International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Comparative Study of Multi Storied Building with Different Sections of Conventional RC Columns and CFST Columns Under Seismic Effect

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ABSTRACT—

In this study, an attempt has been made to check the feasibility of Concrete-Filled Steel Tube column in terms of both performance and cost. Due to the expansion of cities and increase in population, the need for construction of high rise buildings becomes more essential in the society. As earthquakes are of the greatest damaging natural hazards to the buildings, the design and construction of structures which are capable of resisting the adverse effects of earthquakes become necessary. The concrete-filled steel tube (CFST) is a unique steel-concrete composite construction that consists of outer steel layer with a concrete layer filled inside it. The inner hollow steel section serves as formwork and concrete reinforcement. Concrete prevents local buckling in hollow steel sections, increasing the section's ductility. CFST has a number of benefits, including high strength, bending stiffness, and earthquake and fire resistance. In this study, a building assumed at Bhuj city was selected as the study frame and RCC column of that frame was taken as economical for given loadings. All the columns of this study frame were then replaced by equivalent steel columns and then by CFST columns, based on FE analysis results after analysing the sections in Etabs software. Performance evaluation of all the frames then carried out and compared. From that we can say that the forces which were present in the RCC section or Steel Section were reduced by significant amount which says that CFST column's performance is better than both RCC and Steel columns under dynamic loadings with that we can say that CFST column can be used as an improvement over RCC or Steel column section.

Keywords: RCC Column, Composite Columns, Concrete-filled steel tubes (CFST), RC Encased Column, Comparative Study, Finite element analysis.

1.1 Introduction -

Conventional RCC members like beams and columns are widely used for the construction. For increased load carrying capacity the use of composite columns is introduced. it combines the advantages of both steel and concrete. Steel-concrete composite columns have been widely used in modern construction industry owing to their high performance in terms of ductility, strength, energy absorption capacity as well as good constructability in comparison with reinforced concrete columns. In a concrete-filled steel tubular (CFST) column, concrete prevents the steel tube from the inward local-buckling and the steel tube acts as the permanent formwork for the concrete so that the construction cost and time can be greatly minimized.

1.2 Concrete-filled steel tubes (CFST)

Concrete-filled steel tubes (CFST) are composite structures of steel tube and in-filled concrete. Concrete filled steel tubular member uses the advantages of both steel and concrete. They comprise of two main parts, an outer steel hollow section of circular or rectangular shape and an inner filler material of plain or reinforced concrete. A CFST member consisting of a steel tube which is filled with concrete material realizes the importance of steel reinforcement to provide confinement for the concrete and to increase the load-carrying capacity of the composite member. From the structural point of view, the inner concrete material not only prevents the occurrence of inward buckling of the outer steel tube but also enhances the ductility of the CFST member up to the ultimate load. CFST member performs under composite action, i.e. both the steel and concrete will resist the external loading by interacting together by bond and friction action. In a CFST member, concrete and steel are combined together in such a fashion that the advantages from both the materials should be effectively utilized.

Advantages of concrete filled steel tubular columns are as follows:

- Due to presence of steel tube on periphery, CFST column deforms in a ductile manner and provides high resistance against lateral cyclic loading. This high ductility of CFST columns gives high strength against seismic loading.
- CFST columns have good ability to absorb energy released due to seismic forces.

- Smaller section sizes of CFST columns are required as compared to conventional RCC columns under equivalent load conditions, therefore there is considerable reduction in self-weight of structure and results in less structural and construction cost.
- Faster construction by utilizing prefabricated components helps in speedy construction and gives quicker return of the invested capital.

One of the few drawbacks of Concrete filled steel tubular members is that they get deteriorated due to the environmental effects like corrosion and ageing. The external strengthening by using fibre reinforced polymer (FRP) materials emerging as a new trend in enhancing the structural performance of CFST members to counteract the drawbacks in the past rehabilitation work. Recent years, FRP is becoming a popular material for rehabilitation due to its superior material properties like corrosion and weather resistance, high mechanical strength, less weight, ease of handling, good fatigue resistance and ductility.

