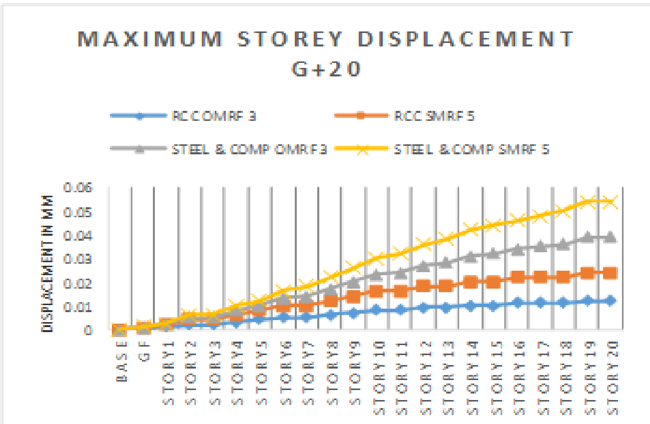

Chart-4: Maximum storey displacement for RCC and steel-composite structure G+20 storey.

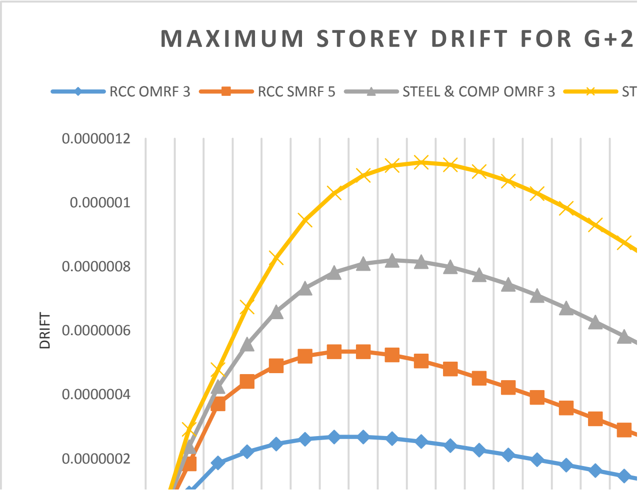

Chart-5: Storey drift for RCC and steel-composite structure G+20 storey.

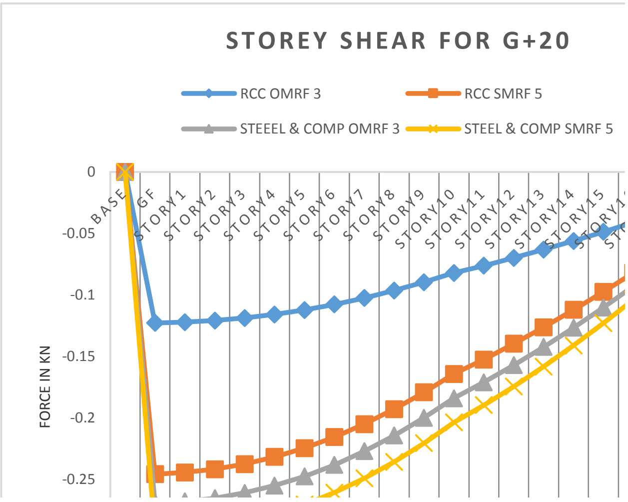

Chart -6: Storey shear for RCC and steel-composite structure G+20 storey.

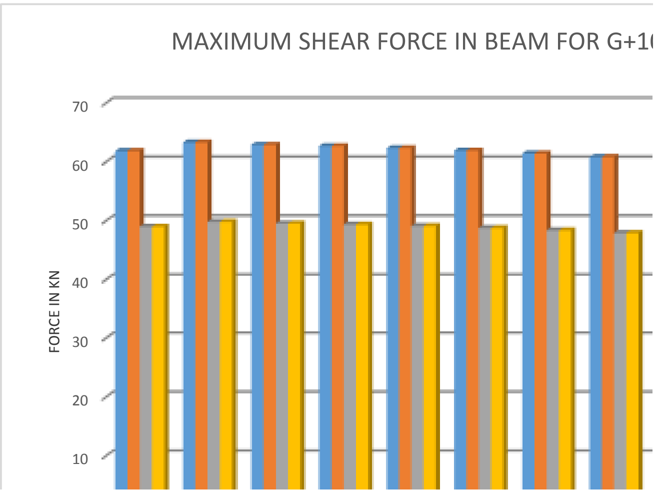

Chart-7: Maximum shear force for RCC and steel-composite structure G+10 storey.

