NUMERICAL ANALYSIS ON COMPRESSIVE BEHAVIOUR OF STEEL CONCRETE CONFINED CFST COLUMNS

A THESIS SUBMITTED BY

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APPROVAL

The paper titled "Numerical Analysis on Compressive Behavior of Steel Concrete-Confined CFST Columns" submitted by Mohammad Shafin Chowdhury, Md. Farhan Ishraq Hassan and Sadman Fahim Dhruba has been accepted as partial attainment of the requisite for the degree, Bachelor of Science in Civil Engineering.

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DECLARATION

It is hereby declared that this thesis/project report, in whole or in part, has not been submitted elsewhere for the award of any Degree or Diploma.

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DEDICATION

We dedicate this thesis to our parents, whose unwavering support, time, and effort have been crucial in shaping our achievements. Their profound dedication and belief in our abilities have empowered us to pursue our technical goals with confidence and determination. We express our deepest gratitude for their immeasurable sacrifices and steadfast support.

We also extend our sincere appreciation to Dr. Md. Imran Kabir, our esteemed supervisor, for his relentless encouragement, insightful guidance, and motivational support. His expert supervision has been pivotal to the success of this research project, and without his dedicated assistance, this endeavor would not have been possible.

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ABSTRACT

This thesis uses numerical analysis to assess the behavior and material properties of Concrete-Filled Steel Tube (CFST) columns reinforced with enclosed steel features. This study utilizes non-linear finite element analysis with ABAQUS CAE 6.14 to predict the behavior of CFST columns, drawing ideas from Zhang et al.[1] Four specimens were simulated and subsequently subjected to axial compression in order to match the numerical models with the experimental data. In order to ensure the accuracy of the model, essential parameters such as ultimate axial strengths, axial load-strain curves, and deformation patterns were carefully matched. The study extensively examined the strength and ductility of CFST columns by several parametric studies on parameters such as the ratio of diameter to thickness, compressive strengths of concrete, and yield strengths of steel. Furthermore, the deformation of the simulated columns, which closely matched the deformations observed in the tested specimens, was examined to verify the accuracy of the numerical models in accurately predicting the structural response of CFST columns under axial stress.

This thesis provides important information about the geometric and material factors that affect the performance of CFST columns as well as their structural performance.

CHAPTER 1: INTRODUCTION

1.1 Background

In structural engineering, the usage of concrete-filled steel tubes (CFST) presents a possible development. In many building instances, these tubes offer a convincing substitute for the more common reinforced concrete (RC) and steel columns. Not only does the incorporation of concrete infill into steel tubes improve the structural efficiency of the structure, but it also offers a variety of performance advantages that are essential for meeting the requirements of current infrastructure development. Reduced susceptibility to buckling, increased stiffness of the steel tube, enhanced fire resistance, higher compressive strength due to confinement effects, superior bearing capacity, durable seismic performance, and minimized shrinkage and creep impacts are some of the advantages that are associated with this material [2], [3], [4], [5], [6], [7], [8].

Additionally, CFST columns provide considerable economic benefits by acting as permanent formwork during the construction process which is a huge advantage. Since the concrete core uses the steel tube as both lateral and longitudinal reinforcement, It removes the need for further reinforcement and improves the building processes [3], [9]. Conversely, the geometric arrangement of CFST columns has a major influence on their efficiency. Regarding circular CFST columns, the confinement effects are enhanced since the concrete experiences equally distributed confining forces over the section. inversely, non-circular CFST columns are more likely to undergo separation of the core concrete and steel tube, which would cause complete structural collapse [3], [9]. In addition, variations in Poisson's ratios between concrete and steel can cause local buckling of the steel tube when it is compressed, which brings to light the complex difficulties that are involved in the design of CFST columns [10].

In recent experimental study, CFST columns have not been fully explored, particularly in terms of their compressive behavior under axial loads. This is despite the fact that they have a number of advantages due to their construction. Experimental studies were carried out by Zhang et al. on regular square CFST short columns. These tests demonstrated better confinement effects, but they also revealed limitations in existing CFST column designs due to the lack of experimental data [1]. As a consequence of this, there is a considerable gap in knowing the comprehensive compressive behavior of steel-concrete constrained CFST columns, which implies that strong numerical research is required to fill this hole. The fundamental purpose of this thesis is to create sophisticated finite element models in order to simulate and study the compressive behavior of steel-concrete constrained CFST columns in a complete manner. A parametric study will be conducted, looking at a great range of geometric and material properties. These parameters will include the diameter of the column, the thickness of the wall, the ratio of slenderness to thickness, the ratio of diameter to thickness, the impacts of local flaws, and residual stresses. This study's objective is to deliver an explanation of the impact that these characteristics have on the structural performance of CFST columns and to optimize the design criteria for these columns by systematically altering these parameters. The use of finite element modeling has become increasingly popular in the field of structural analysis, particularly for the purpose of recreating the detailed interaction that occurs between the steel and concrete components that make up CFST columns. Detailed modeling of composite actions, boundary conditions, residual stresses, and defects can be accomplished with the help of commercially available software packages such as ABAQUS [6], [11], [12]. However, the models that are now in use might need to be improved in order to improve the accuracy of their predictions and to meet the ever-changing material properties and design constraints. In addition, the limitations of traditional RC, steel, and plain concrete columns will be evaluated rigorously in this study project in comparison to the constraints of CFST columns. In order to obtain comparable strength and stiffness to CFST columns, RC columns frequently require large quantities of additional reinforcing. This results in an increase in construction costs and increase in the complexity of the construction process. Although steel columns offer a great level of strength, they may be susceptible to fire and corrosion if they are not adequately protected. Conventional concrete columns, despite their cost-effectiveness, typically possess a lower strength and necessitate bigger cross-sectional dimensions in order to fulfill the necessary performance standard. The combination of steel and concrete, two essential building materials known for their strength and longevity, results in Concrete-Filled Steel (CFS) structures, which are especially common in high-rise structures around the world.

This thesis aims to significantly contribute to the progress of information about the behavior of CFST columns when they are compressed by means of detailed numerical simulations. This study intends to help to develop structural solutions more efficient and lasting for building projects. This will be accomplished by addressing the constraints of existing structural systems and optimizing the design of CFST columns. The purpose of this part is to present a detailed review of CFST columns, to emphasize the advantages that these columns have over standard column types, to examine the gaps that exist in the current research, and to define the intended outcomes of thesis.

1.2 Objectives of the thesis

This research explores the complex structural dynamics of Concrete-Filled Steel Tube (CFST) columns using a non-linear finite element analysis. It seeks to understand the resilience and efficiency of CFST columns in modern construction. The objectives of the study are to:

- Develop a three-dimensional FE model and validate it against test results.
- Examine variations in the mechanical characteristics of Concrete and steel
- Consider the impact on compressive strength and stiffness caused by the confinement effect of the steel tube on the concrete core of CFST columns.
- Using parametric analysis, finding out how various concrete strengths affect the behavior of CFST columns.
- Determine the maximum load capacity and stiffness of CFST columns by analyzing the influence of different steel tube thicknesses using finite element models
- Analyze how various loading patterns affect the CFST column's behavior.
- Identify promising areas for future study and development in the fields of CFST columns, comprising developments in material science, building procedures, and computational modelling tools.

1.3 Outline of the Thesis

Chapter 1 presents a summary of CFST columns, emphasizing their structural benefits, design specifications, and consequently, the necessity for thorough finite element analysis to anticipate their response to axial compression.

Chapter 2 provides an overview of previous research conducted on reinforced concrete (RC) and steel columns, with a specific focus on experimental studies and theoretical models that assess their structural performance, fire resistance, and corrosion resistance.

Chapter 3 provides a comprehensive explanation of how to construct finite element models using ABAQUS CAE 6.14. This includes the process of creating elements and assembly, describing materials, meshing, defining surface interactions, and boundary conditions.

Chapter 4 represents comparison among the axial load-strain curves of CFST columns with a verification investigation based on expected ultimate axial strengths. .

Chapter 5 provides a comprehensive parametric analysis that investigates the impact of modifications in geometry and material on the strength and ductility of CFST columns. The study analyses parameters including tube thickness, diameter, material yield strength, and concrete compressive strength.

In Chapter 6, a comprehensive summary of the main findings has been provided. This includes an analysis of how different parameters affect the performance of the column. Additionally, suggestions for future research have been made to address areas that need further investigation.

CHAPTER 2: LITERATURE REVIEW

2.1 General

Both steel and concrete are essential building materials that have been used individually or in combination in a variety of historical construction projects. Composite structures, however, combine the advantages of both steel and concrete. A specific type of composite column is the Concrete Filled Steel Tube (CFST) column. Composite columns have developed significantly over time, beginning with Reinforced Concrete (RC) columns and progressing to the more complex double layered CFST columns. Each step of this evolution has improved structural integrity and durability, thus fixing the shortcomings noted in previous designs [2], [3].

2.2 Research on RC columns

Fifteen reinforced concrete columns measuring twelve inches (305 mm) square and nine feet (2.74 m) long were subjected to extensive flexural testing in order to cause significant inelastic deformations when subjected to a constant axial load. The study revealed a reduction in the compressive strength of concrete under flexural loading as the axial load increased. Several columns whose lateral reinforcement levels were approximately 50% below the seismic design requirements could not meet the estimated theoretical moment capacity for unconfined sections. However, increasing the quantity of lateral steel would substantially enhance the flexural behavior of a structural section [8].

2.3 Research on Steel Columns

There have been numerous studies on steel columns. One such research involved the construction of 12 columns made of high-strength carbon steel in order to evaluate the buckling behavior of the columns. One of the main goals of the study was to simulate inelastic local buckling in slender columns as accurately as possible, which showed significant ductility limitations [13].

2.4 Research on Conventional CFST columns

A review study highlighted chronological order of the development Concrete-Filled Steel Tube (CFST) columns and mentioned China's pioneering role in this regard. Several studies have investigated CFST columns. In 1966, CFST columns were first used instead of reinforced concrete (RC) or steel columns for the building of subway columns in Beijing and Tianjin. This creative method was then applied to several infrastructure projects throughout the globe, such as the Petronas Towers in Kuala Lumpur (1998), the Wang-Chang East River Bridge in Sichuan (1992), and the World Trade Center in New York (1971) [3].

CFST combines the structural benefits of both RC and steel, resulting in more effective construction by diminishing the requirement for formwork during the concrete casting. These columns come in two different types: the round ones are better at confinement and resisting local buckling, and the rectangular ones strengthen beam-to-column connectivity, have better bending stiffness, and appear aesthetic in architectural designs. Even with its effectiveness, design principles based on Chinese research may not be applicable in all global circumstances, thus further study is needed to optimize CFST structures. One of the main goals is to reduce the thickness of steel tubes without reducing structural integrity or bending stiffness in order to achieve lower weight [2], [3] .

