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BEHAVIOUR OF CFDST AND CES COLUMNS UNDER AXIAL LOAD

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Abstract**—** The process of constructing composite columns involves integrating materials such as concrete and steel to create elements capable of bearing loads. This combination optimizes the strength-to-weight ratios and structural efficiency, providing support for buildings and bridges. The focal point of this study lies in a comprehensive analytical comparison between a conventional G+15 high-rise building and a composite building using ETABS software. The analysis of high-rise building performance meticulously takes into account the impact of seismic and wind loads, adhering to the relevant IS codes and standards. The primary objectives of this research endeavor encompass the identification of the most efficient column under axial load. To achieve this, an in-depth analysis is conducted using the sophisticated ABAQUS software. Within this context, the Concrete filled double-skin steel tubular (CFDST) and Concrete Encased Steel (CES) columns emerge as notable contenders, characterized by reduced displacements and stress levels in column named column 1a, column 1b, and column 4b, forming the basis for analytical comparisons within the high-rise building context. The ensuing analytical comparison yields insights into key parameters such as storey shear, storey drift, and the dead load of the high-rise building. Notably, it is revealed that the composite building exhibits a marked reduction in dead load when compared to its conventional counterpart. Furthermore, the storey shear and storey drift are also found to be notably diminished in the composite building, underscoring its superior structural performance.

Index Terms**—** Composite high-rise building, CFDST, CES, ABAQUS, ETABS

I. INTRODUCTION

In engineering a composite column refers to a column that is made up of two or more materials, steel and concrete. These materials work together as one unit resulting in increased load bearing capacity and structural efficiency. As the composite column is used widely in all kinds of high-rise buildings, there emerge many new shapes and configurations due to architectural appearance. The various types of composite columns are in the construction. The paper mainly focuses on CFDST and CES columns behaviour under axial load. CFDSTs combine ductility and strength of steel and concrete and, beams, columns or in slabs. The outer steel tube provides tensile strength and inner confinement of concrete core, improves the overall structural performance and load-bearing capacity of the composite structure. Concrete encasement helps to increase the slenderness ratio of the composite column without compromising its load-carrying capacity. This can lead to more efficient use of materials, space and aesthetics in building design.

The objective of the study is to analyse CFDST and CES columns under axial load using ABAQUS software. Additionally, the study aims to conduct an analytical comparison between conventional and composite high-rise buildings using ETABS software, referencing the behaviour of composite columns under axial load. This investigation contributes to a broader understanding of composite column behaviour and provides valuable analytical information for structural engineers and designers working on projects where axial load considerations are of utmost importance.

II. Helpful Hints

A. Figures and Tables

The analytical comparison of conventional and the composite structure in ETABS software require to define the properties of materials used mainly, the steel and the concrete. In composite columns, steel density is taken as 7850 kg/m^3. Through literature survey yielding stress of outer steel tube is 353.3MPa and inner steel tube is 376.5MPa is considered [7]. The calculation done by referring the engineers stool kit for the true stress strain curve [11] and inner and outer steel tube properties in [Table 5] and [Table 6]. The material concrete used in the composite column need to be added with properties. Concrete Density is taken as 2400 kg/m^3. Concrete generally having an elastic modulus varying between 30 to 50 GPa. Concrete damaged plasticity property values for concrete in [Table 7] and [Table 8]. In this paper elastic modulus is taken as E = 30 GPa and explains materials parameters M40 grade [12]. In the same context, the conventional building materials are steel with Fe500 grade and the M40 grade concrete.

The selection of CFDST and CES columns was based on references from various journals and the column layout presented in [Figure 1]. The dimensions of these columns were established through a comprehensive literature review, ensuring consistency across all columns to enhance the accuracy of the analysis results [8]. The applied axial load is sourced from the bottom column named C80, as depicted in [Figure 2], which is part of a G+15 storey high-rise building. In [Table 1], detailed cross-section information for the columns is provided, including specifications such as the outer steel shell (D) properties [Table 5], inner steel shell (d) properties [Table 6], length (900mm), and load (5700kN). These parameters are consistent across all columns. The analysis was carried out using ABAQUS software. [Figure 1] illustrates the 8 columns plans for analysis in ABAQUS software under axial load. The column with the least displacements and stresses is considered the effective column for further analytical comparisons. Detailed analyses of column 1a, column 1b, and column 4b are presented in [Figure 12], [Figure 13], and [Figure 14]. Subsequently, these three columns are further analyzed in ETABS software within the context of a composite building [Figure 11], and the results are compared to those of a conventional building.

Through comprehensive analysis and comparison, this paper seeks to enhance our understanding of advantages of composite high-rise building, can be used as seismic retrofit due to its various advantages.

Table 1: Modelling data for Columns using ABAQUS

Column no's	DXt_{so}(mm)	dXt_{si}(mm)	L (mm)	Load (KN)
1a	400 X 1.7	200 X 1.53	900	5700
1b	400 X 1.7	200 X 1.53		
2a	400 X 1.7	200 X 1.53		
2b	400 X 1.7	200 X 1.53		
3a	400 X 1.7	200 X 1.53		
3b	400 X 1.7	200 X 1.53		
4a	400 X 1.7	200 X 1.53		
4b	400 X 1.7	200 X 1.53		

Table 2: Modelling data for G+15 conventional structure

Structural member	Dimensions
RCC Beam	450 X 300 mm
RCC Column	600 X 600 mm
Floor Height	3m
No of Floors	G+15
Material- Concrete	M40 grade
Steel	Fe500 grade

Table 3: Modelling data for G+15 composite structure

Structural member	Dimensions
RCC Beam	450 X 350 mm
Composite Column	400 X 400 mm
Floor Height	3m
No of Floors	G+15
Material- Concrete	M40 grade
Steel	MS Tube

Table 4: Results from CFDST and CES columns using ABAQUS software

Column No	Stress (S)-MPa	Displacement- mm
1a	536.91	12.79
1b	534.84	12.77
2a	639.56	26.68

2b	653.47	37.09
3a	656.80	31.23
3b	656.80	33.58
4a	780.26	12.77
4b	540.77	12.60

Table 5: Material properties for outer steel section [9]

STRESS (MPa)	STRAIN
353.30	0
383.65	0.001504
414.00	0.003702
444.35	0.006858
474.70	0.011306
505.05	0.017466
535.40	0.025853
565.75	0.037093
596.10	0.051937
626.45	0.071283
656.80	0.096188

Table 6: Material properties for inner steel section [9]