CFSTs are of different shapes, mainly circular CFST, square CFST, and rectangular CFST as shown in figure below –

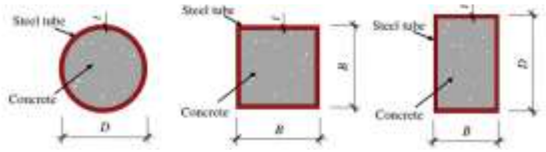


Fig. - CFST columns of different shapes

[Source: https://images.app.goo.gl/gcu6ucjcCrb18EJc7]

Stress-strain properties

Confinement of in filled concrete is the main advantage of CFST sections. Fig.3 shows the stress-strain behaviour of confined concrete. The reinforcing steel is assumed to be elastic until the yield strain y and perfectly plastic for strains between y and the hardening strain or until the limit strain Sv, represented by tri-linear relationship. However, bi-linear stress-strain relationship is still being used, and simply expressed as

fs = Es s for s ≤ y

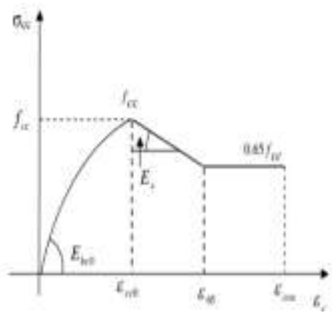
fy=fy, if s > y

fs - Stress in reinforcing steel at any level y due to s

Es - Modulus of elasticity of reinforcing steel.

Relationship between stress and strain depends on basic material composition, initial conditions, state of strain, direction of strain, history of strain, time since initial strain, temperature, cyclic strain and rate of strain change.

STRESS



STRAIN

Fig. Stress-strain behaviour of confined concrete [Y. Bouafia et. al.(2018)]

Where,

Es – Slope of the descending curve

ε_{65} – Strain corresponding to the stress equal to 0.65fcc

σ_{cc} – Confined concrete stress

f_{cc} – Compressive strength of unconfined concrete

E_{bc0} – Initial confined concrete Young modulus

ε_{cc0} – Confined concrete strain compounding to the peak stress

ε_{ccu} – Confined concrete ultimate strain

ε_c – Confined concrete strain

Behaviour of CFST column during loading

Due to initial concentric axial loading of the CFST column both concrete infill and structural steel will deform longitudinally. Therefore, it is assumed that concentric loading is applied uniformly across the CFST section. Thus, the lateral expansion of confining tube is larger than the confined concrete. At a certain strain, the expansion of concrete infill gradually increases until it reaches the lateral expansion of steel. Expansion of structural steel remains constant and micro-cracking in the concrete begins to takes place. Longitudinal stress in the confining tube varies based on the transfer of force between steel and concrete. In the second stage of loading where the confinement of concrete is present, circumferential stresses are developed due to longitudinal stresses from loading and lateral pressure from concrete dilation.

Failure Modes

There are various modes of failure for the CFST column based on material properties and geometric configuration. The most important failure mode is local buckling. Fig.4. shows the changes in buckling mode due to the presence of infill. CFST column can delay the local buckling due to the presence of concrete core when compared with empty steel tube. The schematic failure modes of hollow steel tube, plain concrete and CFST column is shown in fig.

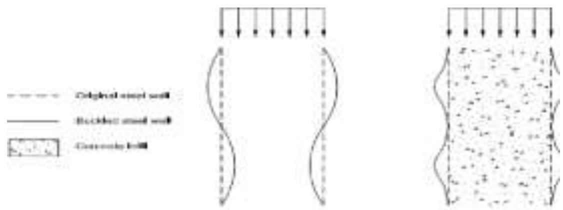
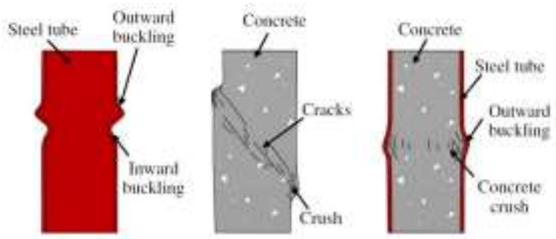


Fig. Changes in buckling mode with length due to the presence of infill [S.Abdalla(2012)]



(a). Hollow steel tube (b). Plain concrete (c).CFST

Fig. Schematic failure modes [P. Sangeetha et. al.(2018)]

1.3 Need of the Study

Review of their structural behaviour is done by changing different parameters like load conditions, geometry, material properties, temperature changes in order to observe the strength parameters like their bearing strength (with which buckling and compressive strength is taken into consideration), fire resistance and response to blast load and also the time depended behaviour which is a major issue in case of CFSTs.

