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MULTIDIMENSIONAL COMPARISON OF G+20 STEEL-CONCRETE COMPOSITE STRUCTURE WITH CONVENTIONAL STRUCTURES USING ETABS

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ABSTRACT

In recent years, Steel-Concrete Composite construction has started acquiringworldwideacceptance as asubstitute to R.C.C. and Steel construction. However,it is relatively a new concept forIndia in comparison to other developing nations. In India,for low-rise building reinforced concrete sections arewidely opted by engineers because it is an economic option. In case of medium and high-rise buildings opting for R.C.C. contributes to massive increasein seismic weight, and less displacement resulting the structure to be uneconomical whereas steel structures are ductile and imparts more displacement. So for high-rise building structural steel is conventional option but Steel-Concrete composite construction can be more suitable and economic solution. Steel-Concrete composite construction puts to use the advantages and overcome the disadvantage of materials when performed individually. This paper aims to present the comparison of two Steel-Concrete composite structure one having concrete-filled steel (CFST) columns and the other having concrete-encased steel (CES) columns along with other composite elements with R.C.C. and Steel structure of G+20 storywhich is situated in Lucknow (earthquake zone-3). Response Spectrum Analysis is performed for seismic analysis of all the four models, using ETABS-2019 software. These models are compared on the basis of parameters such as story displacement, drift, stiffness, base shear, weight of the structure, bending and shear force of a beam and a column of the four models. After the comparison it is final concluded that steel-concrete composite construction is a viable alternative to R.C.C. and steel as the composite structures are able to gain sufficient ductility required to resist lateral due to the presence of steel along with enough stiffness due to concrete. Other factors such as absence of formwork not only reduces the cost but also assists in speedy construction.

Keywords- *CES columns; CFST columns; Composite Construction, ETABS, Steel-RCC Composite*.

1. Introduction

In India, in the world of construction engineers being familiar with the pros and cons of R.C.C find it comfortable to opt for reinforced cement concrete. Inspite of India being the second largest producer of steel in the world, structural steel has not been able to gain wide acceptance in comparison to other developed nations. The usage of structural steel is very minimal in India and has been confined only in the construction of industrial buildings. R.C.C. not being an economical option in case of high-rise buildings, engineers should try to explore new aspects and technology in the field of construction. One such aspect is composite construction which extracts the advantages of both the materials effectively and complement each other by overcoming the disadvantages when used individually.This concept exists in Indian Standards (IS: 11384-1985) which needs to be updated as it does not involve the designing of composite columns, thereafter it should be brought into practice.

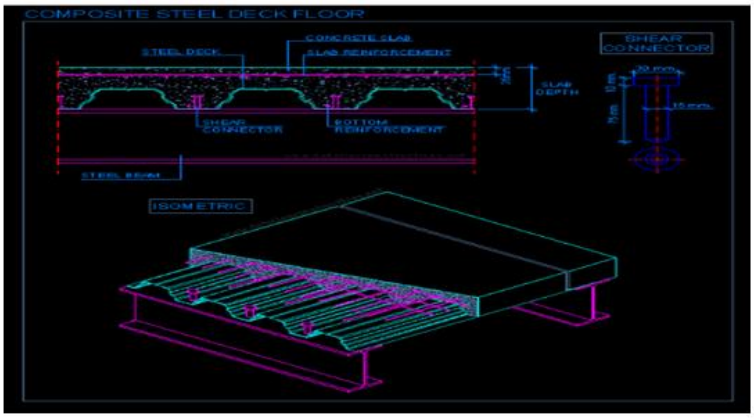

Fig. 1: Typical SC Composite Slab Sections

2. Composite Construction

In composite construction, the structural components of a building are manufactured by using more than one dissimilar materials and are referred as composite elements.The primary advantage of a composite element is that when the two materials are bonded together strongly in order to act as a single entity resulting in fusion of properties of both the material and thus performing better individually, when this occurs it is known as composite action.