STRESS (MPa)	STRAIN
376.50	0
404.53	0.001443
432.59	0.003549
460.59	0.006581
488.62	0.010875
516.65	0.016863
544.68	0.025082
572.71	0.036202
600.74	0.051043
628.77	0.0706
656.80	0.096069

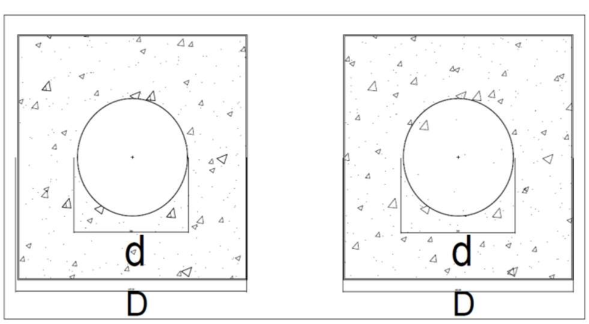
Table 7: Concrete Plasticity parameters [10]

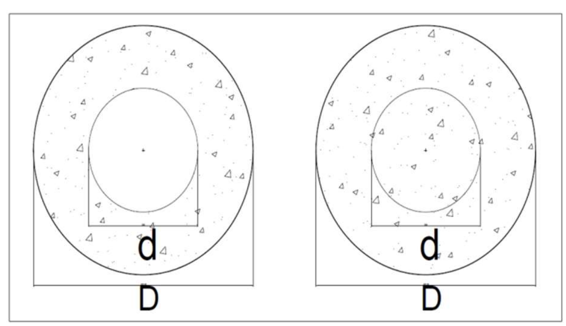
Plasticity parameters	
Dilation angle	31
Eccentricity	0.1
Fbo/fc0	1.16
K	0.67
Viscosity paramter	0

Table 8: Material properties for concrete [10]

Concrete compressive behaviour		Concrete compressive damage	
Yield stress (MPa)	Inelastic strain	Damage parameter C	Inelastic strain
20.4	0	0	0
25.6	2.66667E-05	0	2.66667E-05
30	0.00008	0	0.00008
33.6	0.00016	0	0.00016
36.4	0.000266667	0	0.000266667
38.4	0.0004	0	0.0004
39.6	0.00056	0	0.00056
40	0.000746667	0	0.000746667
39.6	0.00096	0.01	0.00096
38.4	0.0012	0.04	0.0012
36.4	0.001466667	0.09	0.001466667
33.6	0.00176	0.16	0.00176
30	0.00208	0.25	0.00208
25.6	0.002426667	0.36	0.002426667
20.4	0.0028	0.49	0.0028
14.4	0.0032	0.64	0.0032
7.6	0.003626667	0.81	0.003626667
Concrete tensile behaviour		Concrete tensile damage	
Yield stress (MPa)	Cracking strain	Damage parameter	Cracking strain
4	0	0	0
0.04	0.001333333	0.99	0.001333333

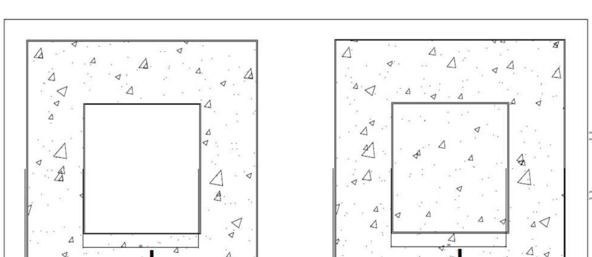
Figure 1: CFDST and CES Columns Plan

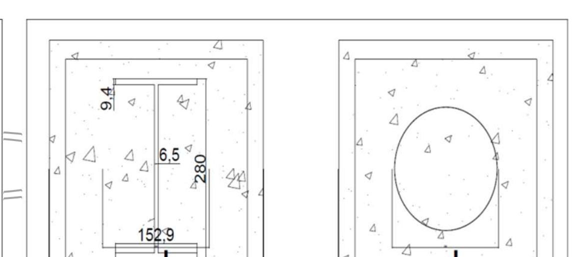




(1a Column) (1b Column) (2a Column) (2b Column)

Figure i: 1a and 1b CFDST Column Plan Figure ii: 2a and 2b CFDST Column Plan



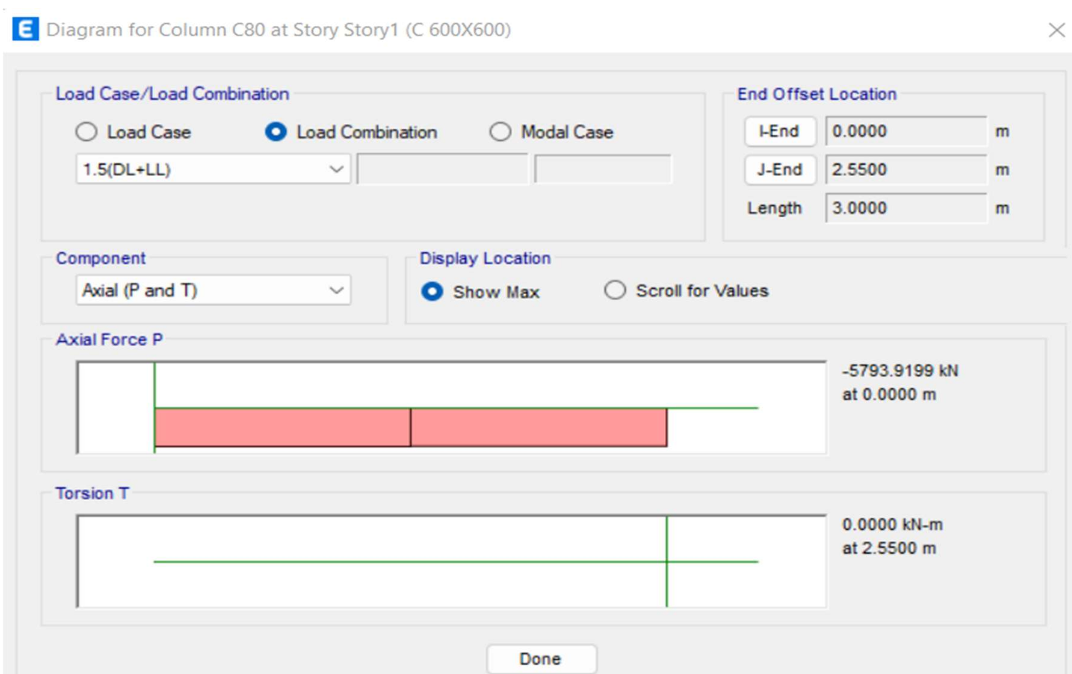


(3a Column) (3b Column) (4a Column) (4b

(3a Column) (3b Column) (4a Column) (4b Column)

Figure iii: 3a and 3b CFDST Column Plan Plan **Figure iv: 4a and 4b CES Column**

Figure 2: Axial Force Diagram



Maximum Displacement of composite column

The CFDST and CES columns are modelled and analyzed under axial load using ABAQUS software and [table 4] gives the displacement of all columns. The Column 1a, Column1b and Column4b [Table 4] results less displacement compare to other. [Figure 15] gives the clear picture through graph force vs displacements. The [Figure 3], [Figure 4], [Figure 5], [Figure 6] shows the column analyzed and points the maximum displacement acting area in the column. As the displacement is less in those columns, that is 12.77mm, 12.79mm and 12.60mm it can resist the lateral loads and building remains within its elastic limits during extreme condition.

