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Buckling Assessment of Concrete Column, RCC Column and Concrete Column Strengthened by CFRP with Different Slenderness Ratio

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Abstract

Using finite element modeling, this study presents a buckling analysis and total deformation assessment of a concrete column, a column made of reinforced cement concrete (RCC), and a concrete column enhanced with Carbon Fiber-reinforced Polymer (CFRP) laminates (FEM). Utilizing the ansys18.1 software, a comprehensive analysis is carried out for columns that have a variety of slenderness ratios to arrive at a more accurate performance estimation. Because they can support the most weight overall, RCC columns are among the most important components of a building's structure. On the other hand, because of the enormous compressive load, these structures risk failing owing to buckling. There is a greater likelihood of rapid buckling occurring in the columns that have a high slender ratio. As a result, it is essential to investigate and evaluate the effects of an excessive load on several separate columns, each of which has a distinct slenderness ratio. For this study, the slenderness ratios were determined to be 20, 30, and 40 for concrete columns, RCC columns, and RCC columns reinforced with CFRP. The findings indicate that the load-bearing capability of the columns can be improved by increasing the quantity of CFRP sheets used in their construction.

Keywords: Finite element method, carbon fiber-reinforced polymer (CFRP), slenderness ratio, reinforced cement concrete, beam-column

INTRODUCTION

In the current scenario, composite columns are being used world-widely in the fields of bridges, buildings, highways, and offshore structures. In such high-rise structures, concrete columns play an important role as load-bearing members [1]. When such columns are subjected to excessive loads, bending of the columns happens i.e., buckling of the concrete columns. In general, buckling can be defined as the failure of the structures under excessive load [2]. Generally, columns are divided into three parts namely, short column (with less slenderness ratio), intermediate column (with intermediate slenderness ratio), and long column (with a high slenderness ratio). Short columns fail due to the crushing whereas long columns fail because of buckling. On the other hand, intermediate columns fail due to the combined effect of crushing and buckling [3, 4]. Concrete columns have been used in various applications. To enhance the service life and for better efficiencies and seismic behavior, reinforced cement concrete (RCC) columns have been used worldwide widely [5–8]. Later, carbon fiber-reinforced polymer (CFRP) was found as a complementary option for the formation of columns in buildings and structures. These CFRP laminates have been used for their high ductility, high tensile strength, and high load-bearing capacity [9–12]. Various experimental analysis has been done by

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various researchers for the performance investigation of a concrete column, RCC column, and concrete column strengthened by CFRP. However, these experimental analyses are time-consuming and costly. Therefore, in this work, we have taken finite element modeling (FEM) using the Ansys18.1 tool [13]. From all the literature surveys, it can be stated that it is necessary to investigate the buckling and total deformation analysis of concrete columns, RCC columns, and concrete columns strengthened by CFRP with different slenderness ratios [14,15]. Finally, in this work, we have presented the FEM analysis of the concrete column, RCC column, and concrete column with CFRP laminates in terms of buckling and total deflection. The investigation is done with different slenderness ratios [16].

This work is partitioned into four sections. Section 1 shows the mathematical analysis of the buckling load. Section 2 presents the finite element modeling and includes three parts. Section 3 describes the results and discussions in terms of buckling analysis and total deformation. Finally, section 4 concludes the work.

MATHEMATICAL ANALYSIS OF BUCKLING LOAD

The classical Euler buckling theory presents the formula as follows [2]:

$$P_{cr} = \frac{\pi^2 EI}{l_e^{\,2}} \tag{1}$$

Here, P_{cr} presents the maximum column load to initiate buckling or critical load, E presents the material elastic modulus, l_e represents the column length and I is the cross-section moment of inertia and can be given as $I = Ad^2$. d is the least lateral dimension.

Similarly, the slenderness ratio can be described as l_e/d. In this work dimensions of columns are considered as depth = 300 mm, and breadth = 300 mm. In this work, we have assumed one end of the column is fixed and another end free. Therefore, l_e is taken to be $2\times l$. The slenderness ratios are calculated as 20, 30, and 40 in the presented work for the assessment of the concrete column, RCC column, and concrete column with CFRP laminates.

FINITE ELEMENT MODELING

To facilitate less time consumption and less cost, software-based non-linear FEM has been done from the concrete column, RCC column, and concrete column with carbon fiber-reinforced polymer (CFRP) laminates. Figure 1 shows the meshing of the concrete column.

Concrete Columns

Concrete columns have been found difficult for modeling purposes. In general, concrete is a quasi-brittle material. Concrete has non-linear behavior along with ductile stress-strain relation. This results in cracks in the concrete columns due to excessive load and compression. In this work, we have considered M30 concrete for the FEM of columns. The parameters considered for modeling are shown in Table 1.

Reinforced Cement Concrete Columns

To achieve high tensile strength and low ductility, it is recommended to subject the concrete columns to reinforced steel with high tensile strength. In this work, we have taken FE415 steel for the modeling of RCC columns. This modeling with steel bars is simpler than the modeling of concrete. Table 2 presents modeling parameters for RCC columns and Figure 2 shows the FEM modeling of RCC column.

Table 1. Material properties for the concrete column.