3. Steel-Concrete Composite Construction

Concrete and steel which are two completely different material but when combined in R.C.C. act completely accordant and complement each other. Concrete performs well under compression but has lesser resistance against tension and susceptible to creep and shrinkage with time. Steel, however is very robust in tension but susceptible to buckling or instability. Both have almost the similar thermal expansion. Concrete complement steel by providing protection from corrosion and thermal insulation at elevated temperatures.Further, concrete is able toconstrainslender steel components from local and lateral-torsional buckling.

In R.C.C. concrete is complemented by steel in form of rebars. Similarly, Steel-Concrete composite element utilizes compressive strength of concrete along with tensile strength of steel, when merged together results in a lightweight and effectivecomponent.The components adopted in Steel-Concrete Composite constructionare as follows:

3.1 Composite Slab

Composite slab consists of a profiled steel deck with an in-situ reinforced concrete topping. The steel-decking not only behaves as a permanent formwork to the concrete slab but also furnish sufficient shear bond and mechanical interlock between the concrete slab so that, when the concrete hardens, the two materials acts as a single unit and undergo composite action. This is accomplished by the rolled indentations and protrusions in the decking.There are numerous types of profiled steel decking, but mainly re-entrant profile and trapezoidal profile are commonly in trend.

3.2 Composite Column

Composite column is subjected to compression and bending,consisting either a concrete filled tubular section (CFST)or a concrete encased steel section (CES) and is considered as a load-bearing member in a composite framed structure.

In case of CFST columns, the steel section provides the permanent formwork for the concrete portion and are designed to act as a single entity under the composite action. Concrete, being fully encased by the steel section ensuring the concrete to be triaxially restrained and making it less prone to shrinkage. On the other hand, in case of CES columns, concrete encasement provides the steel section from buckling and makes it fire resistant. CES column requires additional reinforcement in form of rebars to prevent spalling of concrete. Composite columns being easy to construct makes it possible to erect high rise buildings in an efficient and time saving manner.

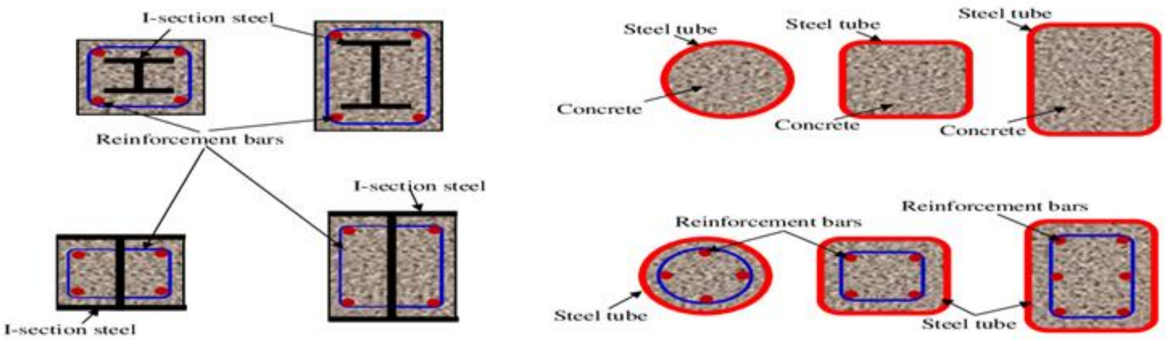

Fig. 2 a) Concrete Encased Steel (CES) Columns; (b) Concrete-filled Steel Tubular (CFST) Columns

3.3 Composite Beams

Composite beam are the beams that behave compositely with the concrete slab. The composite interaction is attained by the attachment of steel beam such as an I-section to the profiled steel decking using shear connector at the top of the flange of the beam.