Maximum Stresses of composite column

The composite 1a column, 1b column and 4b column results the less stresses under axial load. The [Table 4] gives the stresses of all 8 no' s of columns analyzed using ABAQUS software. The stress created in the column are all almost at the top position due to the axial load applied on that area. The [Figure 7], [Figure 8], [Figure 9], [Figure 10] shows the stresses that is 536.91MPa, 534.84 MPa and 540.77 MPa and in this the contour with red color shows the maximum stress developed area. Due to behaviour of the column, overall structural integrity of the building increases and sway and also vibrations decreased up to some extent.

Figure 3: Displacement in 1a and 1b Column using ABAQUS software

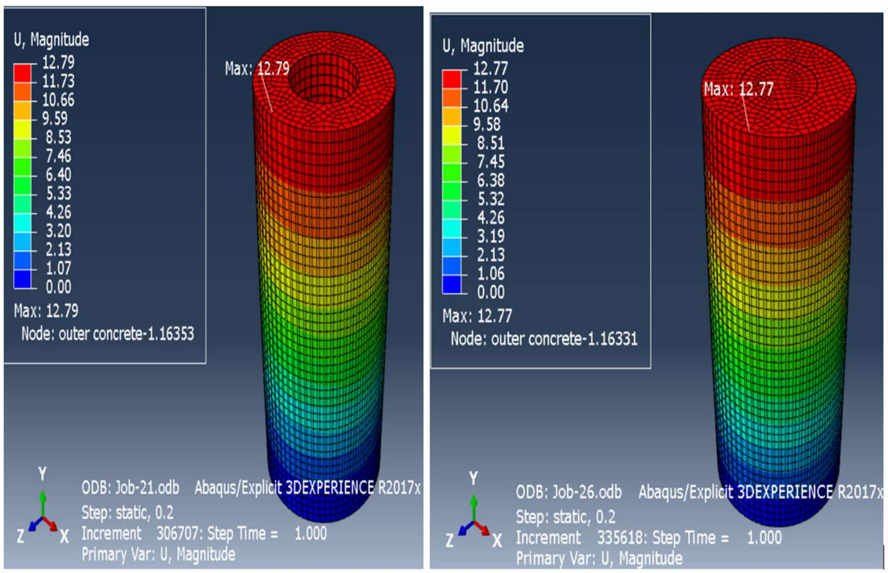


Figure 4: Displacement in 2a and 2b Column using ABAQUS software

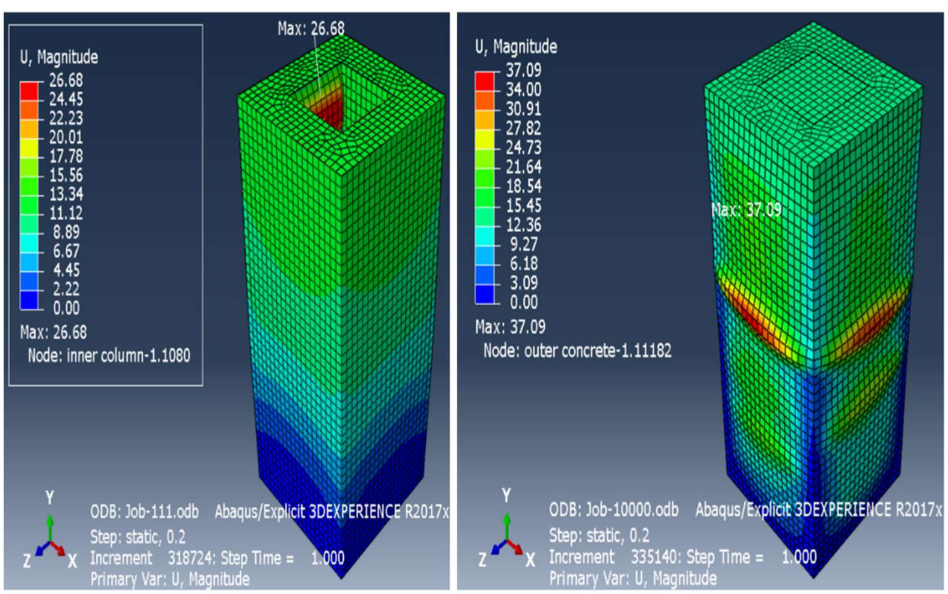


Figure 5: Displacement in 3a and 3b Column using ABAQUS software

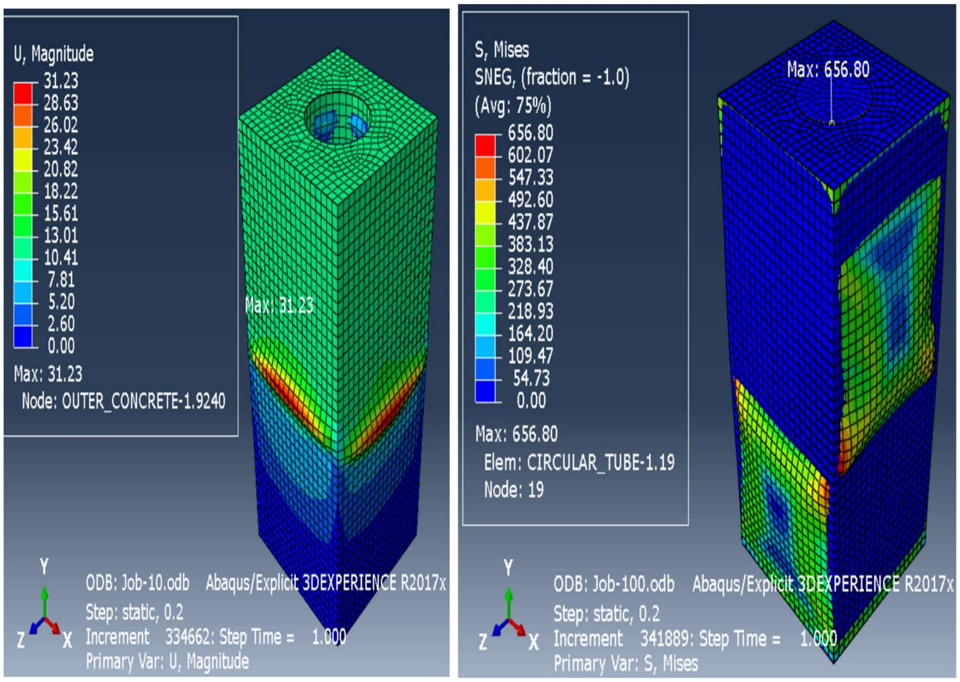


Figure 6: Displacement in 4a and 4b Column using ABAQUS software

