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Effectiveness of ECC Encasement on the Compressive Behaviour of Slender CFST Column–A Numerical Study

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EFFECTIVENESS OF ECC ENCASEMENT ON THE COMPRESSIVE BEHAVIOUR OF SLENDER CFST COLUMN–A NUMERICAL STUDY

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DECLARATION OF CANDIDATES

We hereby declare that the project/thesis work under the supervision of Dr. Md. Imran Kabir entitled " Effectiveness of ECC Encasement on the Compressive Behavior of Slender CFST Column–A Numerical Study ", has been performed by us and this work has not been submitted elsewhere for reward of any degree or diploma (except for publication).

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Abstract

This paper presents a numerical study on the compressive behavior of Engineered Cementitious Composite (ECC) encased slender Concrete Filled Steel Tube (CFST) column under concentric loading. In this study, a detailed Finite Element (FE) model was developed using ABAQUS to investigate the compressive behavior of the columns. The FE model was first validated against the existing test results and then employed to conduct a comprehensive parametric study. In the parametric study, the effects of various parameters such as the concrete-to-steel ratio, the thickness of the ECC layer, the strength of the steel tube, and the compressive strength of ECC and core concrete were investigated on the compressive behavior of the columns. The parametric study provided valuable insights into the compressive behavior of slender ECC-CFST columns under concentric loading and highlighted the potential application of ECC as effective encasing material for enhancing the performance of CFST columns. Furthermore, this study investigated the failure modes of the columns, including local buckling of the steel tube and the crushing of the concrete. The result of this study showed that ECC, as an encasing material dramatically enhanced the columns' load carrying capacity under compression. The findings of this investigation would be beneficial for day-to-day design practitioners.

Keywords:

Finite element analysis, engineered cementitious composites, ECC encasement, concrete-filled steel tube, compressive behavior.

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Chapter 1: Introduction

The use of steel reinforced concrete structures is becoming increasingly popular in modern construction. The combination of steel and concrete creates a composite material with higher strength and durability than either material on its own. One of the most common applications of this composite material is in the construction of columns, which provide vertical support for buildings and other structures.

One type of column that has gained popularity in recent years is the Concrete Filled Steel Tubular (CFST) column (Figure 01). Steel tube filled with concrete makes up this sort of column. The combination of the two materials provides high strength and stiffness, while also allowing for a significant reduction in weight compared to traditional reinforced concrete columns.

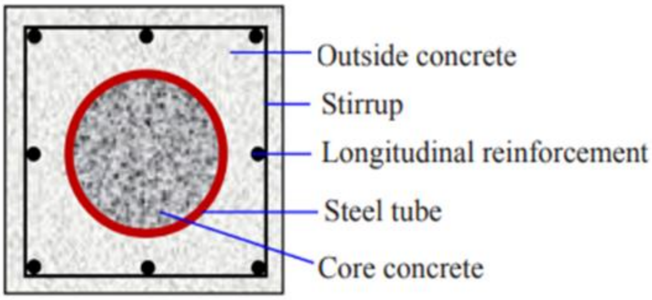


Figure 01: CFST column

1.1 Background:

Structures are building everyday everywhere around us. These super structures are frame structures. These structures transfer load using beam and column. These Columns transfer the load to the foundation and then it transfers to soil. These columns are of different shape and type. Normal Reinforced concrete are good. They're good against tension. From past few years' concrete filled steel tubular (CFST) is a topic of great interest for the structural engineers. The square, rectangular, or circular steel tubes that make up CFST structures are filled with either plain or reinforced concrete. CFST columns are very special types of construction materials.

Over the past few decades, the utilization of steel-reinforced concrete buildings in the construction sector has seen a major change. The construction of columns, which offer vertical support for buildings and other structures, is one of the most widespread uses of this composite material. One type of column that has gained popularity in recent years is the CFST column.

The very first time CFST columns were utilized was during the construction of bridges in the 1960s. The first bridge to use CFST columns was the Morandi Bridge in Italy. Since then, CFST columns have been used in a wide range of applications, including high-rise buildings, industrial structures, and transportation infrastructure.

The various benefits of CFST columns are what account for their widespread use. For one, the combination of steel and concrete provides a high degree of stiffness and strength. This allows for the use of smaller column cross-sections, which can lead to significant cost savings. Additionally, the use of a steel tube filled with concrete can result in a reduction in weight compared to traditional reinforced concrete columns, which can be beneficial in seismic zones and where weight is a concern.

Another advantage of CFST columns is their ability to resist fire. The steel tube provides a protective layer for the concrete, preventing it from being exposed to high temperatures. This allows the column to maintain its structural integrity during a fire and reduces the risk of collapse.

In the construction of high-rise buildings, the usage of Concrete Filled Steel Tubular (CFST) columns has grown in popularity, especially in areas prone to earthquakes. The combination of steel and concrete provides high stiffness and strength, allowing for the construction of mega structures that are resistant to lateral stresses and can withstand seismic loads. The use of CFST columns in high-rise buildings has several advantages, including reduced column cross-sections, leading to significant cost savings. In addition to high-rise buildings, CFST columns have also been utilized in industrial structures like power plants. The capacity to handle heavy loads and withstand fire is crucial in such buildings, and the use of CFST columns provides an optimal solution to meet these requirements. The steel tube acts as a protective layer for the concrete, reducing the risk of collapse during a fire. Overall, the use of CFST columns in construction provides several advantages, making them an attractive option for a wide range of applications. Their high stiffness and strength, resistance to fire, and ability to withstand seismic loads make them ideal for use in high-rise buildings and industrial structures. With the proper design, connection, and quality control measures in place, CFST columns can provide a safe and cost-effective solution for vertical support in modern construction.

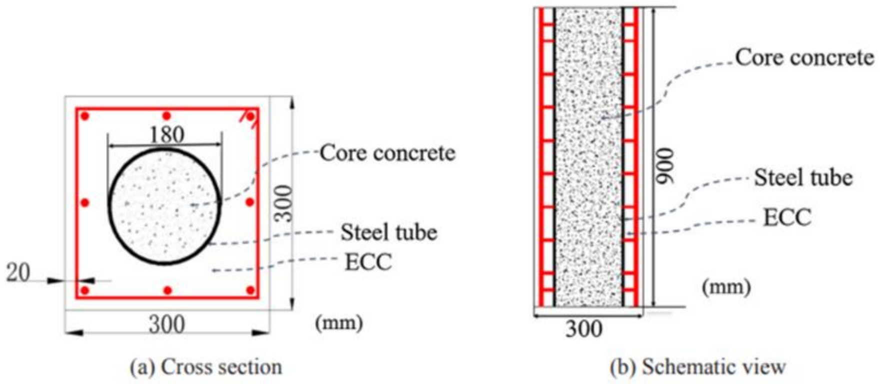
Despite their many advantages, there are also some challenges associated with the use of CFST columns. One of the biggest challenges is the design of connections between CFST columns and other structural elements. The performance of the structure as a whole may be significantly impacted by the connection's behavior under varied loading circumstances. Therefore, careful consideration must be given to connection design to ensure that the structure is safe and performs as intended.

