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Numerical Analysis of Circular, Square, and Rectangular Composite Columns Under Axial and Torsional Loads

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Abstract: This paper presents a numerical analysis of different sections of circular, square, and rectangular composite columns subjected to axial and torsional loads to characterize the composite columns section performance for different purposes of construction. To accomplish the objective of this study, a parametric examination was conducted. Nine different types of composite columns were investigated. A [circular, square, rectangular] composite column with concrete-filled, with reinforcement bars, and with embedded steel profile were investigated in detail under axial load only and combined effect of axial and torsional loads separately. The strength of composite column materials considered uniformly for concrete, Steel profile, Reinforcement bars in quality, and utilized to determine their impacts under ultimate axial load capacity was examined. The composite columns under load impacts of various percentage 40%, 50% and 60% of its ultimate axial load capacity (P) with a constant magnitude were numerically analyzed. In this paper, different types of composite columns are taken for analysis by making bottom end fully fixed and another top end as pinned support, while the concentrated load and torsion are applied at this point for loading analysis. The FEM software called Abaqus was used for modeling and analysis of composite column by method of finite element considering three-dimensional models for all composite columns' materials. Concentrated load and Torsion will be applied on the top end of the composite column at the reference point constraint at top-end by coupling. The result analysis is demonstrated to determine the impacts of various levels of axial loads on the behaviour of columns subjected to axial and torsional loading on different composite material, and assessing high and low stress and strain zones, loading compression, rotation and twisting structural properties was investigated.

Keywords: Axial Load, Circular, Square, Rectangular, Composite Column, FEM, Torsion

1. Introduction

In the recent world, different structural systems are used in combination to meet performance and functional requirements in structures. In this case, composite structures used to fulfil construction structure purposes. Most of the composite structures in construction are steel and concrete. So, when they used in the composite, give more advantageous and preferable rather than using them separately. Mainly composite structures used for high rise buildings, long-span bridge or slab, warehouse buildings, etc. Composite structures provide additional load-bearing strength, lateral stiffness, easy construction formwork and easy to place. When steel and concrete properly combined, can produce high load carrying capacity, excellent structural integrity and dimensional stability Since steel has high ductility and high strength-to-weight and stiffness-to-weight ratios while concrete is highly performed under resisting compression.

In high rise buildings, complex multi-purpose storey building, structural steelwork is typically used together with concrete. Example: thin-walled steel tube infilled by concrete and steel beams with concrete floor slabs. The clear purpose of structures can be selected by considering different construction circumstances. In this case, composite structures are widely used to solve the problem that may arise if used only one element of the structure. It is a fact, however, that engineers are increasingly designing composite and mixed building systems of structural steel and reinforced concrete to produce more efficient structures when compared to designs using either material alone.

In this paper, the main attention is paid to the numerical and behaviour analysis of the infilled composite column considering different tubular steel shape under axial and torsion loads taking in to account the loading at different level of plastic resistance of section. Composite Column section of circular, square, and rectangular steel tube was investigated by considering the cross-sectional areas and length of these section were equivalent. The test parameters included the cross-sectional shape, the axial load level, the cross-sectional area of the section and the specimen type. The prediction accuracy of the cross-section is verified by comparing it with the test results with Abaqus software outputs in this paper.

1.1. Statement of Problem

The fundamental point of composite column section development is to accomplish a more significant level of performance than would have been using those two or more materials worked independently. As it was studied by H-L. HsuC - L. Wang, the flexural capacity of composite columns decreases as incremental of load action, and ductility of composite columns also decreased when a constant torsion was simultaneously applied [1]. Recently, construction industries developed to build the complex structures parametrically with limited resources considering various condition of structure types and locations. Though investigating how the structures reacts while materials combined under different level of incremental load and torsion effects is better for structural functional purposes wherever over the world under different zones is necessary. In this study, the researcher investigates numerical analysis and behaviour of different sections of composite columns subjected to axial and torsional loads to characterize suitable section of composite columns under different structural purposes.

1.2. Objective of Study

1.2.1. The General Objective

The principal objective of this paper is to investigate the behaviour and numerical analysis response of various composite column under the effects of incremental axial load and constant torsion.

1.2.2. The Specific Objectives

1) To assess and dissect the impact of axial and torsional loads together on the infilled composite column.
2) To evaluates the infilled composite column section under compression of axial loads.
3) To recognize conceivable steel section types and column section suitable for composite subjected to axial and torsional loads from different types of literature and experimental results.
4) To recognize the low and high stress and strain zones of composite column subjected to axial and torsional loads by using Abaqus software.

1.3. Significance of Study

1) This study helps to investigate various composite columns strength under the effects of torsion.
2) The study evaluates the compressive strength of different infilled composite column sections under axial loads.
3) This study discusses the comparative study between different sections of concrete-filled steel tube under compression and twisting effects.
4) Composite column to be used in under different construction circumstances i.e., seismic areas, based on structural purpose.

1.4. Scope of Study

The scope of this project covers layout, modeling, analysis, and design of concrete infilled composite column which is subjected to axial and torsional loads. For modeling and analysis, ABAQUS software was used. This study also covers the comparison with experimental results with ABAQUS software output inaction of the infilled steel tabular composite column subjected to applied axial load and torsion effects with the aim to verify the numerical model referencing previous founded studies. The axial loads first applied separately in software and in the second case, both axial load and torsion applied, and the effects of both compression and twisting effect were covered. The effects of material nag geometry also addressed in this study.

2. Review Literature

At times structural analysts face difficulties in characterizing Concrete filled steel tabular Composite columns are structural members, which are subjected mainly to axial compressive and torsional loads. The general term ‘composite column’ refers to any member under compression stresses that the steel element and concrete act together to contribute to structural strength and performance together. This concrete filled composite columns have been utilized broadly as they accelerate construction development by reducing formwork requirements, simple for putting and the requirement for tying of longitudinal support. Composite sections have as of late gone through expanded use all through the world, which has been performed by the improvement of high strength concrete allowing these composite structures to be impressively conserved. Sections intended to oppose the greater part of the axial force by concrete alone can be additionally conserved utilizing encased steel profile and thin-walled steel columns. Both steel and concrete materials are totally viable and substantial to one another; they have practically similar thermal expansion, and they have an ideal interrelated qualities with the concrete proficient in compression forces and the steel in tension, concrete likewise gives steel section thermal insulation at high temperature and insist strength under local or lateral torsional buckling of strut columns. In recent real-world construction, the usage of using this concrete-filled steel tubes (CFST) are surprisingly increasing. Using CFST columns by providing reinforcement bars or steel profile shows a vital strength to using the ordinary concrete columns and shows resilience under twisting and torsional effects which could probably be required to be used in seismic prone zones.

To investigate the strength and behavior of CFST columns, many researchers have carried out experimental and theoretical studies.

In the experimental investigation of Qing-Xin Ren, Lin-Hai Han, Chao Hou, Zhong Tao, and Shuai Li [2] on Concrete-filled CFST columns under combined compression and torsion, it was investigated that, the behavior of concrete-encased CFST and concrete-filled columns under combined compression and torsion. Based on the experimental results, the following conclusions can be drawn.

1). The tested CFST columns under combined compression and torsion behaved in a ductile manner owing to the existence of the inner CFST component.

2). The axial load level has slight effects on the rigidity and strength of the concrete encased CFST columns under combined compression and torsion. whilst the effects of CFST ratio, the existence of inner CFST and outer RC are significant. For both types of column cross-sections, more than 20% decrease of the rigidity index RI and strength index SI was detected when the CFST ratio decreased by about 30%. These two indexes of CFST increase significantly compared to the individual CFST or RC components.

Where: RI-Implies to quantify the torsional rigidity variation, a relative rigidity index and SI- implies to quantify the torsional strength variation.

3). It was advised simple superposition method to predict the torsional strength of CFST columns under combined compression and torsion.

David Hernández-Figueirido, Carmen Ibañez, Ana Piquer, and Óscar Martínez-Ramos [3] were studied Experimental study of cross-section shape and infill influence on CFST stub columns subjected to axial loads. In their paper, it was summarized by three aspects that are analyzed to draw conclusions about the most efficient combination of geometries: ultimate load, strength index, and concrete contribution ratio. As though, the use of high strength concrete results in an increment in the ultimate load and in the concrete contribution ratio of the CFST columns. As regards to the shape effect, the configuration with circular steel tubes provides to be the most efficient, contrarily to the square sections, which presents the poorest ultimate load and indexes values.