Name of quantities	Assigned values
Modulus of elasticity, Ec (Pa)	3E+10
Poisson's ratio (γ)	0.18
Density (kg/m^3)	2300

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Table 2. Material properties for RCC columns

Name of quantities	Assigned values
Modulus of elasticity, Ec (Pa)	2E+11
Poisson ratio (γ)	0.3
Density (kg/m^3)	7850

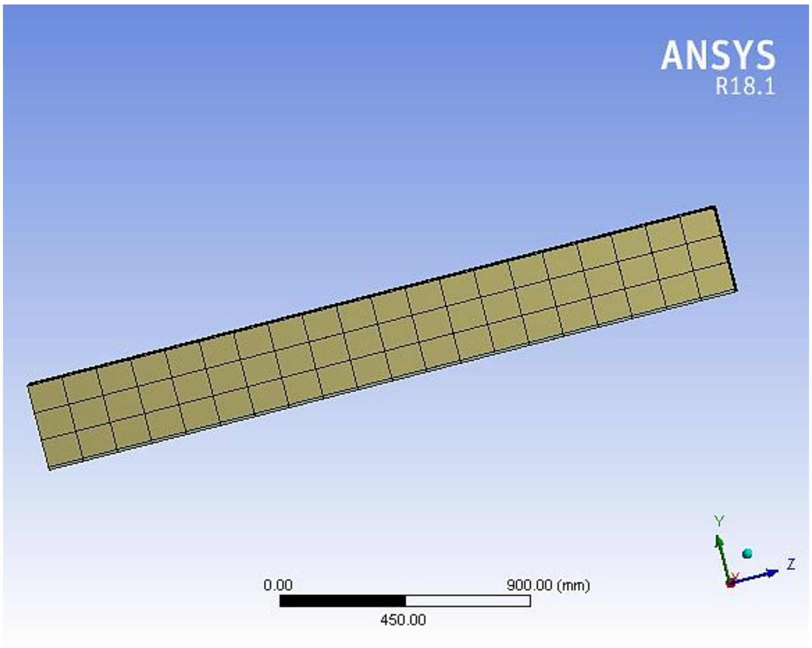

Figure 1. Meshing for the concrete column.

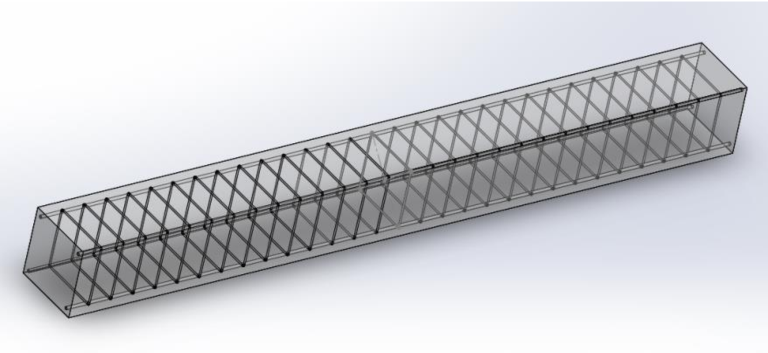

Figure 2. Modeling of RCC column.

Concrete Columns with Carbon Fiber-Reinforced Polymer Laminates

For structural strengthening, the CFRP technique has also been used in this work. Non-corroding properties of the CFRP, high strength-to-weight ratio, and good fatigue characteristics are the key features of CFRP materials. In this work, we have taken the concrete columns laminated with 5 mm thick upper and 10 mm thick lower CFRP. The modeling parameters and their assigned values are presented in Table 3. Figure 3 presents the FEM of concrete columns with CFRP laminates.

Table 3. Material properties for CFRP laminates.

Name of quantities	Assigned values
Modulus of elasticity, Ec (Pa)	2.3E11
Poisson ratio (γ)	0.3
Density (kg/m^3)	1800

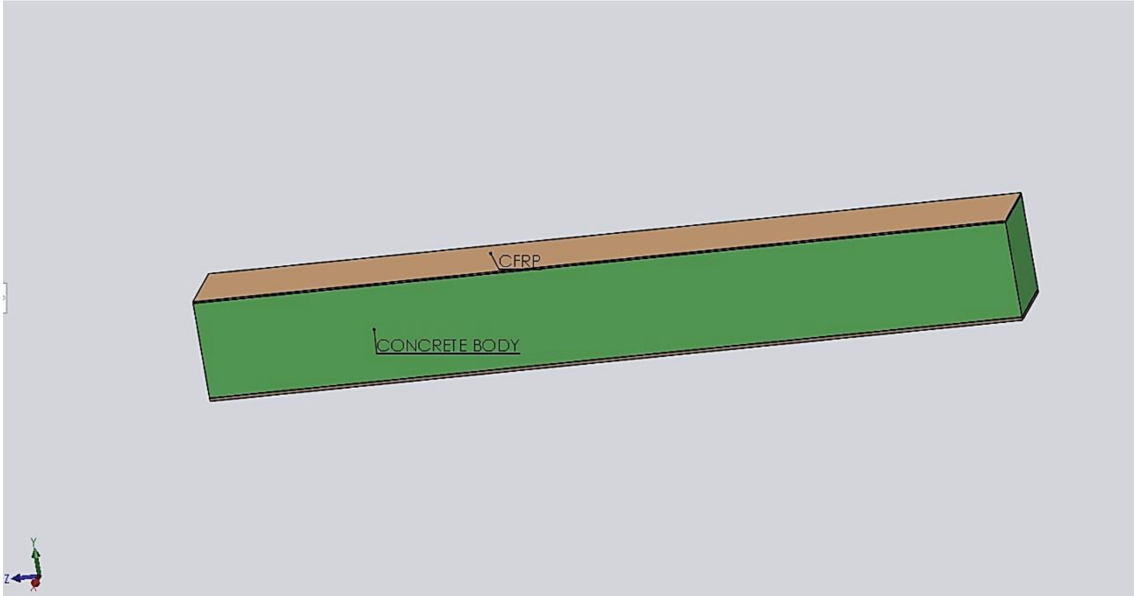

Figure 3. Modeling of CFRP.