The design of CFST columns also requires specialized knowledge and expertise. The behavior of the column under various loading conditions, including compression, bending, and axial loads, must be carefully considered during the design phase. The design of the column must also take into account the properties of the steel tube and the concrete filling, as well as the interaction between the two materials.

The construction of CFST columns requires a high level of quality control to ensure that the column meets the necessary design specifications. The steel tube must be free from defects, such as cracks and corrosion, and the concrete filling must be of the appropriate strength and consistency. The quality control measures must be in place throughout the construction process, including the transportation, storage, and placement of the materials.

Due to their numerous benefits, CFST columns are being used more and more frequently in contemporary construction. The combination of steel and concrete provides high strength and stiffness while also allowing for a reduction in weight. CFST columns are a desirable alternative for many applications since they can withstand fires as well. To make sure that the structure is secure and works as planned, however, connection design and quality control must be carefully considered. Overall, the use of CFST columns for the building of columns in a variety of applications is a promising one.

One promising material is Engineered Cementitious Composites (ECC), which has shown significant potential in improving the performance of concrete structures shown in Figure 02. ECC is a high-performance fiber-reinforced cementitious composite material that exhibits high tensile ductility and crack width control, which makes it a potential candidate for enhancing the compressive behavior of slender CFST columns.



(a) Cross section (b) Schematic view

Figure 02: ECC encased CFST column

1.2 Motivation of Research

The researches on the effectiveness of ECC (Engineered Cementitious Composite) encasement on the compressive behavior of slender CFST (Concrete-Filled Steel Tube) columns are motivated by several factors:

i. Structural Performance Enhancement: Because of their great strength, ductility, and fire resistance, CFST columns are frequently utilized in the construction of buildings and bridges. However, under compressive stresses, thin CFST columns may be vulnerable to buckling and local instability. The purpose of the study is to find out if adding ECC encasement to thin CFST columns can enhance their structural performance, particularly about compressive behavior.

ii. ECC Material Properties: ECC is a specific kind of fiber-reinforced cementitious composite that performs better than regular concrete in terms of durability, multiple cracking behavior, and greater tensile strain capacity. It is expected that by encasing the columns with ECC owing to the material's unique properties, the load-bearing capacity of the CFST columns may be boosted and the danger of early failure can be decreased.

iii. Cost and Practicality: The study also takes into account the financial and operational implications of employing ECC encasement on CFST columns. If ECC encasement is successful in strengthening the compressive behavior of the columns, it may provide a practical way to build new structures or improve the performance of existing ones. The research may assess the viability and practicality of using ECC encasement in actual construction projects by conducting a numerical study.

iv. Sustainability and Environmental Impact: ECC is renowned for being more environmentally friendly than ordinary concrete since it frequently uses recycled resources and lowers the construction industry's carbon impact. The research promotes the use of environmentally friendly materials in structural applications while examining the possibility of ECC encasement to support sustainable engineering practices.

v. Knowledge Gap and Innovation: Further research is needed to determine how ECC encasement affects the compressive behavior of thin CFST columns. The research seeks to fill the knowledge gap and offer insights into the behavior and performance of these composite structural systems by undertaking a numerical investigation. The research's conclusions can inspire novel design strategies and aid in the creation of standards and recommendations for CFST column designs that use ECC encasement.

In more general terms, the use of ECC encasement will be used to enhance the structural performance, practicality, sustainability, and innovation of thin CFST columns while filling in knowledge gaps in the area.

1.3 Research Objectives

The research objectives of the investigation on the effectiveness of ECC encasement on the compressive behavior of slender CFST column through a numerical study can include

i. Investigate the behavior of slender CFST columns: Understanding the compressive behavior of thin CFST columns including their load-carrying capacity, buckling modes, and failure mechanisms is the goal of the research. To create a baseline for comparison, this requires examining the reaction of CFST columns without any encasing.

ii. Assess the effectiveness of ECC encasement: The main goal is to determine how well ECC encasement improves the compressive performance of thin CFST columns. This entails assessing how, in comparison to naked CFST columns, the encasement affects the columns' load-carrying capability, stiffness, and general structural performance.

iii. Optimize the ECC encasement design: The purpose of the study is to determine several aspects of ECC encasement, including their thicknesses and dispersions of the ECC layer. The research can investigate the ideal design configurations that maximize the performance of CFST columns when encased in ECC by using numerical simulations.

iv. Investigate the influence of ECC material properties: ECC demonstrates special material characteristics, such as improved ductility and strain capacity. Research goals include determining how these characteristics impact CFST columns' behavior when enclosed in ECC. Analyzing the stress distribution, crack growth, and energy loss inside the encased columns is necessary to achieve this.

v. Validate the numerical model: The purpose of the numerical study should be to verify the precision and dependability of the numerical model that was employed to analyze the behavior of CFST columns. To accomplish this, experimental data from earlier studies or other pertinent sources can be compared with the simulation results.

vi. Provide design recommendations and guidelines: The research goals may include creating design suggestions and guidance for the use of ECC encasement on thin CFST columns based on the results of the numerical study. These recommendations can help structural engineers when planning and evaluating how well CFST columns with ECC encasement function in actual installations.

vii. Contribute to the existing body of knowledge: By shedding light on the behavior and functionality of thin CFST columns with ECC encasement, the research seeks to advance our understanding of composite structures. This may result in improvements to design processes and aid in the creation of industry regulations and standards.

Overall, the research objectives focus on investigating the effectiveness of ECC encasement, optimizing its design, understanding its influence on the behavior of CFST columns, and providing practical recommendations for its application.

1.4 Outline of the Research

This first chapter presented a short background on the Effectiveness of ECC Encasement on the Compressive Behavior of Slender CFST Column–A Numerical Study. Along with the goals of this study, the investigation's scope was also outlined.

Chapter 2 presents the literature review conducted for this study.It describes about the CFST Columns. A detailed discussion on the guidelines followed for numerical analysis of column design by using ABAQUS is presented. A brief description of previous experimental work and finite element modelling relating CFST columns are discussed.