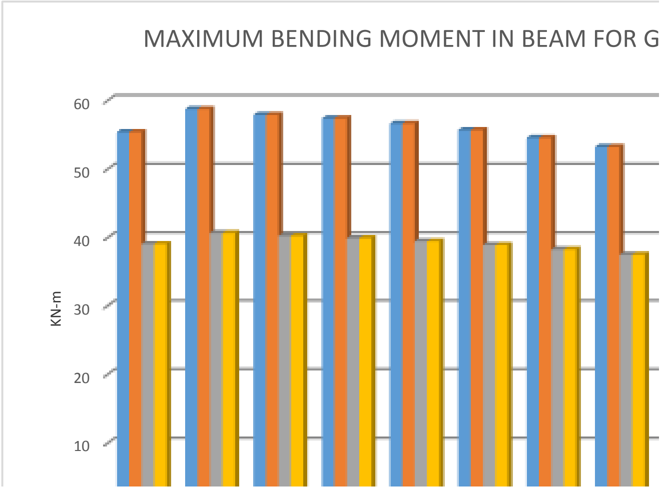

Chart -8: Maximum bending moment for RCC and steel-composite structure G+10 storey.

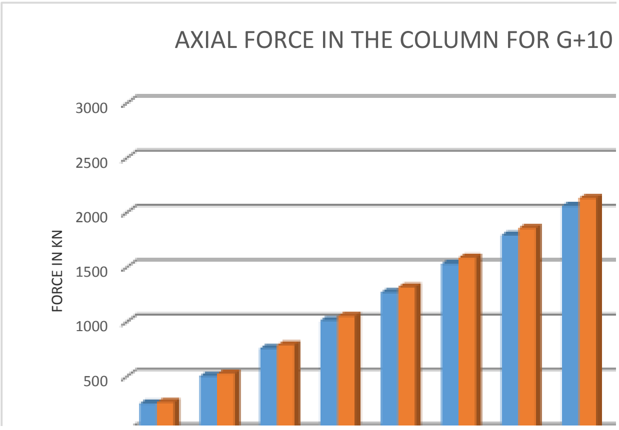

Chart -9: Axial force on column for RCC and steel-composite structure G+10 storey.

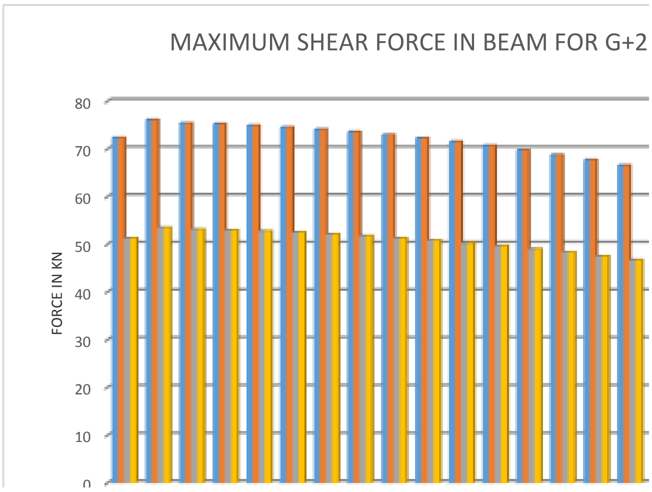

Chart -10: Maximum shear force for RCC and steel-composite structure G+20 storey.

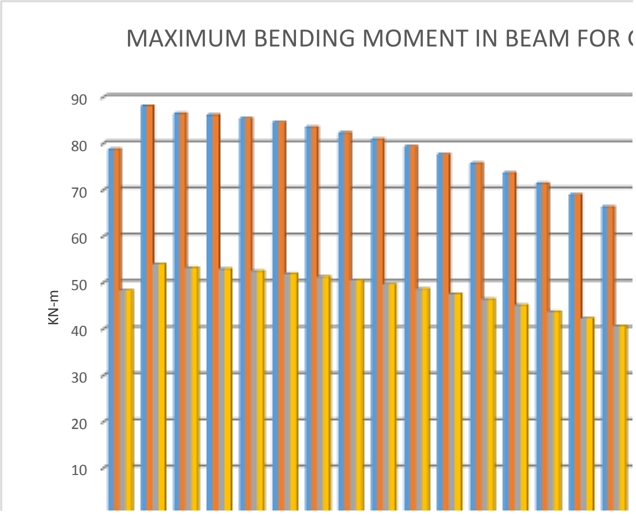

Chart -11: Maximum bending moment for RCC and steel-composite structure G+20 storey.