Consequently, in order to improve the quality of CFST columns, a study was conducted. In that research both experiment and finite element analysis (FEA) were used to analyze 36 specimens of concrete-encased square stub CFST columns that were subjected to axial compression. In order to compare the load-deformation behaviors of RC columns, conventional CFST columns, and concrete-encased CFST columns, a detailed comparison was carried out. From that study it was concluded that extensive research is needed on columns having different concrete strength [4]. Similarly, a numerical study on axial loading conditions used 689 experimental datasets to validate 126 finite element models. It was observed that normal strength steel (NSS) and concrete (NSC) had more confinement effect. However, when high-strength concrete (HSC) was introduced instead of NSC, this impact was greatly reduced [14]. A comparable study involved 18 circular CFST columns categorized by different sizes. This study also pointed out the brittleness of high-strength concrete and recommended the use of thicker steel tubes as a preventative measure [15]. In a similar way, 8 specimens were selected for a numerical analysis study. However, the research lacked the inclusion of a wide range of geometric and material properties necessary for a comprehensive parametric study [6]. Both circular CFST columns and rectangular ones were tested in another study, encompassing a dataset of 124 cases that only focused on short and compact columns [16]. In order to assess how concrete strength and cross-sectional shape affect the load-bearing capacity of the columns, another research conducted on 12 concrete-filled steel tubes (CFST) with different cross-sections that were filled with normal strength and high-strength concrete. The capacity to bear loads was higher in circular ones compared to other columns. One important finding was that, in comparison to standard strength concrete (NSC), high-strength concrete (HSC) columns had a greater load bearing capacity but less ductility [9]. Additionally, in another study the main finding was the result of concentric compressive load on 12 stub columns and 12 slender columns. The load capacity of those CFST columns were increased by higher hoop stress, and the stub columns had higher ductility than slender ones. Nevertheless, eccentric loading conditions, which are prevalent in real-world applications, were not taken into account in that study. Furthermore, there was no discussion of the impact of geometric imperfections on the buckling effect of slender columns [17]. The goal of a study conducted on the basis of finite element method was to improve the design process for CFST columns under bi-axial loads to 240 cases. The study's shortcomings were decrease in the ultimate load-bearing capacity as a result of greater eccentricities and lesser column capacities associated with higher slenderness ratios [18] . In a similar process, Finite Element Analysis (FEA) and experimental analysis were conducted on 11 specimens to thoroughly examine high-strength circular concrete-filled steel tubular (CFST) columns under both concentric and eccentric loading conditions. In particular, it addressed how partial confinement effects lead to increased strength in columns with a D/t ratio of 25. Furthermore, the study observed that CFST columns filled with concrete of lower strength exhibit more ductility than those filled with concrete of higher strength. The results of the study showed that buckling strength did not significantly decrease under axial loading conditions. On the contrary, columns with D/t ratios between 40 and 100 did not show the same rise in moment under eccentric loading as columns with a ratio of 25. The behavior of CFST columns under eccentric loading conditions, especially those having higher D/t ratios and high-strength materials, is one significant drawback of the study that should be noted [19]. From the above mentioned research works, it is understandable that parametric study, over a wide range of parameters including geometric properties, material properties, loading conditions, geometric imperfections, is a must to overcome the limitations.

Furthermore, in some studies validation was not accurately done. For instance,142 circular high strength CFST specimens were the subject of a study where during validation, the post peak phase was not in line with the experimental results [11]. To mitigate this issue, a prominent study included the use of corrugated steel tube. The outcome depicted decreased axial stress, enhanced ductility, and little strength loss during the post-peak phase. Corrugations efficiently redistributed forces inside the tube by concentrating stress at certain locations, improving the tube's functionality under axial compression [20]. As a conclusion, it can be said that accuracy of a validation process of numerical models should be done carefully so that parametric study can be conducted reliably upon the validated numerical models.

2.5 Research on double layered CFST columns

In a recent research done in 2022, circular steel tube confined CFST columns were suggested as a feasible solution for the disadvantages of conventional CFST columns. A test was conducted using axial compressive force on twelve conventional square CFST short columns and twelve circular steel tube-confined columns. These tests' findings indicated that the outer circular steel tube adequately covered the inner square CFST from the outside, significantly improving bearing capacity while minimizing the risk of brittle failure. Furthermore, the constraint of the outer steel tube promoted a more uniform distribution of stresses throughout the square CFST, reducing stress concentrations and improving overall structural performance.

Nonetheless, a number of limitations were found out. Even if the square steel tube was effectively confined, the overall structural efficiency may be compromised by the unequal distribution of sandwich grout at its corners. In addition, the research was conducted on axial compressive loads, which means that additional study to cyclic, eccentric, and dynamic loading conditions is required. Furthermore, there is potential for numerical analysis because this was an empirical study. Numerical datasets would need to be validated against experimental data for that to proceed. Due to the small number of tested columns, a parametric study could subsequently explore a wide variety of parameters, that include material properties (such as the yield strength of steel and the compressive strength of concrete) and geometric properties (such as the diameter-to-thickness ratio, length variations, and the effects of column slenderness). Through employing that approach, the findings would be more accurate and applicable to a wider range of loading conditions and structural configurations [1].

CHAPTER 3: FORMATION OF THE FINITE ELEMENT MODEL

The primary objective of the research was to improve the understanding of steel-concrete confined CFST (Concrete-Filled Steel Tube) columns, which are essential structural element that is well-known for its durability and capacity to withstand loads. ABAQUS 6.14, a versatile software package that is well-known for its capabilities in simulating complicated structural behaviors, was utilized in the research project to help with the application of advanced 3D finite element modelling methodologies. The investigation was based on experimental data previously gathered by Zhang et al. [1], which served as a reliable base for developing and validating finite element models. The traditional square CFST columns were precisely recreated in these models to attain the intended outcomes. The building of each type of column involved the use of a circular design model, where steel tube confinement was placed around concrete cores. The models were arranged into distinct groupings with the following names: T26, TB26, T28, and TB28. This was done so that the structural performance could be systematically investigated across a variety of configurations. Every grouping consisted of three separate specimens, each of which had been precisely created with standard criteria that were identical. This comprehensive categorization made it possible to conduct a comparison analysis, which in turn made it possible to identify the subtle effects that various design variables and geometric features have on the mechanical behavior of the columns. The study's importance lies in the fact that it may provide useful data for enhancing the design and performance of CFST columns for real-world applications. The research attempted to improve the structural efficiency of CFST columns in a variety of engineering scenarios by capitalizing on computational simulations that were founded on empirical data. This was done in order to enrich the design approaches that were already in place.

Furthermore, the outcomes of these simulations possess the capacity to direct the advancement of structural engineering techniques, resulting in the development of infrastructures that are more durable, secure, and capable of withstanding a broader spectrum of operational and environmental pressures.

Group	Specimen	Inner tube dimensions ($D_1 \times t_1$) (mm × mm)	Outer tube dimensions ($D_2 \times t_2$) (mm × mm)	Concrete	Steel	
					E_s (GPa)	f_y (MPa)
T26	T26-1	142.7 × 2.03	217.1 × 2.03	C60	184	357.0
	T26-2	142.7 × 2.03	215.2 × 2.05			
	T26-3	142.7 × 2.02	216.3 × 2.04			
TB26	TB26-1	142.7 × 2.01	270.0 × 2.05		196	378.9
	TB26-2	142.7 × 2.02	272.0 × 2.05			
	TB26-3	142.7 × 2.03	271.1 × 2.03			
T28	T28-1	142.7 × 2.02	217.1 × 2.05	C80	184	357.0
	T28-2	142.7 × 2.04	216.6 × 2.04			
	T28-3	142.7 × 2.05	216.5 × 2.04			
TB28	TB28-1	142.7 × 2.01	269.6 × 2.03		196	378.9
	TB28-2	142.7 × 2.02	269.2 × 2.04			
	TB28-3	142.7 × 2.03	270.1 × 2.05			

Table 1: Description of the specimens

3.1 Nomenclature of specimens from Zhang et al [1]

Extensive information regarding the specimens that were utilized in the research is shown in Table 1. This information is necessary for understanding the structural properties and the experimental equipment. The nomenclature system that is utilized in the process of identifying these specimens refers to the utilization of specific symbols. The prefixes "T" and "TB" are used to differentiate between tubed CFST members, with "TB" signifying specimens with a greater diameter. The numbers that come after that, such as "2" and "6" or "8," denote other characteristics of the specimens under consideration. As an illustration, the number "2" represents a square steel tube that has a thickness of 2 millimeters, but the numbers "6" and "8" correspond to specimens that have core concrete strengths of C60 and C80, respectively. Within each test group, the trailing numbers "1, 2, and 3" serve to differentiate between specimens that are identical to one another.

The physical dimensions of the steel components are extremely specific. For the square steel tube, "D1" represents the length of one side, and for the circular steel tube, "D2" defines the diameter. Two of these dimensions are extremely informative. Important mechanical qualities, such as the yielding strength (fy1 for square steel tubes and fy2 for circular steel tubes) and thickness (T1 for square steel tubes and T2 for circular steel tubes), are also provided. All of these properties are important. Defining the structural integrity and load-bearing capacity of the CFST columns that are the subject of this inquiry requires these criteria to be considered crucial. Furthermore, it is worth noting that the steel ratios, which are represented by the symbol α1 for square steel tubes and α2 for circular steel tubes, contribute significantly to the determination of the confinement efficiency and overall behavior of the CFST columns. The amount of steel reinforcement in relation to the core of the concrete is quantified by these ratios, which have an effect on a variety of parameters including ductility, strength, and resistance to deformation when loads are applied.

To summarize, the experimental setup and structural characteristics of the CFST column specimens examined can be better understood with the help of the detailed specifications provided in Table 1. This data is useful for a number of reasons related to the research endeavor, including validating numerical simulations and comparing them to experimental circumstances.

3.2 Parts and Assembly

For the purpose of conducting an in-depth investigation into the structural behavior of CFST (Concrete-Filled Steel Tube) columns, comprehensive finite element models were constructed specifically for this research. Four unique deformable components were painstakingly included into the model in order to represent the situations that would be encountered in the real world. The concrete core is strategically positioned as the key structural element that is responsible for bearing the primary loads, and it is located at the extremely center of each and every model. This core is surrounded by an inner layer of carbon steel, which serves to strengthen the reinforcement and increase the column's overall structural strength. An additional layer of sandwich grout infill is used to reinforce the assembly. This layer is carefully positioned to strengthen the structural integrity of the assembly and to guarantee that the component materials interact cohesively with one another. Within the context of a wide range of loading situations, this layer is an essential component in the process of stress distribution and the enhancement of overall performance. The entire assembly is covered in an outer tube made of stainless steel, which has been purposefully constructed to completely enclose the specimen. For the purpose of simulating actual loading circumstances, stiff loading plates with dimensions of 200 millimeters x 200 millimeters x 20 millimeters were carefully positioned at the top and bottom of every model. These plates are designed to uniformly distribute loads that are applied and to accurately imitate the boundary conditions that are encountered in applications that take place in the real world. The components were brought into harmony by bringing their centers of gravity into alignment with one another. In order to locate the CFST part occurrences, reference points were established on the centers of the near sides of the plates. Figure 1 shows the models' shapes:

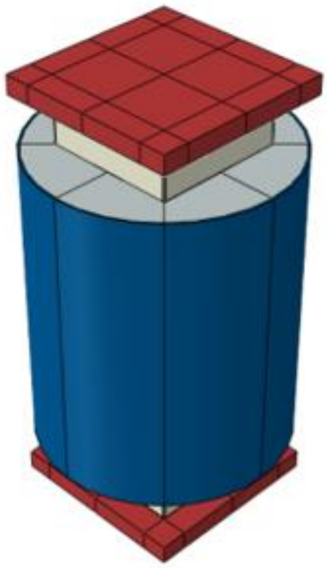

Figure 1: Assembled Model

Not only does the configuration and integration of these components inside the finite element models strive to duplicate the physical behavior of the system, but it also aims to permit extensive analysis of stress distribution, deformation characteristics, and overall structural response. As a result of this technique, valuable insights into the performance and optimization of CFST columns are provided, which contributes to improvements in structural engineering procedures and enhances the resilience of developed infrastructures.