In detail, Chapter 3 describes the necessary assumptions and considerations utilized during the design and development of the FE model. It also provides preliminary validation for the FE model with code results.

Chapter 4 presents and discusses the sensitivity analysis conducted on CFST Columns considering various levels of concentric loading. There is also stress curve evaluation for ECC-encased CFST which is subjected to concentric loading.

Chapter 5 wraps up the thesis with a summary of the outcomes from this study as well as recommendations for future research. This chapter is followed by appendices and FE analysis results

Chapter 2: Literature Review

2.1 Introduction

Literature review plays an important role in scholarly endeavors, providing an all-encompassing synthesis of the existing knowledge and research pertaining to the subject matter. Within this chapter, we delve into the extensive body of literature that has both influenced and informed the present study. Through a meticulous examination of the works of renowned scholars, researchers, and experts within the field, our aim is to establish a robust theoretical foundation, identify existing gaps in knowledge, and develop a conceptual framework that guides our research objectives. The principal objective of this literature review is to critically analyze and synthesize the pertinent literature that has explored topics similar to or associated with our own. Through a comprehensive review and evaluation of existing studies, our intention is to gain valuable insights into the current state of knowledge, identify key theories and concepts, and shed light on areas that warrant further investigation. It is our hope that through this process, we will contribute to the existing body of knowledge by building upon prior research, identifying inconsistencies or contradictions, and proposing innovative directions for future studies. In order to ensure a systematic and rigorous approach, we have employed a structured framework for organizing the literature review. Commencing with an overview of the theoretical foundations that underpin our research, we emphasize key theories, models, and concepts that have significantly shaped the field. Subsequently, we delve into empirical studies that have addressed similar research questions or explored related phenomena, thoroughly analyzing the methodologies employed, key findings, and limitations of each study. This comprehensive analysis will enable us to identify patterns, discrepancies, and gaps in the literature, thereby informing our research design and facilitating the development of research hypotheses. Moreover, we acknowledge the vital importance of interdisciplinary perspectives in comprehending complex phenomena. Hence, we extend our literature review beyond the confines of our specific discipline, incorporating insights from related fields to foster a holistic understanding of the research topic. This interdisciplinary approach allows us to leverage diverse perspectives, theories, and methodologies, ultimately contributing to a more comprehensive and enriched analysis. Throughout the course of this chapter, we conduct a critical evaluation of the strengths and limitations inherent in the existing literature, with a particular emphasis on identifying the gaps that our study endeavors to address. By conducting a rigorous and thorough literature review, our aim is to position our research within the broader academic discourse, establish the significance of our study, and provide a robust foundation for the subsequent chapters.

In conclusion, we can say that the literature review serves as an exhaustive exploration of the existing knowledge and research pertaining to our research topic. By critically analyzing previous studies, identifying gaps in the literature, and incorporating interdisciplinary perspectives, our objective is to make a valuable contribution to the existing body of knowledge and lay the groundwork for our own research endeavors.

2.2 The Study on CFST Column

The paper "Structural behavior of concrete-encased CFST box stub columns under axial compression" by Zhang et al. (2019) provides a comprehensive review of the current state of knowledge on the structural behavior of this type of column. The paper begins by providing an overview of the different types of concrete-encased CFST columns, and then discusses the factors that influence their behavior under axial compression. The remainder of the study then summarizes the findings of many experimental tests conducted on CFST box stub columns encased in concrete, and compares the results to those of theoretical models.

The experimental tests conducted by Zhang et al. (2019) showed that traditional concrete columns lack the strength and rigidity that concrete-encased CFST box stub columns do. The columns also exhibited good ductility, with some columns sustaining large deformations before failure. The tests also showed that there are several variables that affect how concrete-encased CFST columns behave, including the connection between the concrete and the steel tube as well as the yield strength of the steel tube.

The theoretical models used by Zhang et al. (2019) were able to precisely foresee the strength and stiffness of the concrete-encased CFST columns. However, the models were less successful in predicting the column’s ductility. This, according to the scientists, was caused by the models' failure to take into account the consequences of the steel tube's local buckling.

The findings of the paper by Zhang et al. (2019) provide valuable insights into the structural behavior of concrete-encased CFST box stub columns. The paper shows that these columns offer a number of advantages over traditional concrete columns, and that they can be used to design safe and reliable structures.

In addition to the paper by Zhang et al. (2019), there are a number of other papers that have been published on the structural behavior of concrete-encased CFST columns. These papers have investigated a variety of topics, including the effects of different parameters on the stiffness, strength, and the ductility of those columns. The findings of these papers have been used to develop design guidelines for concrete-encased CFST columns.

The following are some of the key findings from the research on concrete-encased CFST columns:

1. The strength and rigidity of CFST columns enclosed in concrete are much greater than those of conventional concrete columns.

2. Concrete-encased CFST columns exhibit good ductility.
3. A variety of variables, including the strength of the concrete, the yield strength of the steel tube, and the connection between the concrete and steel tube, affect how CFST columns encased in concrete behave.
4. The strength and stiffness of CFST columns encased in concrete may be precisely predicted using theoretical models. The ductility of the columns, however, is a harder property to estimate using these models.

The research on concrete-encased CFST columns has shown that these columns offer a number of advantages over traditional concrete columns. They can be used to design safe and reliable structures, and they are becoming increasingly popular in the construction industry.

The paper "Axial behavior of CFST stub columns strengthened with steel tube and sandwiched concrete jackets" by Zhang et al. (2020) investigates the axial behavior of concrete-filled steel tubular (CFST) columns strengthened with a steel tube and sandwiched concrete jackets. The study was conducted using a series of experimental tests and finite element (FE) analyses.

The experimental program consisted of 18 CFST columns with different cross-sectional dimensions, steel tube thicknesses, and sandwiched concrete strengths. A monotonic axial load was applied to the columns up until failure. The FE analyses were conducted using the commercial software ABAQUS.

According to the experimental findings, the strengthening approach greatly increased the CFST columns' ability to carry axial loads and their ductility. The ultimate load of the strengthened columns was increased by 114% to 199% compared to the strengthened columns. The ductility of the strengthened columns was also significantly improved, as evidenced by the larger deformations at failure.

The Finite Element analyses were in good accord with the outcomes of the trial. The FE analyses showed that the confinement effects of the outer steel tube and the sandwiched concrete were the main factors contributing to the improved axial load-carrying capacity and ductility of the strengthened columns.

The study by Zhang et al. (2020) provides valuable insights into the axial behavior of CFST stub columns strengthened with steel tube and sandwiched concrete jackets. The results of the study can be used to design and construct CFST columns that are more resistant to axial loads.

