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SEISMIC BEHAVIOUR OF CFST AND CES COLUMNS IN STEEL-CONCRETE COMPOSITE STRUCTURE USING ETABS

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Abstract*:*

Now days populations is increasing at a great pace and rates of land are getting higher in urban areas, this generates an urge for high-rise buildings, tall structures, towers and blocks which will assist in utilizing the land effectively. When the structure starts attaining stories, use of RCC in building increases the size of the members along with dead load of the structure. This paves the way for an innovative and effective construction technique that is Steel-Concrete Composite Construction. It consists of composite members which involves the bonding of concrete and steel in such a manner that they act integrally as a single unit. It is the behaviour of this bond between the concrete and steel that makes this construction peculiar. The composite structure includes composite beams, composite columns and composite slab as the composite members. This study aims in comparing the seismic behaviour of composite columns i.e. one model with concrete-filled steel tubular(CFST) columns in which concrete is filled inside the hollowed steel sections and the other with concrete encased steel(CES) column sections in which structural steel i.e. I-Section is fully encased with concrete along with other composite members. Two models of G+20 story building situated in Lucknow (earthquake zone-3) are considered for seismic analysis. Equivalent Static Method conforming to IS: 1893:2016, is performed using ETABS-2019 software. The two models are compared on the basis of seismic parameters such as story displacement, story drift, story stiffness, base shear, weight of the structure, story shear and time period. Results are compared by plotting graphs, which concluded that for a particular loading the size of CFST columns was much lesser than CES columns and the results did not have much variations. If economy is to be considered then CFST can be preferred over CES columns.

Keywords— CES Columns, CFST Columns, Equivalent Static Method, ETABS, Seismic Analysis.

1. Introduction

Steel-Concrete (SC) composite construction has gained worldwide acceptance because of its excellent seismic performance over conventional concrete. In China, all of the high-rise buildings that rise more than 300 m in China are of a steel-concrete composite structure [1]. The primary advantage of a composite element is that when the two materials are bonded together strongly in order to act as a single unit resulting in combining the properties of both the material and thus performing better individually, when this occurs it is known as composite action. In steel-concrete composite members, steel elements will be susceptible to local and lateral buckling and on the other hand concrete is prone to tensile forces, creep and shrinkage. However, when the proper bonding of steel and concrete element is fully attained, and the composite action occurs, these disadvantages will be put to rest which is discussed in the next section. Also thermal expansion (coefficient of thermal expansion) of both, concrete and steel being nearly the same [2]. Therefore, there is no induction of different thermal stresses in the section under variation of temperature [2]. SC composite construction is more beneficial in resisting seismic forces and it costs less, allows speed in construction and also provides good fire protection [3]. It is also believed to have more load carrying capacity than any conventional concrete [4].

SC composite structure involves composite members such as composite beams, composite columns, composite slab and shear connector. SC composite beam is a steel beam on which the RCC slab or slab with profiled sheet decking or precast RCC slab rests and is connected by using shear connectors as shown in Fig.1. SC composite column is a compression member in which the steel element is a structural steel section. There are mainly two types of composite columns used in practice which are Concrete Encased, Concrete filled as shown in Fig.3, 4. These are discussed in detail in the next section. SC composite slab is composed of profiled deck sheeting which acts as formwork for pouring concrete slab as shown in Fig.3.