In conclusion, the finite element models that have been mentioned are an example of a methodical approach to the research of CFST columns. This method makes use of modern simulation tools in order to investigate the mechanical behavior of these columns under realistic situations. For the purpose of expanding our understanding of CFST columns and their use in contemporary structural design and engineering techniques, these models serve as a basic tool.

3.3 Material Model

3.3.1 Steel

The model comprises parameters that characterize the elastic and plastic behaviors of the material. These behaviors are defined for the material. When considering the elastic phase, it is important to emphasize two key parameters: Young's modulus (E) and Poisson's ratio (v). In this context, a particular value of $\nu = 0.3$ is taken to be the value. These parameters determine the manner in which the material deforms elastically when subjected to stress, hence providing foundational properties utilized in structural analysis. Furthermore, these elements are vital since they govern the beginning of deformation in the material, which is essential for comprehending how the steel reacts when it is stretched past its elastic limit. The plastic behavior was characterized by defining the yield stress and the corresponding plastic strain. The model proposed by Tao et al. [11] is expressed as follows:

$$\sigma = \begin{cases} E_s\varepsilon & 0 \le \varepsilon < \varepsilon_y \\ f_y & \varepsilon_y \le \varepsilon < \varepsilon_p \\ f_u - \left(f_u - f_y\right) \cdot \left(\frac{\varepsilon_u - \varepsilon}{\varepsilon_u - \varepsilon_p}\right)^p & \varepsilon_p \le \varepsilon < \varepsilon_u \\ f_u & \varepsilon \ge \varepsilon_u \end{cases} \tag{1}$$

One important difference between high-strength and normal-strength steel that is highlighted by statistical research cited in the paragraph is that the former shows less strain hardening. This property is crucial for design considerations since it influences a material's plastic deformation threshold, which in turn impacts the material's ductility and structural robustness.

In conclusion, the section emphasizes how crucial it is to accurately simulate the behavior of steel in both elastic and plastic settings, paying special attention to the ways in which various steel strengths and modelling techniques affect the resilience and structural performance of steel structure in real world conditions.

3.3.2 Concrete

First and foremost, the model that was suggested by Tao et al. [11] is utilized for the concrete material here. This model is based on the Concrete Damaged Plasticity framework, which is a well-established technique in the field of structural engineering that accurately describes the nonlinear behavior of concrete under a variety of stress circumstances. In order to simulate how concrete reacts under compression, tension, and shear, it is essential to use this model. It takes into consideration issues such as strain softening and strain hardening. The material model is designed to follow the technique that Tao et al. developed for circular CFST columns. This approach is specifically created for the sandwich grout infill in CFST columns. This model takes into account the unique interaction that occurs between the steel tube and the core concrete. The core concrete undergoes lateral expansion before being effectively restricted by the steel tube while it is subjected to axial compression. In addition to considerably improving the concrete core's strength, this passive confinement process also makes it significantly more ductile. The core concrete itself is constructed using a modified version of the model developed by Tao et al. for square CFST columns. Zhang et al. made the necessary adjustments to this model. This modification most likely comprises changes that are specific to the geometry and loading properties of square CFST columns, which guarantees more accurate simulation results. In order to successfully execute the concrete damaged plasticity model within the ABAQUS simulation environment, it is necessary to have certain important parameters, including the three following: In the context of loading, the dilation angle (ψ) is responsible for regulating the volumetric expansion or contraction of the concrete. The strain softening/hardening rule describes the manner in which the stiffness of the material shifts in response to an increase or decrease in strain. The ratio of the second stress invariant on the tensile meridian to that on the compressive meridian (Kc) is a factor that influences the anisotropic behavior of concrete in a variety of stress states. eccentricity of the flow potential (e): Describes the imbalance within the flow.

When it comes to structural engineering, having a solid understanding of how concrete behaves when it is compressed, particularly when it is contained by steel tubes, is essential because of the implications it has for both its strength and its ductility. In order to accurately replicate the stress-strain relationship (σ–ε) under such conditions, researchers have conducted significant research on this phenomenon and created numerical models.

The three-stage model that was presented by Tao et al. [11] is a significant addition that has been made throughout this discipline. This model provides a comprehensive framework that is capable of properly capturing the complicated behaviors of concrete that is subjected to compression while they are contained within steel confinement.

The initial linear elastic response of the concrete is the first thing that the model takes into consideration. This stage is characterized by a linear increase in strain with stress, and it is during this stage that the material undergoes elastic deformation in response to the stress that is applied.

In the second place, strain hardening occurs in the concrete when the stress continues to build beyond the limit of its elastic properties. During this phase, the material increases in stiffness and strength as a result of microcracking and other internal causes. This phase is characterized by an increase in stiffness. The behavior of strain hardening is extremely important because it improves the capacity of the concrete to support higher loads before it reaches its final failure point.

the model takes into account strain softening, which takes place as the concrete gets closer and closer to breaking. The steady deterioration of the material's mechanical characteristics is represented by the phenomenon known as strain softening, which refers to a drop stress that occurs in conjunction with an increase in strain. This stage is crucial since it marks the beginning of the material's instability and the eventual collapse of the material when subjected to sustained compression. In particular, the three-stage model developed by Tao et al. [11] stands out due to its capacity to effectively describe the complex phases of concrete behavior that occur when the material is contained. This model also offers insights into the manner in which steel tubes improve the ductility and strength of concrete buildings. This model helps engineers to forecast and optimize the performance of concrete-filled steel tube (CFST) columns and other structures that are similar to them under a variety of loading circumstances. This is accomplished by adding parameters that govern elastic, hardening, and softening behaviors.

3.4 Meshing

the process of conducting mesh convergence studies in finite element (FE) analysis in order to discover the ideal mesh design for producing simulation results that are accurate and efficient. When performing finite element analysis (FE analysis), selecting the appropriate mesh is of utmost importance in order to achieve dependable numerical results while simultaneously reducing the amount of computational resources required. As part of the research, the 'C3D8R' element was deployed. This element is a hexahedral element with eight nodes that was developed specifically for three-dimensional analysis. When modeling complicated structural processes, this element is recommended because of its reduced integration, which achieves a compromise between the computing efficiency and accuracy of the modeling process. In order to determine the best mesh size, the researchers went through a series of trials in which they adjusted the element sizes across the course of the entire model. The objective was to locate a mesh design that would produce results that were sufficiently accurate without requiring an excessively fine resolution, which would lead to an increase in the amount of computational work required. Throughout the course of the tests, each component of the model was given the same element size in order to preserve uniformity and guarantee that the findings would be compared in an objective manner. It is possible to have a better understanding of how the accuracy and convergence of simulation results are affected by the varied mesh densities by using this approach. Following a series of tests, the research came to the conclusion that a mesh size of twenty millimeters was the most suitable for the complete model.

The mesh was found to be fine enough to capture critical elements of the structural response, but not so fine that it brought about an undue increase in the amount of time required for computing. This size was determined to establish a balance between the two extremes. The mesh for one model is represented in Fig. 2:

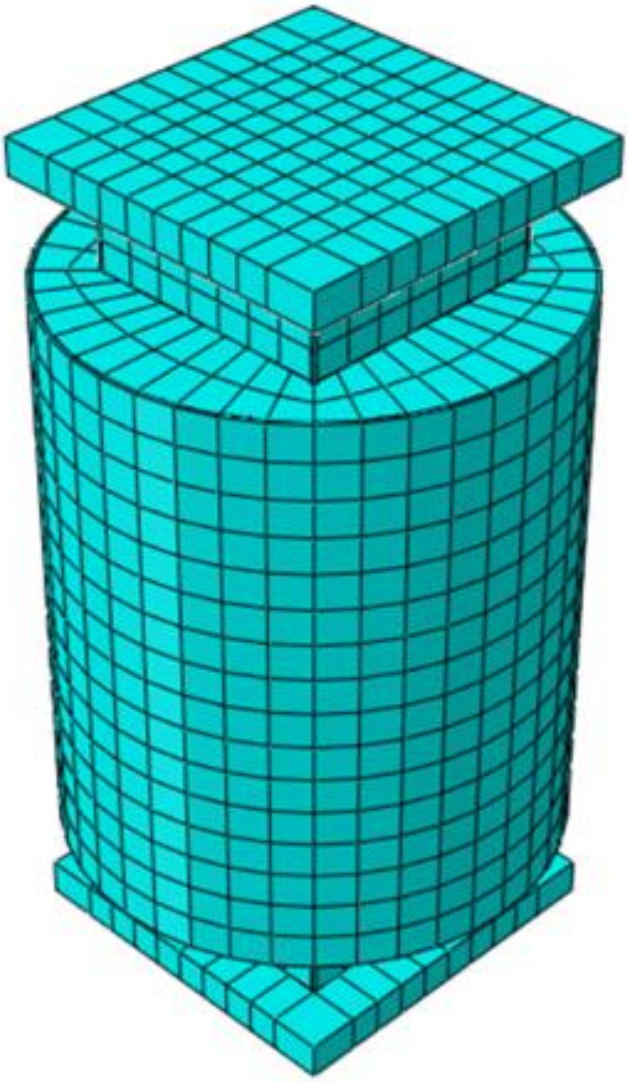

Figure 2: Mesh of a Column Specimen

As a whole, the procedure that was explained emphasizes how important mesh integration studies are in the field of energy transfer research. Engineers are able to confidently pick a mesh configuration that optimizes both accuracy and computing efficiency by methodically adjusting mesh parameters and analyzing their impact on outcomes. This, in turn, ensures that realistic predictions of structural behavior in practical applications are made.

3.5 Interactions and Boundary conditions

In ABAQUS, a 'surface-to-surface' contact was used to model the contact that occurred between the steel tubes and the concrete core and sandwich filler. This took into consideration the tangential contact behavior as well as the typical contact behavior of the components. The simulation of a concrete-filled steel tube (CFST) column was carried out with the ABAQUS program. In order to precisely duplicate the behavior of the structure in the actual world, significant attention was paid to modeling the interactions that occurred between the various components of the column. The principal strategy consisted of identifying the steel tubes as master surfaces, with the exception of situations in which interactions with the bottom plate took place, in which case the bottom plate also assumed the function of master surface. Because of this strategic designation, the simulation was able to properly capture structural interactions, taking into account circumstances such as the penetrability of the material and variations in the surface friction characteristics within the analytical framework.