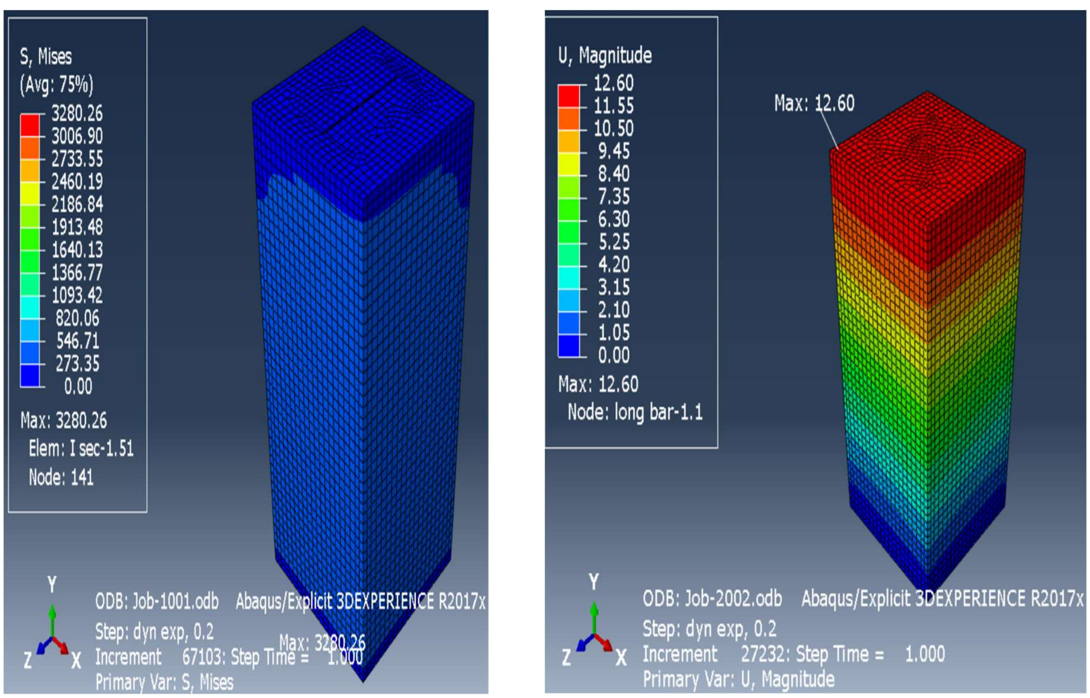


Figure 7: Stresses in 1a and 1b Column using ABAQUS software

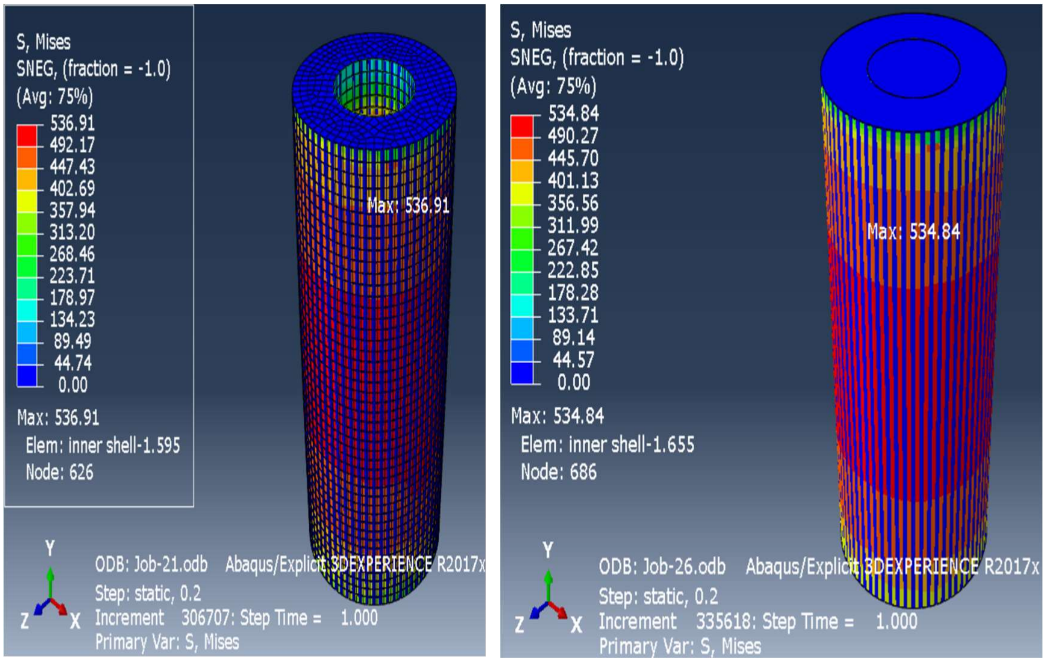


Figure 8: Stresses in 2a and 2b Column using ABAQUS software

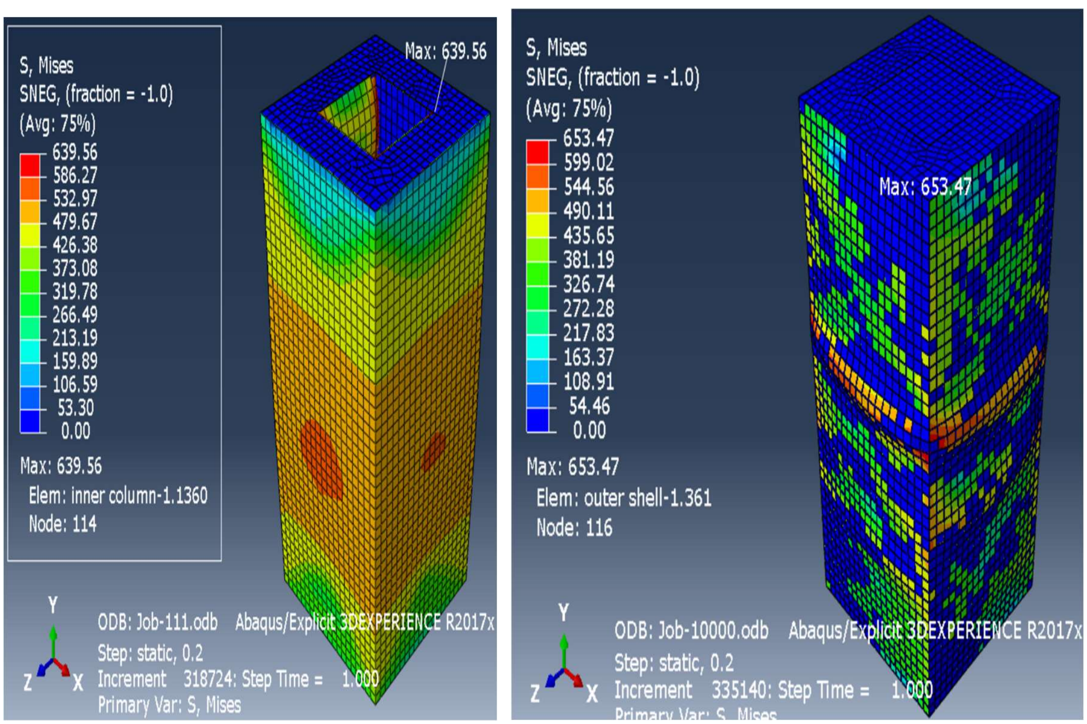


Figure 9: Stresses in 3a and 3b Column using ABAQUS software

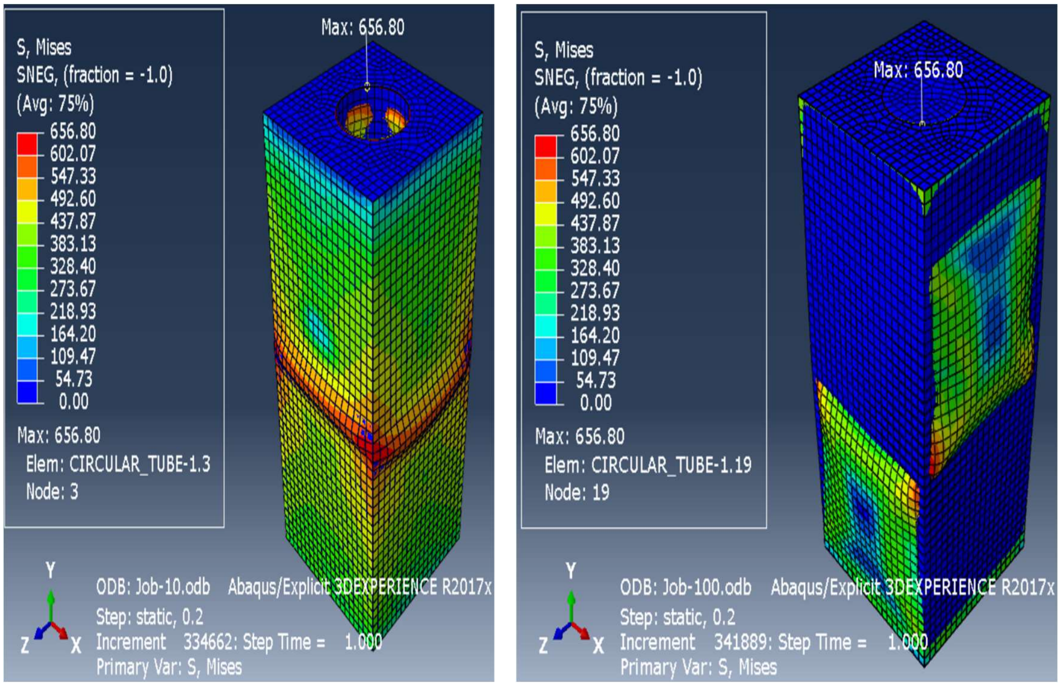


Figure 10: Stresses in 4a and 4b Column using ABAQUS software

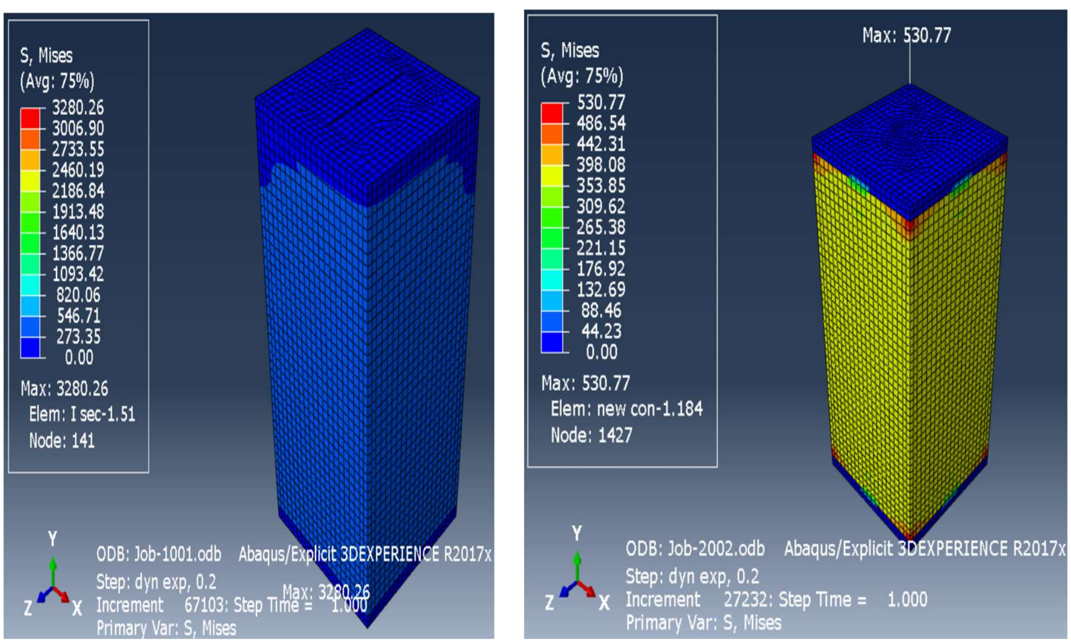


Figure 11: G+15 storey building modelled in ETABS software.