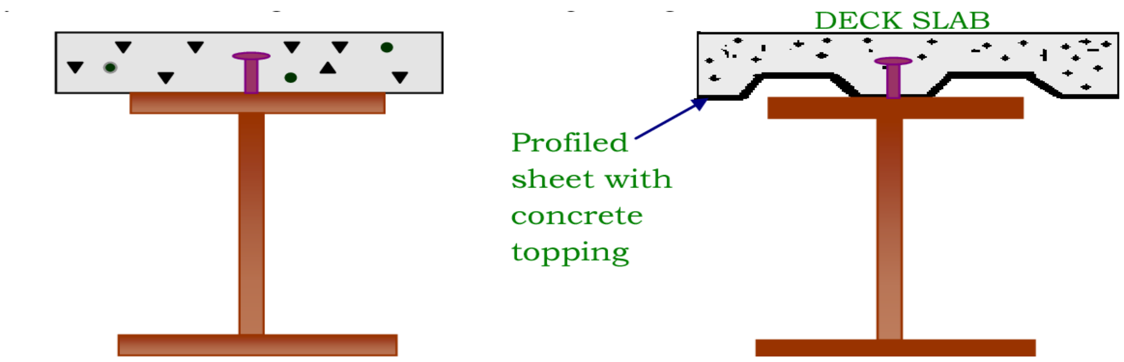

Fig. 1 Composite beam

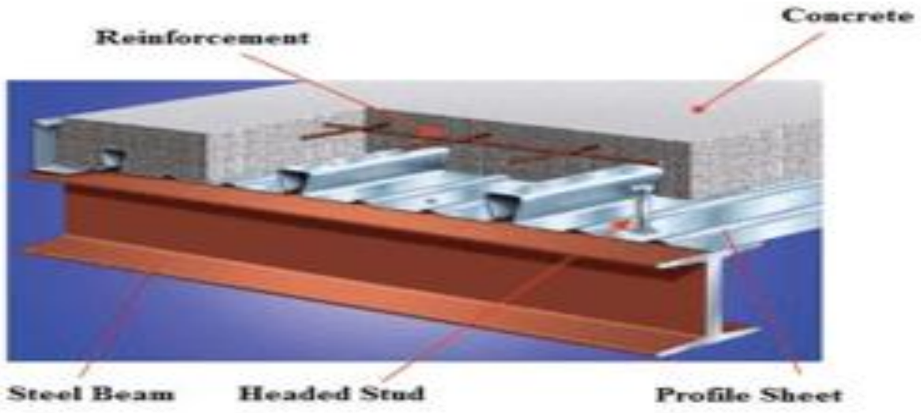

Fig. 2 Composite slab

2. Composite Columns

Composite columns are assembled using various combination reinforced concrete and structural steel in order to effectively utilize beneficial properties of both the material. The bare steel sections support the initial construction loads, including the weight of structure during construction. Concrete is later cast around the steel section, or filled inside the tubular sections. In a composite column both the steel and concrete would resist the external loading by interacting together by bond and friction. Nowadays, composite columns are being used in high rise building and bridge piers due to the fact that for these structure traditional concrete will provide bulky sections due to increased size. With the use of composite columns along with composite decking and composite beams it is possible to erect high rise structures in an extremely efficient manner. The lighter weight and higher strength of steel permit the use of smaller and lighter foundations. The subsequent concrete addition enables the building frame to easily limit the sway and lateral deflections. The major types of composite columns which are commonly in practice are as follows:

a. Concrete-filled Steel Tubular (CFST) Columns

CFST columns are those in which a hollow steel tube is filled with concrete as shown in Fig. 3. Concrete-filled steel tubular columns have been used for earthquake-resistant structures, bridge piers subject to impact from traffic, columns to support storage tanks, decks of railways, columns in high-rise buildings and as piles [5].This is due to the fact that the CFST columns possess high load bearing capacity both axially and laterally. In CFST columns, the concrete adds strength and stiffness, whereas the steel tube provides the confinement. Concrete, due to this confinement is triaxially restrained and is less vulnerable to shrinkage and acts integrally with steel gaining higher compressive strength. Further, steel is now restrained to buckling away from concrete, so less prone to buckling. A further advantage is, steel tube acting as a permanent formwork for casting of concrete which will reduce the cost of shuttering.

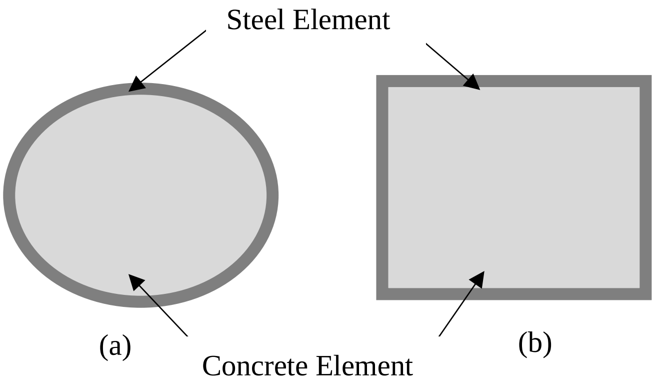

Fig. 3: Concrete filled steel tubular (CFST) column (a) Circular CFST column (b) square CFST column

