A Comparative Study of the Seismic Behavior of Composite (Steel-Concrete) and Reinforced Concrete Structure

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ABSTRACT

The low weight, high strength, and durability of steel-concrete composite construction have made it quite popular worldwide. However, it is not commonly used in Nepal. For the country, avoiding composite construction when it is economically viable is a great loss. Using composite materials is of particular interest due to their potential to improve performance through rather small changes in manufacturing and construction technologies. Steel concrete composite construction means the concrete slab is connected to the composite beam with the help of shear connectors so that they act as a single unit. In this paper we intend to compare the parameters like storey drift, time period, deflections, etc. between composite and RC structures for 6, 10 and 15 stories regular and irregular buildings situated in earthquake zone V. ETABS software was used for the analysis and linear static method, linear time history method and static pushover method were performed. The results are compared and we found out that composite constructions are more suitable in multi- storied buildings compared to RC structures.

Keywords: Composite buildings, Storey drift, Shear connectors, Seismic performance, Concrete-Steel Section.

1. Introduction

In Nepal, concrete is the most used, convenient and economical construction material in low-rise buildings. Nowadays due to overcrowding of city areas, the need for high-rise buildings has arisen. For medium to high-rise buildings RC structure is not suitable because of the increased dead load, requirement of formwork (which makes the construction process longer) and increase in cost. So, for these structures, steel-concrete composite construction can provide better performance and an effective economical solution**.** The main benefit of composite elements is that the properties of each material can be combined to form a single unit that performs better overall than its separate constituent parts.

Panchal & Marathe (2011) worked on steel-concrete composite, steel, and RC structure options which are considered for the comparative study of G+30 storey commercial building which is situated in earthquake zone IV. The equivalent Static Method of Analysis is used. The comparative study includes deflections of the members, size and material consumption of members in composite concerning RC and Steel sections, seismic forces and behaviour of the building under the seismic condition in composite with respect to RC and Steel. He concluded that composite structure was more economical.

Prajapati & Panchal (2013) discussed the analysis & design procedure adopted for the evaluation of symmetric high-rise multi-storey buildings (G+30) under the effect of Wind and Earthquake forces. In these building, RC, Steel & Composite buildings with shear walls were considered to resist lateral forces resisting system. This study examines G+30 stories building that are analyzed and design under the effect of wind and earthquake using ETABS. A total of 21 numbers of various models are analyzed by equivalent static method and it proves that steel-concrete composite building is the better option.

Mahajan & Kalurkar (2016) performed a performance analysis of RC and steel concrete composite structures under seismic effect. They showed the effect of FEC (Fully Encased Composite) on a G+ 20-storey special moment frame. The linear static analysis and nonlinear static analysis i.e. "Pushover analysis" is done for G+20-storey structure. Results are compared for the base shear, modal time period, storey displacement and storey drift for both structures. As the composite has more lateral stiffness, the results of the time period and storey displacement show significant variation. While analyzing for "Non-linear static analysis the performance point for the FEC is significantly much more as compared to the RC model.

Shah & Pajgade (2013) performed a comparative study of RC with a Composite (G+15) Storey building. Steel-concrete composite with RC options is considered for the comparative study of G+15 storey office building which is situated in earthquake zone IV & wind speed 39 m/s. An Equivalent Static Method of Analysis was used. For the modeling of Composite & RC structures, STAAD-Pro software was used. The results were compared and it was found that composite structures are more economical.

Etli & Güneyisi (2020) performed a seismic performance evaluation of regular and irregular composite moment-resisting frames. The seismic behavior of regular and irregular composite moment-resisting frame buildings was investigated. 5, 8, 10, 13 and 15-story composite moment-resisting frames having concrete-filled steel tube columns and composite beams were designed at high ductility levels and their performances were evaluated comparatively.

Uddin & Azeem (2020) performed a comparative study on the seismic behaviour of composite and RC plan irregular structures. All the models considered are G+15 storey and are irregular in plan and the irregularity condition as per IS 1893-2002 is satisfied resulting in a T shape and a Plus Shape models.

Anagha S. S & Raghu K (2023) performed a comparative study on the seismic behaviour of RC and Composite structures for different types of irregularities. ETABS is used to model and analyze the comparison of RC and composite structures with CFT columns for different kinds of irregularities, such as vertical geometric irregularity, mass irregularity, and stiffness irregularity, in accordance with IS codes.

Pannirselvam & Sreelekshmi (2022) performed a study on irregular tall RC structures and composite structures by pushover analysis. They addressed the study and behaviour of structures with composite columns–concrete-filled steel tube columns (CFST) having irregularities in plan and elevation, subjected to ground motion. In this paper, a study on how composite column–concrete-filled steel column meets seismic demands in five irregular structures and its advantages over RC has been carried out by pushover analysis in ETABS.

After reviewing all these works, we set the following as the objective of our study:

- To investigate the seismic behavior of steel-concrete composite frames over the reinforced concrete (RC) frames in both regular and irregular buildings.
- To compare ductility by performing inelastic (pushover) analysis of steel-concrete composite sections and RC sections.