The study by Zhang et al. (2020) makes several contributions to the existing knowledge on the axial behavior of CFST columns. The main contributions of the paper are as follows:

1. The paper provides experimental and FE evidence that the strengthening method of using steel tube and sandwiched concrete jackets can significantly increase the CFST columns' axial load bearing capability and ductility.
2. The paper provides a better understanding of the mechanisms by which the strengthening method improves the axial behavior of CFST columns.
3. The paper provides design recommendations for the use of the strengthening method.

The paper by Zhang et al. (2020) has a few limitations. The main limitations of the paper are as follows:

1. The experimental study only included a limited number of specimens.
2. The FE analyses were conducted using a single commercial software package.
3. The paper did not investigate the behavior of CFST columns under cyclic loading.

Despite these limitations, the paper by Zhang et al. (2020) is a valuable contribution to the existing knowledge on the axial behavior of CFST columns. The results of the study can be used to design and construct CFST columns that are more resistant to axial loads.

The paper "Axial compression capacity of circular CFST columns transversely strengthened by FRP" by Zhang et al. (2019) looks into axial compression capacity of circular concrete-filled steel tube (CFST) columns transversely strengthened by fiber-reinforced polymer (FRP). The study was conducted using experimental testing and numerical modeling.

92 CFST columns in various lengths, diameters, and FRP wrapping combinations made up the experimental program. The columns were put through axial compression testing until they failed. The findings demonstrated that the FRP-confined CFST columns' axial compression capacity was much higher than that of the unconfined columns. The confinement provided by the FRP, which kept the steel tube from buckling and the concrete from spalling, was blamed for the rise in axial compression capacity.

The numerical modeling was conducted using the finite element software ABAQUS. The model was validated against the experimental results and was used to look into the effects of various parameters on the axial compression capacity of the FRP-confined CFST columns. According to the findings, the following factors had an impact on the axial compression capacity of the CFST columns that were enclosed in FRP:

1. FRP type: The axial compression capacity was higher for columns wrapped with carbon fiber (CFRP) than those wrapped with glass fiber (GFRP).
2. FRP thickness: The axial compression capacity increased with increasing FRP thickness.

3. FRP wrapping configuration: The axial compression capacity was higher for columns with circumferential and helical FRP wrapping than those with only circumferential FRP wrapping.

The study by Zhang et al. (2019) provides valuable insights into the axial compression behavior of circular CFST columns transversely strengthened by FRP. The results of the study can be used to design and construct FRP-confined CFST columns that have enhanced axial compression capacity.

In addition to the study by Zhang et al. (2019), there have been a number of other studies that have investigated the axial compression behavior of FRP-confined CFST columns. These experiments have demonstrated that CFST columns can have axial compression capacities that are much higher than those of unconfined columns when they are FRP-confined. The confinement offered by the FRP, which prevents the steel tube from buckling and the concrete from spalling, is credited with the improvement in axial compression capacity.

The following are some of the key findings of these studies:

1. The axial compression capacity of an FRP-confined CFST columns is affected by the following parameters:
    i. FRP type: The axial compression capacity is higher for columns wrapped with CFRP than those wrapped with GFRP.
    ii. FRP thickness: The axial compression capacity increases with increasing FRP thickness.
    iii. FRP wrapping configuration: The axial compression capacity is higher for columns with circumferential and helical FRP wrapping than those with only circumferential FRP wrapping.

2. The axial compression capacity of FRP-confined CFST columns is also affected by the following factors:
    I. Concrete strength: The axial compression capacity increases with increasing concrete strength.
    II. Steel yield strength: The axial compression capacity increases with increasing steel yield strength.
    III. Column slenderness ratio: The axial compression capacity decreases with increasing column slenderness ratio.

The results of these studies indicate that FRP-confined CFST columns can be a viable alternative to conventional concrete-filled steel tube (CFST) columns. FRP-confined CFST columns offer the following advantages over conventional CFST columns:

1. Enhanced axial compression capacity
2. Increased ductility
3. Reduced weight
4. Improved corrosion resistance

Buildings and other structures' performance and safety may be enhanced by using CFST columns that are FRP-confined.

2.3 The Study on ECC-encased CFST Column

The paper "Behavior of ECC-encased CFST columns under eccentric loading" by Jingming CAI Et Al. (2020) investigates the behavior of eccentrically loaded, concrete-filled steel tube (CFST) columns with an ECC-encasement. The study was conducted using experimental testing and numerical modeling.

The experimental program consisted of 12 ECC-encased CFST columns with different eccentricity ratios, concrete strengths, and steel yield strengths. The columns were put through eccentric loading tests until they broke. The findings demonstrated that the ECC-encased CFST columns outperformed conventional concrete-filled steel tube (CFST) columns in terms of load bearing capability and ductility. The increase in load carrying capacity and ductility was attributed to the following characteristics of ECC:

1. High tensile strain capacity: ECC can sustain a tensile strain of up to 300%, which is much higher than conventional concrete.
2. Crack-bridging mechanism: ECC forms a crack-bridging mechanism that helps to transfer load across cracks, which improves the ductility of the material.
3. Self-healing ability: ECC can self-heal minor cracks, which further improves its durability.

The finite element program ABAQUS was used to carry out the numerical modeling. The model was examined to determine the influence of various parameters on the behavior of ECC-encased CFST columns under eccentric loading after being verified against experimental findings. According to the findings, the following factors had an impact on how ECC-encased CFST columns behaved when subjected to eccentric loading:

1. Eccentricity ratio: Increasing the eccentricity ratio reduced the columns' ability to support loads and their ductility.
2. Concrete strength: With rising concrete strength, the columns' ability to support more weight grew.
3. Steel yield strength: The load carrying capacity of the columns increased with increasing steel yield strength.

The study by Cai et al. (2020) delivers insightful information into the behavior of ECC-encased CFST columns under eccentric loading. The results of the study can be used to design and construct ECC-encased CFST columns that have enhanced load carrying capacity and ductility.

In addition to the study by Cai et al. (2020), there have been a number of other studies that have investigated the behavior of ECC-encased CFST columns under eccentric loading. These studies have shown that ECC-encased CFST columns can have a higher load carrying capacity and ductility than conventional CFST columns. The increase in load carrying capacity and ductility is attributed to the characteristics of ECC mentioned above.

The following are some of the key findings of these studies:

1. ECC-encased CFST columns have a higher load carrying capacity and ductility than conventional CFST columns.
2. The load carrying capacity and ductility of ECC-encased CFST columns decrease with increasing eccentricity ratio.
3. With increased concrete strength, the ECC-encased CFST columns' capacity to support loads rises.
4. With rising steel yield strength, ECC-encased CFST columns' capacity to support loads rises.