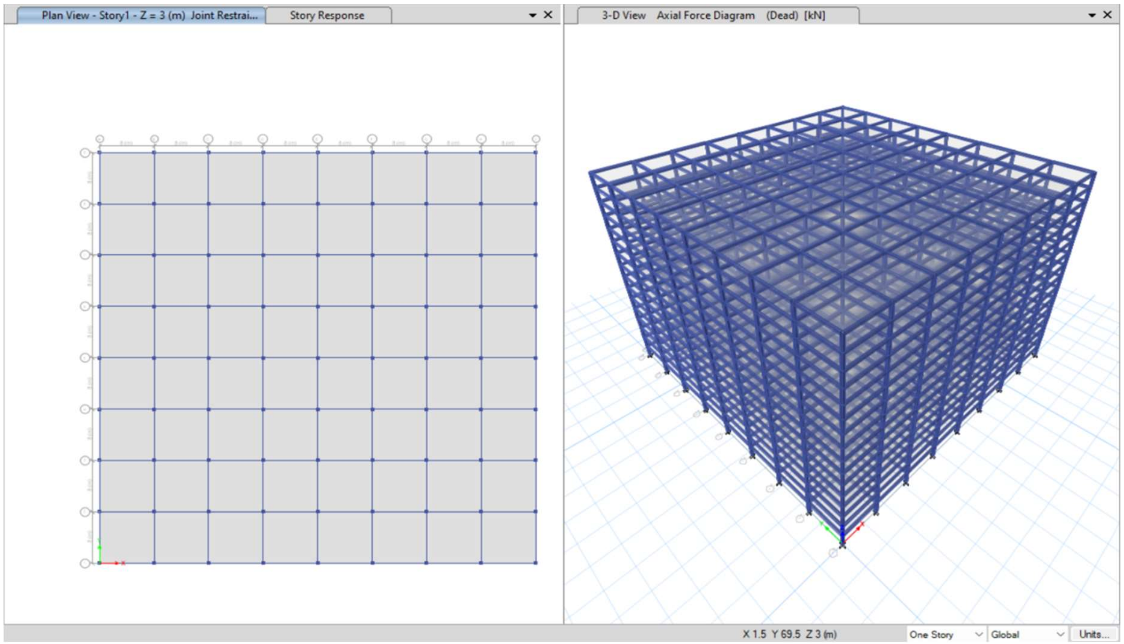


Figure 12: Detailing of CFDST 1a Column

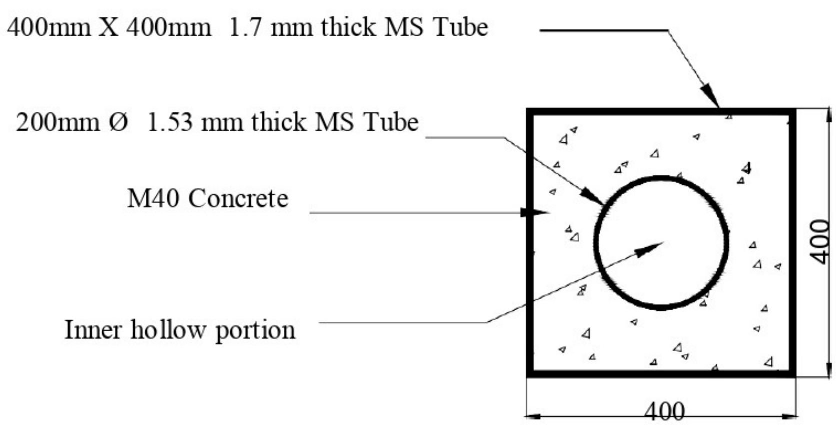


Figure 13: Detailing of CFDST 1b Column

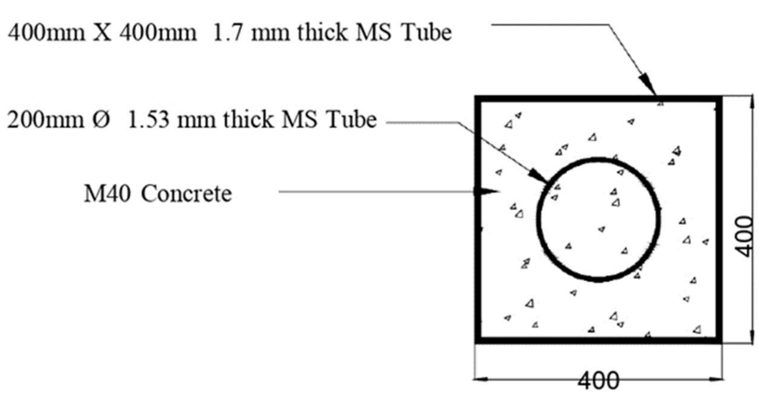


Figure 14: Detailing of CES 4b Column

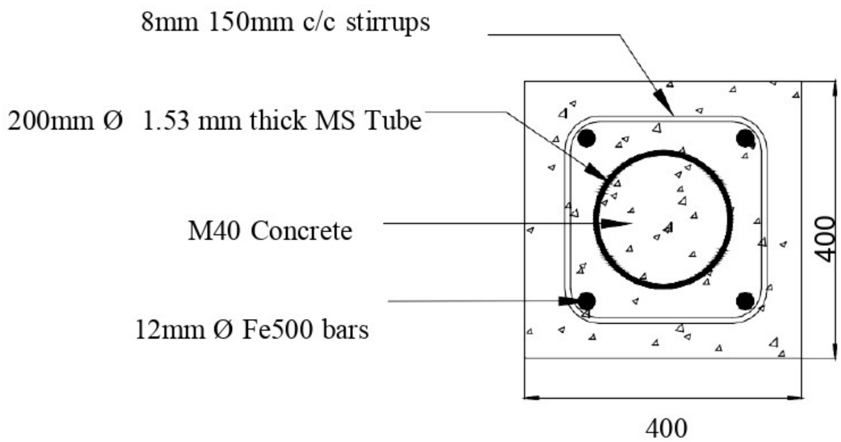
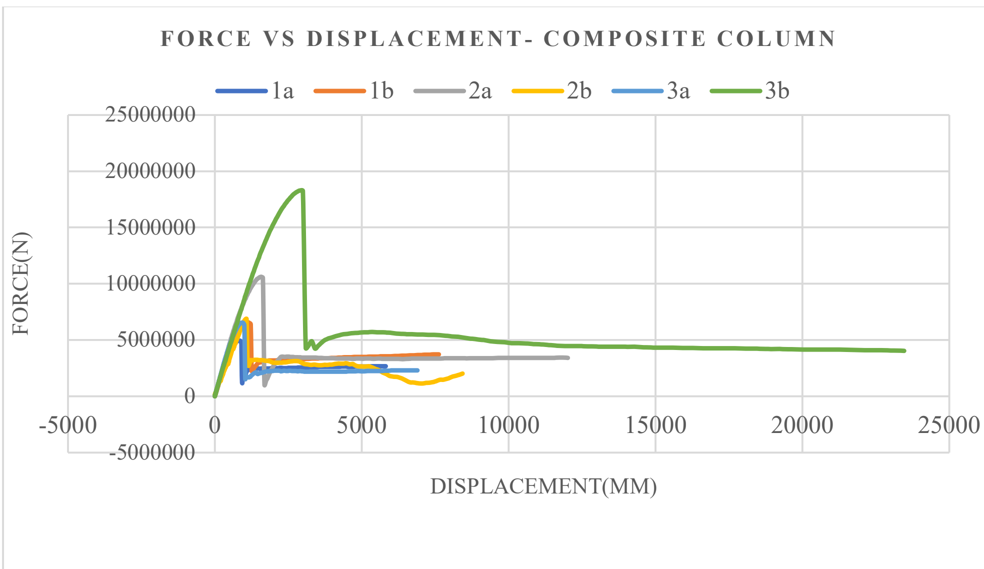