For the purpose of modeling the interactions that occurred between the steel tubes, concrete core, sandwich infill, and loading plates, surface-to-surface contact mechanics were brought into play. A 'hard contact' condition was utilized in the simulation to simulate natural behavior. This condition prevented any penetration between contacting surfaces while the product was being loaded. The Coulomb friction model was utilized for tangential behavior, and a friction coefficient was obtained through empirical testing to reflect the resistance to sliding across materials. This value was used to represent the tangential behavior. For the purpose of faithfully depicting fixed boundary conditions that are frequent in practical applications, the simulation setup consisted of two rigid loading plates. The bottom plate was totally constrained against movement in all degrees of freedom. While this was going on, the top loading plate was given a displacement of 15-20 mm along the y-axis in order to impart axial compression. This was done in order to simulate the true loading circumstances that CFST columns encounter when they are used in structural settings. The application of 'tie' constraints was done in order to guarantee precise load transmission and interaction between the loading plates and the core concrete and inner steel tubes. These limitations ensured that there was constant contact between the loading plates and the structural components for the entirety of the simulation, which made it easier to conduct an accurate analysis of the load distribution and the reaction of the structure.

The prediction and optimization of CFST column performance under a variety of loading situations is made possible by this all-encompassing modeling approach. A structural model was subjected to a 45 mm downward displacement on top of all other translational, deflectional, and rotational restrictions in the finite element analysis. However, in all six degrees of freedom, the bottom surface was completely restrained. Realistic predictions of structural behavior under compression were achieved by precisely simulating the axial loading conditions typically used in structural analysis.

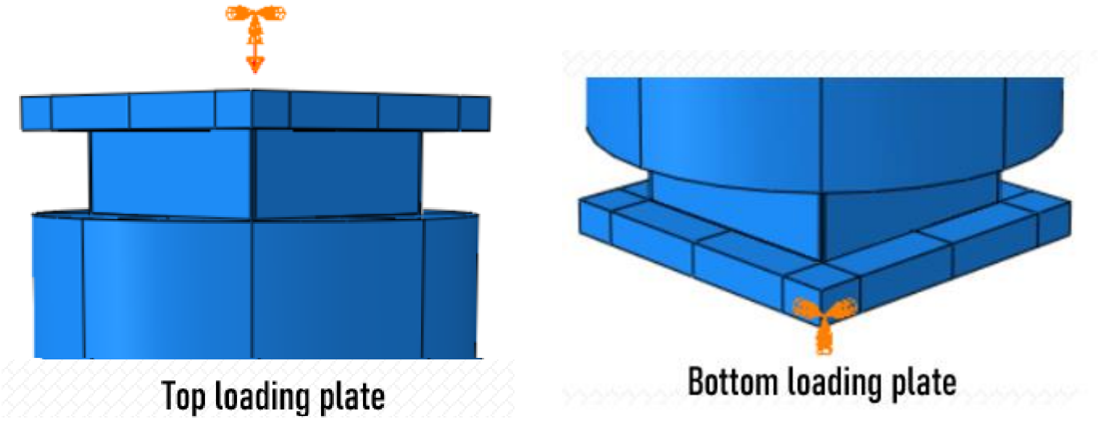

Figure 3: Boundary conditions applied at the top and the bottom

To optimize and anticipate CFST column performance under different loading scenarios, this inclusive modeling solution combines modern simulation methods with real-world engineering concepts. When designing and analyzing CFST columns, engineers may confidently evaluate their structural integrity and behavior because to the correct representation of complex interactions and boundary conditions.

CHAPTER 4: VALIDATION

The axial load-strain curves and peak load curves for double-layered CFST columns were compared with experimental data from Zhang et al. [1] in order to validate the models of the column specimens in the numerical analysis. To improve the validation procedure, we additionally looked at the specimens' ultimate deformation and damage patterns. This thorough comparison guarantees that the Finite Element models (FEM) accurately anticipate the behavior of the structure under axial loading conditions.

4.1 Ultimate Axial Strength

For thicknesses of 4 mm and 2 mm, respectively, the inner square steel tubes' yield strengths in Zhang et al.'s study were 320.7 MPa and 345.6 MPa. For nominal diameters of 219 mm and 273 mm, respectively, the outer circular tubes' yield strengths were 357 MPa and 378.9 MPa. With concrete strength grades of C60 and C80, the corresponding inner concrete core compressive strengths were 52.5 MPa and 65.67 MPa. Furthermore, all of the specimens had a compressive strength of 67.9 MPa for sandwich grout. **Table 1** displays the predicted and experimental ultimate strengths of double-layered CFST columns under axial compression.

Table 2: Comparison Between the Experimental and Finite Element Capacities

Specimen	Experimental peak load (kN)	Numerical peak load (kN)	Ratio (Num/Exp)
T26-3	2540.37	2475.16	0.97
TB26-3	2506.92	2660.88	1.06
T28-1	3123.01	2921.99	0.94
TB28-1	3118.51	2902.63	0.93
		Mean	**0.98**
		Coefficient of variance	**6.20**

The ultimate strengths of axially loaded double layered CFST columns have been predicted with great accuracy using the finite element analysis approach, as seen in Table 1. This method predicts a mean ultimate axial strength with a coefficient of variation (COV) of 6.20% that is 98% of the experimental value.

4.2 Axial Load Strain Curves

Under axial compression, four double-layered CFST columns were studied using Finite Element Method. The experimental data from Zhang et al. [1] was compared with the axial load-strain curves predicted by the numerical models. The numerical analysis successfully predicts the stiffness, ultimate strength, and post-peak behavior of double layered CFST columns under axial loading conditions, as shown in Figures 4, 5, 6, and 7, which focus on specimens T26-3, TB26-3, T28-1, and TB28-1, respectively. Notably, except for specimen T26-3, all four numerical models showed more ductility in comparison to the experimental findings. Similar load-strain characteristics were shown by this specimen up to its maximum capacity, but in the post-peak phase, it showed significantly less ductile behavior. In addition, a variation in ultimate strength was noted even though the models TB26-3, T28-1, TB28-1 showed consistent post-peak performance.

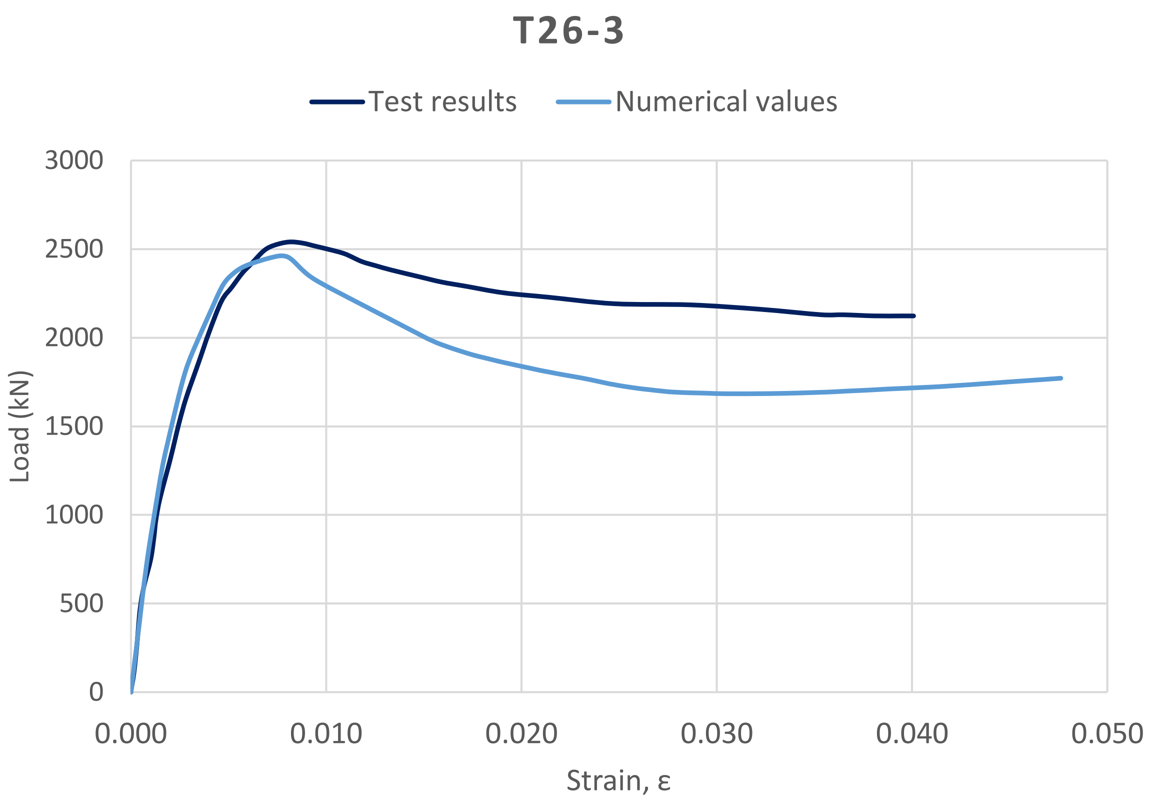

Figure 4 : Analysis of predicted and experimental axial load-strain curves for specimen T26-3