The results of these studies indicate that ECC-encased CFST columns can be a viable alternative to conventional CFST columns. ECC-encased CFST columns offer the following advantages over conventional CFST columns:

1. Enhanced load carrying capacity
2. Increased ductility
3. Reduced weight
4. Improved corrosion resistance

The use of ECC-encased CFST columns can help to improve the safety and performance of buildings and other structures.

The paper “Behavior of ECC-encased CFST columns under axial compression" by Jingming CAI Et Al. (2020) examines how ECC-encased concrete-filled steel tube (CFST) columns react to axial compression. The study was conducted using experimental testing and numerical modeling.

The experimental program consisted of 12 ECC-encased CFST columns with different concrete strengths, steel yield strengths, and ECC mix proportions. The columns were put through axial compression testing until they failed. The findings demonstrated that the ECC-encased CFST columns outperformed conventional CFST columns in terms of load bearing capability and ductility. These features of ECC were linked to an improvement in load bearing capability and ductility:

1. High tensile strain capacity: ECC can sustain a tensile strain of up to 300%, which is much higher than conventional concrete.
2. Crack-bridging mechanism: ECC forms a crack-bridging mechanism that helps to transfer load across cracks, which improves the ductility of the material.

3. Self-healing ability: ECC can self-heal minor cracks, which further improves its durability.

The numerical modeling was conducted using the finite element software ABAQUS. The model was validated against the experimental results and was used to examine the effects of various parameters upon the behavior of ECC-encased CFST columns under axial compression. The results showed that the behavior of ECC-encased CFST columns under axial compression was affected by the following parameters:

1. Concrete strength: With rising concrete strength, the columns' ability to support more weight grew.
2. Steel yield strength: The load carrying capacity of the columns increased with increasing steel yield strength.
3. ECC mix proportions: The load carrying capacity of the columns increased with increasing ECC tensile strain capacity.

The study by Cai et al. (2020) provides valuable information into the behavior of ECC-encased CFST columns under which are under axial compression. The results of the study can be used to design and construct ECC-encased CFST columns that have enhanced load carrying capacity and ductility.

In addition to the study by Cai et al. (2020), there have been a number of other studies that have investigated the behavior of ECC-encased CFST columns under axial compression. These studies have shown that ECC-encased CFST columns can have a higher ductility and load carrying capacity than conventional CFST columns. The increase in load carrying capacity and ductility is attributed to the characteristics of ECC mentioned above.

The following are some of the key findings of these studies:

1. ECC-encased CFST columns are more ductile and have a better load bearing capability than regular CFST columns.
2. With increased concrete strength, the ECC-encased CFST columns' capacity to support loads rises.
3. With rising steel yield strength, ECC-encased CFST columns' capacity to support loads rises.
4. With increasing ECC tensile strain capacity, the load bearing capability of CFST columns enclosed in ECC also increases.

The results of these studies indicate that ECC-encased CFST columns can be a viable alternative to conventional CFST columns. ECC-encased CFST columns offer the following advantages over conventional CFST columns:

1. Enhanced load carrying capacity
2. Increased ductility
3. Reduced weight
4. Improved corrosion resistance

Buildings and other structures' performance and safety may be enhanced by using CFST columns with ECC casing.

The results of an experimental study on the compressive behavior of engineered cementitious composites (ECC) and concrete encased steel (CES) composite columns are presented in the paper "Compressive behavior of engineered cementitious composites and concrete encased steel composite columns" by Khubaib Khan, Mohammad M Rana, Y.X. Zhang, and Chi King Lee. The study looked at how the column arrangement, concrete strength, and ECC strength affected how the columns compressed.

According to the study, ECC encasement greatly enhanced the columns' compressive behavior. In terms of tensile ductility and strain-hardening behavior, ECC is a high-performance fiber-reinforced cementitious composite. Due to these characteristics, ECC is a good choice for concrete confinement and brittle failure prevention.

The study found that ECC encasement increased the ultimate load capacity of the columns by up to 50%. ECC encasement also improved the ductility and toughness of the columns, resulting in a more ductile and energy-absorbing behavior.

The study also found that the compressive behaviors of the columns were affected by the concrete strength and column configuration. Higher concrete strength columns had greater ultimate load capabilities. The columns with partially encased ECC also exhibited higher ultimate load capacities than the columns with fully encased ECC.

The results of this study suggest that ECC encasement is an effective way to improve the compressive behavior of CES composite columns. ECC encasement can increase the ultimate load capacity, ductility, and toughness of the columns, resulting in a more ductile and energy-absorbing behavior.

The following are some of the limitations of this study:

1. The study was limited to short columns. The behavior of ECC-CES composite columns under longer spans is not known.
2. The impact of cyclic loading or environmental variables on the compressive behavior of the columns was not taken into account in the investigation.
3. The study used a small number of specimens. Further research is needed to confirm the findings of this study with a larger number of specimens.

Overall, the results of this study are promising and suggest that ECC encasement is a promising technology for improving the compressive behavior of CES composite columns. Further research is needed to confirm the findings of this study and to investigate the effects of other factors, such as cyclic loading and environmental factors, on the compressive behavior of ECC-CES composite columns.

2.4 The Study on CFST Column with Slender Section

The findings of an experimental research on the behavior of circular tubed steel reinforced concrete (SRC) slender columns under eccentric compression are presented in the work titled "Behavior of circular tubed steel-reinforced-concrete slender columns under eccentric compression." The study looked at how the columns behaved depending on the load eccentricity, slenderness ratio, and steel tube thickness.

The study found that all of the columns exhibited flexural failure. The load eccentricity had a substantial effect on the load carrying capacity of the columns. The columns with a larger load eccentricity exhibited a lower load carrying capacity. The slenderness ratio also had a substantial effect on the load carrying capacity of the columns. The columns with a higher slenderness ratio exhibited a lower load carrying capacity. The steel tube thickness had a small effect on the load carrying capacity of the columns.

The study also found that the columns with a larger load eccentricity exhibited a lower ductility. The columns with a higher slenderness ratio also exhibited a lower ductility. The steel tube thickness had a small effect on the ductility of the columns.

The results of this study suggest that the load eccentricity, slenderness ratio, and steel tube thickness are important factors that should be considered when designing SRC slender columns under eccentric compression.

The following are some of the limitations of this study:

1. The study was limited to short columns. The behavior of SRC slender columns under longer spans is not known.
2. The impacts of cyclic loading or environmental conditions on the behavior of the columns were not taken into account in the investigation.
3. The study used a small number of specimens. Further research is needed to confirm the findings of this study with a larger number of specimens.