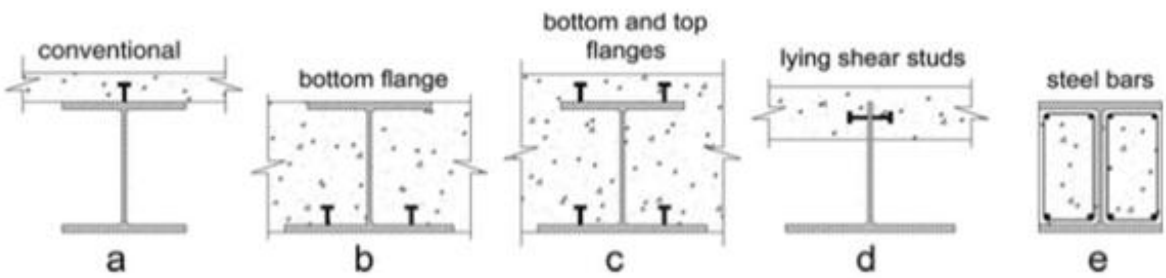

Fig. 3: Typical SC Composite Beam Section

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3.4 Shear Connector

There are various types of shear connectors varying in size, shape and methods of attachment. The general form of connector in case of composite construction is headed studs. The headed studs are steel dowels that are embedded at the flange of the steel beam or profiled steel decking along with the concrete. The studs are designed to transmit the longitudinal shear forces and to resists normal tensile forces and hence provides the required bond at the steel-concrete interface which allows the composite action to take place.

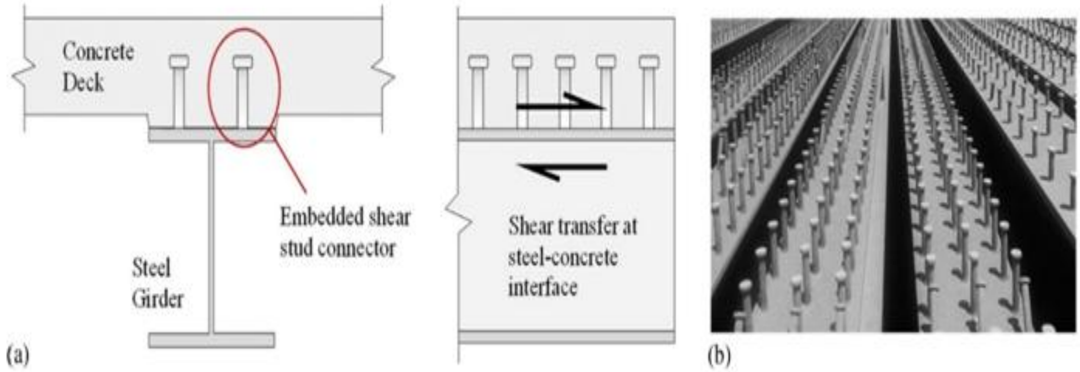

Fig. 4: (a) Mechanism of shear studs for load transfer at the steel–concrete interface; (b) shear studs embedded on plate girder.

4. RESPONSE SPECTRUM ANALYSIS

Response Spectrum is an approximate linear-dynamic statistical analysis method which estimates the contribution from each natural mode of vibration to demonstrate the anticipated seismic response of an essentially elastic structure. Response of multiple nodes is taken into account. There are different methods for obtaining peak response by the combination of responses of different modes, which are as follows:

a. Absolute Sum (ABSSUM) Method
b. Square root of the sum of squares(SRSS)
c. Complete quadratic combination(CQC)

In this study, CQC method is used for the combination of modes and for directional combination SRSS method is used.

5. OBJECTIVE

The objective of this research is to:

a. Compare the seismic behavior in terms of story displacement, story drift, story stiffness, base shear of the following four models:

   Model 1: Reinforced Cement Concrete Structure

   Model 2: Steel Structure

   Model 3: CFST; Composite Structure with concrete-filled steel tubular columns along with composite beams and slab.

   Model 4: CES; Composite Structure with concrete-encased steel columns along with composite beams and slab.

b. Compare the column and beam of the four models on the basis of bending moment, shear force and axial force.

6. METHODOLOGY

The four models of G+20 storied building located in Lucknow; seismic zone III are modelled in ETABS-2019. All the four models are subjected to static and dynamic analysis.The load combinations and the seismic analysis done by Response Spectrum Analysis conform to the provisions of IS: 1893-2016[4]. Other design considerations of R.C.C., Steel and composite structureconform to IS:456-2000[5], IS:800-2007[6], AISC 360-16[7] respectively. The elevation and plan of model are shown in Fig.5, and other relevant data is tabulated in Table 1. The material properties and shown in Table 2. The basic loading on all models of structures are kept same and all the loadings considered are mentioned in Table 3. The section properties of all the models are mentioned in Table 4. Secondary beams are placed in model 2, 3 and 4 for the support of R.C.C. slab.