RESULTS AND DISCUSSIONS

In this section, the results and analysis of the concrete column, RCC column, and concrete column with CFRP laminates in terms of buckling and total deformation are presented. Further, to present a clear overview the analysis is done with different slenderness ratios for different columns.

Buckling Analysis with Different Slenderness Ratio

Firstly, the effect of compression is analyzed with a 20 slenderness ratio for the concrete column, RCC columns, and concrete columns with CFRP laminates. Figure 4(a), (b), and (c) shows the buckling for the concrete column, RCC columns, and concrete columns with CFRP laminates for a 20 slenderness ratio, respectively.

Similarly, Figure 5(a), (b), and (c) shows the buckling for the concrete column, RCC columns, and concrete columns with CFRP laminates for a 30 slenderness ratio, respectively. Further, the effect of the excessive load is analyzed for the 40 slenderness ratio. Figure 6(a), (b), and (c) depicts the buckling of a concrete column, RCC columns, and concrete columns with CFRP laminates for a 40 slenderness ratio, respectively.

To present a clear overview of buckling analysis, we have compared the results in Tables 4, 5, and 6. From these results, it can be said that RCC columns have a high buckling load.

Table 4. Buckling analysis for different columns with a 20 slenderness ratio.

	Load multiplier	Critical load (mathematical analysis)	Buckling load (FEM)
Concrete	0.99956	5546025	5543585
RCC column	5.674	5546025	3.1E+07
Concrete with CFRP laminate column	1.0526	5546025	5837746

Table 5. Buckling analysis for different columns with a 30 slenderness ratio.

	Load multiplier	Critical load (mathematical analysis)	Buckling load (FEM)
Concrete	1.001	2464900	2467365
RCC column	10.848	2464900	2.7E+07
Concrete with CFRP laminate column	1.0567	2464900	2604660

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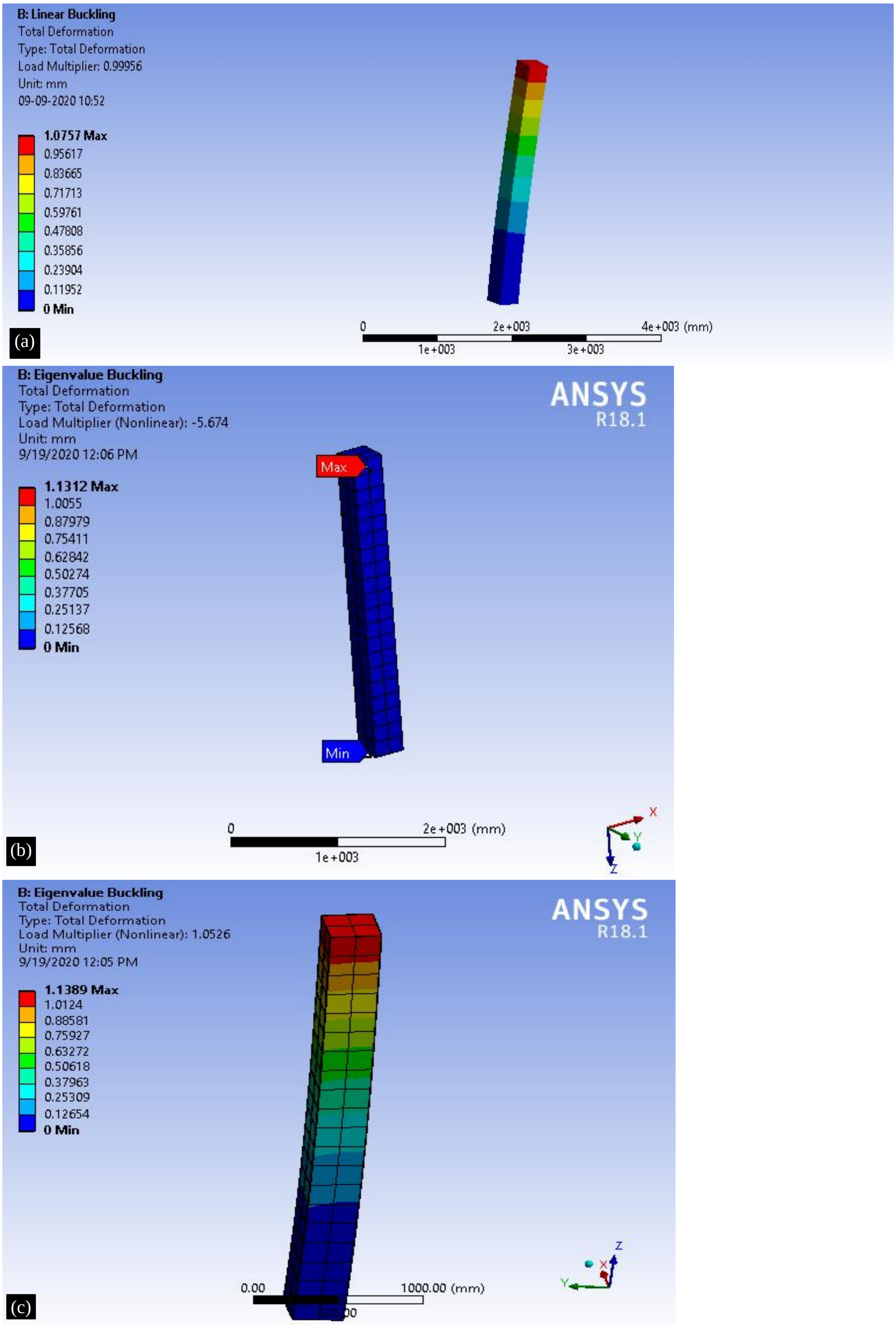


Figure 4. Buckling analysis with 20 slenderness ratio for (a) concrete column, (b) RCC column and (c) concrete column with CFRP.