1.4 Objectives of the Study

On the basis of the previous researches, the following objectives of this paper related to CFST are –

1. To understand the behaviour of CFST Columns in Structural System under linear dynamic analysis.
2. To find out the displacement and Drift of the structural system using CFST Columns under linear dynamic analysis.
3. To carry out the economical system by comparing it with RC & Steel Column System.
4. To find the use of CFST in seismic regions as per Indian Standards.
5. To evaluate the value of base shear of structural system with CFST Columns

2. STRUCTURAL MODELLING

Three models for G+10 storey Building of plan area 25 m x 25 m each with shear wall at the centre portion of the building have been prepared and compared in zone V as per IS 1893:2016 and compared with other models having different systems.

Details of Models:

Model 1 – G+10 Structure with RC Columns

Model 2 – G+10 Structure with Steel Columns

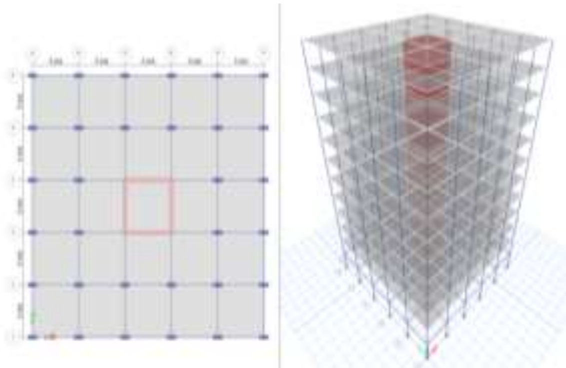
Model 3 – G+10 Structure with Concrete Filled Steel Tube Columns

Since there is no particular code for the design of CFSTs in India, the American Standard code, AISC 360-10 was used for the design of the building. The beams of the buildings were modelled using the steel I section, ISMB 300.

The dimensions of beam, slab and other parameters are kept constant for the purpose of analysis. Other data used for the purpose of analysis have been taken from IS 1893:2016

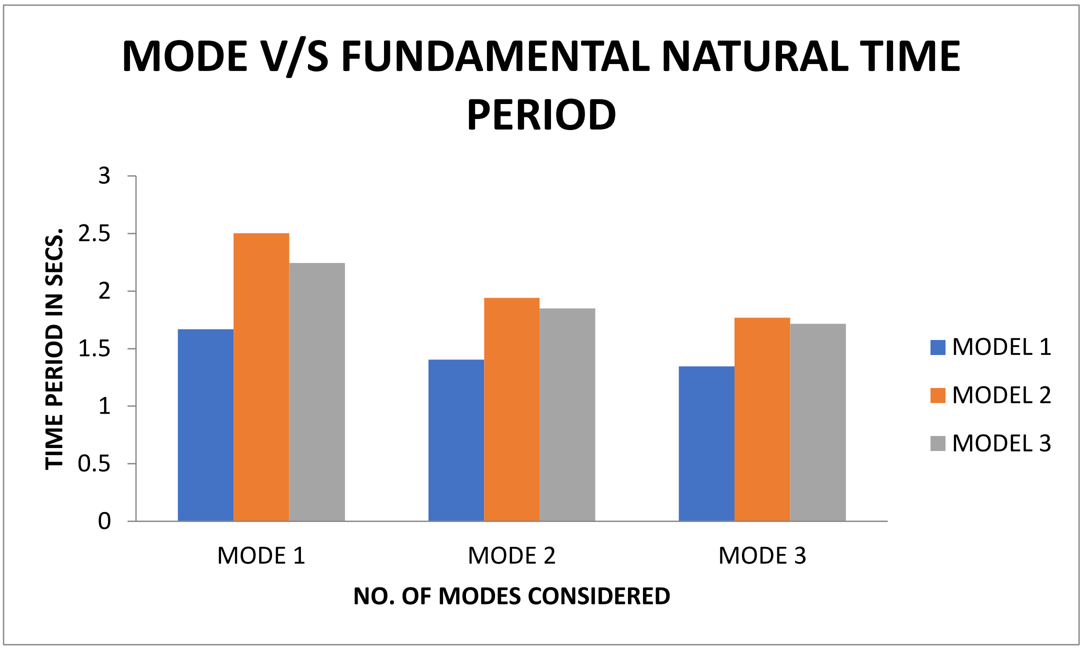
General Properties	
Location of Building	Bhuj, Gujrat, India
No. of storeys	G+10
Typical Storey Height	3.5 m.
Size of RC Column	400 mm x 1000 mm
Size of Steel Column	ISHB - 450
Size of CFST Column	400 mm x 400 mm with 12 mm thick steel tube
Size of Beam	300 mm x 600 mm / ISMB 300
Thickness of Slab	150 mm.
Thickness of Wall	230 mm.
Material Properties	
Grade of Concrete	M 30
Grade of Steel Rebar	Fe 500
Grade of Structural Steel Section	Fe 345
Type of Loading	
Wall Load	12.5 KN/m
Live Load	2 KN/m^2
Floor Finishing	1.5 KN/m^2
Seismic Details (IS 1893:2016)	
Seismic Zone	V
Zone Factor	0.36
Importance Factor	1
Type of Soil	II - Medium
Building Type (R)	5 (SMRF)