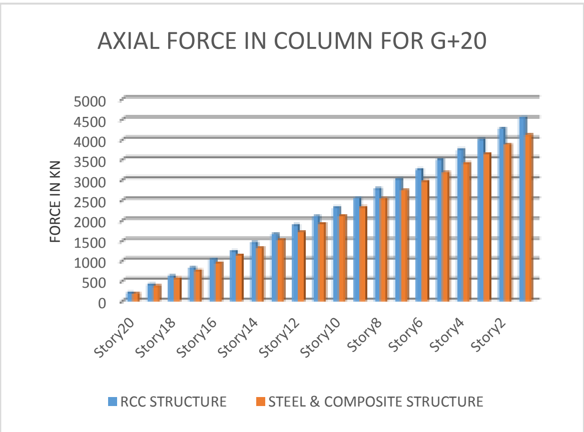

Chart -12: Axial force on column for RCC and steel-composite structure G+20 storey.

3.8 Base Shear

Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure. It is the horizontal reaction to the earthquake forces and horizontal forces results from the storey weight. Storey weight includes the self-weight of the structure also; hence in the reinforced cement concrete model the self-weight is seems to be the more and hence maximizing the earthquake forces which results in the maximum base shear. As we have the static formula for base shear as base shear is the direct function of the seismic weight therefore naturally base shear is more in the case of RCC structure. The graph clearly shows that the Base Shear of RCC is more than Composite.

Table 5: Comparison of Base shear for RCC and steel-composite structure

COMPARISION	RCC		STEEL & COMPOSITE		REDUCTION %
	OMRF	SMRF	OMRF	SMRF	
BASE SHEAR ALONG EQX G+10 STOREY	5159.47	7429.64	3943.23	5678.25	23.57%
BASE SHEAR ALONG EQY G+10 STOREY	2765.36	3982.11	1837.84	2646.49	33.54%
BASE SHEAR ALONG EQX G+20 STOREY	3764.86	5421.4	2374.39	3419.12	36.93%
BASE SHEAR ALONG EQY G+20 STOREY	1955.16	2815.43	1107.16	1594.31	43.37%

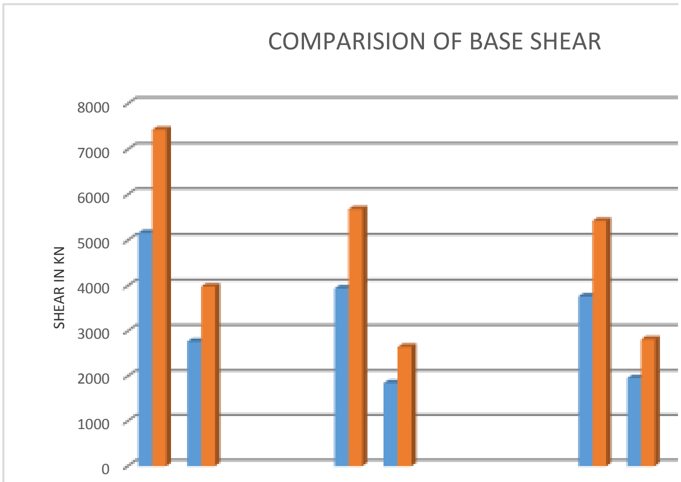

Chart -13: Base shear acting for RCC and steel-composite structure G+20 storey.

3.9 Comparison of cost

From the analysis, the axial force, bending moment & shear force it is visible that the force in steel composite structure is lower than RCC structure. From the obtained concrete and steel take off value the cost of the steel composite structure is lower compared to RCC.

Table 6: Comparison of cost for RCC and steel-composite structure

STRUCTURE TYPE	RCC STRUCTURE	STEEL & COMPOSITE STRUCTURE	REDUCTION IN COST
G+10	21211620.0 ₹	20944200.0 ₹	267420.0 ₹
G+20	42423240.0 ₹	41888400.0 ₹	534840.0 ₹