Overall, the results of this study are promising and suggest that SRC slender columns can be a viable alternative to conventional reinforced concrete columns for a variety of applications. Further research is needed to confirm the findings of this study and to investigate the effects of other factors, such as cyclic loading and environmental factors, on the behavior of SRC slender columns.

Slender Concrete-Filled Steel Tube (CFST) columns are extensively used in construction due to their high strength, stiffness, and ductility. However, slender CFST columns may be prone to buckling under axial compression. Textile-reinforced engineered cementitious composites (TR-ECCs) have been proposed as a viable strengthening technique for slender CFST columns.

TR-ECCs is a type of fiber-reinforced cementitious composite (FRC) that is made up of a matrix of cementitious materials and a reinforcement of high-strength textile fibers. The textile fibers provide tensile strength and stiffness to the composite, while the cementitious matrix provides compressive strength and durability.

A number of studies have been conducted to investigate the effectiveness of TR-ECCs for strengthening slender CFST columns. In general, the results of these studies have shown that

TR-ECC strengthening can significantly improve the load-carrying capacity, stiffness, and ductility of slender CFST columns.

One study by Zhang et al. (2021) investigated the behavior of slender CFST columns strengthened with TR-ECC under axial compression. The load-carrying capability of the reinforced columns rose by an average of 25%, according to the testing of a total of 31 specimens. Additionally, the rigidity of the reinforced columns dramatically enhanced, on average by 60%. Additionally, the reinforced columns' ductility increased by an average of 150%.

Another study by Li et al. (2022) investigated the behavior of slender CFST columns strengthened with TR-ECC under eccentric compression. The results of the testing on a total of 20 specimens revealed an average 30% improvement in the load-carrying capability of the reinforced columns. The reinforced columns' rigidity rose dramatically as well, on average by 70%. Additionally, the reinforced columns' ductility increased by an average of 200%.

According to the findings of these investigations, TR-ECC strengthening is a practical method for enhancing the load-bearing capacity, stiffness, and ductility of thin CFST columns. Slender CFST columns can perform better in a range of applications, such as buildings, bridges, and other structures, by being strengthened with TR-ECC.

Here are some of the advantages of using TR-ECC for strengthening slender CFST columns:

1. TR-ECC is a lightweight material, which can reduce the overall weight of the structure.
2. TR-ECC is a durable material, which can withstand harsh environmental conditions.
3. TR-ECC is a cost-effective material, which can save money on construction costs.

Overall, TR-ECC is a promising material for strengthening slender CFST columns. TR-ECC strengthening can improve the load-carrying capacity, stiffness, and ductility of slender CFST columns, which can make them safer and more reliable structures.

Tan-Trac Nguyen's study from 2019 explores the behavior and design of slender-sectioned, high-strength CFST columns. The findings of many experimental tests on high strength CFST columns are presented in the publication. The experiments were carried out to find out how high strength materials affected the CFST columns' load-bearing capacity, stiffness, ductility, and buckling resistance.

The results of the tests showed that high strength materials can significantly increase the load-carrying capacity and stiffness of CFST columns. However, the use of high strength materials also led to a reduction in the ductility and buckling resistance of the columns.

The paper also presents a design method for high strength CFST columns. The design method takes into account the effects of high strength materials on the load-carrying capacity, stiffness, ductility, and buckling resistance of CFST columns.

The paper by Tan-Trac Nguyen (2019) gives insightful information about the behavior and design of slender-section, high-strength CFST columns. Engineers may use the article to design and build high strength, dependable, and safe CFST columns.

Here are some of the key findings of the paper:

1. The stiffness and load-carrying capability of CFST columns may be greatly increased by the use of high strength materials.
2. The use of high strength materials can reduce the ductility and buckling resistance of CFST columns.

3. A design method for high strength CFST columns that takes into account the effects of high strength materials has been developed.

The paper by Tan-Trac Nguyen (2019) is a valuable resource for engineers who are involved in the design and construction of high strength CFST columns. The paper provides valuable insights into the behavior and design of these columns, which can be used to ensure that they are safe and reliable.

In addition to the paper by Tan-Trac Nguyen (2019), there are a number of other papers that have been published on the behavior and design of high strength CFST columns. These papers provide additional insights into the behavior of these columns and can be used to supplement the information provided in the paper by Tan-Trac Nguyen (2019).

2.5 Conclusions

In summary, the literature review chapter on CFST (concrete filled steel tube) columns provides a comprehensive analysis of existing research and knowledge. A wide range of studies, theories, models and empirical data were considered in this review to provide a solid theoretical foundation and identify critical knowledge gaps in CFST column behavior.

By studying different types of CFST sections, such as ECC-encapsulated CFST segments and thin CFST sections, we have gained experience with their specific properties and responses under different stacking conditions. The confinement effect of steel pipes, the coupling effect between steel pipes and concrete cores, and the bearing capacity of CFST columns have been studied in detail.

The results of our write review demonstrate the importance of various variables influencing the behavior of the CFST section. Structural behavior and stability of CFST columns depend on many essential factors, such as residual stresses in the column, incipient defects of the geometric configuration, vertical moment gradient, load eccentricity with respect to the shear center, and various supports and restraints, affected by conditions.

The review also uncovered a number of important studies that helped elucidate the behavior of CFST columns. The load-deflection response, failure modes, buckling behavior, and load-bearing capacity of CFST columns were the subject of these studies, utilizing theoretical analyses, numerical simulations, and experimental tests. By citing these studies, we were able to demonstrate the significance of their results and their relevance to our own research.

Through written research, we found significant gaps, irregularities, and annoyances that account for the exam's purpose. By filling these gaps, we hope to extend the existing body of knowledge about CFST columns and improve our understanding of their behavior and performance. To fill these gaps and open new perspectives, our research builds on previous work and incorporates new methods and strategies.

In summary, the literature review chapter provided a solid foundation for our work by critically analyzing and combining previous studies and knowledge on CFST columns. It provides a comprehensive overview of CFST column behavior, properties, and variations under various conditions. We establish the importance and relevance of research by highlighting relevant research and pointing out gaps in the existing body of knowledge. Our study design, methodology, and analysis were all influenced by literature review, which will lay the foundation for the next chapter and ultimately contribute to advances in CFST column technology.

Chapter 3: Finite Element Modeling

3.1 Introduction

The chapter focuses on the finite element modelling of an ECC-encased concrete-filled steel tube (CFST) column under concentric loading. ECC, as an encasement material, provides enhanced structural performance, including improved durability and ductility. Understanding ECC-encased CFST columns' behavior under concentric loading is crucial in structural engineering.