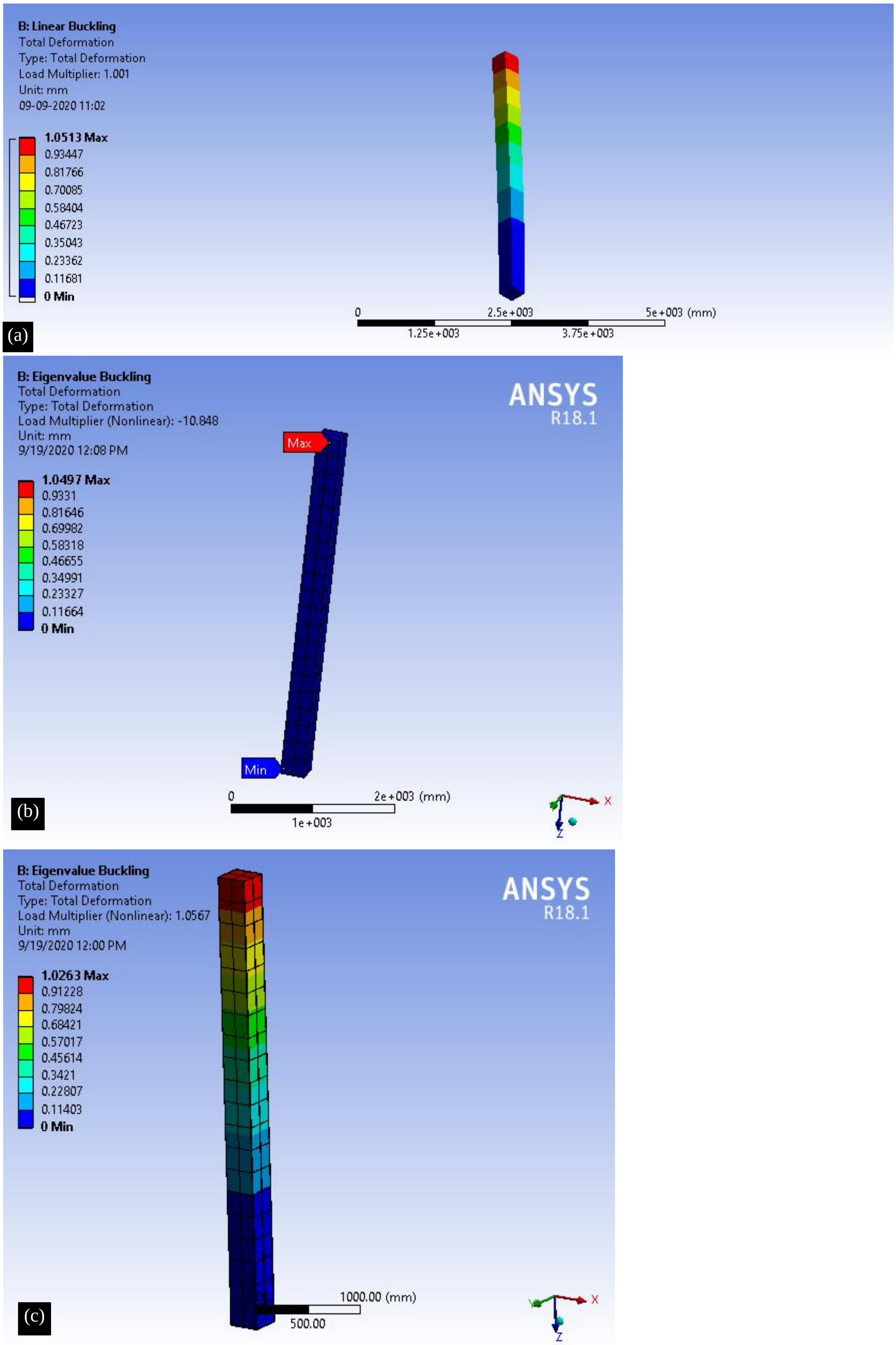


Figure 5. Buckling analysis with 30 slenderness ratio for (a) concrete column, (b) RCC column and (c) concrete column with CFRP.