2. Materials and Methods

2.1 Building details

3D modeling of all the RC and composite buildings was done using ETABS software. The models used are not the real existing buildings. 12 models were used in this research: G+5, G+9, G+14 regular composite buildings, G+5, G+9, G+14 regular RC buildings, G+5, G+9, G+14 irregular composite buildings and G+5, G+9, G+14 irregular RC buildings. The plan of the irregular building is chosen to consider torsional irregularity i.e. 1st or 2nd mode of the building istorsion. A floor plan of 28m x 28m dimensions was considered for regular structures in this study where the center-to-center distance between two grids is 4 m as shown in Fig.s 2.1 to 2.4.

The sizes of the beam, column and slab used are illustrated in Table 2.1. Different sections are used in different storey buildings as per design criteria given in IS 456: 20000 and AISC 360-16.

The loading conditions used in the analysis and all other parameters considered in the design according to IS 875(1987-Part 1), IS 875(1987-Part 2), IS 1893, Part 1 and IS: 800:2007, are provided in Table 2.2.

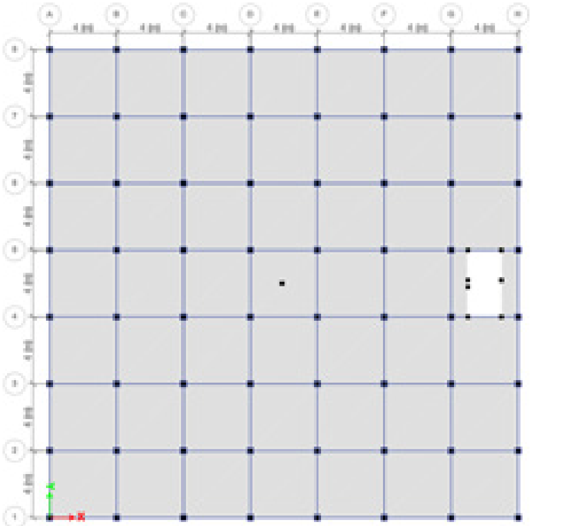

Fig. 2.1: Plan of regular buildings

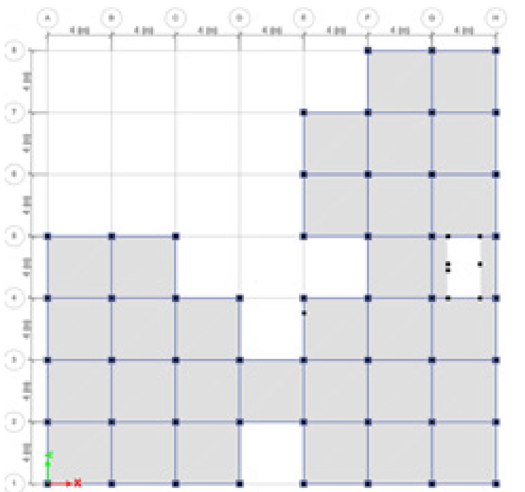

Fig. 2.2: Plan of irregular buildings

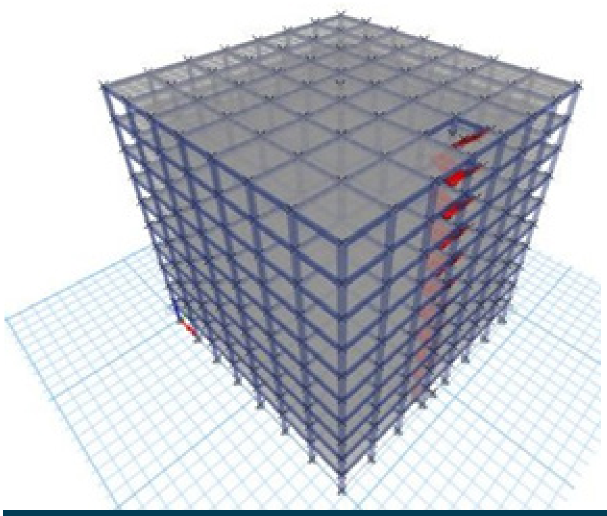

Fig. 2.3: 3D view for regular RC composite structures

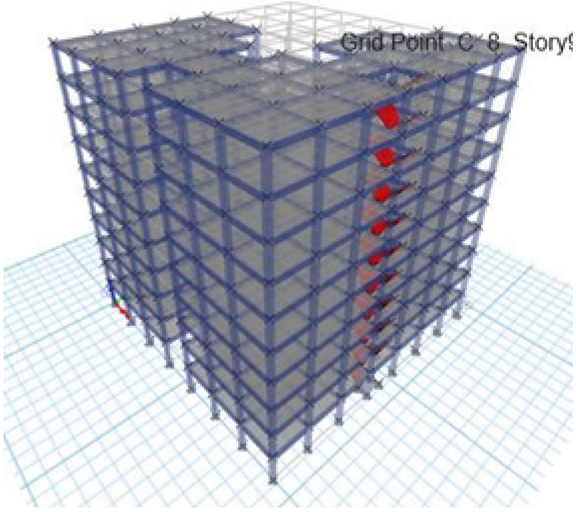

Fig. 2.4: 3D view for irregular RC and composite structures

Table 2.1: Column and beam sizes of structure

Building type	Plan	Story	Column size(mm*mm)	Beam size (mm*mm)	Secondary beam	Slab and deck size
RC	Regular	6	375*375	350*275	-	200
		10	400*400	350*275	-	200
		15	450*450	450*350	-	200
	Irregular	6	375*375	350*275	-	200
		10	450*450	375*300	-	200
		15	500*500	500*400	-	200
Composite	Regular	6	400*400 (ISHB-200)	ISMB-225	ISJB-175	200
		10	400*400 (ISHB-200)	ISMB-225	ISJB-200	200
		15	450*450 (ISHB-225)	ISMB-300	ISJB-175	200
	Irregu-lar	6	400*400 (ISHB-200)	ISMB-225	ISJB-175	200
		10	400*400 (ISHB-200)	ISMB-225	ISJB-200	200
		15	450*450 (ISHB-225)	ISMB-300	ISJB-175	200

Table 2.2: Basic loadings and parameters considered for the design

Seismic zone	V
Soil condition	Soft soil
Floor finish	1.5 kN/m^2
Live load at all floors	4.0 kN/m^2
Live load at staircase	4.0 kN/m^2
Zone factor	0.36
Importance factor	1.0
Grade of concrete	M30
Grade of structural steel	Fe345
Grade of rebar	HYSD500
Response reduction factor	5 for SMRF

2.2 Analysis

Structural analysis of all the RC and composite buildings was done using ETABS software. The analysis procedure used in ETABS was the linear static method, linear time history method and static pushover method. Here the conventional RC structure is designed according to IS 456-2000 and the composite structures is designed according to the AISC 360-16 code provisions.

2.2.1 Linear Static Procedure

A linear static analysis is an analysis where a linear relation holds between applied forces and displacements. The linear static procedure is a method of estimating the response of the structure to earthquake-induced forces by representing the effects of this response through the application of a series of static lateral forces applied to an elastic mathematical model of the structure and its stiffness. The forces are applied to the structure in a pattern that represents the typical distribution of inertial