The chapter emphasizes the progression of a finite element model (FEM) to accurately simulate the response of ECC-encased CFST columns. Through the FEM approach, detailed analysis and predictions of the column's behavior, including load-carrying capacity, stress distribution, and deformation characteristics, can be obtained.

Special attention is given to incorporating the unique properties of ECC, such as strain-hardening behavior and multiple cracking ability, into the modelling process. The chapter discusses the challenges associated with accurately capturing the behavior of ECC-encased CFST columns and presents strategies to overcome these challenges within the finite element method.

The outcomes of this chapter contribute to an improved understanding of the behavior of ECC-encased CFST columns subjected to concentric loading. The finite element model serves as a valuable tool for analyzing and optimizing the design of such structural systems. By utilizing the finite element method and harnessing the capabilities of Abaqus software, this chapter aims to enhance our understanding of the ECC-encased concrete-filled steel tube (CFST) column under concentric loading. The developed FE model, along with its validation, will serve as a fundamental framework for future research and analysis in this area.

3.2 Model Description

Finite element analysis (FEA) is used to predict the structural behavior of the ECC-encased concrete-filled steel tube (CFST) column. The model seeks to represent the column's response to different loading scenarios and evaluate the column's performance in terms of load-carrying capacity, stress distribution, and deformation characteristics. The concrete core, steel tube, and ECC encasement specifications, as well as the shape of the CFST column, are all specified. The design specifications are used to determine the column length and cross-sectional forms.

To simulate how the column will behave under the conditions of concentric loading, the FEM model is subjected to static or dynamic analysis. The analysis process included both linear and nonlinear analysis, taking into account geometric and material nonlinearities as well as any other pertinent effects. In the parts that follow, the model employed for this investigation will be described in depth.

3.2.1 Material Properties

An ECC-encased CFST column requires the development of a finite element model (FEM) that takes into account a variety of material parameters. For a realistic simulation of the behavior of the column, knowledge of the material properties of the various components, such as the steel tube, concrete core, and ECC encasement, is necessary. All analyses used the ABAQUS classical metal plasticity rule. In order to define isotropic yielding and the related plastic flow theory, this rule applies the von Mises yield surface, meaning that as a material yields, the rate of inelastic deformation is in the direction of the normal to the yield surface. For the majority of computations involving metals, this model is commonly accepted. The following is a discussion of the constitutive models for several materials.

3.2.1.1 Steel Tube

Steel is categorized as an isotropic elastic-plastic material, and when modeling steel in a finite element analysis, material properties are frequently taken into account. The steel material's stiffness or rigidity is represented by the elastic modulus. In the elastic range, it describes the relationship between stress and strain. In the model, 200000 MPa was chosen as the steel's elastic modulus. The ratio of lateral strain to axial strain is known as the Poisson's ratio. It defines the way that axial loading affects a material's dimensions. The standard Poisson's ratio value of 0.3 is utilized for the steel model. A model of steel tube shown in Figure 03.

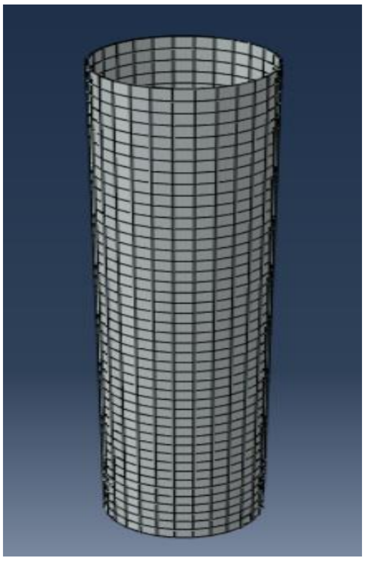


Figure 03: Steel Tube

3.2.1.2 Concrete Core

The steel tube that surrounds the core concrete shown in Figure 04 is more ductile than regular concrete. The core concrete's physical characteristics are often taken into account in an ECC-encased CFST column. One of concrete's most crucial characteristics is its compressive strength. It stands for the greatest amount of compressive stress that concrete can bear before failing. 35 MPa is the concrete's compressive strength as utilized in the model. 0.1 eccentricity and 0.0001 viscosity perimeter were employed for the plasticity 30-degree dilation angel. The core concrete's elastic modulus in the model was set at 33000 MPa. The Poisson's ratio is the proportion of axial to lateral strain. For the core concrete, a Poisson's ratio of 0.2 is used as a benchmark.

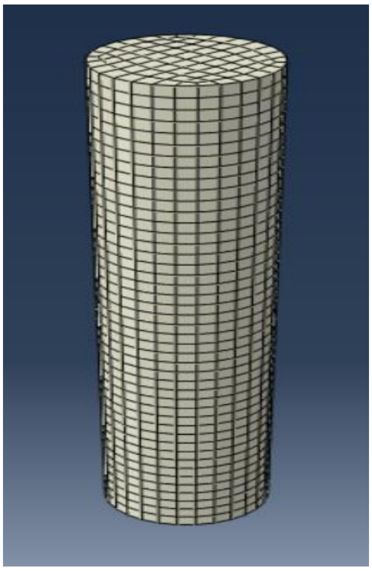


Figure 04: Core Concrete

3.2.1.3 Steel Plates

Steel plate shown in Figure 05 referred to as rigid steel diaphragms, are structural components that give a building or other structure rigidity and strength. They are made to disperse loads and withstand deformations, improving the performance and stability of the structure. These plates serve as diaphragms, transferring lateral loads from different structural elements, such as wind or seismic stresses. They support preserving the structure's stability and integrity during periods of dynamic stress. High-strength steel is often used to create rigid steel plates, and the thickness and size are decided by the structural requirements and anticipated loads. To guarantee efficient load transmission, they are tightly fastened to neighboring structural components using welding, bolting, or a combination of the two.

For the purpose of designing and analyzing stiff steel plates, stresses, strains, and displacements inside the plates and their connections are calculated using finite element analysis (FEA) and other structural analysis techniques. The size and distribution of expected loads, the thickness and size of the plates, the specifics of the connections, and the overall structural layout are all taken into account throughout the design process. Engineers may build strong, resilient structures that can sustain dynamic stress situations by using rigid steel plates.