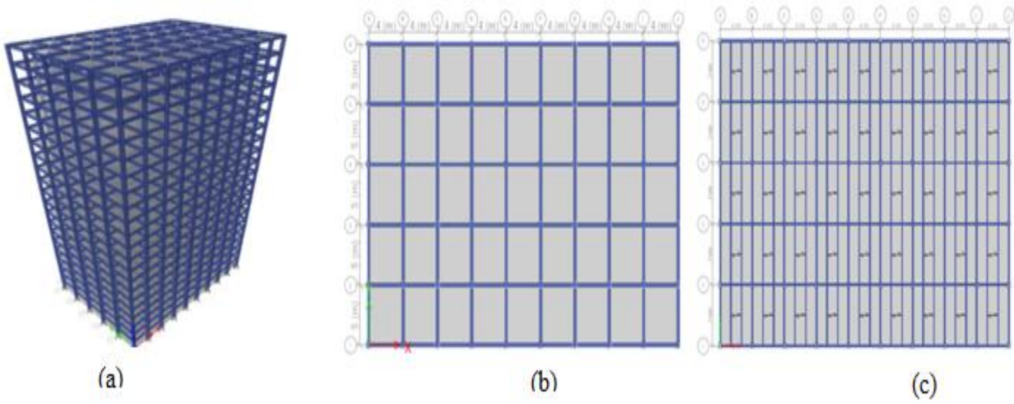

Fig. 5: (a) Elevation Of Model; (b) Plan Of R.C.C. Model; (c) Plan Of Steel, Composite Structure

Table 1: Model Details

PARAMETERS	DIMENSIONS/VALUE
Plan Dimensions	36m x 25m
Spacing Of Bays in X-direction	4
Spacing Of Bays in Y-direction	5
No. of Stories	G+20
Story Height	3m
Thickness Of wall	230 mm
Height Of parapet wall	1 m

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Table 2: Material Properties

PROPERTIES		R.C.C.	STEEL	CFST	CES
Grade of concrete		M25	M25	M25	M25
Compressive Strength Of Concrete		25N/mm^2	25N/mm^2	25N/mm^2	25N/mm^2
Grade of steel	Reinforcement	HYSD Fe500	HYSD Fe500	HYSD Fe500	HYSD Fe500
	Steel Section	—	Fe 250	Fe 250	Fe 250
Modulus of Elasticity for R.C.C		$5000(f_{ck})^{1/2}$ = 25000 N/mm^2			
Modulus of Elasticity for Steel		2.1 x 10^5 N/mm^2			
Brick Wall Density[8]		20 KN/m^3			

Table 3: Load Considerations

LOAD		CALCULATIONS		
Dead load		Self weight		
Live load on floors	Typical Floors[9]	4 KN/m^2		
	Terrace[9]	1.5 KN/m^2		
Floor finish load	Typical Floors	1 KN/m^2		
	Terrace	1.5 KN/m^2		
Load of walls on floor beams		20 x 0.25 x (3-0.4)= 13 KN/m		
Load of parapet wall on terrace beams		20 x 0.25 x 1= 5KN/m		
Seismic Parameters: As per IS 1893:2016[4]		Seismic zone		III
		Zone factor		0.16
		Response Reduction Factor		5
		Importance factor		1.2
		Damping ratio		0.05
		Fundamental natural time period	RC framed building	$0.075h^{0.75}$
			Composite framed building	$0.08h^{0.75}$
			Steel framed building	$0.085h^{0.75}$

Table 4: Section Properties

PARAMETERS	MODEL-1 R.C.C.	MODEL-2 STEEL	MODEL-3 CFST	MODEL-4 CES
Size of primary beams	230mm x 400 mm	ISMB 350	ISMB 500 at periphery ISMB 300 inner beams	ISMB 500 at periphery ISMB 300
Size of secondary beams	—	ISLB 200	ISLB 200	ISLB 200
Size of columns	500mm x 500mm	W14x211	350mm x 350 mm steel tube with thickness of 18mm	550mm x 550 mm concrete section embedded with I section of ISHB 450
Thickness of slab	125 mm Slab	110mm Solid deck	110mm Filled deck	110mm Filled deck