Stephen Schneider [4] studied the effects of geometric shapes of concrete-filled steel tubes (CFST) columns subjected to concentric loads on his paper ‘Axially Loaded Concrete-Filled Steel Tubes’, and from this experimental program, it was investigated, Circular steel tubes offer much more axial ductility than the square or rectangular tube sections under torsion.

Khanh Ba Le, Vui Van Cao, Hung Xuan Cao [5] concluded that the commonly advantageous cooperation and interaction between the steel tube and the infill concrete brought about the improvement in the compression or tension failure mode. The coordinated effort and connection help both steel tube and concrete to get better performance under externally applied load.

Han, L. H. and Zhong, S. T. (1995), [6], studied that steel tubes gives vital role in the tension resistance of composite columns, and the square, circular infilled composite columns showed good performance in structural stability and torsion resistance.

M. A. Dabaon, M. H. El-Boghdadi, and M. F. Hassanein, (2009) [7] performed research on composite columns under earthquake loads. He found that CFT columns under seismic loads, show very high levels of ductility and energy dissipation. It was also observed that the test samples maintained the flexural capacity until the test to be concluded.

S. Taufik1, G. Utomo, and A. Sugianto (2018) studied the behavior of Filled and Encased Composite Column Using 3D Numerical Modelling ANSYS. [8] In their paper the behavior of concrete-filled steel tubes was investigated and used finite element method for analysis and modeling. As whole the findings from this paper results for parametric changes effect in the ultimate load. To increase the ultimate load of the most significant changes in the thickness of the steel tube which resulted in an increased area of steel profiles which are crucial in cross-section capacity calculation. The addition of thick flange steel profiles of 2 mm to 4 mm can increase the ultimate load of composite columns by 14% to 16%. [8]

This paper presents a detail investigation on a various section of the composite column. Those sections can be seen below in Figure 1. It includes the [circular, square, and rectangular] composite column with embedded reinforcement bars, concrete-filled only, and embedded steel profile in concrete-filled section as shown below Figure 1 in detail for circular (a, b, c), square (d, e, f) and rectangular (g, h, i) composite column section.

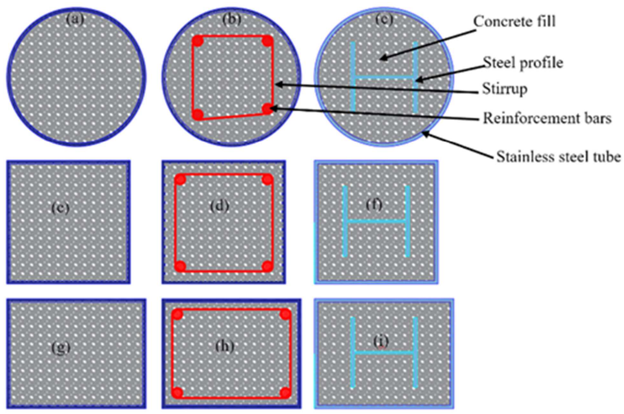


Figure 1. *Proposed CFST Composite columns.*

3. Research Methodology

3.1. Solution Strategy and Specimen for Analytical Study

The fundamental reason for this study was to decide the impacts of torsional load on various levels of axial load on the compression and tension resistance of a different section of composite columns. To accomplish this, a FEM investigation was applied for detailed analysis.

This study focused on the following composite columns sections:

1) [Circular, square, and rectangular] concrete-filled composite column [Figure 2].
2) [Circular, square, and rectangular] concrete-filled composite column with longitudinal reinforcement [Figure 3].
3) [Circular, square, and rectangular] concrete-filled composite column with H- section embedded steel profile [Figure 4].

Totally 9 specimens investigated under incremental levels of axial loads and constant torsion will be utilized for analysis. The behaviour of [circular, square, and rectangular] concrete-filled steel tube column under the action of axial and torsional loads is discussed by comparing the result from Abaqus software with an Experimental program that was discussed by previous researchers.

First, the analysis considered by assigning all specimens under 40%, 50% and 60% of axial load capacity only. The considered composite column specimens are not subjected to torsional loads on this case. The analysis of results from the Abaqus software were used considering stress distribution, displacement distribution under incremental of loads of each specimen.

Additionally, the analysis considered by assigning all specimens under 40%, 50% and 60% of axial load capacity and constant torsion. The considered composite column specimens are subjected to torsional loads on this case.

Finally, the analysis of all specimens under case 1 and 2 was recorded and used for parameter determination referencing reinforced concrete column for all concrete filled steel tube encased reinforcement bars and concrete fill steel tube with encased steel profile separately.

The cross-section of the composite columns taken is composite columns with concrete-filled, composite columns with reinforcement bars embedded in the concrete-filled and composite column with embedded steel profile in the concrete-filled section as shown in Figure 2, Figure 3, and Figure 4 respectively.

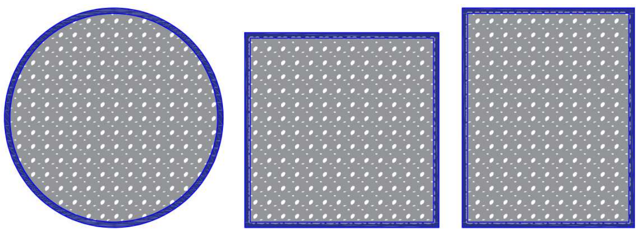


Figure 2. *Circular, square, and rectangular cross-section layout without reinforcement.*

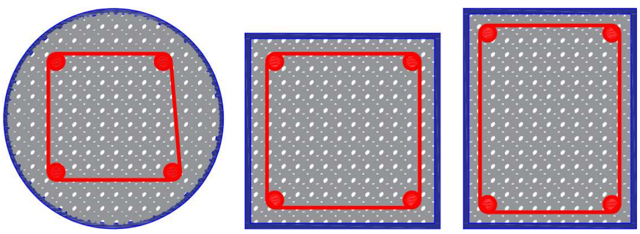


Figure 3. *Circular, square, and rectangular cross-section layout with reinforcement.*

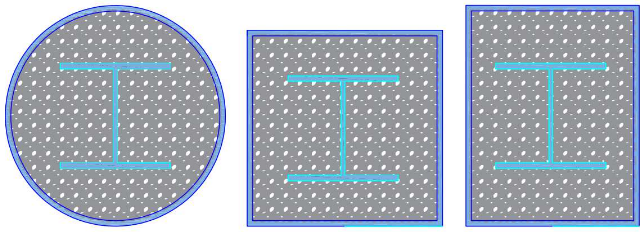


Figure 4. *Circular, square, and rectangular cross-section layout with steel profile.*

3.2. Material Definition

The material properties play a vital role in finite element analysis. Therefore, the properties of materials utilized for analysis is properly considered for concrete, Stainless-steel, reinforcement bars and steel profile respective to their intersections when acting together.

3.3. Proposed Geometry of Section

The analysis is conducted on the FEM numerical model. The first model consists of two or more isolated material parts which are later combined to each other by interaction and constraints modeling. The geometry proposed for concrete filled steel tube sections specimens are:

1) The circular steel tube of Circular composite Columns (CCC) is dimeter (D)=400 mm. The Stainless-steel tube thickness considered is 10 mm.
2) The square and rectangular steel tube, with width bxd and height h. and the two thick steel plates make up the geometry of the square and rectangular composite column (SCC and RCC) model.
3) To compare and analyses the effects of axial load and torsion over the different shapes of the cross-section, the cross-section area is assumed to be equal regardless of shape and infilled concrete or embedded steel profile.
4) For circular steel tube, with the D=400mm, thickness of steel tube=10 mm, and the height h=3500mm. This parameter also used for Concrete filled circular column with reinforcement and steel profile embedded.
5) The square steel tube, with width bxb=355x355 in mm and height h=3500mm. For both circular and square cross-section, the other option like with or without reinforcement and steel profile were considered from this parameter as reference.