Figure 15: Results Force vs Displacement graph



Story Shear analyzed for comparative study

The G+15 high rise building analyzed using ETABS software for conventional and composite structure analytical comparison. The storey shear is nothing but a horizontal or lateral forces acting on the structure external factors mainly wind and seismic loads. All Column1a, Column 1b and 4b column used in building analysis gives the better performance base shear. RCC Column used high rise building has less story shear and the composite column storey shear has been decreased by 14.28% and 28.57% as the height ofthe storey increases [Figure 16]. Thus the structural safety and stability is increased.

Figure 16: Storey shear vs no of storey

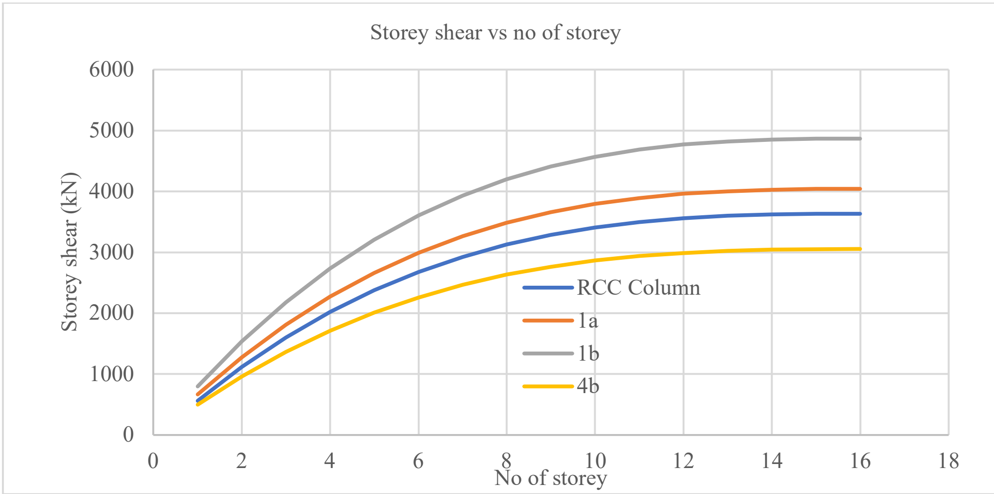
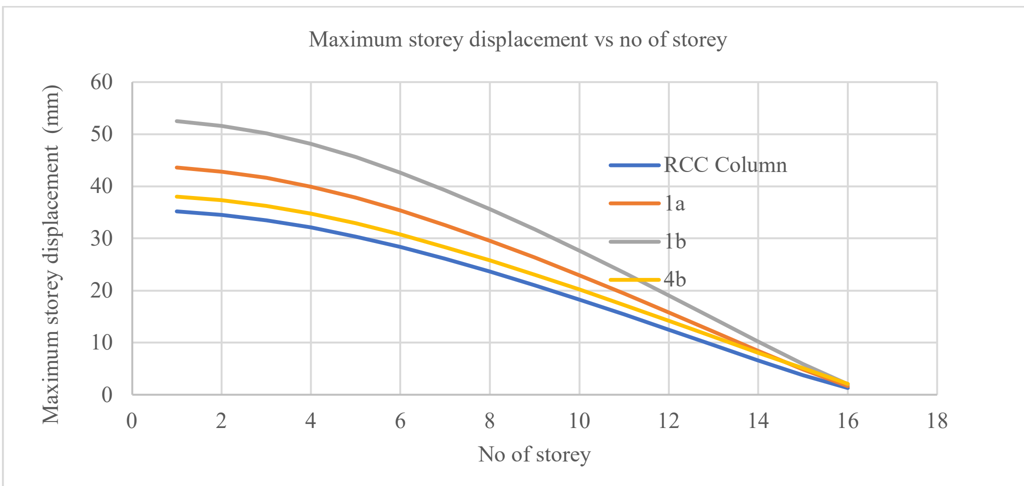


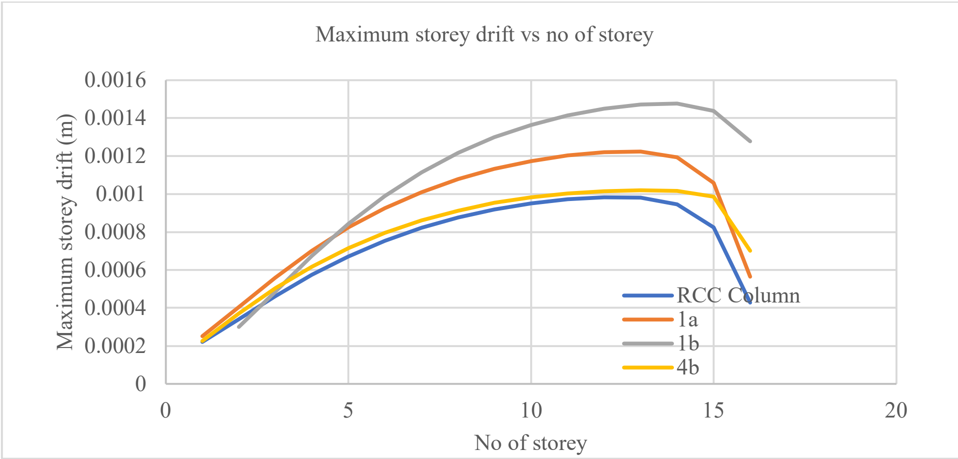
Figure 17: Maximum storey displacement vs no of storey



Maximum Story drift in high rise building

The analytical comparison of conventional and composite structure results better in case of storey drift as the composite column performance better with the CFDST and CES Columns. Maximum storey displacement vs no of storey are shown in [Figure 17]. Storey drift has been reduced by 20% and 33.33% [Figure 18] when compared to conventional building. Further in case of seismic areas, Storey drift can be reduced utilizing structural components such as shear walls, bracing systems, and moment-resisting frames, to resist lateral loads and control storey drift.