b. Concrete Encased Steel Columns

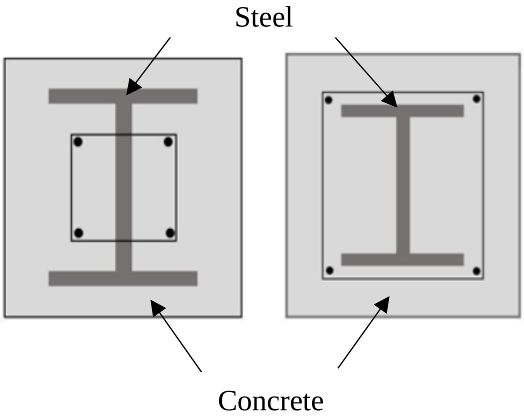

Fig. 4 Concrete encased steel columns

Concrete-encased steel structures are the ones which consist of different sections of steels generally I-sections encased in concrete as shown in Fig. 4. Even these columns are used widely in the construction of medium to high rise buildings. Under severe flexural overload, concrete encasement cracks resulting in reduction of stiffness but the steel core provides shear capacity and ductile resistance to subsequent cycles of overload [5]. In CES columns, the steel section is restrained from the concrete encasement and thus the local buckling of steel section is removed. Supplementary reinforcement in the concrete encasement prevents excessive spalling of concrete both under normal load and fire conditions.

3. Equivalent Static Method

The equivalent static lateral force method is a simplified technique to substitute the effect of dynamic loading of an expected earthquake by a static force distributed laterally on a structure for design purposes.. It is restricted to single mode of vibration. The total applied seismic force *V* is generally evaluated in two horizontal directions parallel to the main axes of the building. According to IS 1893:2016 [6], clause 7.6.1, the design base shear V_B along any principal direction of a building shall be determined by (1):

$$V_B = A_h W \tag{1}$$

Where,

A_h = design horizontal acceleration coefficient (2) value using fundamental time period along the considered direction of shaking as per clause 6.4.2 [7]

W = seismic weight of the building as per clause 7.4 [7]

4. Objective

The objective of this research is to:

a. Compare the seismic behaviour of Model 1 and Model 2 in terms of story displacement, story drift, story stiffness, time period, base shear, total weight of the structure, and story shear of the following two models:
   - Model 1: CFST; Composite Structure with concrete-filled steel tubular columns along with composite beams and slab.
   - Model 2: CES; Composite Structure with concrete-encased steel columns along with composite beams and slab.

5. Methodology

The two models are of G+20 storied building located in Lucknow; seismic zone III are modelled in ETABS-2019. The load combinations and the seismic analysis done by Equivalent Static Method conforming to the provisions of IS: 1893-2016 [6]. Other design considerations of composite structure conform to 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 are considered are mentioned in Table 3. The section properties of all the models are mentioned in Table 4. Secondary beams are placed in both the model for the support of R.C.C. slab.