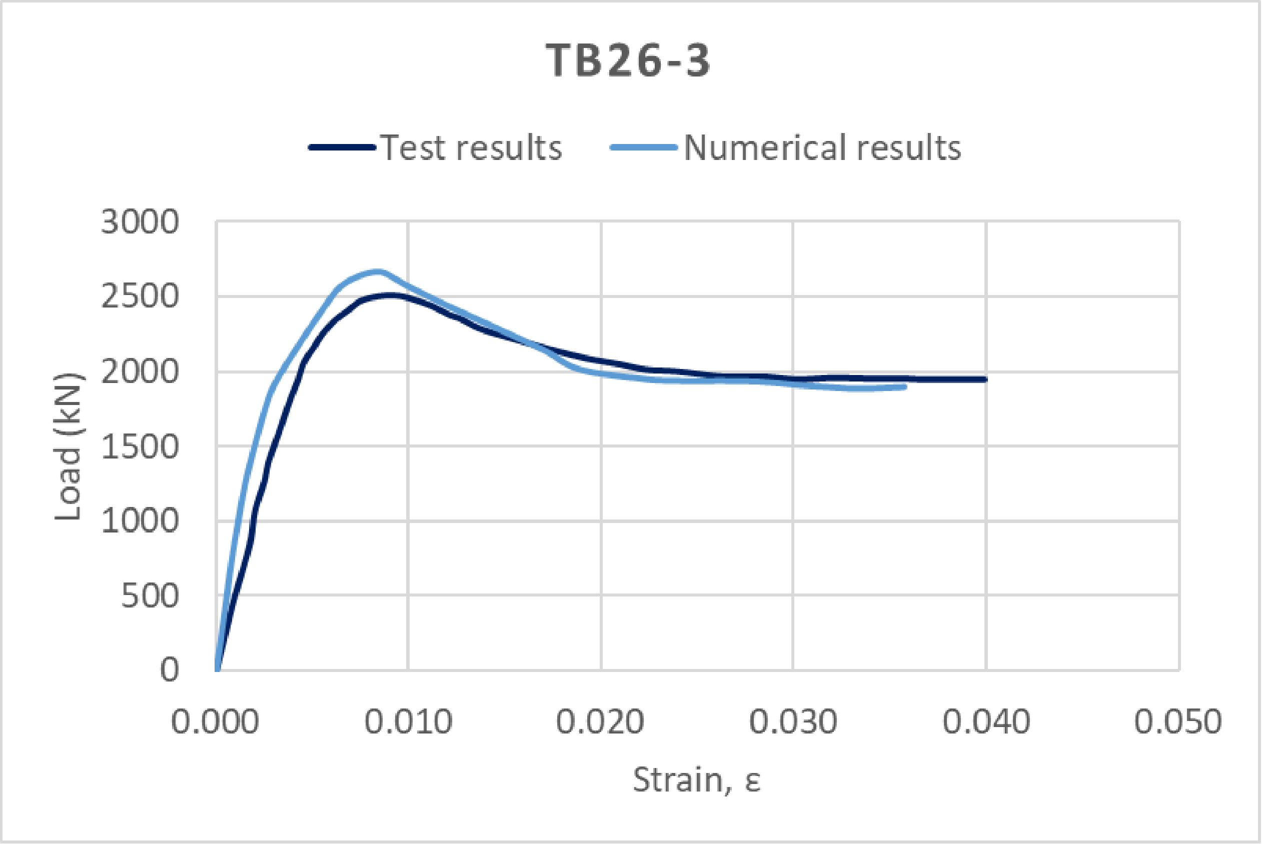

Figure 5: Analysis of predicted and experimental axial load-strain curves for specimen TB26-3

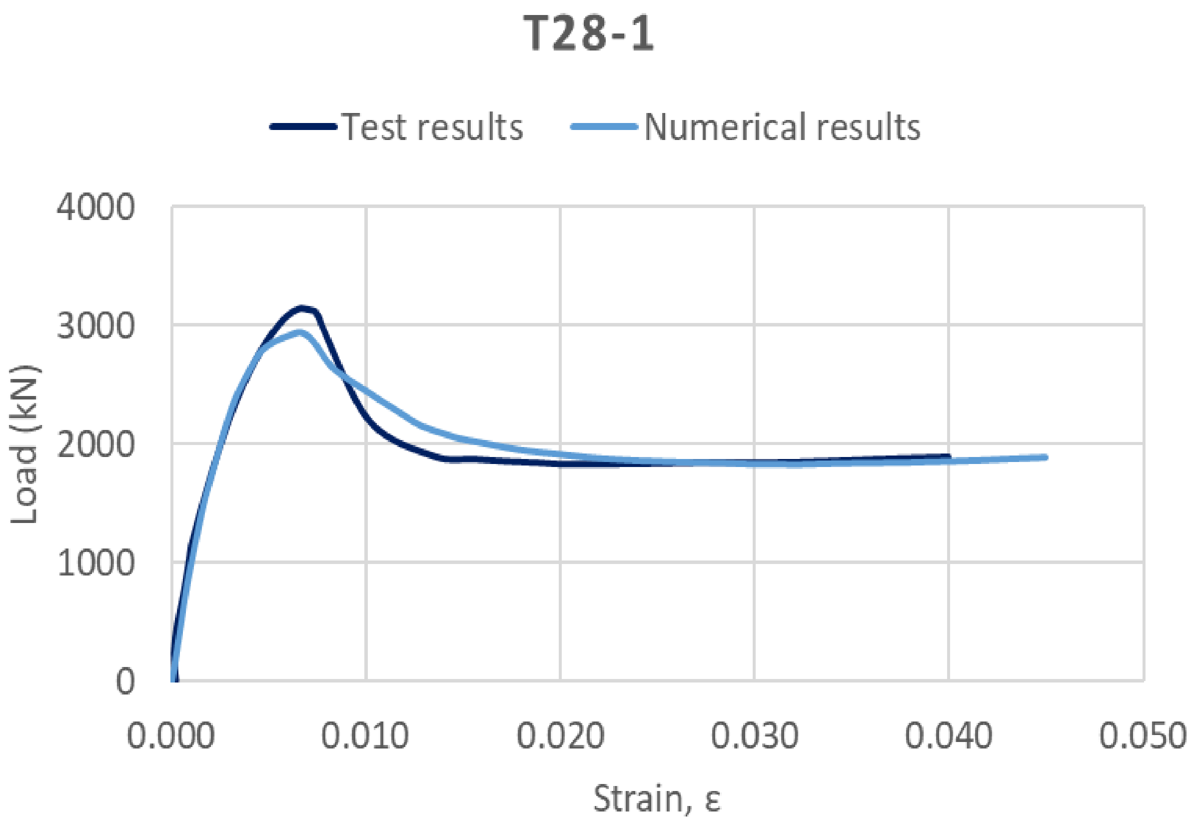

Figure 6 : Analysis of predicted and experimental axial load-strain curves for specimen T28-1

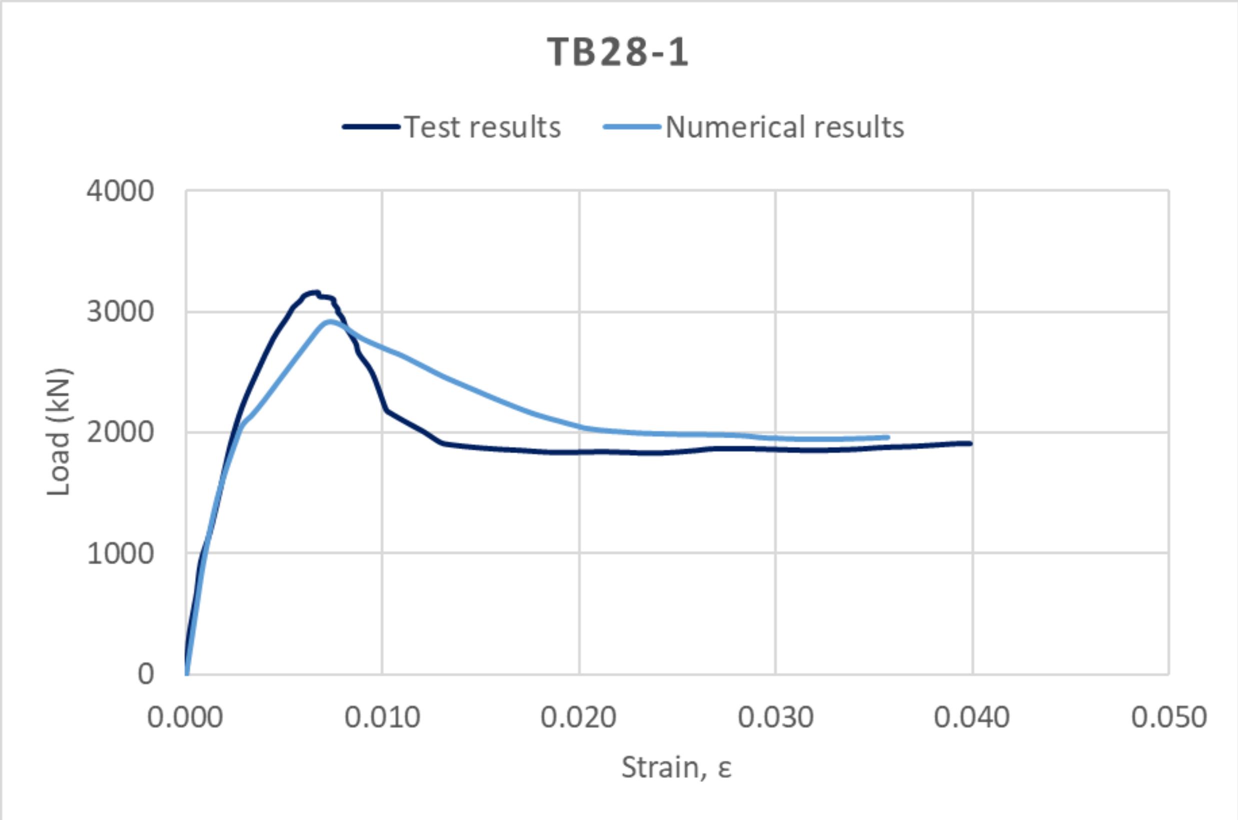

Figure 7: Analysis of predicted and experimental axial load-strain curves for specimen TB28-1

CHAPTER 5: PARAMETRIC STUDY

5.1 General

A validated finite element model was used to conduct an extensive study into the impact of modifications in geometry and material on double layered CFST columns. The yield stress of the inner and outer steel tubes, the length of the column, the width of the inner square tube, the thickness of the outer and inner steel tubes, the outer diameter of the circular steel tube, compressive strength of concrete core and sandwich grout were among the parameters that were investigated in order to determine how these composite columns behaved structurally and how strong they were. Twelve groups of parameters made up the study; six groups had to do with geometric aspects and six groups had to do with material properties (see Tables 2 and 3). There were three column specimens in each group, for a total of 36 columns. The axial strength capacities of column specimens have been analyzed in relation to the ratios of the inner steel diameter to thickness (Di/ti) and the outer steel width to thickness ratio (Do/to).

Group	Models	Length, L (mm)	Outer Steel tube		Inner Steel tube		Steel yield strength		Concrete strength		L/D_o	λ_{ro}	λ_{ri}
			$D_o \times t_o$ (mm)	D_o / t_o (mm)	$D_i \times t_i$ (mm)	D_i / t_i (mm)	f_{syo} (MPa)	f_{syi} (MPa)	f'_{co} (MPa)	f'_{ci} (MPa)			
	1		300 x 4	75									
1	2	1000	300 x 3	100	150 x 3	50	380	345	70	75	3.33	100	100.14
	3		300 x 2	150									
	4				150 x 4	37.5							
2	5	1000	300 x 3	100.00	150 x 3	50	380	345	70	75	3.33	100	100.14
	6				150 x 2	75							
	7				120 x 3	40							
3	8	1000	300 x 3	100	150 x 3	50	380	345	70	75	3.64	100	100.14
	9				180 x 3	60							

Table 3: Categorization of Geometric Parameters (Part 1)

Group	Models	Length, L (mm)	Outer Steel tube		Inner Steel tube		Steel yield strength		Concrete strength		L/D_o	λ_{ro}	λ_{ri}
			$D_o \times t_o$ (mm)	D_o / t_o (mm)	$D_i \times t_i$ (mm)	D_i / t_i (mm)	f_{syo} (MPa)	f_{syi} (MPa)	f'_{co} (MPa)	f'_{ci} (MPa)			
4	10	1000	250 x 3	66.67	150 x 3	50	380	345	70	75	5.00	100	100.14
	11		300 x 3	100.00							3.33		
	12		350 x 3	116.67							2.86		
5	13	500	300 x 3	100	150 x 3	50	380	345	70	75	1.67	100	100.14
	14	1000									3.33		
	15	1500									5.00		
6	16	1000	300 x 5	60.00	150 x 3	50	380	345	70	75	3.64	100	100.14
	17		300 x 6	50.00									
	18		300 x 7	42.86									