TYPICAL MODEL PLAN & ELEVATION



3. RESULTS

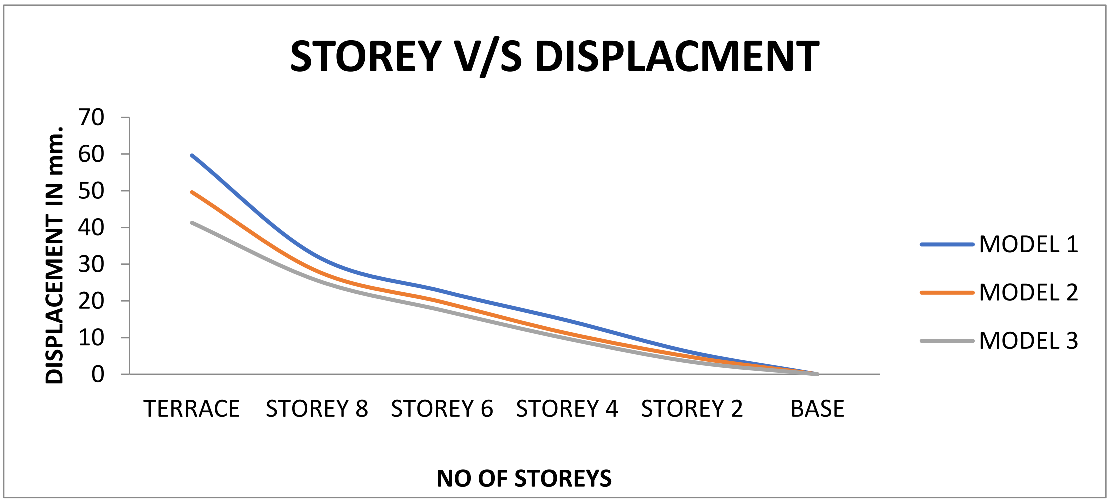
- NATURAL TIME PERIOD –



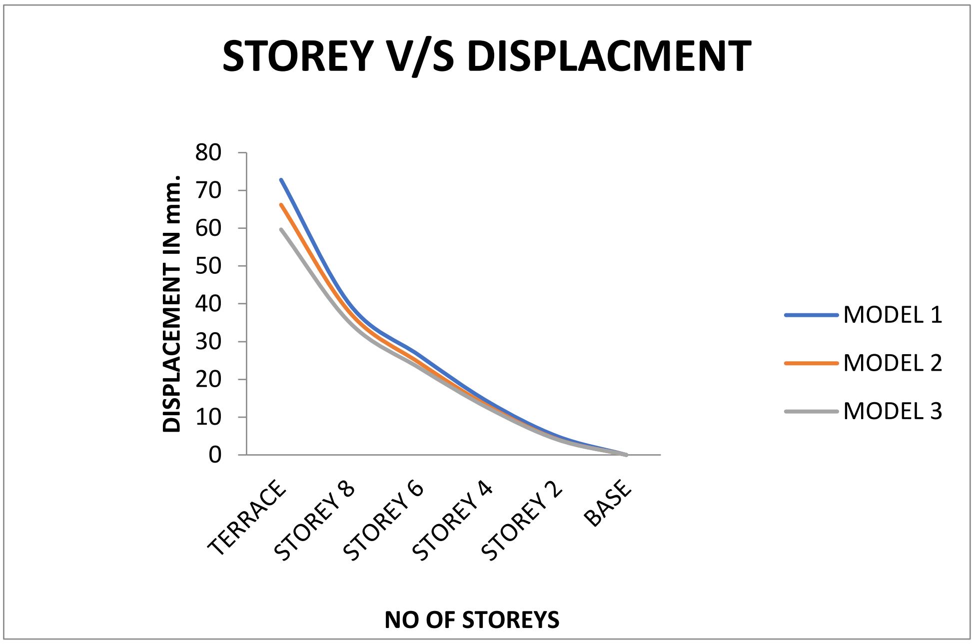
- MASS PARTICIPATION RATIOS –

S NO.	MODELS	MODE	MASS PARTICIPATION RATIOS		
			UX	UY	RZ
1	MODEL 1	1		74.26	
		2			84.52
		3	76.51		
2	MODEL 2	1		69.63	
		2	72.2		
		3			86.84
3	MODEL 3	1		70.62	
		2	72.93		
		3			85.94