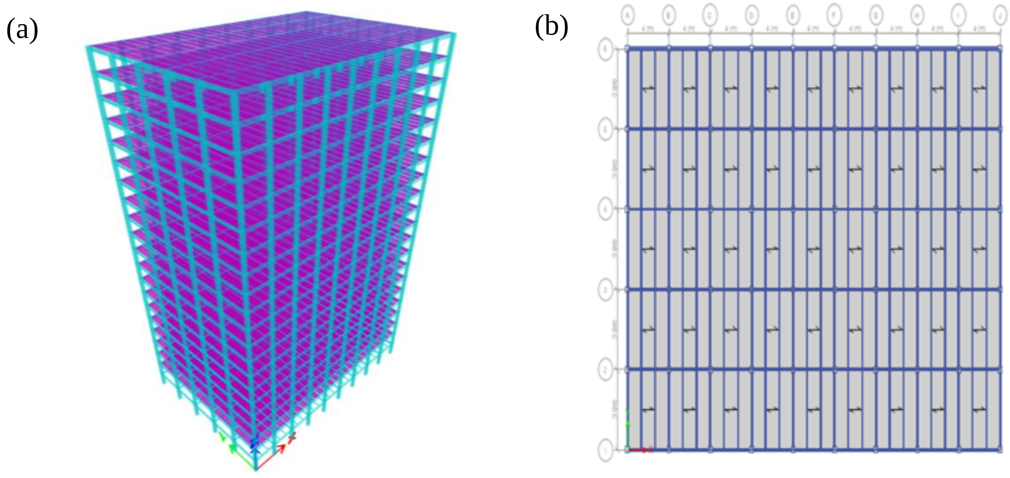

Fig. 5 (a) 3-D elevation (b) Plan

Table 1 Model Details

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

Table 2 Material Properties

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

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[6]		Seismic zone	III
		Zone factor	0.16
		Response Reduction Factor	5
		Importance factor	1.2
		Damping ratio	0.05
		Fundamental natural time period: Composite framed building	0.08h$^{0.75}$

Table 4 Section Properties

PARAMETERS	MODEL-1 CFST	MODEL-2 CES
Size of primary beams	ISMB 500 at periphery ISMB 300	ISMB 500 at periphery ISMB 300
Size of secondary beams	ISLB 200	ISLB 200
Size of columns	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	110mm Filled deck	110mm Filled deck

6. Results & Discussions

After the analysis of all the two 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, and story shear is considered and their variation in the form of graph is plotted.

6.1 Story Displacement

On comparing the results of CFST model and CES model for story displacement in X-direction, it was concluded that story displacement in X-direction for CFST model has decreased by an average of 4.17%.

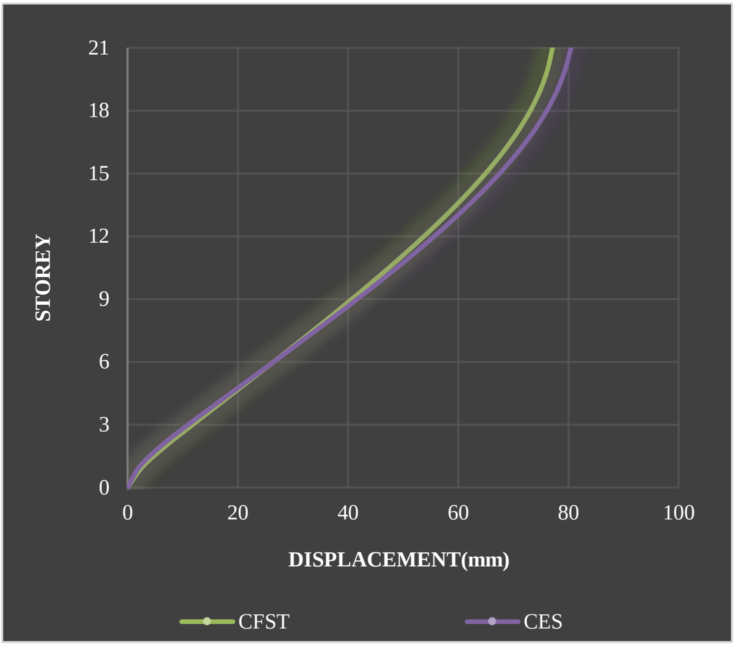

Fig. 6 Comparison of story vs story displacement in X-direction

On comparing the results of CFST model and CES model for story displacement in Y-direction, it was concluded that displacement in Y-direction for CES model has decreased by an average of 3.9%