Table 4: Categorization of Geometric Parameters (part 2)

Group	Models	Length, L (mm)	Outer Steel tube		Inner Steel tube		Steel yield strength		Concrete strength		L/D_o	λ_{ro}	λ_{ri}
			$D_o \times t_o$ (mm)	D_o / t_o (mm)	$D_i \times t_i$ (mm)	D_i / t_i (mm)	f_{syo} (MPa)	f_{syi} (MPa)	f'_{co} (MPa)	f'_{ci} (MPa)			
7	19	1000	300 x 3	100.00	150 x 3	50	380	290	70	75	3.33	100	131.03
	20							345					110.14
	21							450					84.44
8	22	1000	300 x 3	100.00	150 x 3	50	290	345	70	75	3.64	131.03	100.14
	23						380					100.00	
	24						450					84.44	
9	25	1000	300 x 3	100.00	150 x 3	50	290	290	70	75	3.33	131.03	131.03
	26						345	345				100.00	110.14
	27						450	450				84.44	84.44

Table 5: Categorization of Material Parameters (part 1)

Group	Models	Length, L (mm)	Outer Steel tube		Inner Steel tube		Steel yield strength		Concrete strength		L/D_o	λ_{ro}	λ_{ri}
			$D_o \times t_o$ (mm)	D_o / t_o (mm)	$D_i \times t_i$ (mm)	D_i / t_i (mm)	f_{syo} (MPa)	f_{syi} (MPa)	f'_{co} (MPa)	f'_{ci} (MPa)			
10	28	1000	300 x 3	100.00	150 x 3	50	380	345	45	75	3.33	100	100.14
	29								70				
	30								85				
11	31	1000	300 x 3	100	150 x 3	50	380	345	70	45	3.64	100	100.14
	32									75			
	33									85			
12	34	1000	300 x 3	100	150 x 3	50	380	345	45	45	3.64	100	100.14
	35								70	70			
	36								75	75			

Table 6: Categorization of Material Parameters(part 2)

5.2 Geometric Parameters

In **Figure 8**, parametric analysis was carried out to study the change in outer steel tube thickness from 2 mm to 7 mm. In this study, groups 1 and 6 were involved. It was observed that the variance did not significantly impact the column strength.

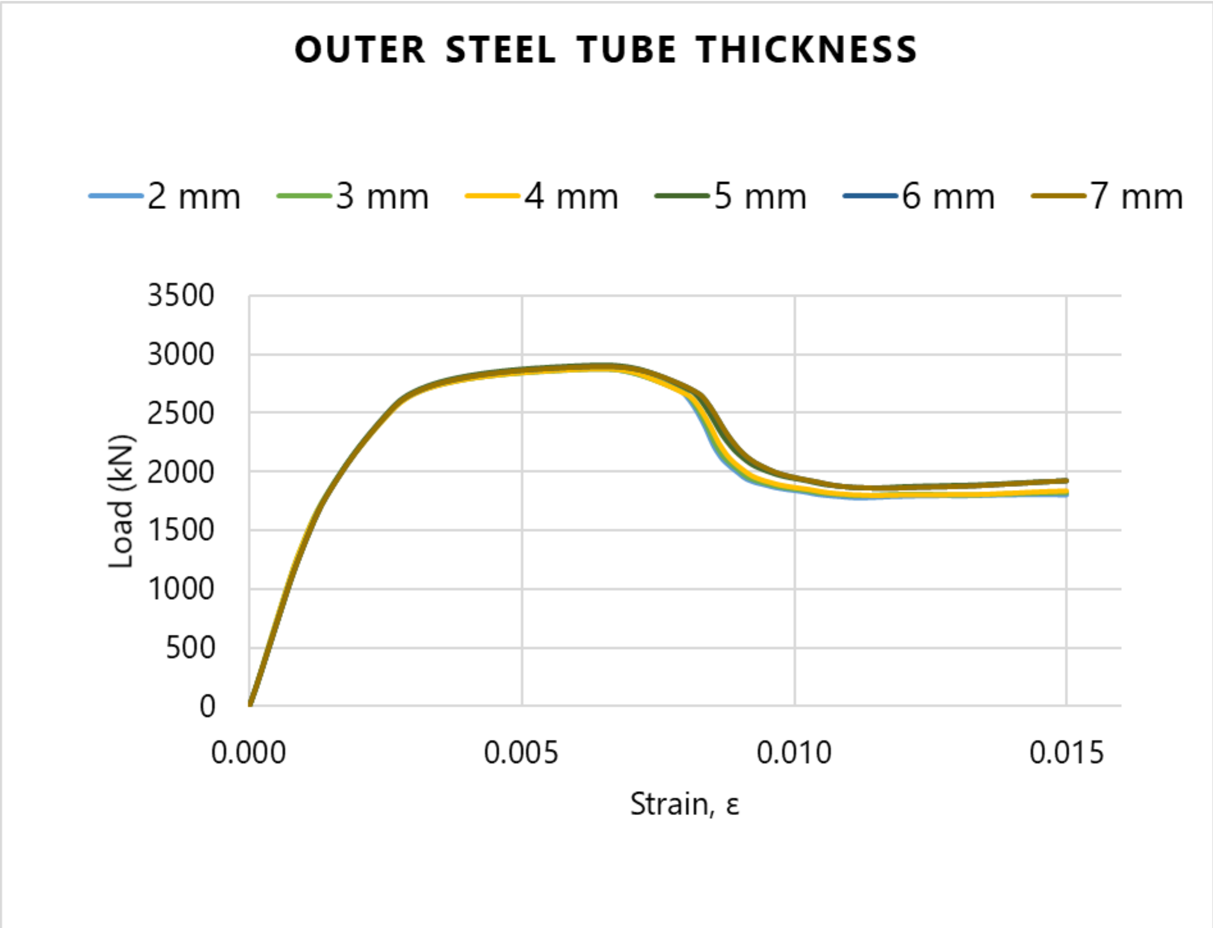

Figure 8: Effect of Variation in Thickness of Outer circular Steel

On other hand, an interesting finding emerged that the axial capacity of columns significantly dropped about 56.48% as the thickness of the inner steel tube varied from 2 mm to 4 mm, which is contrary to normal predictions where increased thickness enhances column strength.

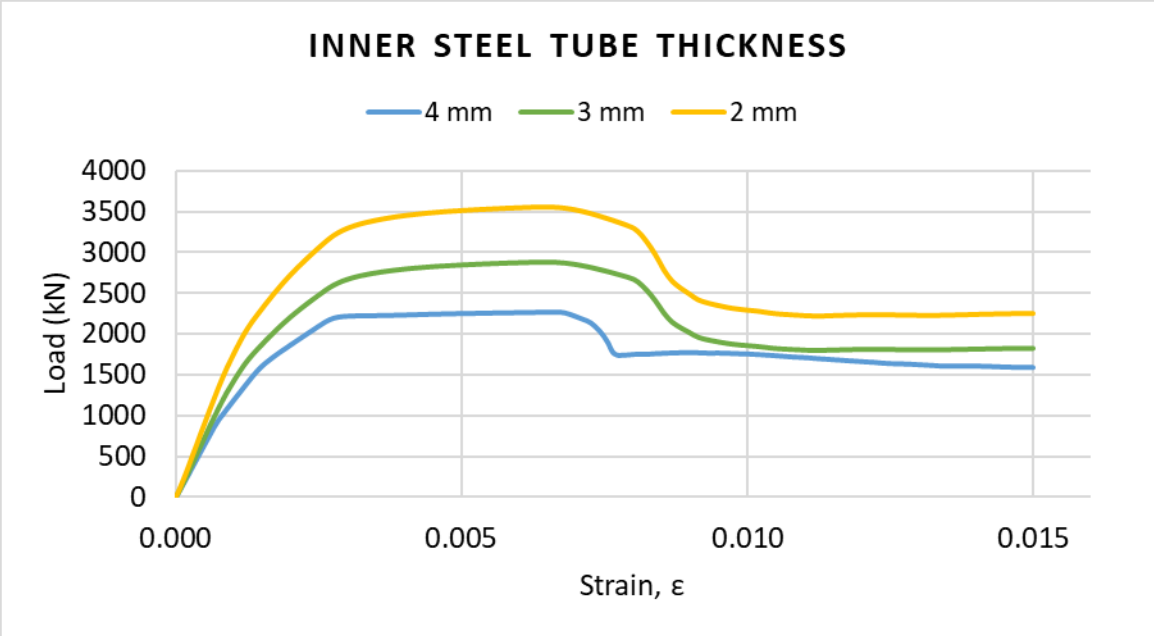

Figure 9: Effect of Variation in Thickness of Inner square Steel

The study looked at three distinct square steel tube side lengths: 120 mm, 150 mm, and 180 mm. It was found that increasing the side length significantly increased column strength by 68.83%. Of all the parameters we looked at, this increase in axial capacity is the highest, which highlights how important side length is to the results that we obtained.

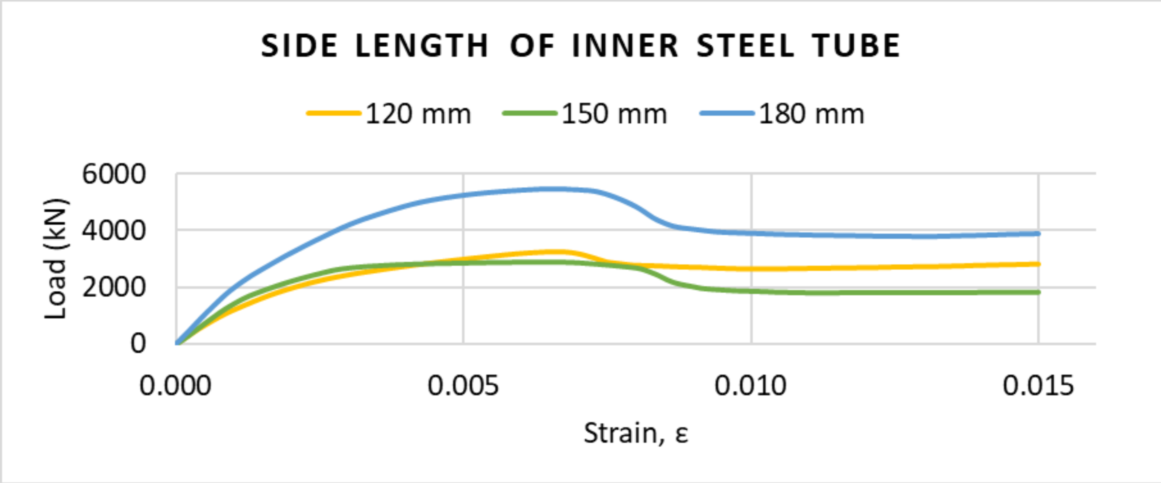

Figure 10: Effect of Variation in side length of Inner square Steel

Contrary to inner tubes, changes in the outer steel diameter had moderate impact on column strength, which increased by 22.06%.