forces in a regular structure responding linearly to the ground shaking excitation, factored into account (here response reduction factor of 5 is as per IS code for both composite and RC structure), in an approximate manner, for the probable inelastic behavior of the structure. In a linear static analysis, the model's stiffness matrix is constant, and the solving process is relatively short compared to a nonlinear analysis on the same model. Therefore, in this paper, for a first estimate, the linear static analysis is used prior to performing a full nonlinear analysis.

2.2.2 Linear Dynamic Procedure

The main purpose of linear dynamic analysis is to \] evaluate the time variation of stresses and deformations in structures caused by arbitrary dynamic loads. In this paper linear time history analysis as per the IS code 1893:2016 is performed for linear dynamic procedure. As per ASCE 7-10(2010), a minimum of seven ground motion histories should be considered in the linear dynamic procedure. So, seven ground motion acceleration histories having magnitudes, fault distances, and source mechanisms consistent with seismic hazard at the design location were selected from the PEER NGA [14] database. The two horizontal ground motion components of each pair were scaled to match with target spectrum, and response spectrum given for the soft soil as per IS code 1893:2016 and were applied in orthogonal directions along the principal axes of the building structure.

Table 2.3: Criteria for ground motion selection

Magnitude (min, max)	6.5-8 Mw
Fault type	Reverse + Oblique
Fault distance	20-100km
Seismic shear wave velocity (Vs30)	180-360 m/s (soft soil)

Table 2.4: Ground motions

Earthquake Name	Year	Station Name	Magnitude (Mw)	Mechanism	Rjb (km)	Rrup (km)	Vs30 (m/sec)
"San Fernando"	1971	"2516 Via Tejon PV"	6.61	Reverse	55.2	55.2	280.56
"San Fernando"	1971	"Carbon Canyon Dam"	6.61	Reverse	61.79	61.79	235
"Friuli_Italy-01"	1976	"Codroipo"	6.5	Reverse	33.32	33.4	249.28
"Friuli_Italy-01"	1976	"Conegliano"	6.5	Reverse	80.37	80.41	352.05
"Tabas_ Iran"	1978	"Boshrooyeh"	7.35	Reverse	24.07	28.79	324.57
"Tabas_ Iran"	1978	"Ferdows"	7.35	Reverse	89.76	91.14	302.64
"Taiwan SMART1(25)"	1983	"SMART1 C00"	6.5	Reverse	95.57	96.06	309.41

2.2.3 Non-Linear Static Procedure

In reality, during earthquakes, buildings are generally subjected to large inertia forces which cause members of buildings to behave in a nonlinear manner. Thus, the earthquake shaking of the structure is a nonlinear dynamic problem and structural analysis should incorporate the nonlinearbehavior of members for evaluating the actual response of the structure. Non-linear static analysis (also known as pushover analysis) is a procedure where a mathematical model incorporating the inelastic post-yield behavior of the structural elements is subjected to monotonically increasing horizontal loads until target displacement is reached. It is generally used to evaluate the performance point and the weak link of structures. In this paper, the performance point is calculated using the capacity spectrum method, where both the capacity curve and the demand curve are converted into acceleration displacement response spectrum (ADRS) format i.e. spectral acceleration vs spectral displacement. The intersection point of the converted demand and capacity curve is the performance point.