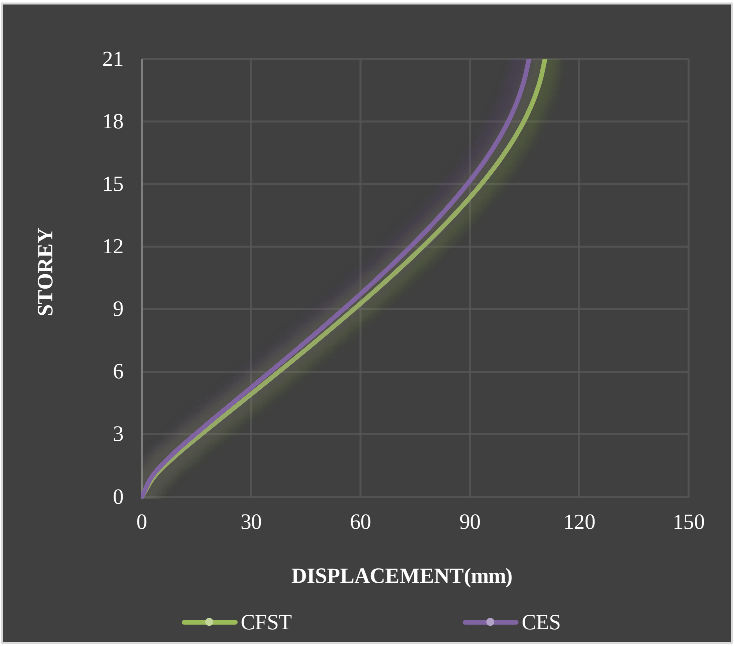

Fig. 7 Comparison of story vs story displacement in Y-direction

6.2 Story Drift

On comparing the results of CFST model and CES model for story drift in X-direction, it was concluded that drift in X-direction for CES model is reduced by an average of 10.67%.

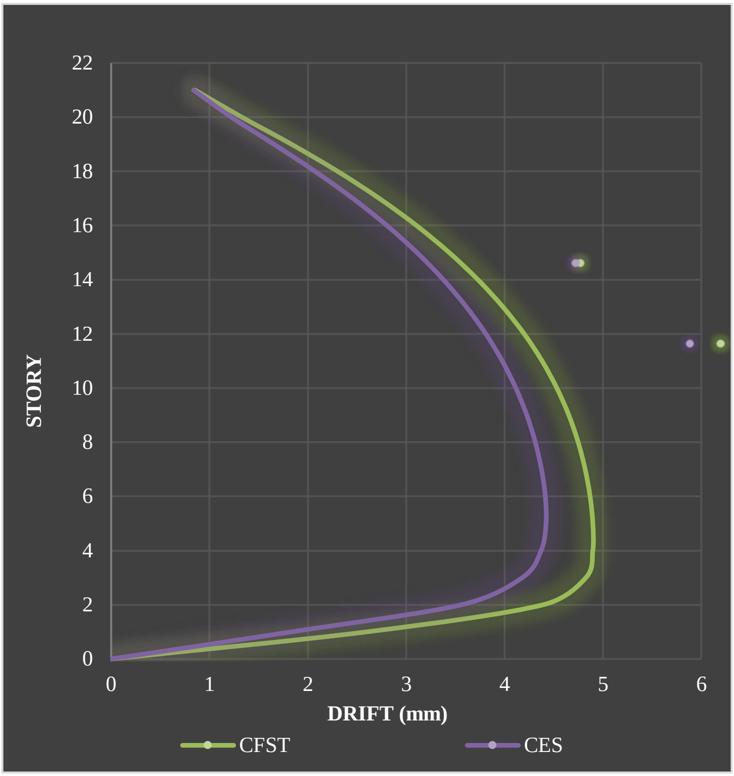

Fig. 8 Comparison of story vs story drift in X-direction

On comparing the results of CFST model and CES model for story drift in Y-direction, it was concluded that drift in Y-direction for CES model has decreased by an average of 4.18%.