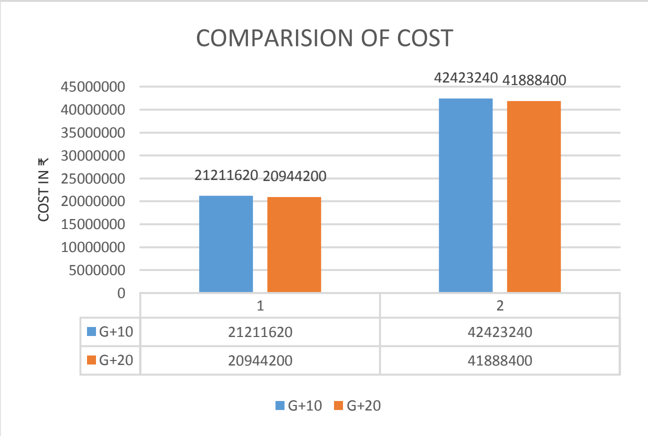

Chart -14: Cost comparison for RCC and steel-composite structure G+20 storey.

4. Conclusion

This Analysis and design results of G+10 & G+20 storey Steel Composite, and R.C.C Structure has been studied and represented here. The comparison results of these building models are as follows.

a) The displacement and storey drift in R.C.C. Structure is merely less than composite structure but are in permissible limit as prescribed by the codal provisions. It is due to the flexibility of composite structure when compared to RCC structures.
b) From the results it is found that Shear force in composite beams is reduced by 13.76KN & 16.63KN for G+10 & G+20 models respectively.
c) It was found also that bending moment in beams of Composite structure is reduced from 18.10KN-m & 16.69Kn-m for G+10 & G+20 models respectively.
d) The dead weight of composite structure reduced from 19.3% & 33.87% for G+10 & G+20 models respectively, which is less than RCC structure thus resulting in reduction of seismic forces.
e) The Base shear in the Steel composite structure varies from 23.57% to 43.37% thus reducing the seismic loads on structure.
f) The Presents investigation shows that by using Steel composite design of tall buildings provides good results when compared to R.C.C and conventional steel building and also economically serve as a better solution for tall buildings by reducing cost up to 1.26% to 2%.
g) Weight of composite structure is low when compared to R.C.C. structure resulting in reduction of foundation cost.
h) For high rise structures, composite structures are found to be the best mode of construction.

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REFERENCES

[1] D. Datta and S. Ghorai, "Multistoreyed Residential Building (B+G+20) Storied with Steel-Concrete Composite construction", Institute for Steel Development & Growth; Publication No.: INS/PUB/117, 2010.

[2] D. R. Panchal and P. M. Marathe, "Comparative Study of R.C.C., Steel and Composite (G+30) storey building", Institute of Technology, Nirma University, Ahmedabad – 382 481 , pp- 1-6, December, 2011

[3] Dr. S. V. Itti1 and A. A. Mahadar, "Seismic Performance of Composite Moment-Resisting Frames: State of the Art", Volume No.5 Issue: Special 3, pp: 725-730 27-28 Feb. 2016 NCASE@2016 doi: 10.17950/ijer/v5i3/045 Page 725.

[4] Euro code 3 & Euro code 4, Design of composite steel and concrete structure, European committee for standardization committee European de normalization europaisches committee fur normung.

[5] IS 800:2007, "Indian Standard code of practice for General Construction in steel" Bureau of Indian Standards, New Delhi, India.

[6] IS 456:2000, "Indian Standard code of practice for Plain and Reinforced concrete", Bureau of Indian Standards, New Delhi, India.

[7] IS 11384:1985, "Code of Practice for Design of Composite Structure", Bureau of Indian Standards, New Delhi, India.

[8] IS 808(1989), Dimensions for Hot Rolled Steel Beam, Column, Channel and Angle Sections, || Bureau of Indian Standards (BIS), New Delhi.

[9] IS393:1966-Code of practice for composite construction.

[10] IS: 1893, Criteria for earthquake resistant design of structures – general provisions for buildings, Part 1, Bureau of Indian Standards, New Delhi, 2002.

[11] Handbook on Composite Construction-Multi-Storey Buildings-Part-3, (2002), Institute for Steel Development and Growth (INSDAG).

[12] Handbook on Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures (IS: 875(Part 1, 2 & 3) –1987), Bureau of Indian Standards, New Delhi, 1989.

[13] Handbook on Criteria for Earthquake Resistant Design of Structures (IS: 1893(Part 1) – 2002), Bureau of Indian Standards, New Delhi, 1989.

[14] SP 64, Explanatory Handbook code of practice for design loads (other than earthquake) building and structure, Part-3 wind load".

[15] INSDAG Papers for Composite Beams, Composite Floors, Composite Columns.

[16] INSDAG Eq. Section Calculator for properties of Composite Structures.