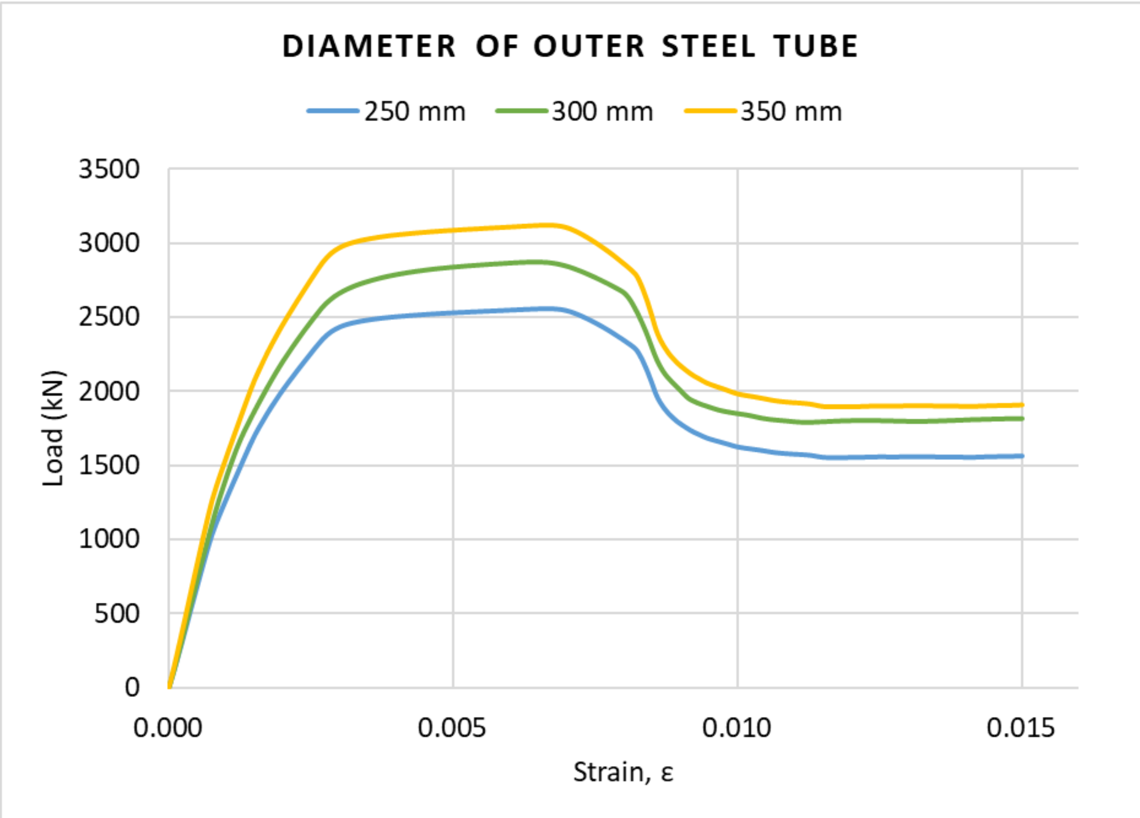

Figure 11: Effect of Variation in diameter of Outer Steel

The column length, which was tested at three different lengths—500, 1000, and 1500 mm was another important factor. The study found that columns with a length-to-outer diameter ratio exceeding 4, such as the 1500 mm columns, were considered slender and exhibited reduced strength due to increased susceptibility to buckling. In particular, the capacity of the 1500 mm columns was 4.73% lower than that of the 500 mm stub columns. However, load bearing capacity increased up to 500 mm length because that length did not exceed the slenderness limit. This emphasizes how crucial it is to take buckling effects into account when designing double-layered CFST columns. It is essential to include geometric imperfections to lessen these effects and ensure structural stability under axial loads.

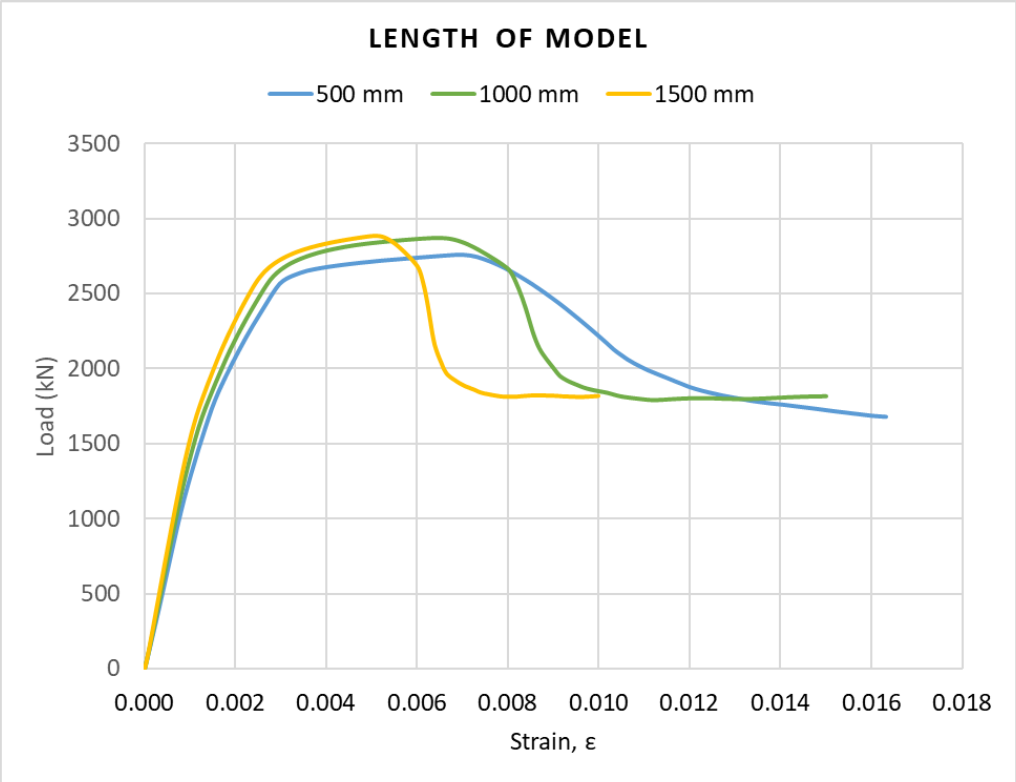

Figure 12: Effect of Variation in Length of Column

5.3 Material Parameters

The inner carbon steel's yield stress at 290 MPa, 345 MPa, and 450 MPa was examined in the study. Higher yield stress materials were shown to be able to improve the columns' overall performance and load-bearing capability, but only to a certain degree. In particular, just 10.79% more column strength was achieved by raising the inner carbon steel's yield stress by roughly 55.17%.

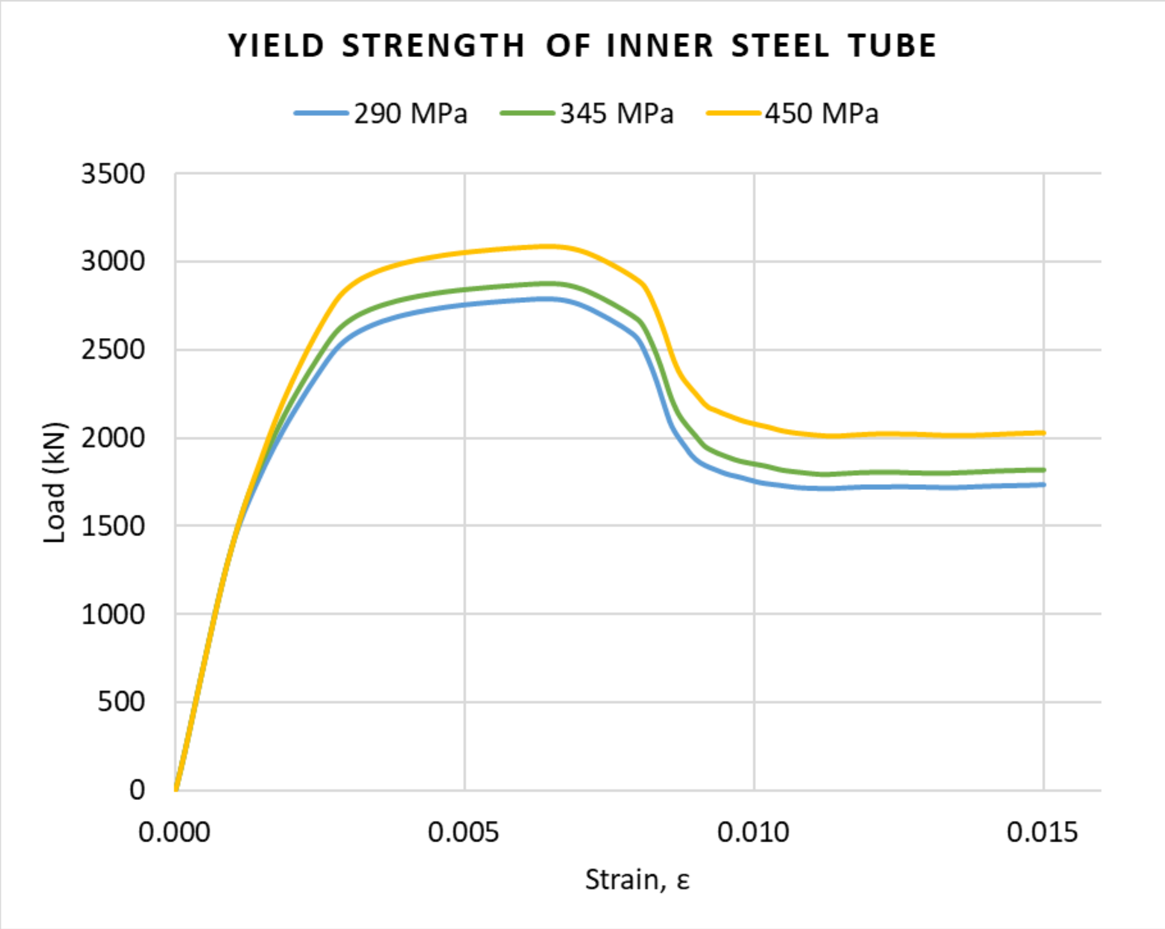

Figure 13: Effect of Variation in Yield Stress of Inner Carbon Steel

In the same way, yield stress of the outer stainless steel was measured at 290, 380, and 450 MPa. Similar to the inner tube, an increase in the outer tube's yield stress had little effect on the strength of the column.