4. Numerical Modeling

4.1. Introduction

The Finite Element Method (FEM) is known nowadays as one of the well-established and convenient numerical techniques for the computer solution of complex engineering problems, such as three-dimensional problems in structural engineering. A method is a powerful tool for the approximate solution of the differential equations that describe the physical phenomena. Before analysing any mechanical problem, there is the need for idealizing reality into analytical formulation first. To make the FEM applicable to a given structure, it should be split into smaller solid finite elements assigned with material properties, boundary conditions, and imposed loads or displacements. These elements are assembled at their nodes to form the structure's geometry, composing the finite element mesh, which is the domain of analysis. The equilibrium equations are then solved through an approximate integration on the finite element domain, usually achieved by defining polynomial approximation functions to describe the displacement field of each element. The number of elements in the mesh and the order of the approximation functions have a fundamental influence on the quality of the results. Aiming at reproducing the behavior of the Composite Column with relative accuracy, finite element models were built using the code from ABAQUS, based on the recommendations of its respective theory manual (Abaqus 6.13 User manual Documentation). Firstly, the properties of the materials are defined after the parts of modeling were created, followed by the basic modeling assumptions and analysis techniques. Afterward, a qualitative and comparative analysis of the results is done.

4.2. Finite Element Modeling

4.2.1. Introduction

Advanced finite element modeling is used for modeling analysis. FEM is prominent tool to consider material non-linearity and geometrical diverse effects for structural analysis, and ABAQUS is one of it. Ellobody, E., & Young, B. (2006) [9] used Abaqus three-dimensional modeling for running analysis and found it good for the analysis since it can be considering the material interactions toward each other's and boundary constraints including material properties in advance.

Horváth, A., Kollár, D. & Kövesdi (2022) [10] used three-dimensional finite element modeling developed in ABAQUS for running analysis CFST Stub Columns Subjected to Pure Compression, and found advanced parametric study results comparing with implemented laboratory taking in to account the material non-linearity, geometric imperfection, non-linear distribution of stress distribution and force-displacement effects utilized by this program. Tao, Z., Bin Wang, Z., & Yu, Q. (2013) studied regarding the finite element modeling and compared the result with collected tested data and concluded that the new FEM developed model more accurate and suitable for high strength concrete with thin steel tube of composite columns for computational investigation. [11]

This paper developed by advanced three-dimensional modeling in ABAQUS for material non-linear analysis, interactions between composite column parts including steel tube, Concrete, Steel profile and reinforcement bars when acting together. The finite segments of composite columns properly meshed in this program in appropriate intervals considering computing time with minimal computing errors. The detail modeling, analysis, meshing, and load steps was followed and conducted by manual context of ABAQUS software. [12]

4.2.2. Geometry of Parts and Its Material Properties Modeling

Under this stage, the material behaviors were selected. The material editor contains several menus that allow us to add most of the material behaviors available in Abaqus/Standard, Abaqus/Explicit, or Abaqus/CFD to a material definition.

I. Concrete: The two basic failure in concrete subjected to axial load crushing due to compression and cracking due to tensile forces examined and developed in ABAQUS by selecting plasticity-based continuum damage model. A. Sameer, and A. Abdul Rahman (2013) studied that the cracking patterns show that the column failure is a kind of torsional failure caused by the combination of torsion and shear. [13]

The parameters defined for the Concrete Plasticity model are the following:

1) For the plasticity, dilatation angle: 30, eccentricity 0.1, fb0/fc0=1.16, K=0.667, Viscosity parameter = 0
2) For the compressive behavior, it is taken that the material yields at the 25MPa.
3) The tensile behavior, the yield stress is taken as 2.25MPa (0.09fc').
4) Poisson's ratio (v) is taken as 0.2

II. Steel section and reinforcement bar.

The elastic-perfectly plastic modeling is used for steel tube and steel profile yield criterion of Von Mises. The steel tube stress distribution is recorded from elastic limit up to plastic region under incremental loading.

Table 1. *Detailed cross-section and material properties.*

Column Types	Dimension		Steel section	Reinforcement	Stirrups	Material properties (Mpa)		
	D (b) [mm]	D (mm)	Thickness [mm]			f_{yc}	f_{ys}	f_{yr}
Circular composite column (CCC)	400	380	t=10	4ϕ14	Φ8	25	335	400
Square composite column (SCC)	355	355	t=10	4ϕ14	Φ8	25	335	400
Rectangular Composite column (RCC)	400	315	t=10	4ϕ14	Φ8	25	335	400
Embedded H-Section (Steel profile) HEA 200	200	190	t_f=10 t_w=6.5	-	-	25	335	400

Where: f_{yc}, f_{ys}, f_{yd} are characteristic strength of concrete, yield strength of reinforcement bar and structural steel, respectively.
t_f and t_w are Thickness of flange and web HEA 200 steel profile, respectively.

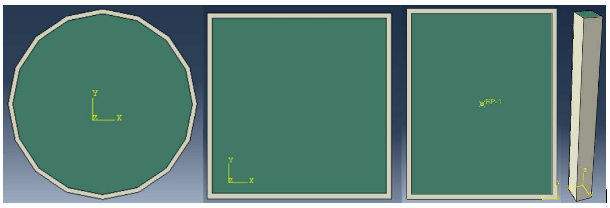


Figure 5. *Circular, square, and rectangular concrete-filled steel tube column.*

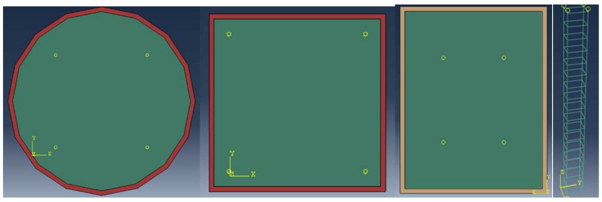


Figure 6. *Circular, square and rectangular CFST column longitudinal reinforcement.*

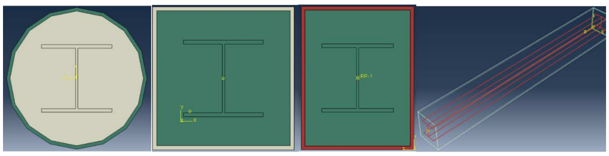


Figure 7. *Circular, square and rectangular CFST with steel profile embedded.*

The parameters defined for the steel tube nonlinearity modeling are the following:

1) Poisson's ratio, μ=0.3.
2) Density, ρ=7860kg/m3.
3) Young's modulus, Es=210000MPa.

For modeling, the dimension of cross-sections is assumed to be equal under interval that investigated from the previous study by Schneider [4] Material properties are used directly the same in all section to respective element. Steel profile embedded, Number of Stirrup and longitudinal are assumed for modeling purpose and kept the same consideration for all types of the composite column in this paper.

4.2.3. Boundary Condition and Load Analyses

Loads and boundary conditions in FEM modeling is the fundamental requirement that should be considered properly to get the intended results for parametric investigation. The proposed boundary condition of all types of composite columns by the bottom end is fully fixed support while on the other end pinned or at the top support by restraining all displacements and allowing free minor rotation. The applied axial load and torsion on all specimens of the composite column are eccentrically at the top end.

The loading step developed in ABAQUS by static and general arithmetic including non-linearity of materials, and the incremental loading at various levels of assigned load 40%, 50%, and 60% of axial load bearing capacity of composite columns. additionally, constant torsion is also applied for numerical parametric studies.

4.2.4. Meshing Parts

The meshing modeling developed in the ABAQUS used by C3D8R three-dimensional continuum solid elements with eight nodes linear brick elements with minimum integration and appropriate fine segments applied to all parts of the composite columns separately then assembled as introduced material interaction conditions for Steel Tube, Concrete Section, steel profiles and reinforcement bars. All parts of composite column like Stainless steel tube, concrete fill, Steel profile, stirrup, and longitudinal reinforcement meshed to the good meshing appearance and good timing for getting results from software.

In the present study, the steel tube, steel profile and concrete volume are divided into fine element after many iterations carried out in program by finding the results from software which is close enough with previous meshed size with the active one. The time factor for getting results also take into consideration. After all convergence tests the section of volume divided into fine elements with (30, 30, 30) mm by structured Hex shape method in the program for square, rectangular, steel profile, and bars sections as it can be seen on Figure 8 for all parts after meshing applied. For the circular section, the extruded wedge element is used.