3. Results And Discussions

The following results were observed from the analysis and comparison of results betweenRC and Composite structures is shown through the graph:

3.1 Regular Buildings

3.1.1. Story Displacement

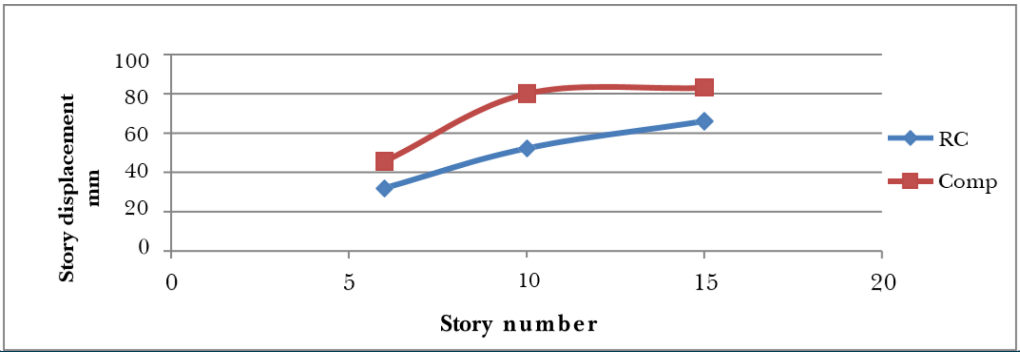

Fig. 3.1: Comparison of displacement X

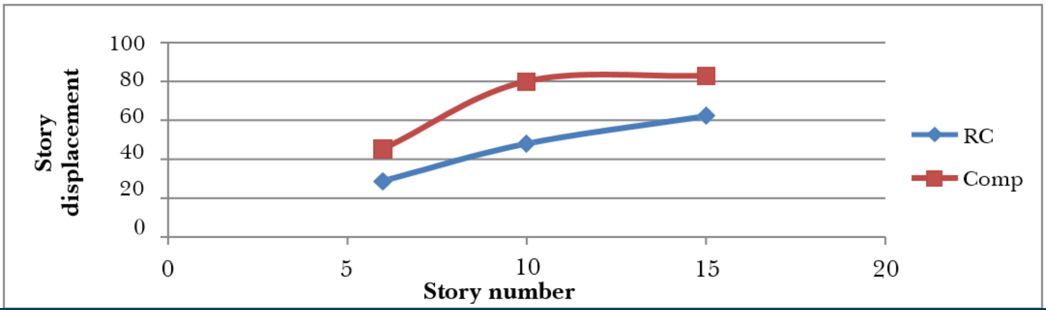

Fig. 3.2: Comparison of displacement Y

3.1.2. Story drift ratio

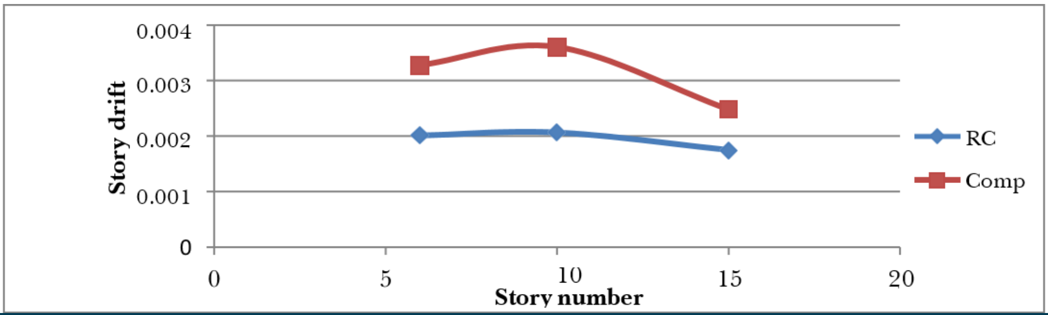

Fig. 3.3: Comparison of story drift X

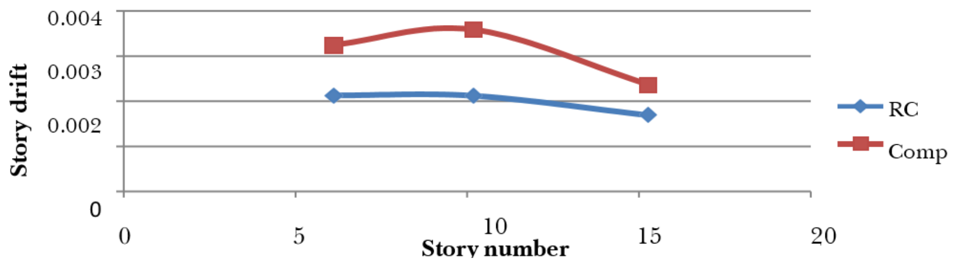

Fig. 3.4: Comparison of story drift Y

3.1.3. Overturning moment

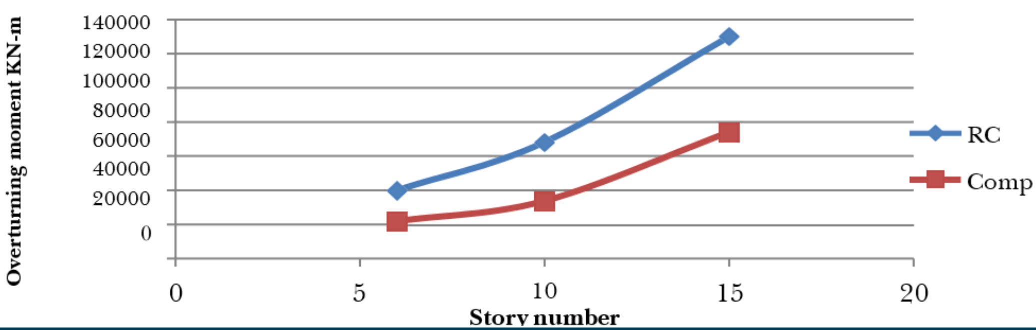

Fig. 3.5: Comparison of overturning moment X