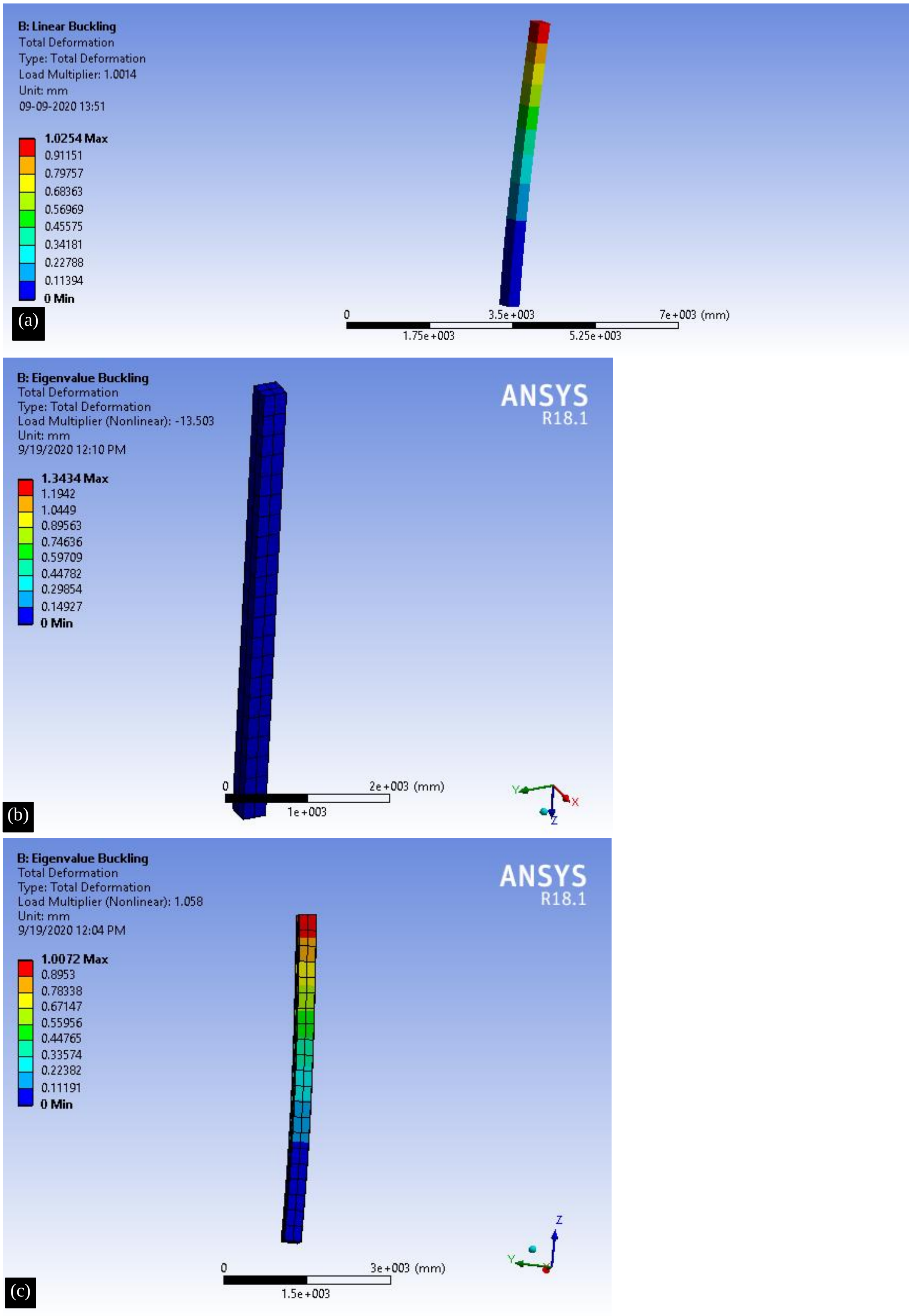


Figure 6. Buckling analysis with 40 slenderness ratio for (a) concrete column, (b) RCC column and (c) concrete column with CFRP.

Table 6. Buckling analysis for different columns with a 40 slenderness ratio.

	Load multiplier	Critical load (mathematical analysis)	Buckling load (FEM)
Concrete	1.0014	1386506	1388447
RCC column	13.503	1386506	1.9E+07
Concrete with CFRP laminate column	1.058	1386506	1466923

Total Deformation Analysis with Different Slenderness Ratio

Next, the impact of the excessive load is analyzed with a 20 slenderness ratio for the concrete column, RCC columns, and concrete columns with CFRP laminates in terms of total deformation. Figure 7 (a), (b), and (c) presents the total deformation for the concrete column, RCC columns, and concrete columns with CFRP laminates for a 20 slenderness ratio, respectively. With a 20 slenderness ratio, it can be stated from the Figure 4 that total deformation is higher for the concrete column. Whereas, total deformation presents a minimum value for CFRP with a similar slenderness ratio. The RCC column shows the intermediate value of total deformation.