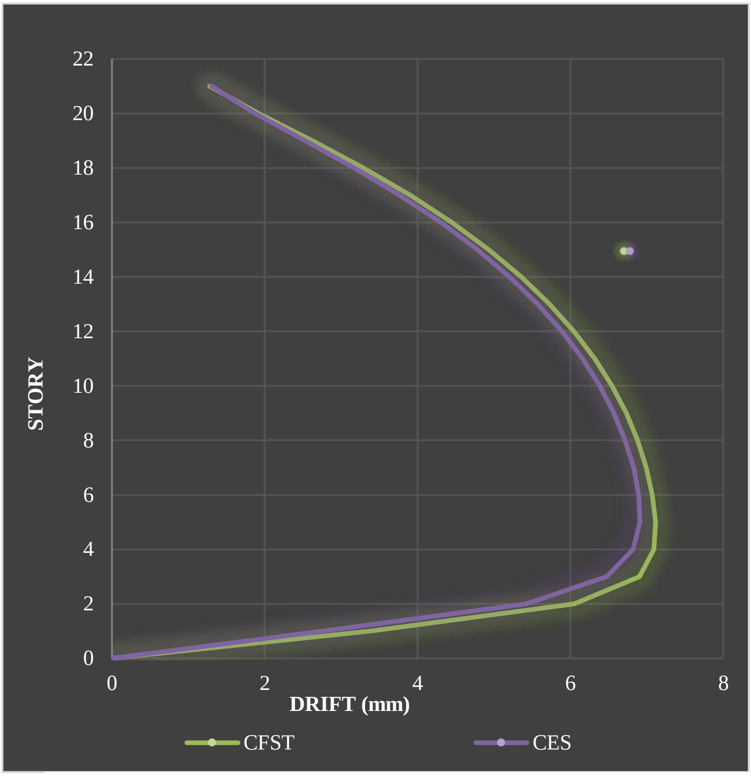

Fig. 9 Comparison of story vs story drift in Y-direction

6.3 Story Stiffness

On comparing the results of CFST model and CES model for story stiffness in X-direction, it was concluded that stiffness for CES model has increased by an average of 20.13%.

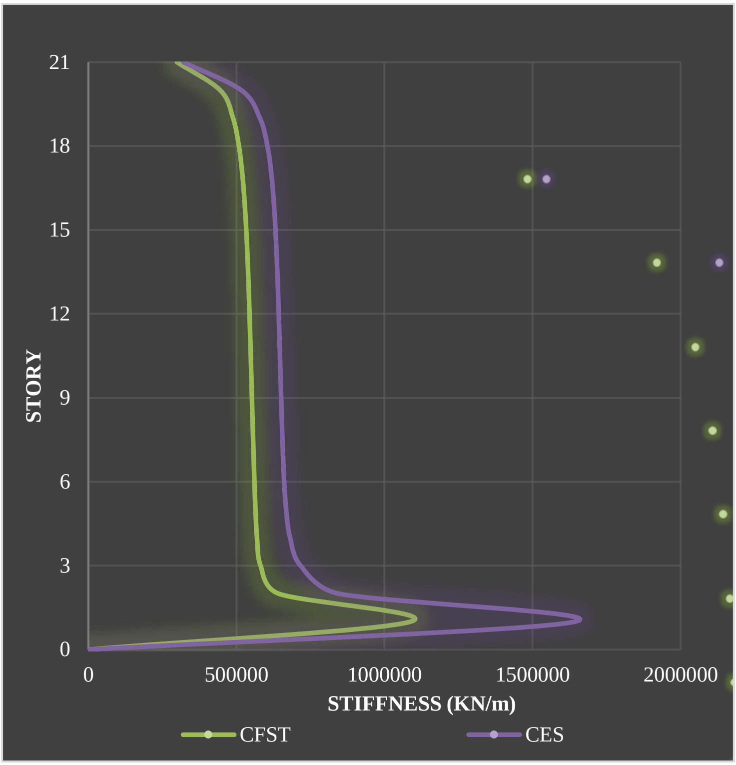

Fig. 10 Comparison of story vs story stiffness in X-direction

On comparing the results of CFST model and CES model for story stiffness in Y-direction, it was concluded that stiffness has increased for CES model by an average of 11.81%.