4.2.5. Characteristics of the Proposed Model for Composite Columns and Analysis

The point is to demonstrate that the model created in this study utilizing the FEM in the ABAQUS is legitimate for the examination of the circular, square, and rectangular composite columns. Finally, the numeric result from software is validated using experimentally studied researcher's conclusion. The fundamental modeling methods for proposed specimens are:

1) Use of the elastic- perfectly plastic material with the Von Misses yield criterion in modeling the steel tube.
2) Use of the concrete damage plasticity model offered by Abaqus/CAE in the modeling of the concrete core.
3) Modeling of both the concrete and the steel with 8 node solid elements with reduced integration C3D8R brick element.
4) The loads are introduced as a concentrated load and concentrated moment. The analysis is done in two steps:
   a) axial loading only and
   b) axial load with Torsional loading.

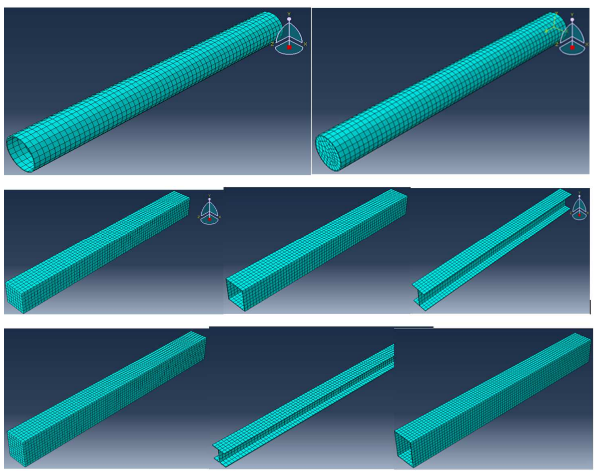


Figure 8. *Meshing of Circular, square, and rectangular section's parts.*

5. Results and Discussions

5.1. General Introduction

The analysis of [Circular, square, and rectangular] section of the composite column was modeled using the Abaqus software package and numerical parametric characteristics concrete filled composite column subjected to axial load and subjected to both axial and torsion load is investigated. The FEM result is drawn for all specimens under various level of loads and torsional effects. The result analysis includes the stress distribution, and the displacement distribution for composite column subjected to compression only, and compression with torsional forces. As a result, detail explanation was considered Circular composite column as sample and same procedure was followed all specimen.

5.2. The Effect of Axial Load Action

a. Von Mises stress distribution [S]

When columns subjected to axial load (compression effect) and displacement under this axial load (U) will be occurred. Figure 8 shows Von Mises stress distribution, which is used to predict the yielding of materials under loading from the results of axial load. This figure showed three patterns of elements of composite column results of stress distribution from Abaqus software. The First part is indicating the stress distribution in the circular steel tube. As it can be seen from diagram stress distributed by a contour color with different values between 80.24 MPa and 89.68 MPa. The magnitude stress at edge support and around edge support shows less stress and maximal stress respectively, while the entire elements are distributed as a moderate nearly constant value. The second part of Figure 9, indicating the stress distribution in the concrete core element. As can be seen from this figure, stress distributed by a contour color with different values between 9.735 MPa and 13.29 MPa. at the edge support, it shows less stress, while the entire elements are distributed as the moderate medium. The third part of Figure 9, Shows the stress distribution of all parts of the composite column when sticking together. In this case from this result, it clearly understood the Mises stress magnitude is between 9.735MPa and 89.68 MPa, which is the lower magnitude stress distributed in concrete and higher value in a steel tube element. From this figure, it concluded that stress distribute in concrete is less by 85.2 % than stress distributed in steel tube.

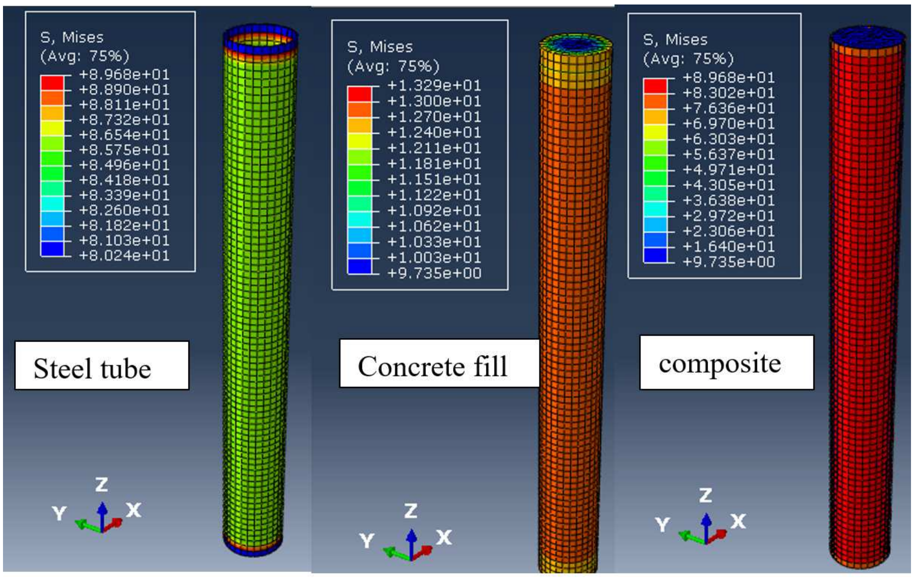


Figure 9. *Stress and U-Magnitude of CCC with concrete fill at 40% of P.*

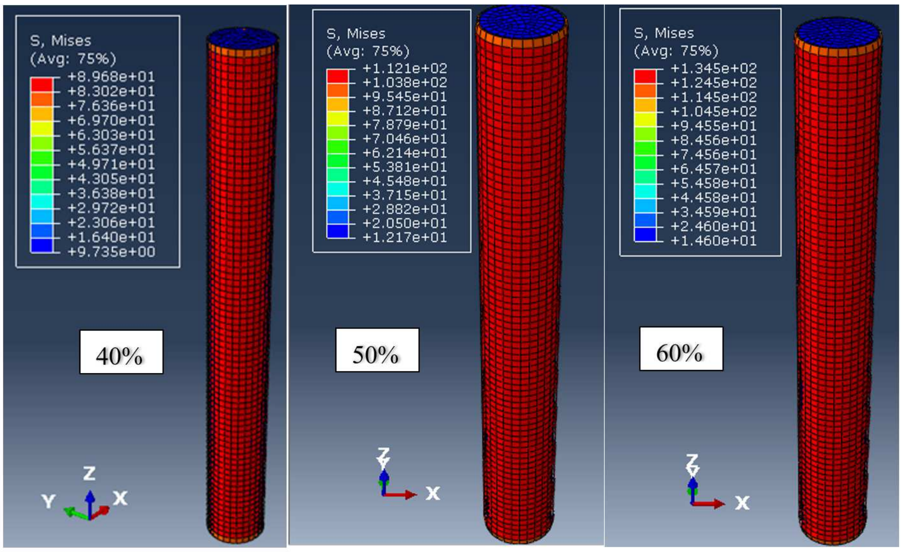
In Figure 10, 12 and 15. (a) below shows Von Mises stress distribution at each load level 40%, 50% and 60% from left to right, which is used to predict the yielding of materials under loading from the results of the axial load for composite section column when parts were combined.

b. The displacement magnitude of cross-section [U]