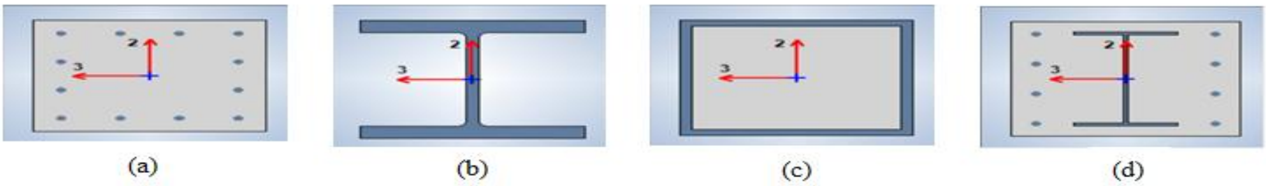

Fig. 6: Column section properties: (a) R.C.C.; (b) Steel; (c) CFST; (d) CES

7. RESULTS

After the analysis of all the four models is performed, results are extracted from ETABS-2019 to present a comparative study. The parameters considered for comparison are story displacement, story drift, story stiffness, natural period, base shear, maximum shear force, axial force and maximum bending moment and story shear is considered and their variation in the form of graph is shown.

7.1 STORY DISPLACEMENT

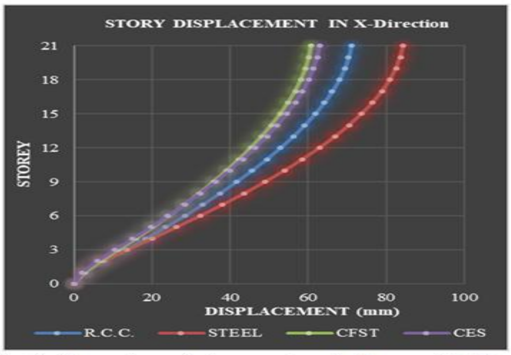

Fig. 7: Comparison of story vs story displacement in X-direction

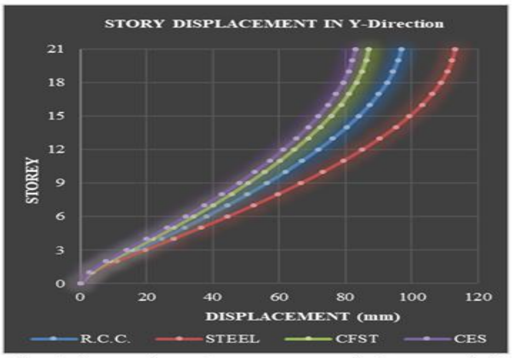

Fig. 8: Comparison of story vs story displacement inY-direction

7.2 STORY DRIFT

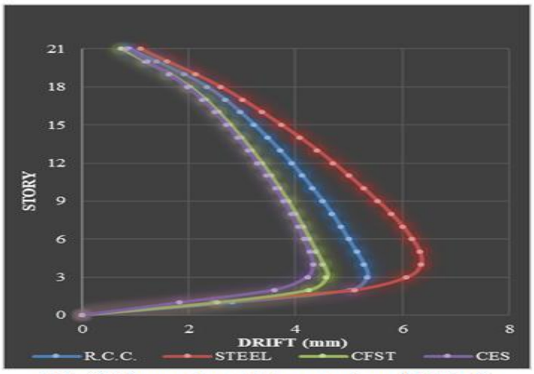