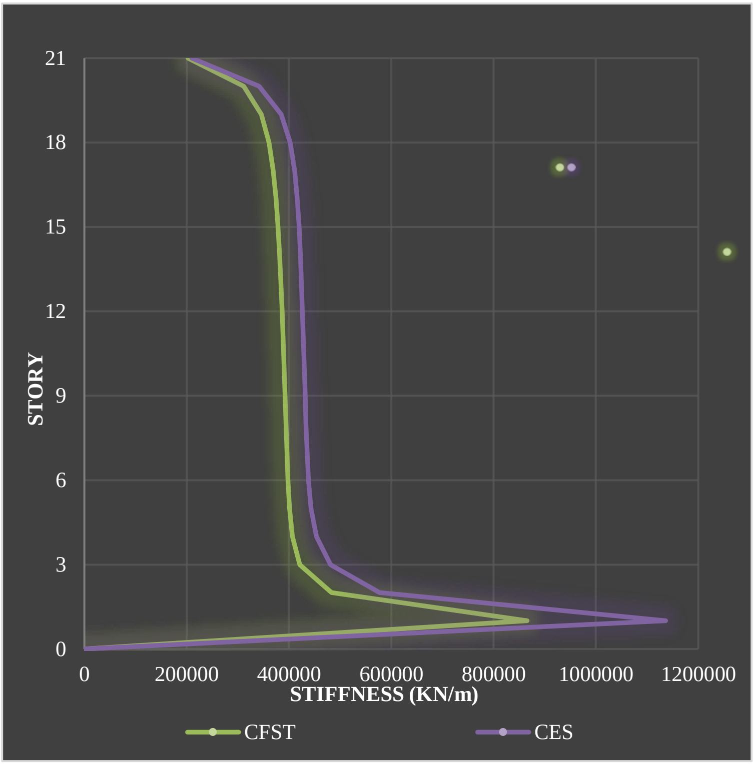

Fig. 11 Comparison of story vs story stiffness in Y-direction

6.4 Total Weight of The Structure

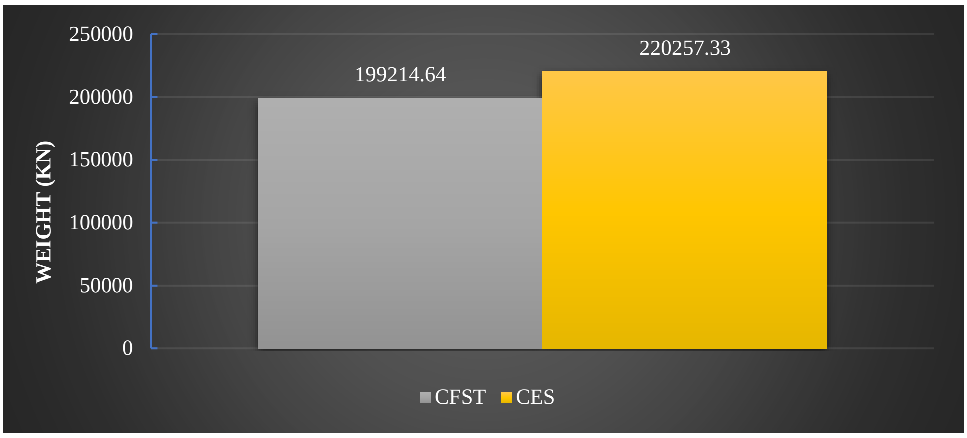

Fig. 1 Comparison of total weight of the structure

On comparing the results of CFST model and CES model total weight of the structure, it was concluded that total weight of the structure of CFST model is reduced by an average of 9.55%.

6.5 Base Shear

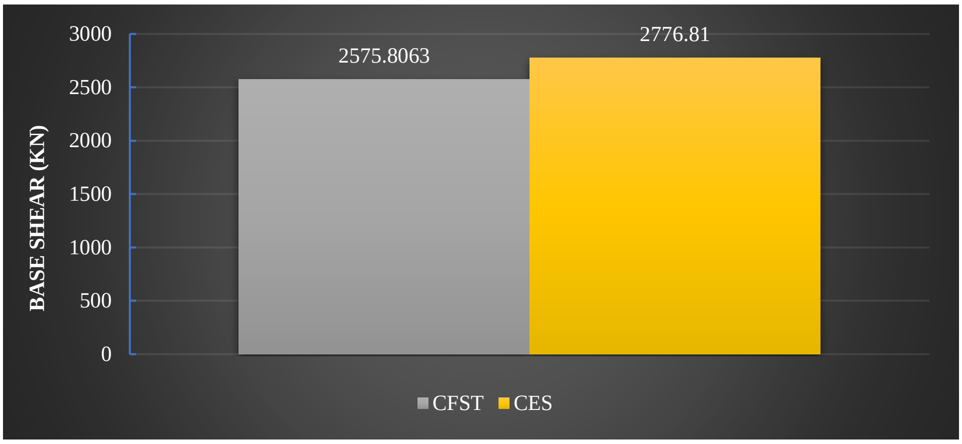

Fig. 23 Comparison of base shear

On comparing the results of CFST model and CES model base shear induced on the structure, it was concluded that base shear of CFST model is reduced by an average of 7.23%.