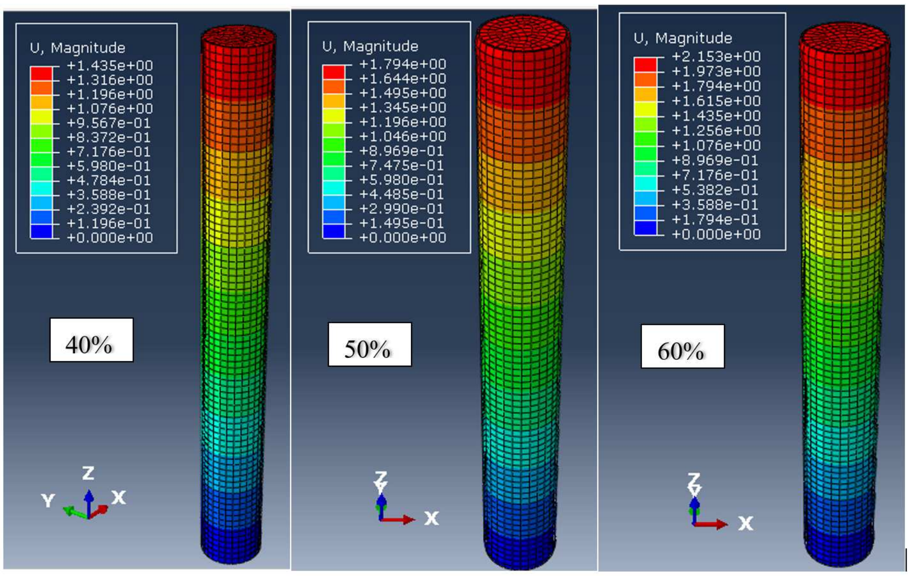
The magnitude of displacement distribution in parts of the composite column is showed in Figure 10, 12 and 15 (b). This figure has three patterns that show the displacement under axial load level at 40%, 50% and 60% from left to right respectively. it is observed that the member is more displaced around section close to points of load application or at the top edge of the column. Here is the maximum magnitude of displacement under 40% of axial load that has occurred at the top which is 1.435mm. Member displacement gradually decreases from top to bottom and negligible at the bottom end of the column which is fully fixed support which the same condition for load level at 40%, 50% and 60% of load-bearing capacity. In all axial load levels displacement gradually decreases from top to bottom and negligible at the bottom end of the column which is fully fixed support and increase as axial load increases.

As the result, When Concentrated load of 40%P, 50%P and 60%P (where Proposed ultimate load) P=6275.1 kN is axial load capacity of circular composite column) applied on circular composite column, as it recorded from software, stress of Composite column section is 89.68 MPa, 112.1 MPa, and 134.5 MPa as axial load of 2502.84 kN, 3128.55 kN, and 3754.26 kN respectively.

The maximum magnitude of the displacement was recorded 1.345 mm, 1.794 mm, and 2.153 mm for 40%, 50% and 60% of axial load level respectively.

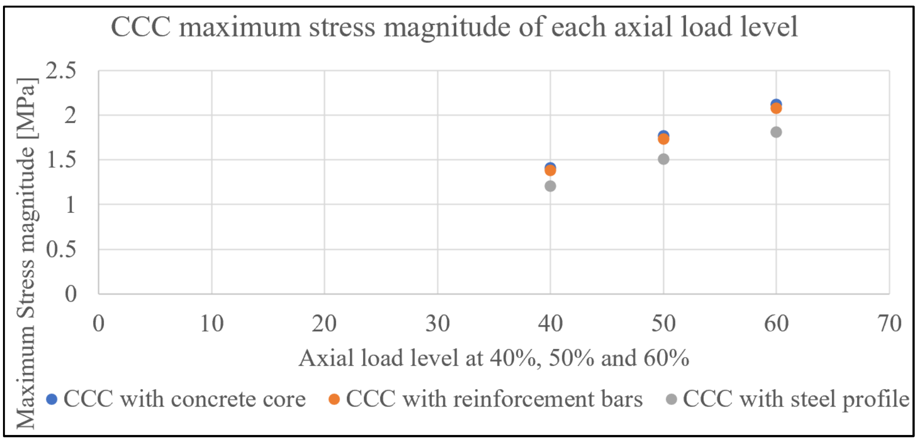


a)



b)

Figure 10. *The Stress and U-Magnitude of CCC with concrete fill under axial load level.*



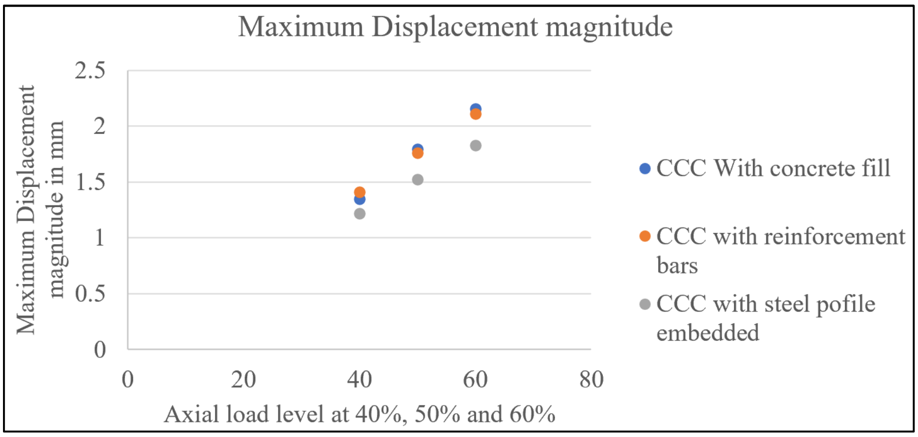


Figure 11. *The Summary result of the CCC under axial load only.*

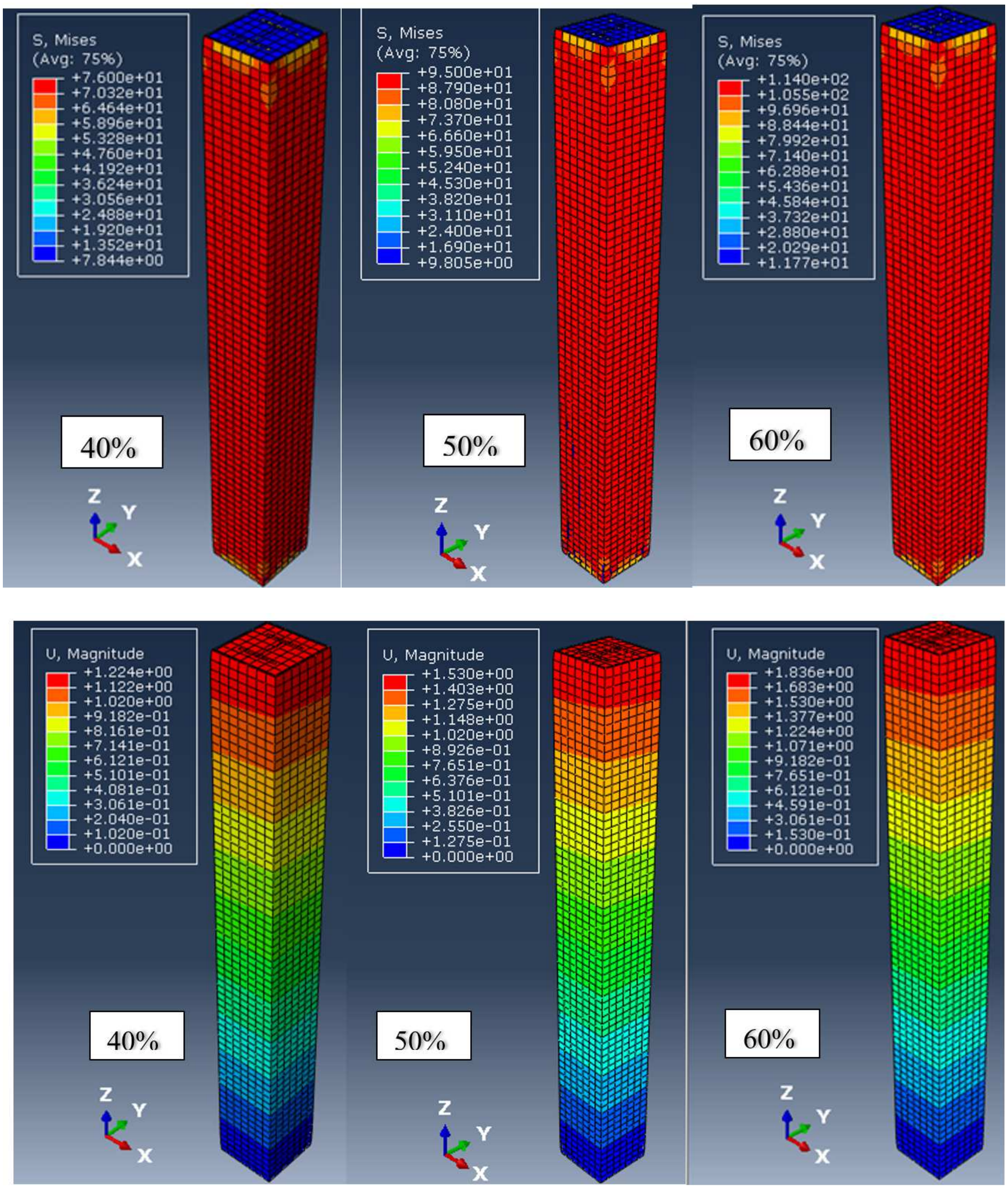


Figure 12. *Square composite column with embedded steel profile at each axial load level.*

From Figure 11, 13 and 14, it's observed that the stress distribution magnitudes are less in CCC, SCC and RCC with steel profile embedded, and it shows minimum displacement (U) under axial load only relatively because of larger normal stiffness (EA) of the section. The circular, square, and rectangular composite column with concrete fill only and with reinforcement embedded in concrete-filled section, it was recorded that the magnitude of displacement [U] is close to each other.