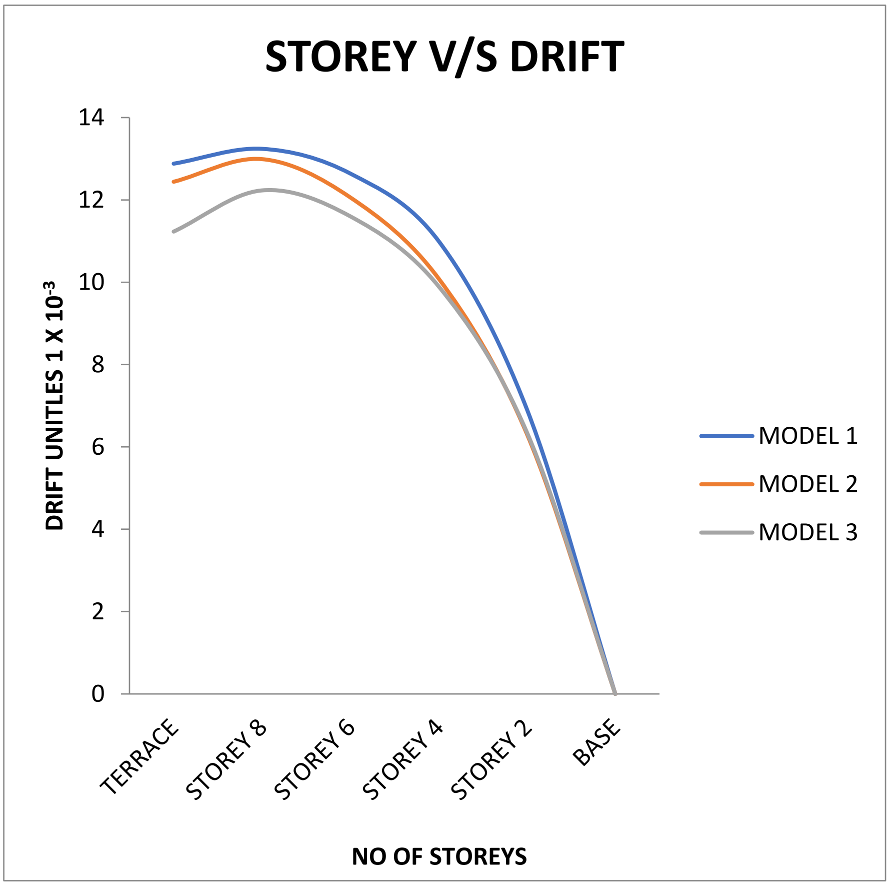
- DISPLACEMENT IN X DIRECTION –



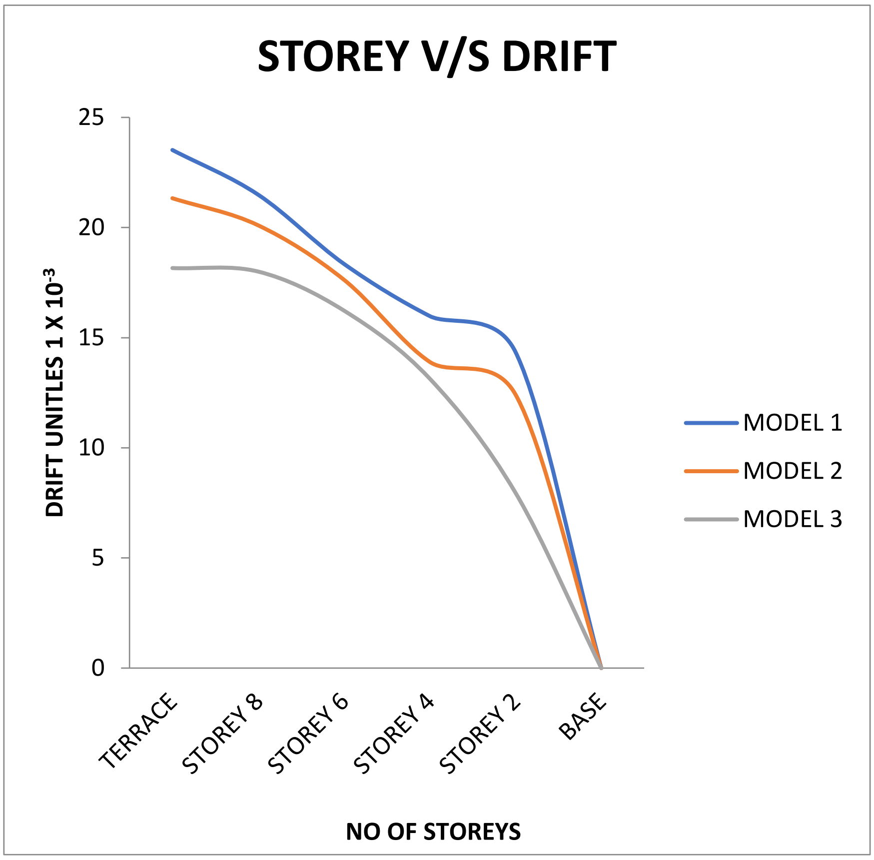
- **DISPLACEMENT IN Y DIRECTION –**



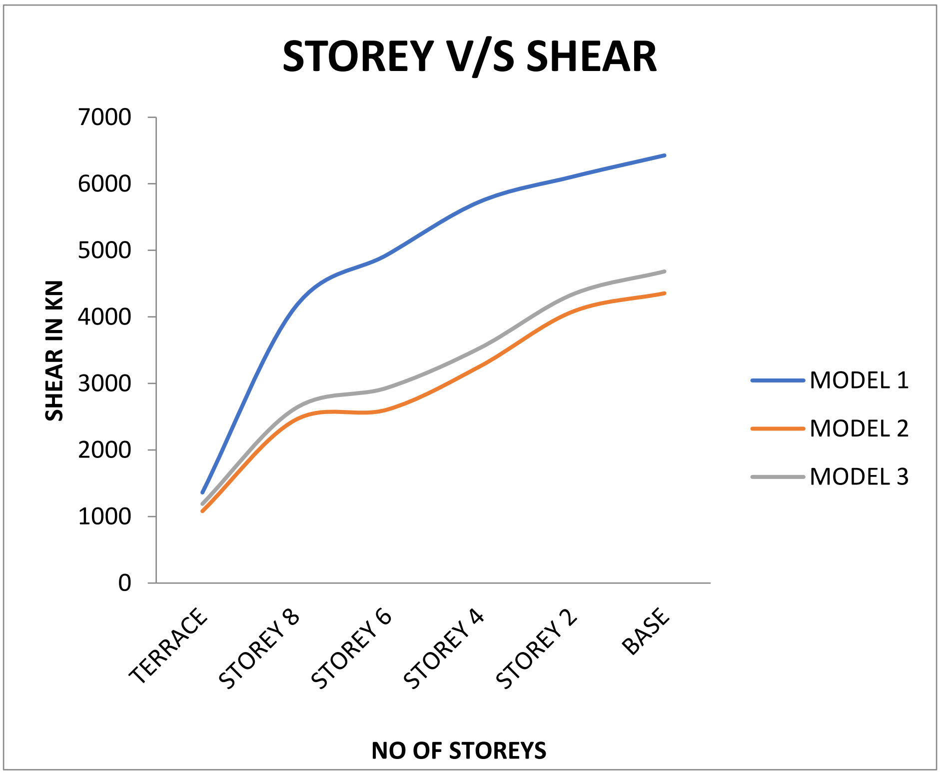
- **DRIFT IN X DIRECTION –**



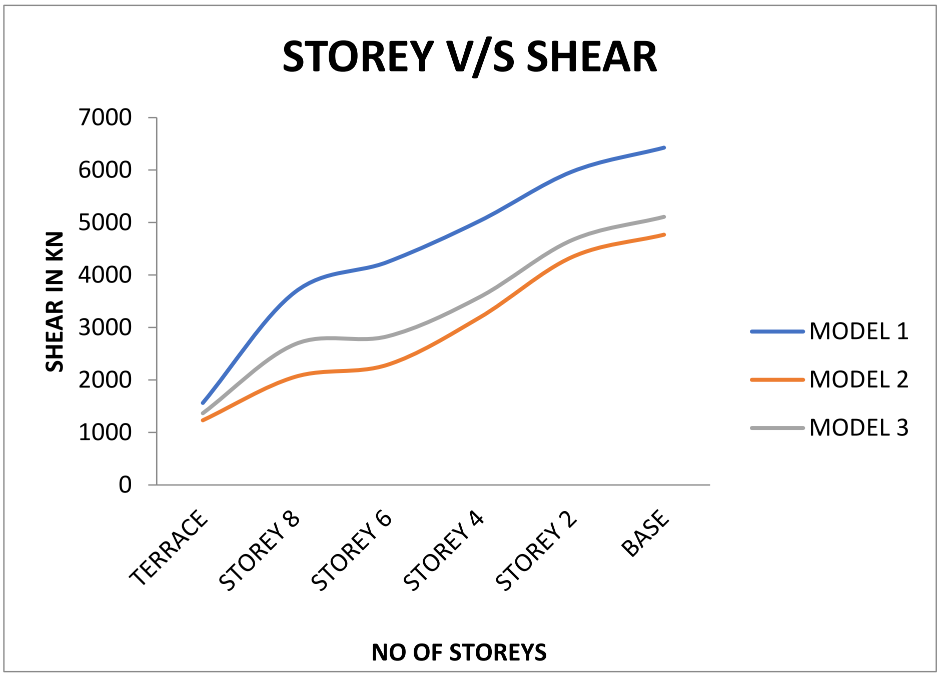
- **DRIFT IN Y DIRECTION –**



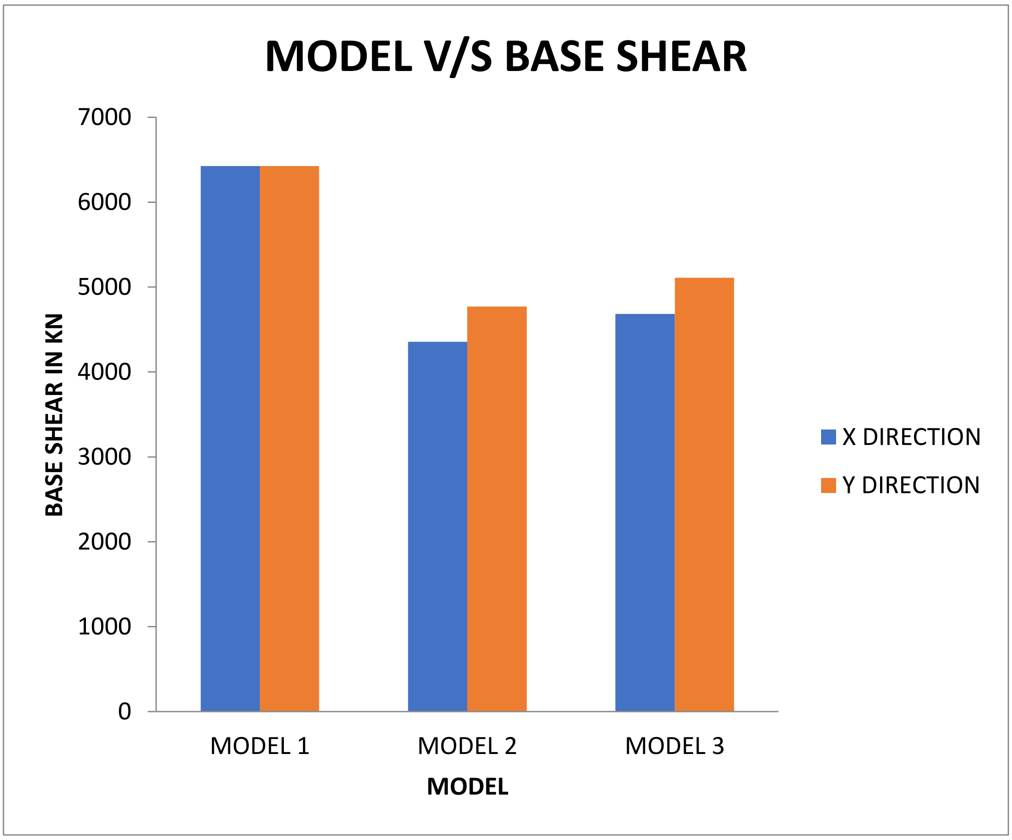
- **STOREY SHEAR IN X DIRECTION –**



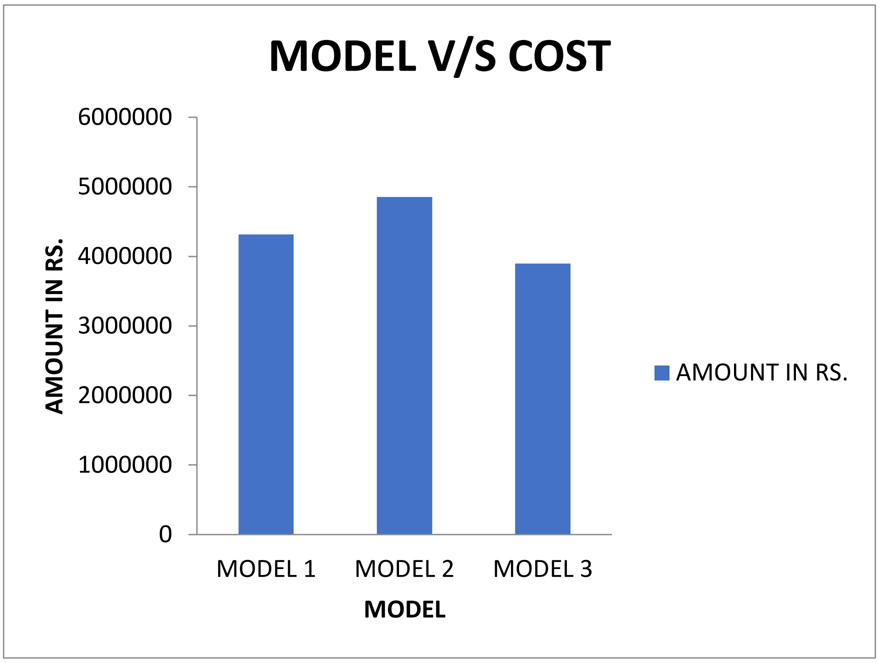
- **STOREY SHEAR IN Y DIRECTION –**



- **BASE SHEAR –**



- **COST ANALYSIS –**



4. CONCLUSION

Following Conclusions have been made from the study undertaken -

- CFST columns exhibits ore ductile behaviour than RCC because the presence of hollow portion.
- Square CFST performed better in terms of lateral displacement and fulfils the serviceability criteria better than the steel & RC frame for the selected study frame.
- Construction and connection of CFST is relatively easy with square cross section than the any other cross section.
- Under Seismic effects, the displacement has been reduced up to 15% for CFST Column Building as compare to conventional columns buildings.
- The value of drift reduces up to 10% for CFST columns for same type of building.
- The base shear of the building also reduces as the whole mass of the building decreases due to the least section of CFST used as compared to RC Column.
- As point of cost effective assessment, CFST is better than the steel & RC frame because the cost of CFST is 30% comparatively less than the steel & 20% less when compare to RC structure as size of column reduces.
- Present work indicate that use of CFST columns has been consistently applied in the design of tall building as they provide good performance under the seismic loading compared to the conventional steel & RC building.
- Better seismic performance can be achieved because of lesser weight and improved energy dissipation mechanism, which can be seen by the results of story displacements, story drifts and base shear.

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