Fig. 9: Comparison of story vs story drift in X-direction

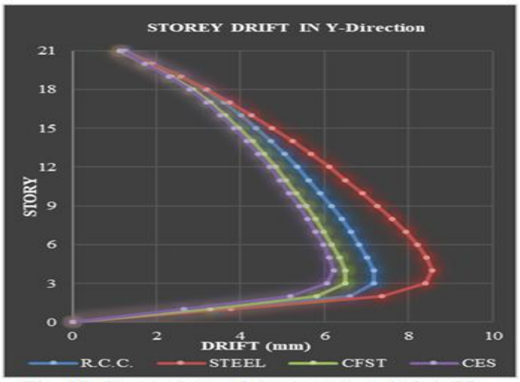

Fig. 10: Comparison of story vs story drift in Y-direction

7.3 STORY STIFFNESS

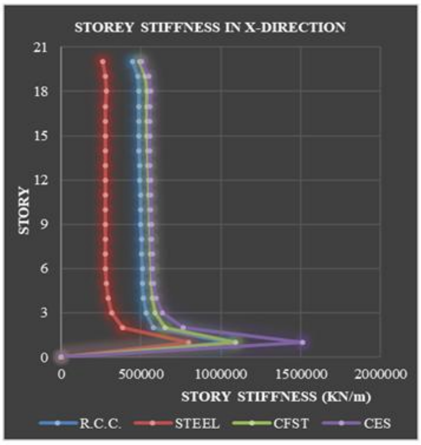

Fig. 11: Comparison of story vs story stiffness in X-Direction

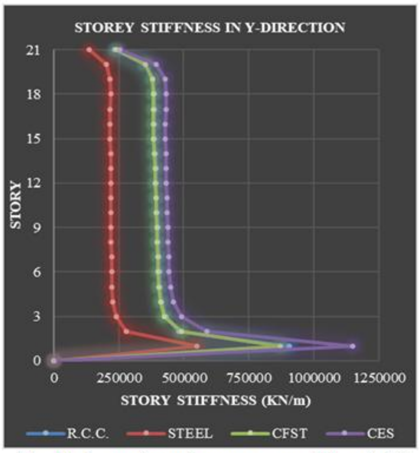

Fig. 12: Comparison of story vs story stiffness in Y-Direction

7.4 TIME PERIOD

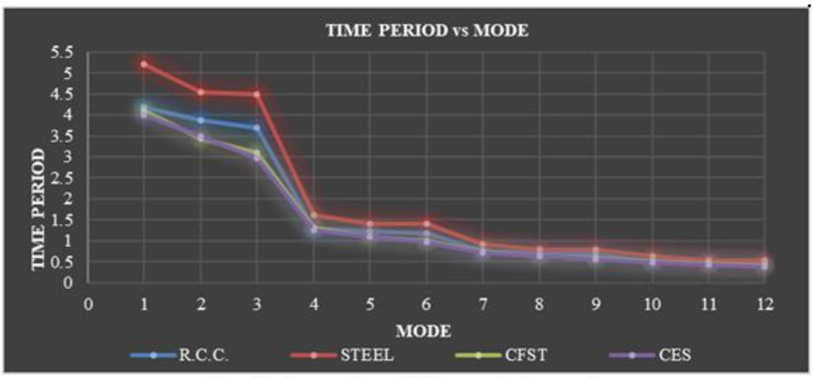

Fig. 13: Comparison Of time period vs mode

7.5 TOTAL WEIGHT OF THE STRUCTURE

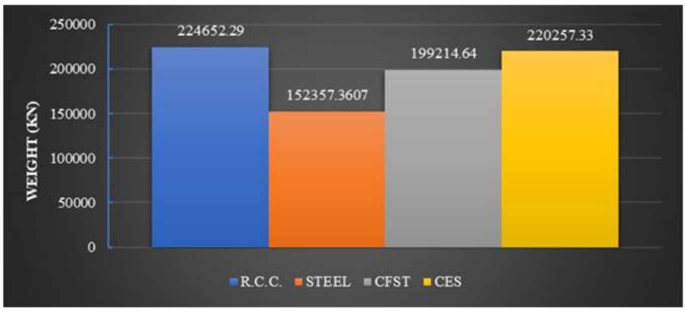

Fig.14: Comparison of total weight of the structure

7.6 BASE SHEAR

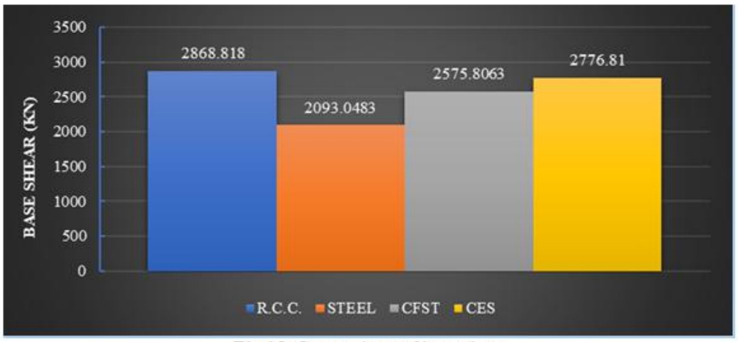

Fig.15: Comparison of base shear

7.7 STOREY SHEAR

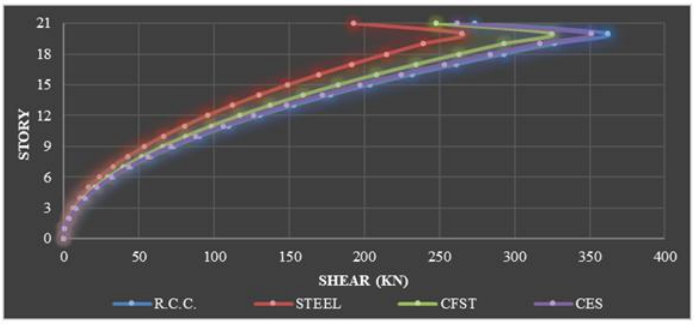