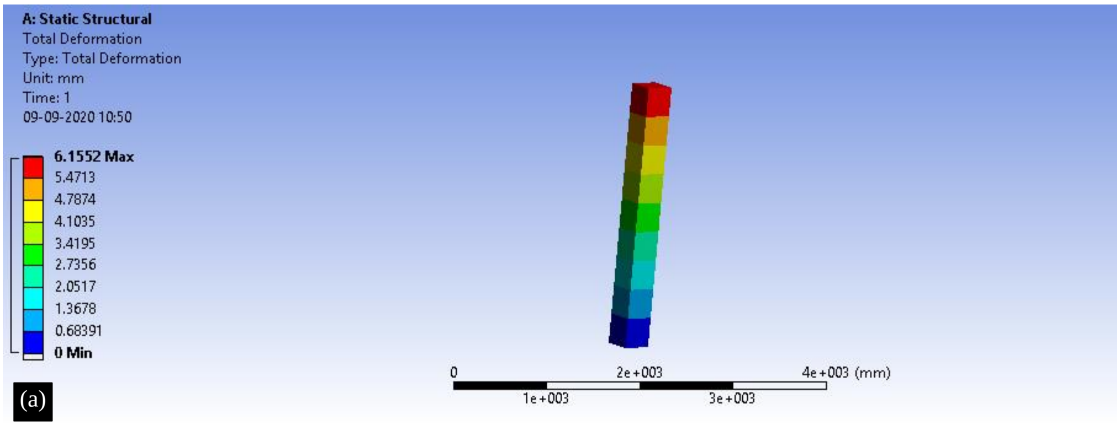
Similarly, Figure 8(a), (b), and (c) depicts the total deformation for the concrete column, RCC columns, and concrete columns with CFRP laminates for a 30 slenderness ratio, respectively. For concrete columns, total deformation is on the higher side as compared to RCC columns and CFRP laminated columns. Total deformation for CFRP also is on the lower side as compared to RCC columns. That means CFRP columns have more load-bearing capability as compared to concrete columns and RCC columns.

Further, the effect of compression is investigated for the 40 slenderness ratio. Figure 9 (a), (b), and (c) shows the total deformation analysis of concrete columns, RCC columns, and concrete columns with CFRP laminates for a 40 slenderness ratio, respectively. With a 40 slenderness ratio, again CFRP laminated columns are showing less total deformation.

Table 7 presents the comparison of concrete, RCC, and CFRP columns with different slenderness ratios in terms of total deformation. This overall analysis of total deformation suggests that concrete columns are less ductile and have the less load-bearing capability. On the account of reinforced concrete columns, CFRP laminated columns present high load-bearing capacity. This property of CFRP columns helps in the less failure of the CFRP columns.

Table 7. Total deformation for different columns with different slenderness ratio.

Slenderness Ratio →	20	30	40
Concrete	6.1552	4.1049	3.0973
RCC column	5.9577	3.9749	2.9788
Concrete with CFRP laminate column	4.1488	2.7548	2.0599



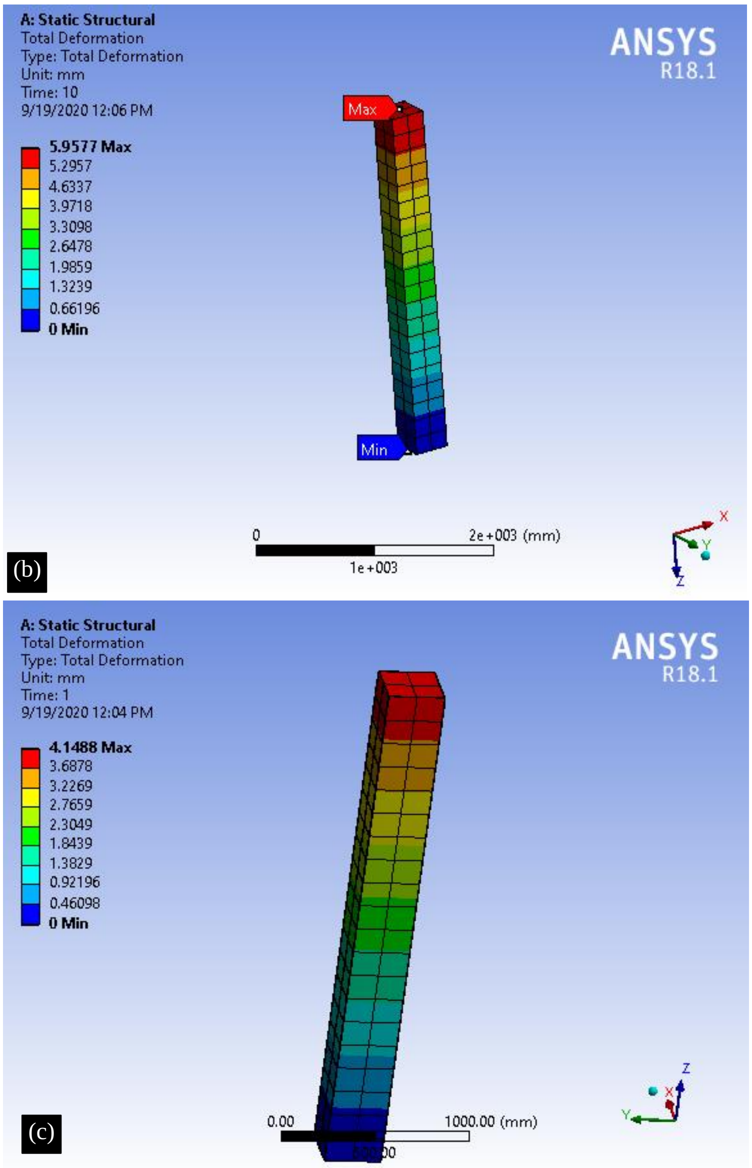
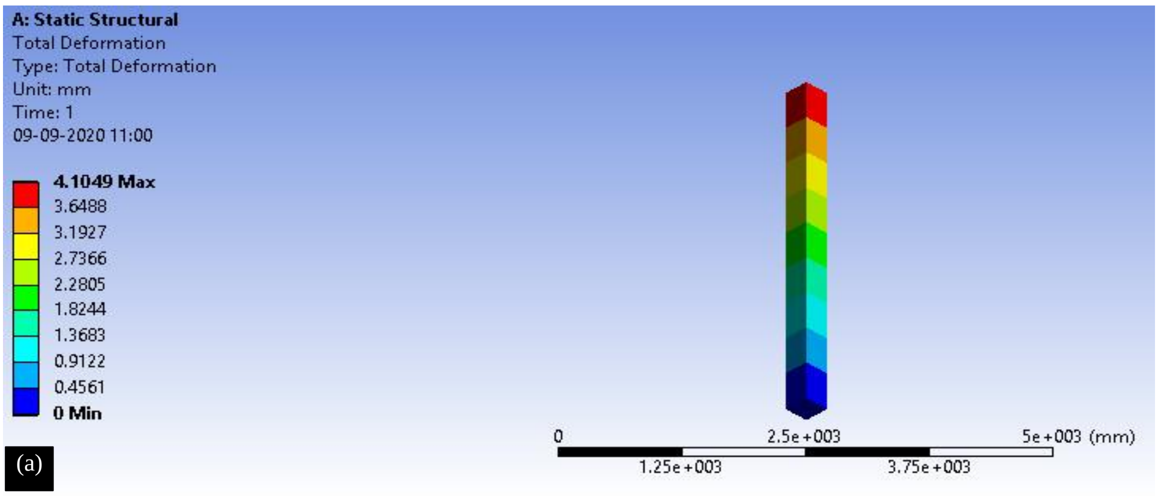