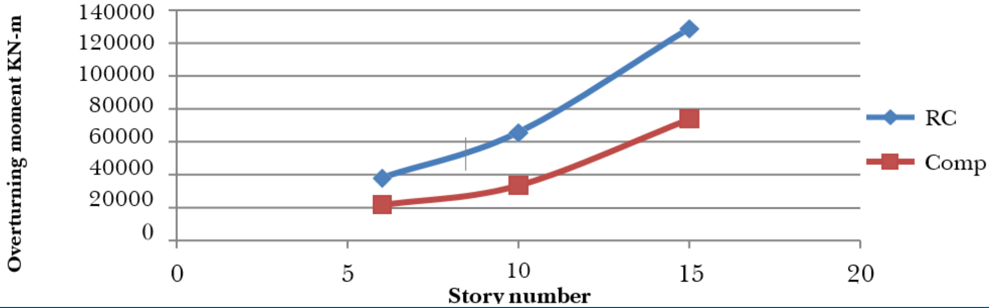

Fig. 3.6: Comparison of overturning moment Y

3.1.4. Time period

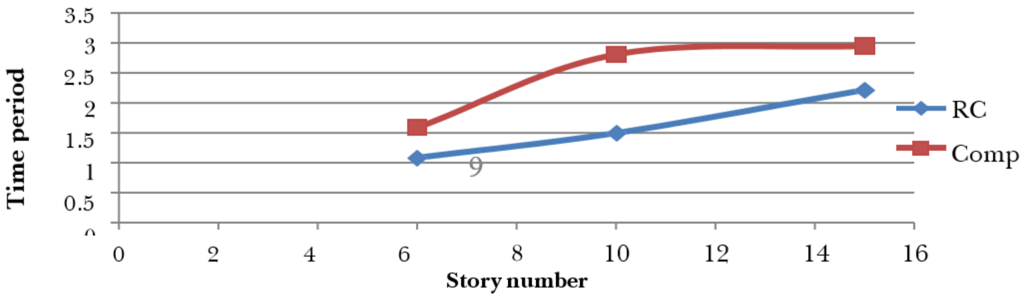

Fig. 3.7: Comparison of time period X

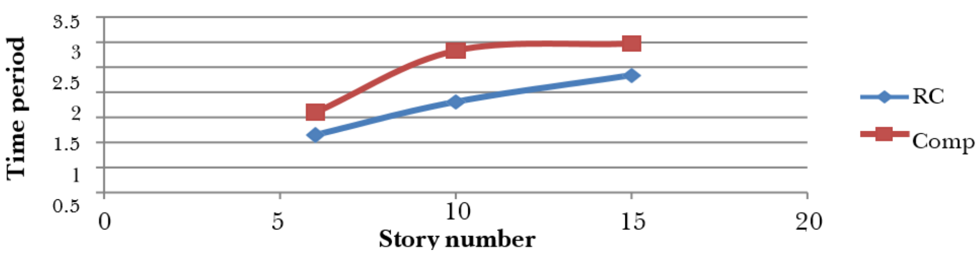

Fig. 3.8: Comparison of time period Y

3.1.5. Base shear

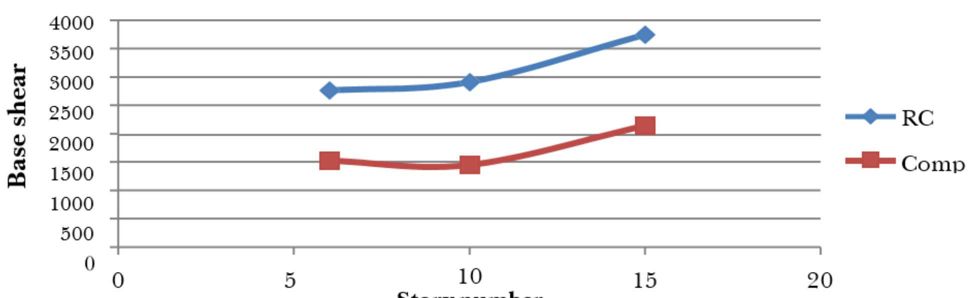

Fig. 3.9: Comparison of base shear X

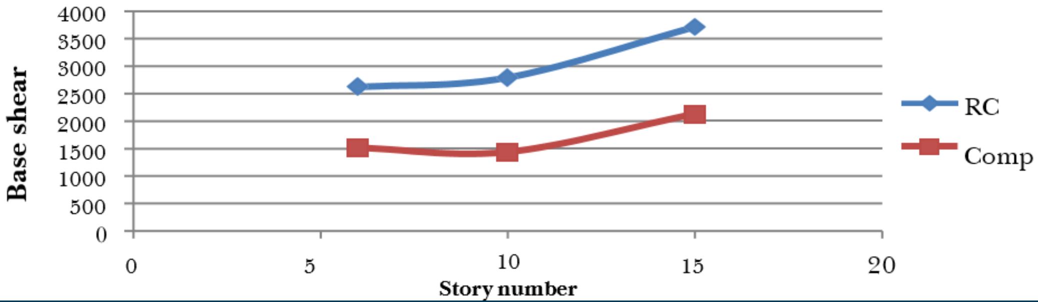

Fig. 3.10: Comparison of base shear Y

3.1.6. Performance point (spectral displacement)

Story Number	Direction	RC (mm)	Composite(mm)	Percentage Change
6	X	136.97	210.82	53.92
	Y	131.48	208.86	58.85
10	X	268.49	312.18	16.27
	Y	226.04	308.32	36.40
15	X	297.44	384.61	29.30
	Y	289.54	381.66	31.77