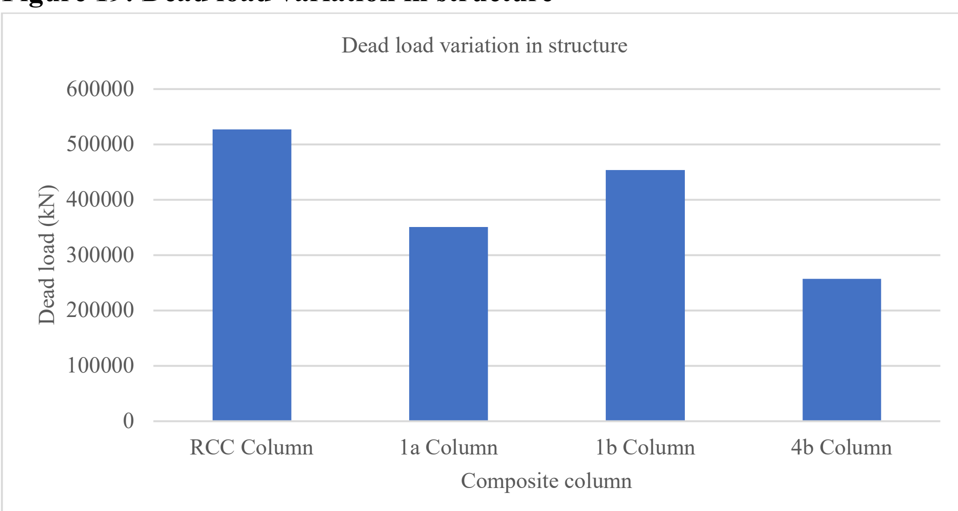
Figure 18: Maximum storey drift vs no of storey



Dead load variation

Dead load variation in the structure as compared to conventional structure and composite structure has less load. Thus, the behaviour of composite structure in seismic prone areas gives the better results. The [Figure 19] graph explains the composite and RCC column structure dead load variation analyzed in ETABS software. The 4b column takes the less load when compare to all other columns. Concrete and steel interact compositely in CFDSTs, leading to enhanced stiffness and load distribution. The [Figure 19] 4b column used building has less dead weight approximately 250000KN [Figure 19] when compare to all other columns selected for the analysis.

Figure 19: Dead load variation in structure



B. References

"Ref [1]", the author Binglin Lai & J.Y. Richard Liew describes a numerical model's ability to capture critical attributes influencing the behaviour of high-strength CES columns. These attributes encompass phenomena such as concrete cover spalling, concrete confinement, buckling of longitudinal bars, and the strain-hardening characteristics of the embedded steel section. The numerical results exhibited favorable agreement with experimental findings, particularly concerning parameters like flexural stiffness, first and second peak loads, and the load-displacement relationship. In “Ref [2]” Binglin Lai, J.Y. Richard Liew, Akshay Venkateshwaran & Shan Li a separate experimental investigation which involved partially encased stub columns encompassing a wide range of concrete compressive strengths (25 to 65 MPa) and steel yield strengths (235 to 515 MPa), key factors influencing design predictions were identified. These factors included the steel area ratio, steel contribution ratio, and the slenderness ratio of the steel sections. Another study “Ref [3]” Hui Ma, Jing Dong, Yunhe Liu & Tingting Guo meticulously examined the compressive behaviour of 11 composite columns composed of recycled aggregate concrete-filled circular steel tubes and profile steel under axial loads. The analysis revealed that these composite columns demonstrated significant axial bearing capacity and ductility. In “Ref [4]” João Paulo C. Rodrigues, Antonio J.M. Correia & Tiago A.C. Pires a different experimental study, the paper reported results related to the behaviour of composite columns comprised of entirely encased steel sections, which were designed to resist thermal elongation when exposed to fire. Impressively, the critical times for these tested columns exceeded 180 minutes, underscoring their robust fire performance. In “Ref [5]” Li, W., Han, L.-H. & Zhao, X.-L a proposed research endeavor, the preload applied to hollow steel tubes was found to introduce initial deformations and stresses. It was observed that the strength of columns made of CFDST sections might experience a moderate reduction when subjected to preload. Lastly, study “Ref [6]” M. Elchalakania delved into the impact of varying the outer steel thickness on composite columns. The findings indicated that increasing the outer steel thickness had the effect of boosting the ultimate axial load capacity, albeit at the expense of reduced ductility. Additionally, increasing the hollow ratio of the columns led to a decrease in the ultimate axial load, while augmenting the thickness of both inner and outer steel sections had the opposite effect, increasing the ultimate axial load.

C. Abbreviations

CFDST- Concrete Filled double-skin steel tubular

CES - Concrete Encased steel

CFST - Concrete Filled steel tubular

III. CONCLUSIONS

1. In ABAQUS software, Column 1b exhibits better performance compared to other columns, with a stress of 534.84 MPa and a displacement of 12.77 mm. Lower stress and displacements indicate improved structural performance under extreme conditions [Table 4].
2. Column 1a has a stress and displacement of 536.91 MPa and 12.79 mm, respectively [Table 4].
3. Column 4b shows a stress and displacement of 540.77 MPa and 12.60 mm, respectively [Table 4].
4. Analyses of columns 1a, 1b, and 4b all demonstrate superior performance in terms of story shear. RCC columns used in high-rise buildings exhibit lower story shear, while composite columns show an increase of 14.28% and 28.57%. Story shear is less on lower stories, and it increases with the story height in kN [Figure 16].

5. Story drift is reduced by 20% and 33.33% compared to conventional buildings. Story drift is higher near the base story than in upper stories, but it still performs better than in RCC column-based buildings [Figure 18].
6. The dead weight of composite structures is found to be 10% to 20% less than RCC structures when CFDST and CES columns are used in the high-rise building analysis conducted using ETABS [Figure 19].
7. In conventional buildings, the column dimensions are 600 x 600 mm, which can be replaced by 400 x 400 mm in composite buildings. This result indicates that the column cross-section can be reduced since composite columns have a higher load-bearing capacity, making them a cost-effective option.

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