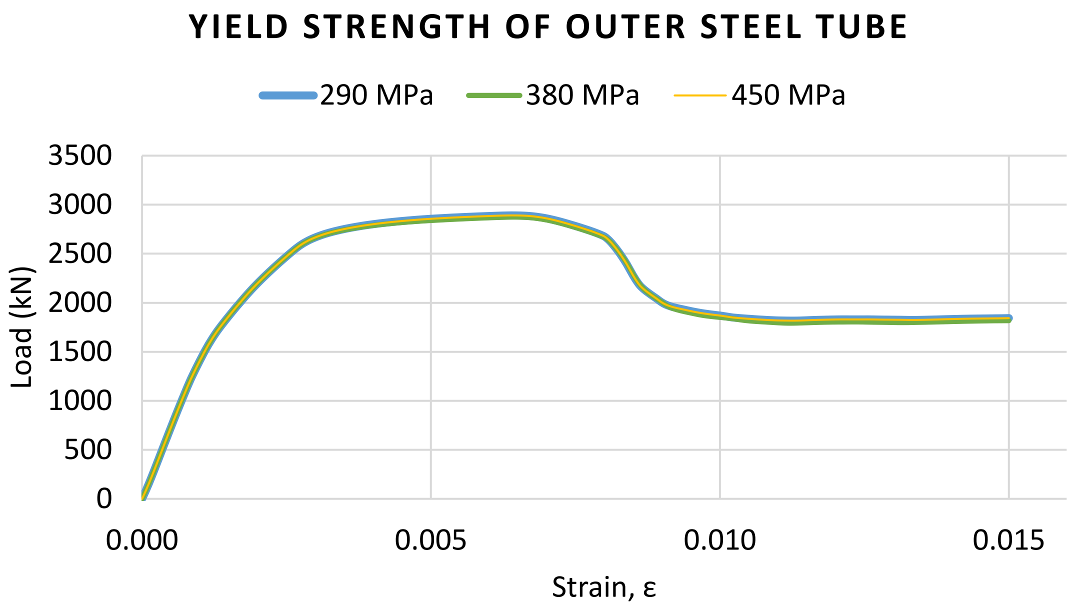

Figure 14: Effect of Variation in yield stress of Outer Stainless Steel

There was only a slight 7.4% increase in column strength when the yield stress of the inner and outer steel was raised from 290 MPa to 450 MPa. Although larger yield stresses have a significant effect on load-bearing capacity, these had a negligible effect in this study.

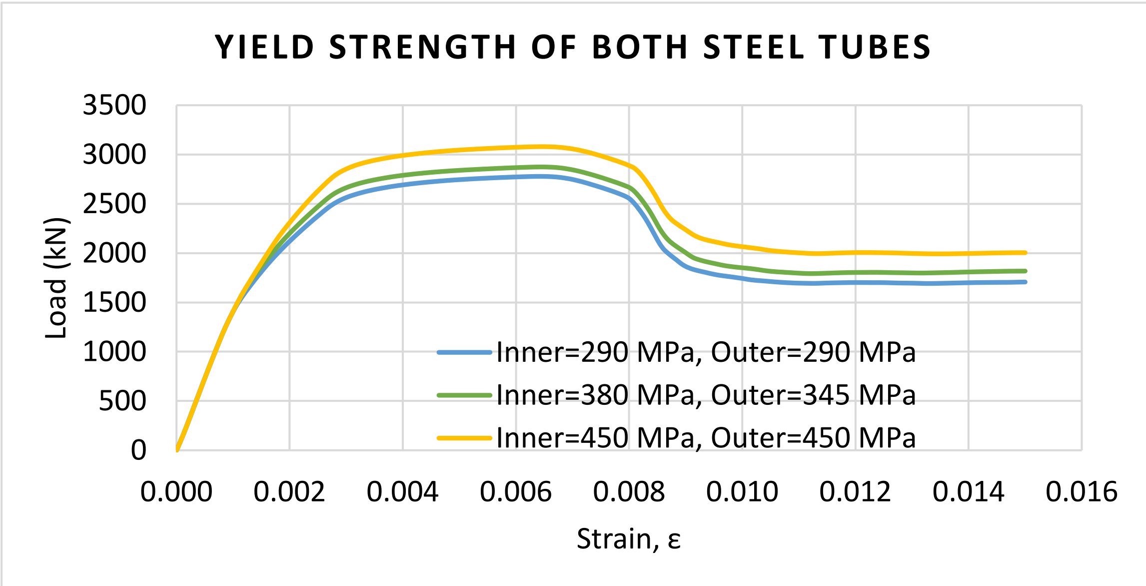

Figure 15: Effect of Variation in Yield Stress of both Outer Stainless and Inner Carbon Steel

Three different compressive strengths were tested for the core concrete: 45, 75, and 85 MPa. According to the study, there was little difference in column strength when the core concrete strength was changed. Increased column strength was not achieved with even combinations of core and sandwich concrete strengths at 45/45 MPa, 70/70 MPa, and 75/75 MPa. Adding these materials did not increase the structural resilience or load-bearing capacities of the columns, despite the fact that higher-strength concrete in both core and sandwich layers is generally expected to significantly enhance structural integrity and load-bearing capacity in double layered CFST columns.

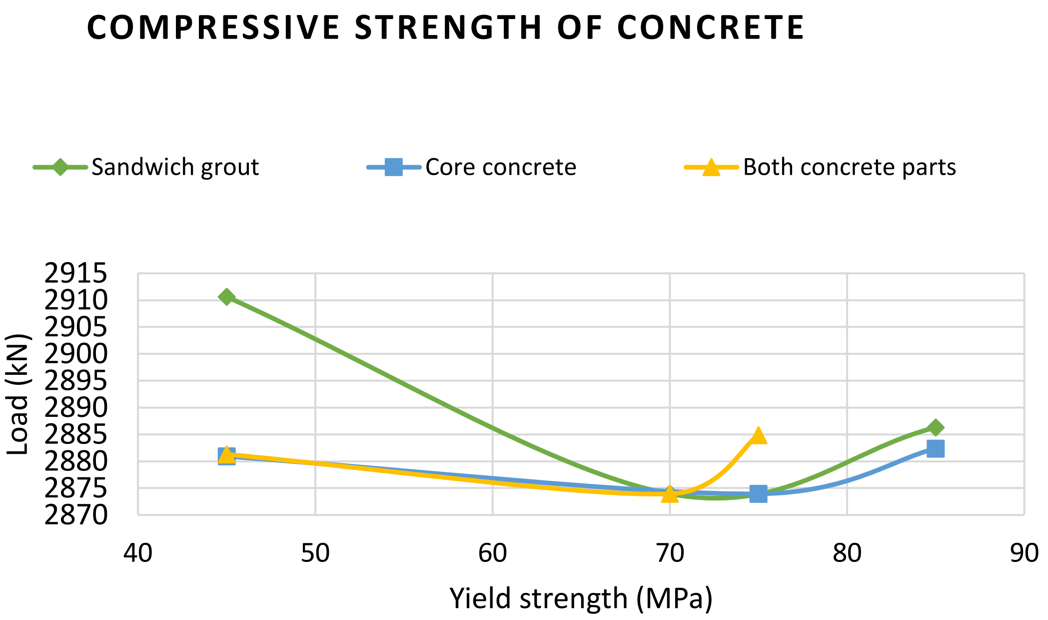

Figure 16: Effect of Variation in Compressive Strength of Core Concrete, sandwich grout and both concrete

5.4 Observations and Findings

Using numerical analysis, the results of the parametric study on the strength and failure modes of double layered CFST columns were thoroughly analyzed. To visually depict and explain the effects of material and geometric modifications on the overall performance of the columns, graphic representations were created. These graphs are useful tools because they show how variations in parameters that include yield stress, compressive strength of concrete, outer diameter, steel tube thickness, and column length impact structural behavior. From these graphs, engineers and designers can derive important insights that help them make decisions throughout the design process. For instance, they can identify the best combination of material characteristics and dimensions to increase column strength while decreasing the possibility of failure modes like material yielding or buckling. With the use of these insights, stakeholders may ensure structural reliability under a variety of loading conditions by optimizing the design of double-layered CFST columns in accordance with exact performance specifications.

Key insights from the study include the following: slender columns demonstrated reduced strength due to increased susceptibility to buckling, particularly evident in the 1500 mm columns which showed a significant decrease in load-bearing capacity compared to shorter counterparts. This signifies the critical need to consider buckling effects when designing slender double layered CFST columns to prevent premature failure. Higher yield stresses in the inner and outer steel tubes did not, as predicted, significantly affect the performance of the columns. No apparent increase in strength was seen, even with a combination of outer and inner carbon steel with yield stresses of 450 MPa each. The assumption that using materials with higher yield stresses will improve the double-layered CFST columns' overall performance and load-bearing capacity is called into question by this finding. Important parameters influencing overall column strength were found to be the steel tubes' size, particularly their thickness and width. The strongest components were the thicker, wider ones, such the inner square tubes, which were 180 mm wide and 4 mm thick. This demonstrates how important it is to maximize the geometric dimensions of steel tubes in order to attain the best possible structural performance. Moreover, this study's unique finding was that, contrary to predictions, combining the compressive strengths of sandwich and core concrete did not result in increased column strength. The combination of these results highlights the intricate interaction between geometric and material parameters that influence structural performance and resilience, and offers significant insights into improving the design of double-layered CFST columns.

CHAPTER 6: CONCLUSION

6.1 Key Findings:

The constructed finite element (FE) model showed a good prediction capacity, regarding the load-deflection behavior of the investigated column. It confirmed the validity and application of the model by accurately projecting the failure modes of the column.

The parametric analysis produced some important new understanding of the elements affecting column load-bearing capability. Unlike earlier research showing a notable drop in load-bearing capacity with increasing column lengths, this study found a 4.73% gain in capacity when the column length ranged from 500 to 1500 mm.

The thickness and yield strength of the inner steel turned out to be very important factors determining the ultimate load-bearing capability. While increasing steel yield strength helped to produce a 10.80% rise in load-bearing capacity, an increase in inner steel thickness produced a significant 56.5% rise. On the Contrary, changes in thickness and yield strength had little effect on the load-bearing capability of the exterior steel.

It is important to note that the load-bearing capacities of core concrete and sandwich grout are not identical. At a pressure of 70 MPa, the capacity is at its lowest, while it is higher between 45 MPa and 85 MPa. Moreover, showing the importance of geometric dimensions in structural design, fifty percent increase in the side length of the inner steel tube produced a 68.82% increase in load-bearing capacity. In addition, for model lengths greater than 2880 mm, the rate of increase slowed, while for lengths less than 1000 mm, the capacity gain was 4.8%.

The strength and ductility of CFST columns were investigated using extensive parametric studies including diameter-to-thickness ratio, concrete compressive strengths, and steel yield strengths under several conditions. Important results of the parametric analysis showed that the structural performance of CFST columns is much influenced by geometric and material characteristics.

6.2 Future Scope:

The current investigation on the compressive behavior of CFST columns opens numerous directions for next investigations. First of all, looking at how eccentric loading patterns affect CFST columns will help one to better understand their performance under more accurate and variable load conditions. Comprehensive parametric analysis considering a greater range of factors, including various cross-sectional shapes, material quality, and boundary conditions would help to better understand the interactions inside CFST columns and enhance predictive models. Moreover, by looking at other CFST configurations including combinations and other confinement strategies, new solutions improving structural effectiveness and durability could be identified. These next investigations will significantly expand our knowledge and application of CFST columns in modern building.

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