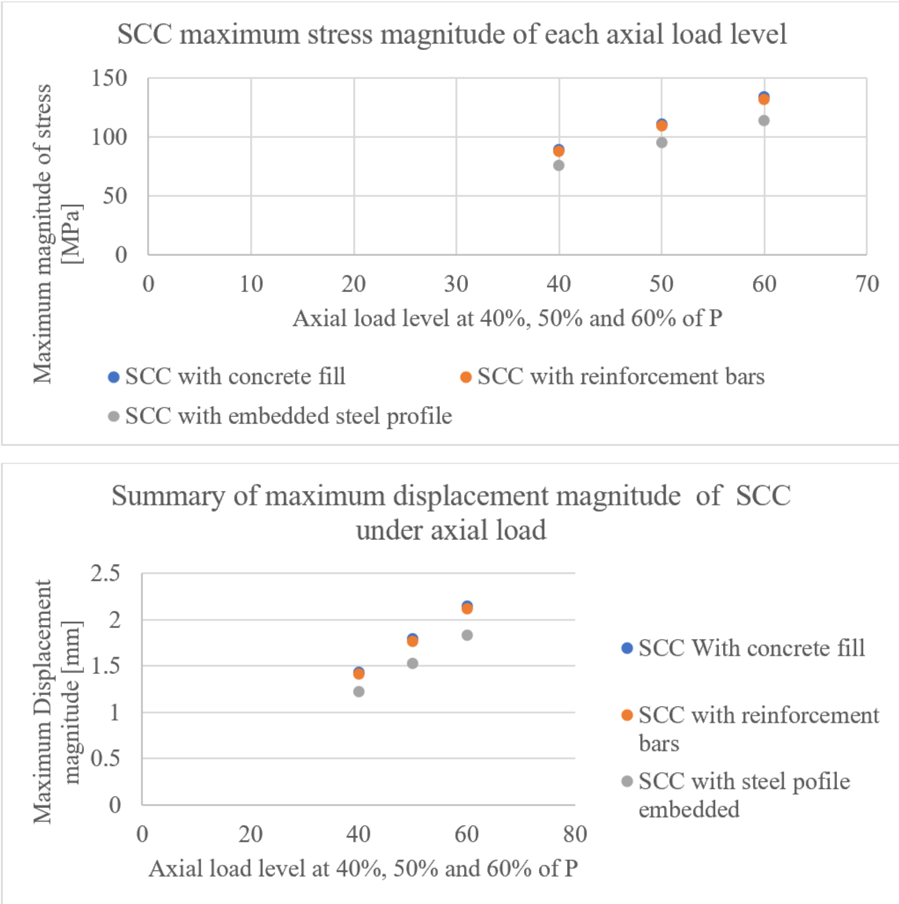
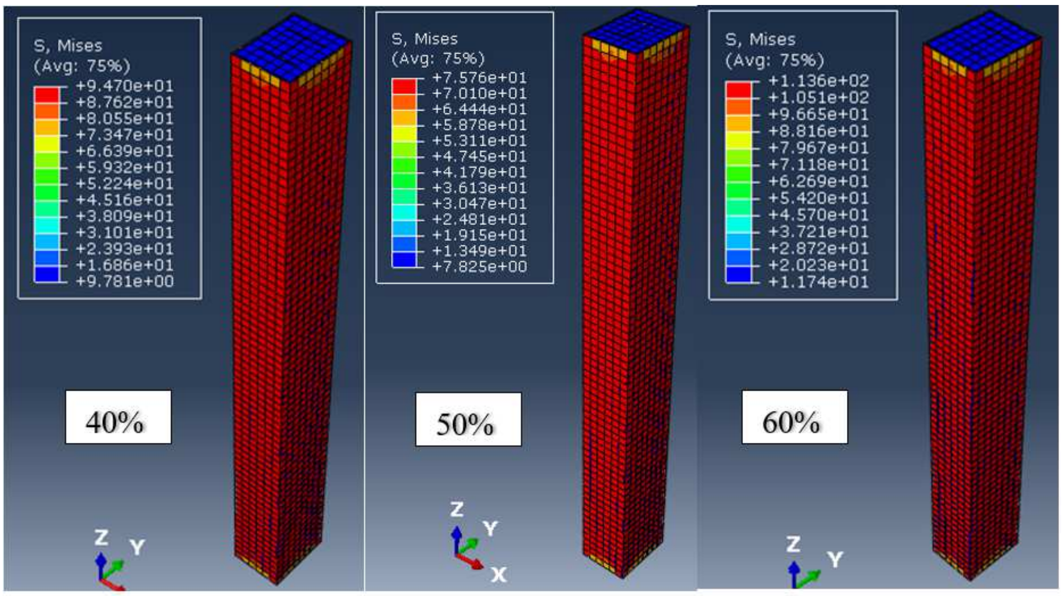


Figure 13. The summary result of the square composite column (SCC) under axial load.



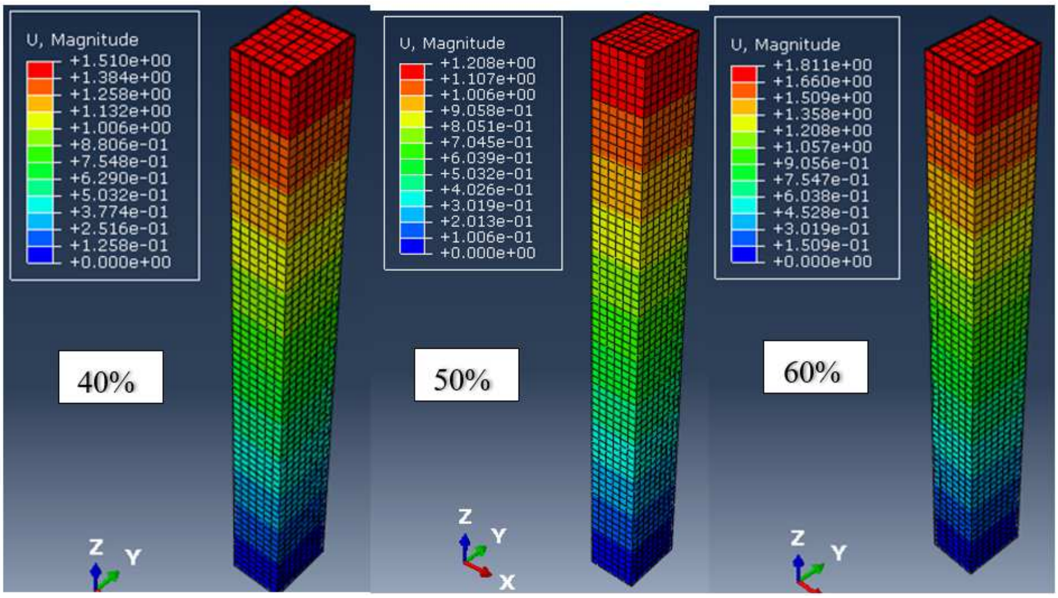


Figure 14. *The summary of result for RCC with embedded steel profile under axial load.*