Fig. 16: Comparison of lateral force vs story

7.8 MAXIMUM SHEAR FORCE IN BEAM AND COLUMN

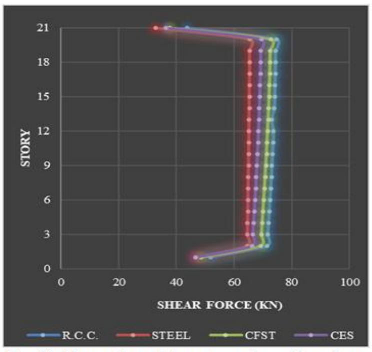

Fig. 17: Comparison of story vs maximum shear force in beam B11

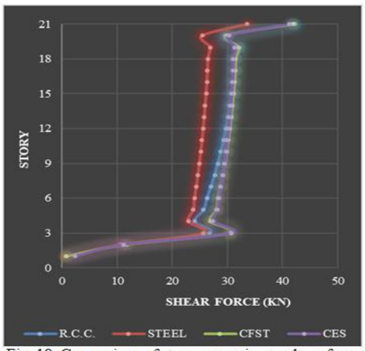

Fig. 18: Comparison of story vs maximum shear force in column C2

7.9 MAXIMUM BENDING MOMENT IN BEAM AND COLUMN

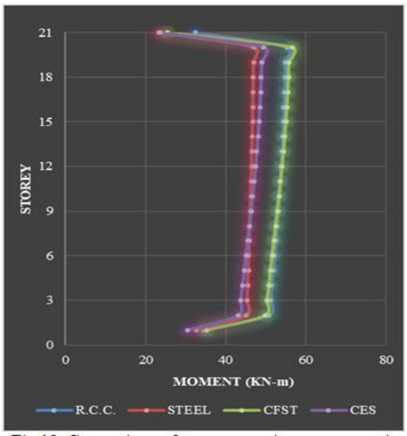

Fig.19: Comparison of story vs maximum moment in beam B11

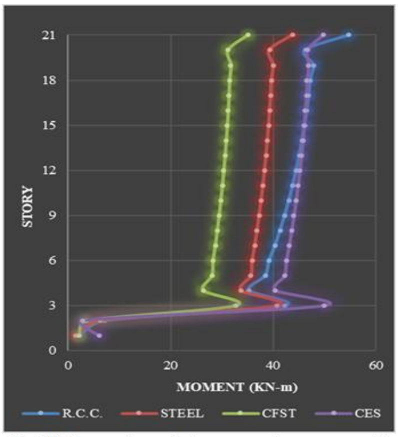

Fig. 20: Comparison of story vs maximum moment in column C2

8. DISCUSSIONS

i. DISPLACEMENT: As the amount of steel increases ductility of the building increases and hence the displacement increases when subjected to lateral forces. Therefore highest displacement exists in steel structure and the lowest in composite structures