3.2 Irregular Buldings

3.2.1 Story displacement

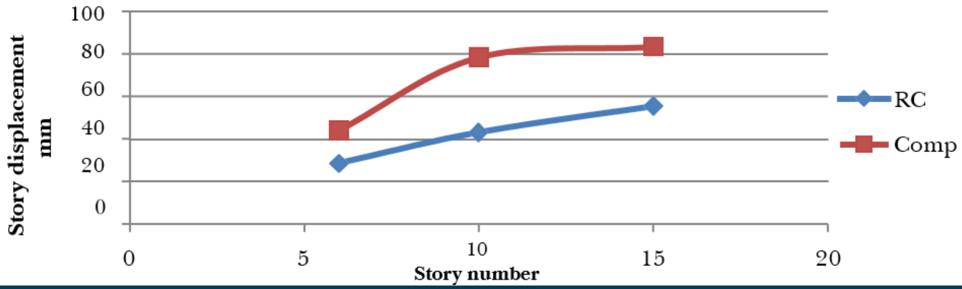

Fig. 3.11: Comparison of story displacement X

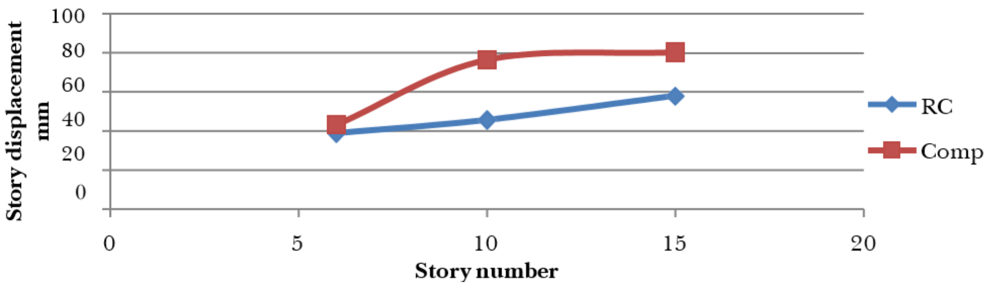

Fig. 3.12: Comparison of story displacement Y

3.2.2. Story drift

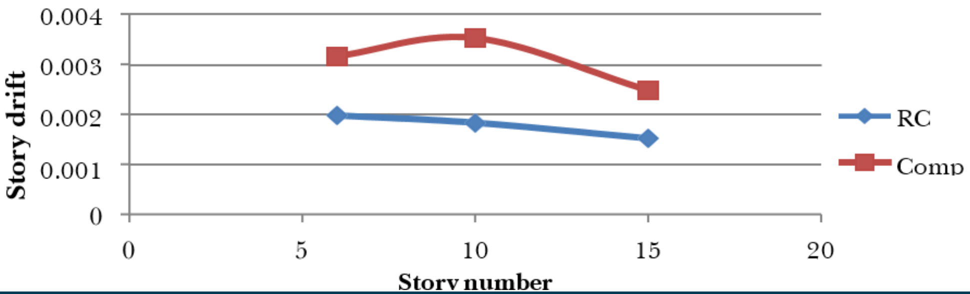

Fig. 3.13: Comparison of story drift X

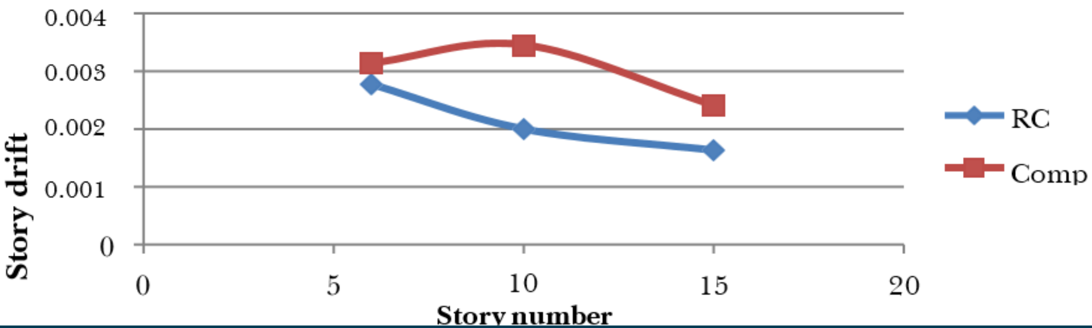

Fig. 3.14: Comparison of story drift Y

3.2.3. Overturning Moment

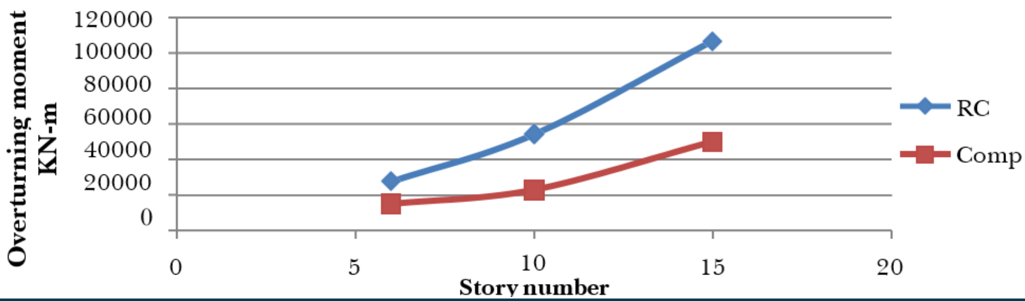

Fig. 3.15: Comparison of overturning moment X

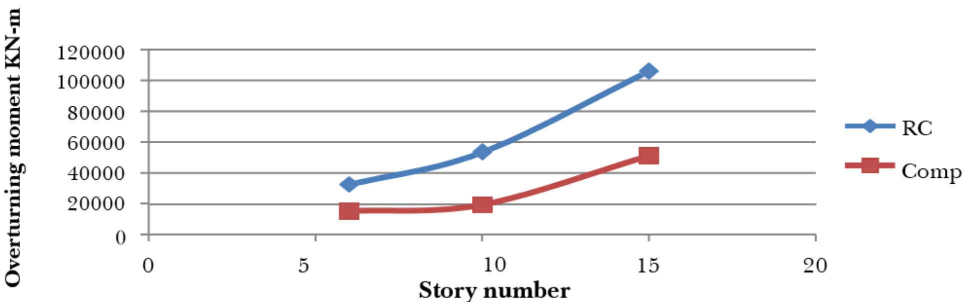

Fig. 3.16 : Comparison of overturning moment Y

3.2.4. Time Period

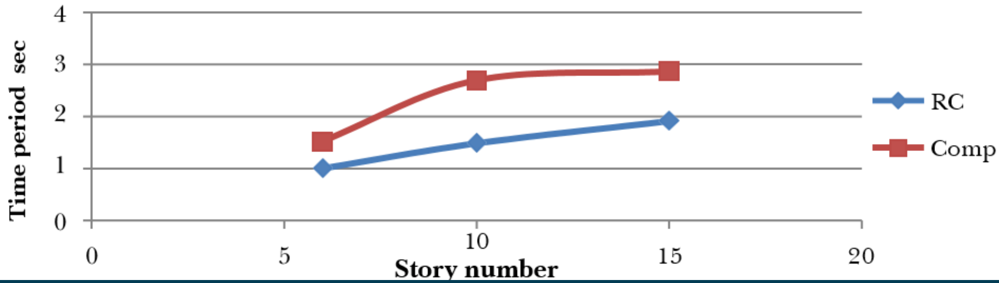

Fig. 3.17 : Comparison of time period X

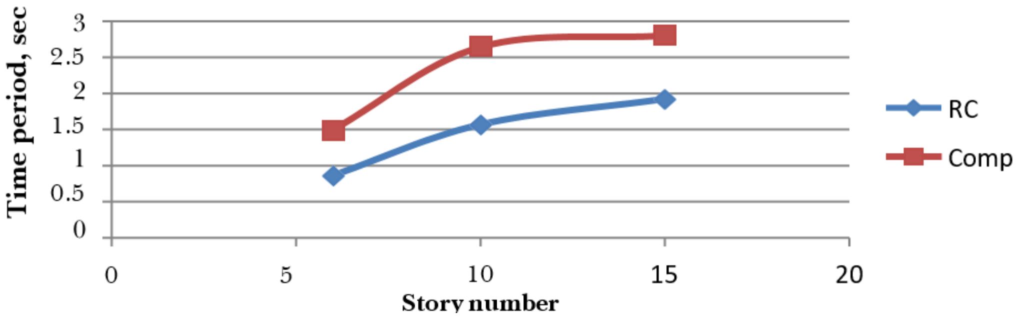

Fig. 3.18 : Comparison of time period Y

3.2.5. Base Shear

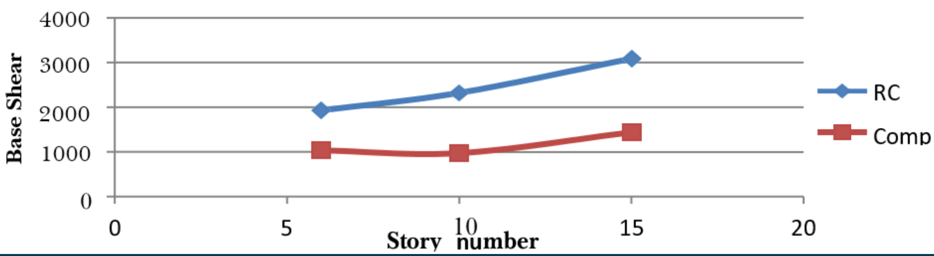

Fig. 3.19 : Comparison of base shear X

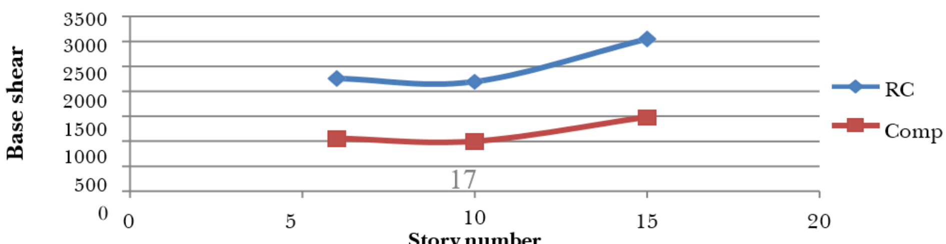

Fig. 3.20 : Comparison of base shear Y

3.2.6. Performance point (spectral displacement)

Table 3.5: Performance point (spectral displacement)

Story Number	Direction	RC (mm)	Composite(mm)	Percentage Change
6	X	161.84	207.12	27.98
	Y	134.82	203.18	50.70
10	X	210.67	302.24	43.46
	Y	209.59	293.94	40.25
15	X	293.55	374.02	27.41
	Y	292.54	363.85	24.38

Shear force of column (C1)

Table 3.6: Shear force of column (C1)

Story number	RC (kN)	Composite(kN)
6	36.12	19.20
10	39.44	20.84
15	55.24	29.37

Bending Moment of column (C1)

Table 3.7: Bending Moment of column(C1)

Story number	RC (kN-m)	Composite(kN-m)
6	93.25	78.79
10	101.16	80.42
15	131.19	98.33

Axial Force of column (C1)

Table 3.8: Axial Force of column(C1)

Story number	RC (kN)	Composite(kN)
6	174.30	141.27
10	823.94	549.92
15	1799.84	1042.00

4. Discussion