Figure 7. Buckling analysis with 20 slenderness ratio for (a) concrete column (b) RCC column and (c) concrete column with CFRP.



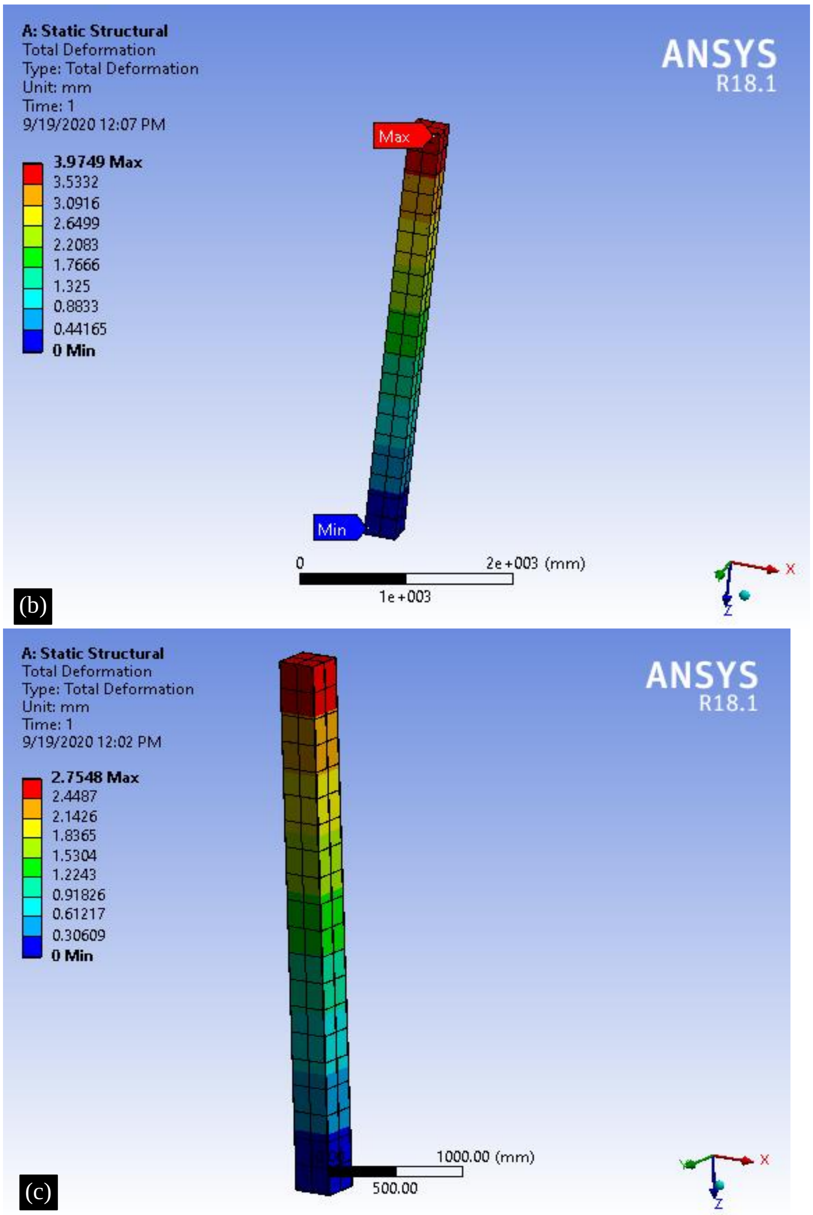
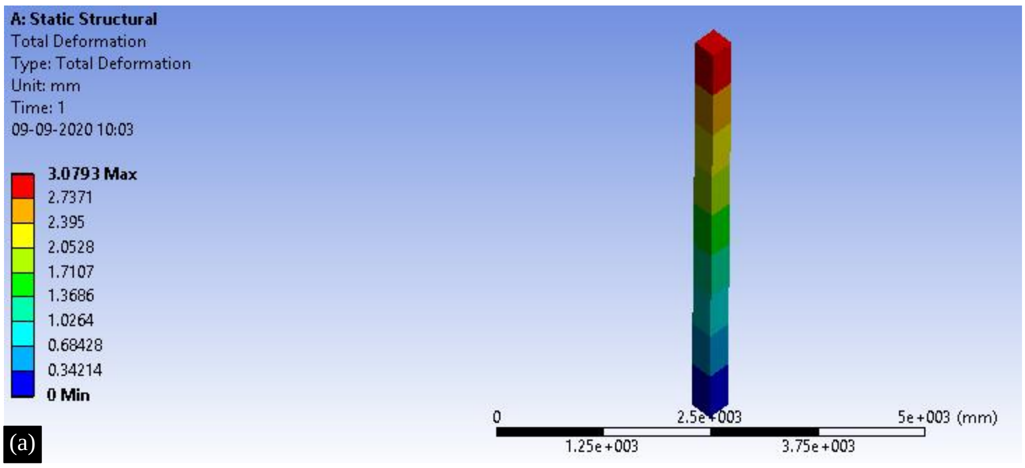