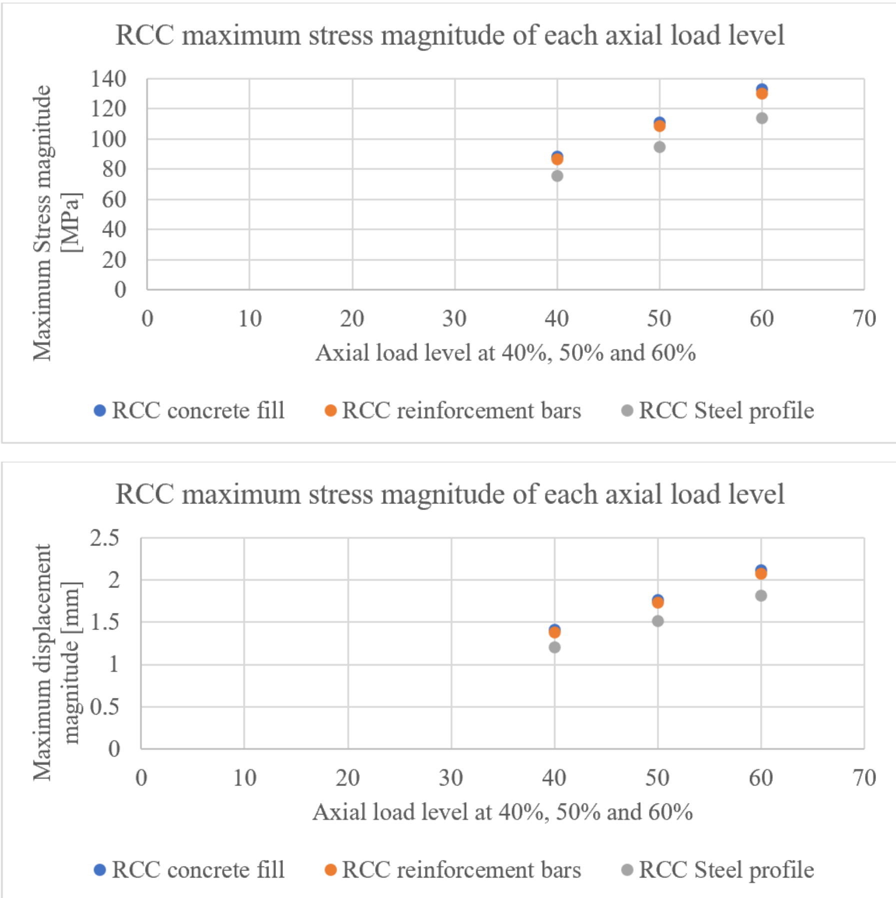


Figure 15. *The summary of stress and U- magnitude for RCC under axial load only.*

5.3. The Parametric Study of Combined Action of Axial and Torsion Loads

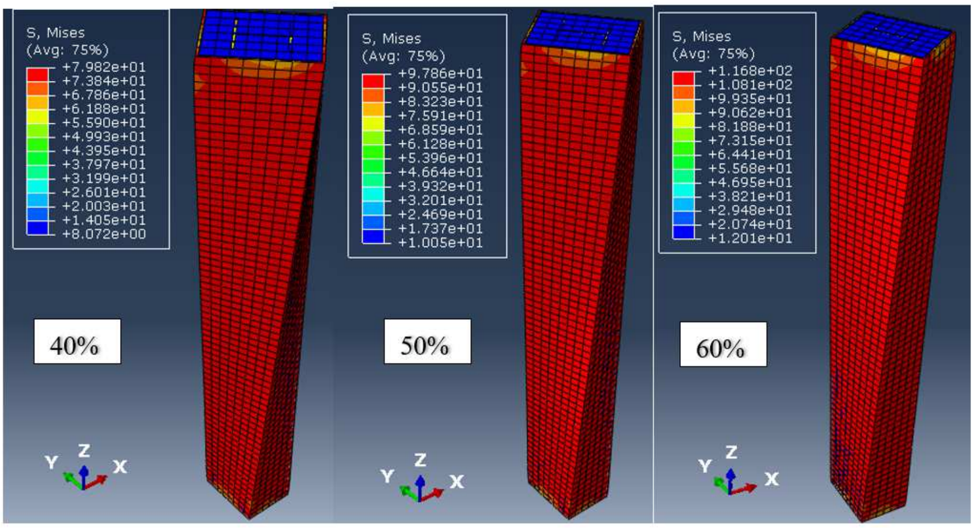
The parametric study of the combined action of axial and torsion load on the composite column is studied based on the numerical result of ABAQUS software for column investigation subjected to axial load and adding constant torsional load to the respective axial load increments. The circular square and rectangular section of the composite column with the circular, square and rectangular section of the steel tube is analyzed and the effect of torsion on the column is studied by using Abaqus software. The parametric study is drawn from software result under combined action of axial and torsional loads, and properly demonstrated by stress and displacement distribution of each combined parts and when acting together. Based on this the following results obtained and discussed in detail. The detail used the magnitude of the axial load level based on the plastic resistance of section.

a. Von Mises stress distribution [S]

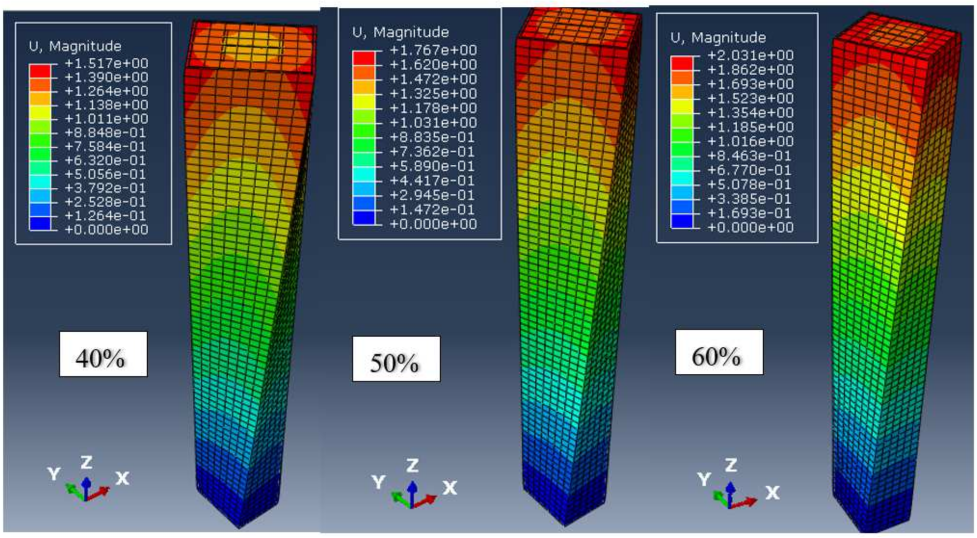
Figure 16 (a) shows the Mises contour color stress distribution from right to left at 40%, 50%, and 60% respectively. The applied Concentrated load of 40%P, 50%P and 60%P (where proposed ultimate load P=6523.33kN is axial load capacity of rectangular composite column) applied on rectangular composite column with constant 60kNm torsional load, As it recorded from software, maximum magnitude of Mises stress of rectangular Composite column section is 79.82MPa, 97.86MPa, and 116.8MPa as axial load of 2609.33kN, 3261.67kN, and 3914.00kN respectively.

b. The displacement magnitude of cross-section [U]

The magnitude of displacement distribution in parts of the composite column is showed in Figure 16 (b) This figure has three patterns that show the displacement under axial load level at 40%, 50% and 60% from left to right respectively. it is observed that the member is more displaced around section close to points of load application or at the top edge of the column. Here is the maximum magnitude of displacement under axial load that has occurred at the top which is 1.517mm, 1.767mm and 2.031mm at 40%, 50% and 60% of axial load level, respectively. Member displacement gradually decreases from top to bottom and negligible at the bottom end of the column which is fully fixed support which the same condition for load level at 40%, 50% and 60% of load-bearing capacity. In all axial load levels displacement gradually decreases from top to bottom and negligible at the bottom end of the column which is fully fixed support and increase as axial load increases.