Composite buildings have a high time period, high maximum story displacement, and high story drift ratio compared to RC buildings, making them more flexible to oscillate in response to lateral forces. Axial force, maximum bending moment & shear force in a column of the RC structure are on the higher side than that of the composite structure for both regular and irregular configuration. Also, the higher performance point in composite buildings than RC buildings indicates higher ductility of composite structures as compared to RC which is best suited to the effect of lateral forces. In composite buildings, seismic forces are less than in RC structures, which may be attributed to their lighter seismic weight.

5. Conclusion

- For regular configuration the lateral displacements of composite structure are found to be 26% to 53% more in the Y-direction and about 32% to 66% more in X direction than the RC structures and for irregular configuration, the lateral displacements of composite structure are found to be 11% to 67% more in Y-direction and about 50% to 82% more in X direction than the RC structures. In irregular configuration lateral displacement is higher than regular.
- For regular configuration the maximum story drift ratio of the composite structure is found to be 22% to 59% more in the Y-direction and about 42% to 74% more in X direction than the RC structures and for irregular configuration the maximum story drift ratio of the composite structure is found to be 12% to 72% more in Y-direction and about 50% to 82% more in X direction than the RC structures.
- For regular configuration the overturning moment of the composite structure is found to be 42% to 48% less in the Y-direction and about 42% to 50% less in X direction than the RC structures and for irregular configuration, the overturning moment of the composite structure is found to be 51% to 54% less in the Y-direction and about 46% to 57% less in X direction than the RC structures.