6.6 Story Shear

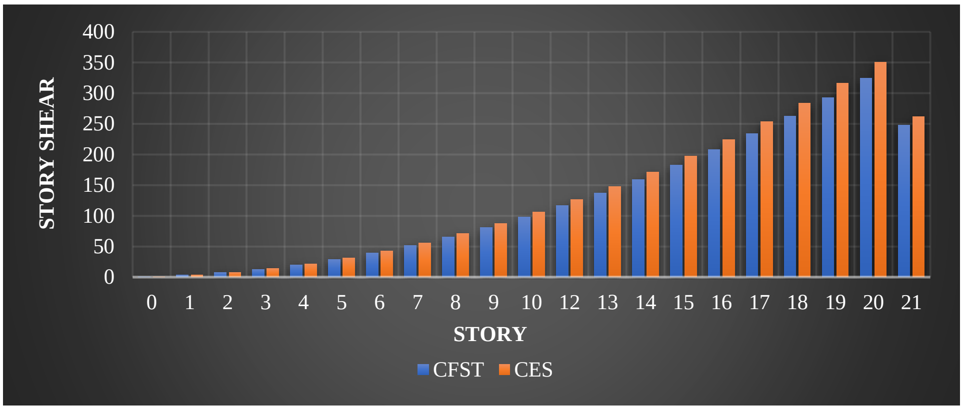

Fig. 34 Comparison of story vs story shear

On comparing the result of Fig. 12, it was concluded that the story shear in CFST model reduces by an average of 7.9%

6.7 Time Period

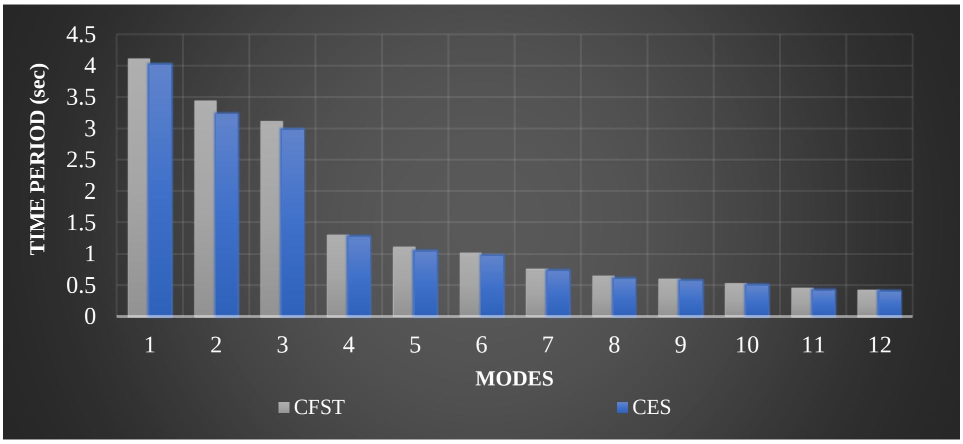

Fig. 45 Comparison of time period vs modes

On comparing the results of time period, it was concluded that the time period of CES model is reduced by an average of 5.51%

7. Conclusion

From the results it is concluded that displacement in X direction for CFST model is higher and in Y-direction it is lesser than CFST columns this abrupt variation is due to the orientation of the CES column. As the displacement of CES is lesser, therefore the story drift in CFST columns is more than the CES columns. Story stiffness in both X & Y direction shows a huge increment in case of CFST columns, this is because the equivalent area of CES column is greater than CFST columns due to which amount of concrete is more in CES columns. For this basic loading, when the equivalent area of CES columns was taken same as that of CFST model then the bottom columns failed due to excessive beam to column capacity ratio. Therefore, for CES column increased section was considered which had higher equivalent area in comparison to CES column. Due to this reason the weight of the structure along with base shear has increased, as base shear depend on weight of the structure. Since the base shear is more CES model therefore the distribution of base shear on each floor i.e. story shear is greater in CES model. The time period in CES model is less than that of CFST model, which implies that it is more flexible to oscillate back and forth when lateral forces act on the building. Overall, CES in spite of lesser cross section of CFST, the behavior of CFST columns is appreciable over CES columns. If economy is to be considered then, CFST can be preferred over CES columns, as it is able to gain sufficient stiffness of concrete and ductility of steel which is required to resist the lateral forces effectively.

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