(a)



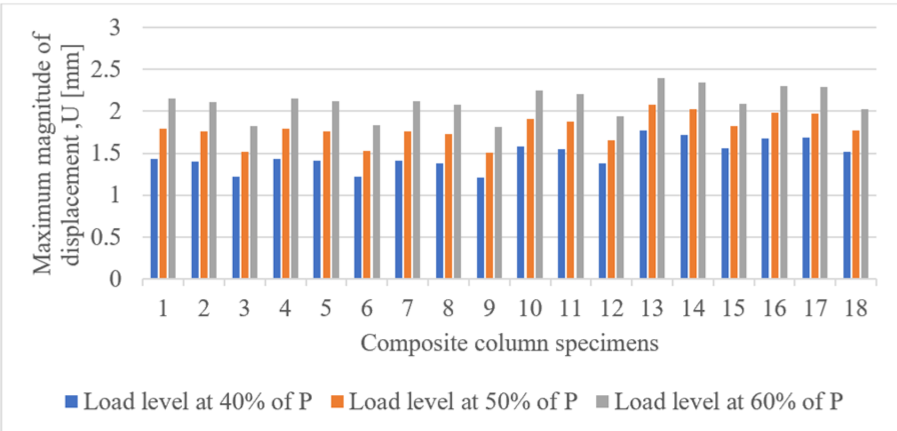
(b)

Figure 16. *RCC with embedded steel profile under each axial load level and torsion.*

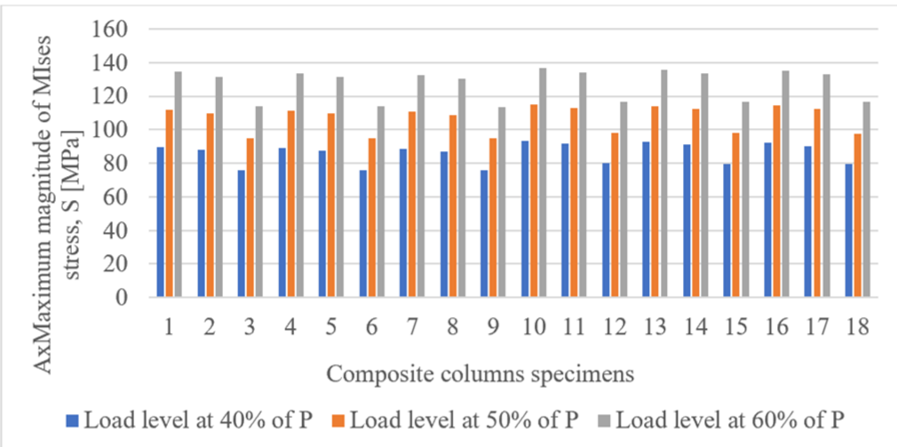
5.4. Comparison of Results for All Specimens

This paper presented eighteen specimens of the composite column under different loading conditions and the summary of the result is given below in Figure 17. These are:

1) Circular composite column (CCC) with concrete-filled subjected to axial load only.
2) CCC with reinforcement bars subjected to axial load only.
3) CCC with embedded steel profile subjected axial load only.
4) Square composite column (SCC) with concrete-filled subjected axial load only.
5) SCC with reinforcement bars subjected to axial load only.
6) SCC with embedded steel profile subjected axial load only.
7) Rectangular composite column (RCC) with concrete-filled under axial load only.
8) RCC with reinforcement bars subjected to axial load only.
9) RCC with embedded steel profile subjected axial load only.
10) CCC with concrete-filled subjected to axial and torsional loads.
11) CCC with reinforcement bars subjected to axial and torsional loads.
12) CCC with embedded steel profile subjected to axial and torsional loads.
13) SCC with concrete-filled subjected to axial and torsional loads.
14) SCC with reinforcement bars subjected to axial and torsional loads.
15) SCC with embedded steel profile subjected to axial and torsional loads.
16) RCC with concrete-filled subjected to axial and torsional loads.
17) RCC with reinforcement bars subjected to axial and torsional loads.
18) RCC with embedded steel profile subjected to axial and torsional loads.



(a)



(b)

Figure 17. *The summary of results for all steel tube composite columns.*

For all specimens in Figure 17, the results of the maximum magnitude of displacement and Von Mises stress were recorded and presented from Abaqus software by specifying the level of axial load. Figure 17 (a) shows the magnitudes of displacement (U) for all specimens. From this, it is observed that specimen number-3, 6 and 9 or CCC, SCC and RCC with embedded steel profile subjected to compression-only are showed better performance from other specimens under compression effect. Specimen from 1-9 shows a composite column subjected to compression only, while specimen 9-18 stands for the composite column under the effect of both compression and twisting. Under both compression and twisting effect, the circular shape section shows over their respected cross-section group type. Example: The circular composite column with concrete-filled, bars and embedded steel profile under both axial and torsional load is better than a square and rectangular composite column with concrete-filled, bars and embedded steel profile respectively under both axial and torsional loads. Ibañez, C., Hernández-Figueirido, D., & Piquer, A. (2021) studied the behaviour of concrete filled steel tube columns and effects of steel tube thickness and different shapes of composite columns. As a result, the mode of failure due to the local buckling in the square and rectangular composite column is less ductility of thin steel tube but shows good performance in circular composite columns relatively with all likewise proportions. [14]

The detail of the performance difference between samples was discussed in the previous section. In general, when the member is subjected to both compression and twisting effect, the magnitude of displacement of cross-section greater than the magnitude of displacement of the cross-section that under compression effect only.

6. Conclusions

This paper investigated the behavior of the circular, square, and rectangular composite column under compression-only and combined compression with torsion separately. The results from the software were validated by referencing previous researcher articles and experimental results. For all specimens, it was investigated the effects of different levels of axial loads at 40%, 50% and 60% of the load-bearing capacity of section applied without torsion loads for circular, square, and rectangular composite column in the first case. Then for all cross-section, constant torsion 60kNm was applied under all levels of axial load by keeping this torsion as constant. Based on the discussed result, the following conclusions can be drawn within the scope of the current study:

1) As axial load level increases by 10% the magnitudes of displacement (U) also increased by 9.2% for all studied composite columns.
2) A circular composite column shows better performance in displacement than Square and rectangular composite column under combined compression and twisting effects by 2.6% and 1.7% under the first and second 10% of the incremental load. The previous researcher also found, The use of high strength concrete results in an increment in the ultimate load and in the concrete contribution ratio of the CFST columns. As regards to the shape effect, the configuration with circular steel tubes provides to be the most efficient, contrarily to the square sections, which presents the poorest ultimate load and indexes values. [2, 3, 4]
3) The circular composite column shows better twisting performance than a square and rectangular composite column by 11.2% averagely.
4) It is found that provision of longitudinal reinforcement increases the performance of the composite column by 2% averagely under compression and torsion. The provision of longitudinal reinforcement and steel profile increases the resistance of the concrete filled composite columns subjected to compression and torsion [2].
5) The twisting of the column under constant Torsion decreases by 33% as the axial load increases by 10% [15].
6) Under the action of axial load, CCC, SCC and RCC columns, as load level increased by 10% the stress distribution also increased by averagely less than 4%.
7) The Steel profile shows better stress resistance than composite column with bars and concrete sections within about 15%.
8) In the case of a composite column with reinforcement bars, the Mises stress distribution is varied widely than steel tube and the concrete section as observed from numerical results.
9) Von Mises Stress distribution magnitudes are decreases in concrete material sections (15%) other than the steel material section (85%).
10) When a member of the composite column subjected to both compression and twisting, the magnitude of displacement is increased than the member subjected to the compression effect only.
11) The concrete-filled steel tube composite column under both axial and torsional loads, the magnitude of displacement (U) increases by 3%, 5% and 5.5% than the member under axial load at level 10%, then 2%, 3% and 3.8% at second level of increment for Circular, square and rectangular composite column respectively.
12) When the diameter of reinforcement bars reduced from 14mm to 12mm the ultimate load capacity reduced by less than 1% for circular, square, and rectangular composite columns with reinforcement bars embedded in the concrete-filled section.
13) The change in plastic resistance of cross-section for circular, square, and rectangular composite column section is by 5.50%, 5.73%, and 5.74% when steel tube strength increased by 10% from 335Mpa to 368.5Mpa respectively.
14) The concrete-filled section plays a vital role in composite columns' strength. When concrete quality is increased by 10% from 25Mpa to 27.5Mpa, the plastic resistance of the composite column is increased by 3.2%, 3.0% and 3.0% for circular, square, and rectangular composite columns by keeping the other parameters constant.

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