- For regular configuration the time period of the composite structure is found to be 26% to 56% more in the Y-direction and about 33% to 62% more in X direction than the RC structures and for irregular configuration the time period of the composite structure is found to be 45% to 73% more in Y-direction and about 49% to 81% more in X direction than the RC structures.
- For regular configuration the base shear of the composite structure is found to be 42% to 48% less in the Y-direction and about 42% to 50% less in X direction than the RC structures and for irregular configuration, the base shear of the composite structure is found to be 51% to 54% less in Y-direction and about 46% to 57% less in X direction than the RC structures.
- From pushover analysis, for regular configuration the performance point of the composite structure is found to be 31% to 58% more in the Y-direction and about 16% to 53% more in X direction than the RC structures and for irregular configuration, the time period of the composite structure is found to be 24% to 50% more in Y-direction and about 27% to 43% more in X direction than the RC structures.

All the percentage variation in different parameters between RC and composite sections shows us that composite sections are efficient in high-rise buildings. Also, the sections used in composite sections are on the lower side which maximizes the space and lowers the dead load. The weight of composite structure is quite low as compared to RC structure which helps in reducing the foundation cost. An emphasis on speedy construction facilitates a faster return on investment & a greater rent-related benefit. That is why we can say that composite buildings are more economical than RC buildings.

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