- From Fig.6, for composite structures (CFST and CES), displacement in X-direction is reduced by 13-15% and 24-26% when compared to R.C.C. andsteel respectively.
- From Fig.7, for composite structures (CFST and CES) displacement in Y-direction is reduced by 9-16% and 22-28% when compared to R.C.C. and steel structure.

ii. DRIFT: As the displacement is least in composite structures, drift is also least in composite structure

- From Fig.8, for composite structures (CFST and CES), drift in X-direction is reduced by 14-18% and 25-29% when compared to R.C.C. and steel respectively.
- From Fig.9, for composite structures (CFST and CES) drift in Y-direction is reduced by 9-14% and 18- 22% when compared to R.C.C. and steel structure.

iii. STIFFNESS: Steel provides ductility and flexibility to the structure and concrete imparts stiffness. Therefore stiffness in steel is least and for composite structures.

- From Fig.10, for composite structures (CFST and CES), stiffness in X-direction is increased by 9-14% and 47-50% when compared to R.C.C. and steel respectively.
- From Fig.11, for CFST structure maximum stiffness in Y-direction is reduced by 3% and in CES structure increased by 8% when compared to R.C.C. and increased by 43-50% when compared to steel structure.

iv. TIME PERIOD: Greater the natural time period of building, more is flexibility of the building to oscillate back and forth when lateral forces act on the building. From Fig.12, time period of composite structures is reduced by 8-12% and 22-26% when compared to R.C.C. and steel structure.

v. TOTAL WEIGHT OF THE STRUCTURE: The weight is reduced by 11.32% and 2% for CFST and CES respectively when compared to RCC structure whereas on comparing with steel weight gets increased by 23.52% and 30.82% in case of CFST and CES respectively

vi. BASE SHEAR: Base shear of steel structure is lowest, as the amount of concrete is minimal thus decreasing the weight of the structure. In case of composite structures base shear is 10% and 3% less than R.C.C. structure for CFST structure and CES structure respectively.

vii. STORY SHEAR: The distribution of lateral force at different story is compared and story shear is reduced at an average of 11% and 18% for CFST structure and 3% and 24% for CES structure when compared to R.C.C. and steel respectively.

viii. SHEAR FORCE

- In beams, maximum shear force is reduced by 3% in CFST and by 7% in CES when compared to R.C.C.
- In columns, maximum value of shear force in column C2 in X-direction is decreased by 1% in CFST and by 2% in CES when compared to R.C.C. and gets increased by 31% in CFST and 35% in CES when compared to steel.

ix. BENDING MOMENT

- In beams, maximum value of shear force in CFST is increased by 2% and decreased by 13% in CES when compared to R.C.C.
- In column C2, maximum value of bending moment in X-direction in case of CFST is reduced by 31% and 9% in case of CES when compared to RCC.

9. CONCLUSION

The results extracted from ETABS-2019 and compared, it can be inferred that Steel-Concrete composite construction can be a better option because with the increase in amount of structural steel in the structure, the structure is able to attain sufficient ductility, flexibility which is required to resist lateral forces efficiently. Also the composite structure is stiff enough to provide the stability that is needed in the case of high-rise building. Further, this study also shows that even though for bending moment and shear force reduction percentage is on lower side but still there is reduction which could result in decreasing the construction cost. Further, the weight of the composite structure has reduced which is the main concern in case of R.C.C. when the stories get increased. With the reduction in total weight of the structure when compared to R.C.C., not only the foundation cost gets reduced but also lesser amount of lateral forces are induced by an earthquake (base shear). In case of comparison with steel structures the result of composite structure are not on the good side but as in G+20 story structure an American section is used for the building to be safe in all load combinations, so there are issues regarding the availability of section in India if pure steel construction is to be considered.

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