Figure 8. Buckling analysis with 30 slenderness ratio for (a) concrete column (b) RCC column and (c) concrete column with CFRP.



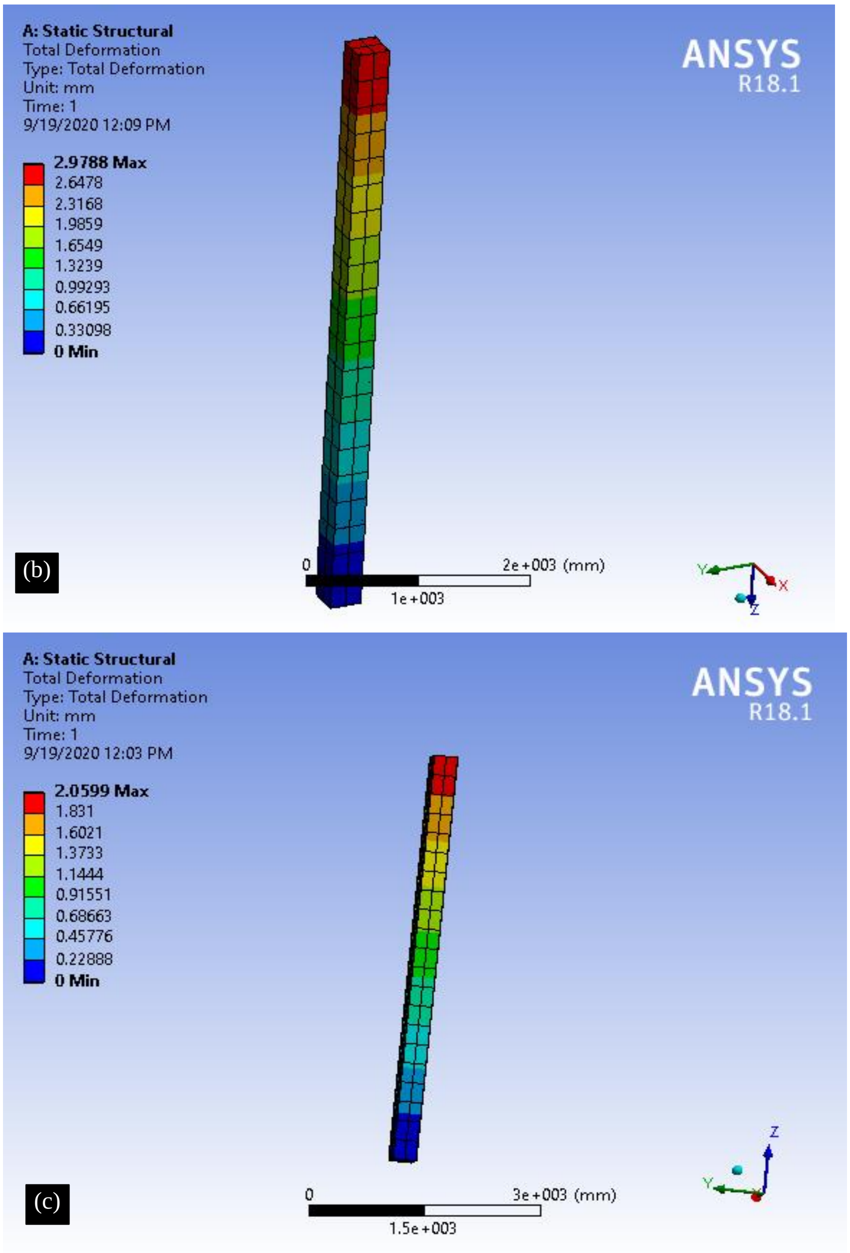


Figure 9. Buckling analysis with 40 slenderness ratios for (a) concrete column, (b) RCC column and (c) concrete column with CFRP.

CONCLUSIONS

This work presents a clear overview of concrete columns, RCC columns, and CFRP columns with different slenderness ratios. The overall assessment is done in the forms of buckling analysis and total deformation assessment. In this work, we have determined the overall performance assessment in the form of comparative tables. Concrete columns and concrete columns with CFRP laminates are having less buckling load as compared to RCC columns. It was observed that concrete columns have less buckling load as compared to the concrete column with CFRP laminates. As per the total deformation analysis, we have observed that concrete columns have the highest total deformation, RCC columns have intermediate total deformation and concrete columns with CFRP laminates have the lowest total deformation. However, total deformation is decreasing according to the increase in the slenderness ratio. This work will be beneficial for further analysis in the domain of marine engineering, bridge formation, and other applications.

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