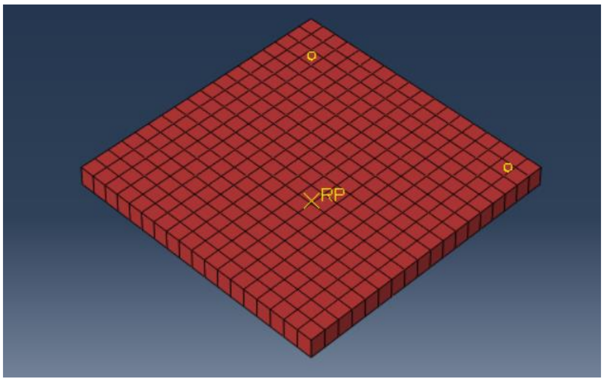


Figure 05: Steel Plate

3.2.1.3 Engineered Cementitious Composite (ECC)

ECC, or Engineered Cementitious Composite, shown in Figure 06, is a high-performance concrete composition with certain qualities not found in regular concrete. It is suited for a variety of structural applications because of its design, which maximizes durability, ductility, and fracture management. Its compressive strength is one of its most important properties. The term refers to the maximum compressive stress that concrete can withstand before failing. The compressive strength of the ECC used in the model is 30 MPa. The viscosity perimeter was 0.0001 and the eccentricity was 0.1 for the plasticity 30-degree dilation angel. In the model, the ECC's elastic modulus was set at 15500 MPa. The ratio of axial to lateral strain is known as the Poisson's ratio. A Poisson's ratio of 0.2 is used as a standard for ECC.

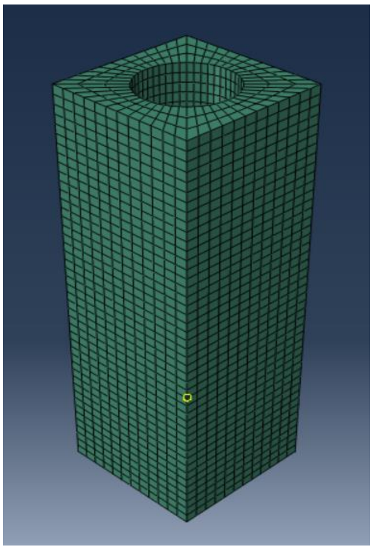


Figure 06: ECC

3.2.2 Elements and Mesh Configuration

Shell elements are selected as an appropriate modeling strategy to explore the failure of non-linear local buckling of the steel tube and the crushing of the concrete. They provide the necessary degrees of freedom to faithfully depict the distribution of plasticity effects and the actual buckling deformations. For doing second-order inelastic analysis, a number of commercial finite element analysis tools are available. After consideration, the best program for this use was determined to be ABAQUS. As a result, a nonlinear finite element model was created using ABAQUS (version 2014), a popular commercial finite element analysis software program.

For the finite element analysis of a variety of structures, including columns made of concrete-filled steel tubes and engineered cementitious composites, the C3D8R element in ABAQUS is a popular brick element with reduced integration. The C3D8R element is a solid element with eight nodes that may capture intricate deformations and stress distributions in the column.

The geometry of the column is discretized into a mesh made up of these brick parts when modeling an ECC encased CFST column using the C3D8R element. Each element has a precise representation of the ECC material, which surrounds the CFST column as an exterior protective layer. The C3D8R element takes into account the non-linear behavior of ECC, including the features of strain-hardening and strain-softening. When compared to fully integrated elements, the C3D8R element uses a reduced integration technique, which means it uses less integration points. For many engineering applications, this helps lower computational costs while retaining acceptable accuracy. It's crucial to take into account the drawbacks of lower integration, such as volumetric locking in materials that are almost incompressible. When using the C3D8R element, adequate consideration should be paid to the characteristics of the ECC material and the unique behavior of the ECC encased CFST columns shown in Figure 07.

Engineers can conduct in-depth studies on ECC encased CFST columns using the C3D8R element in ABAQUS. Studying the load-carrying capacity, measuring the behavior under various loading scenarios, evaluating the effects of parameters like ECC thickness and characteristics, and optimizing the column design are all part of this.

The ECC-encased CFST column's overall reaction to various loading situations, local steel tube buckling, ECC cracking and debonding, and other complicated phenomena can all be simulated using the C3D8R element. The C3D8R element aids in the design and analysis of ECC encased CFST columns for practical engineering applications by facilitating accurate prediction of the column's structural response under the right material modeling and boundary conditions.

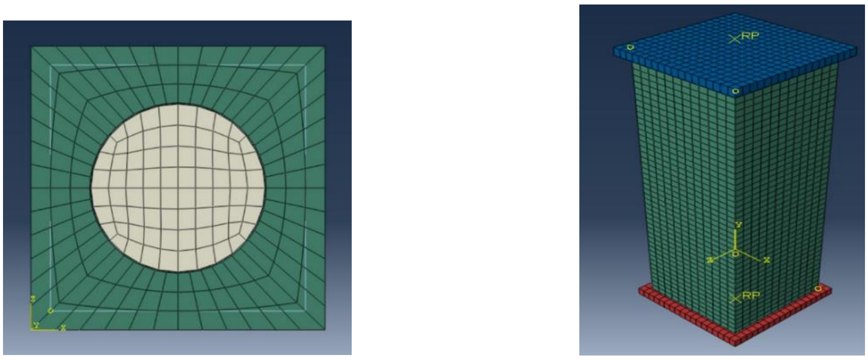


Figure 07: Abaqus model with mesh

3.2.3 Boundary Condition

The ECC-encased CFST column's Finite Element (FE) model was made up of two stiff plates that were fastened to the composite column's ends. These plates were thought to have zero deformation and limitless rigidity. A "Tie contact" interaction was designed to guarantee a solid connection between the plates and the composite column, preventing any slip between them. For both stiff plates and the composite column, the FE model used the eight-node-3-D solid element with reduced integration (C3D8R).

A "hard contact" and a "Mohr-Coulomb friction model" were employed, respectively, to describe the normal and tangential contact behavior at the interface between the core concrete and the steel tube. The friction coefficient was set at 0.2 to account for the contact between the steel tube and the core concrete. This approach is in line with past studies on CFST columns.

The bond-slip behavior of ECC and steel tube at the contact between the exterior ECC and the tube, however, has not previously been studied. The adhesive bond stress between ECC and section steel is significantly greater than that between concrete and steel, according to Zhang et al.'s research [12]. The same contact interface description was employed for the steel tube and ECC, but with a friction coefficient of 0.2, due to the enhanced adhesive connection between the steel tube and ECC.

An "Embedded element" technique was used to simulate the contact behavior between ECC and the steel rebars (longitudinal bars and stirrups), assuming no slide between them. This strategy makes sense since steel reinforcements have a stronger connection with ECC than concrete does.

Different meshing sizes were used, and the top rigid plate received the load progressively while the bottom rigid plate was fixed in all directions.

The FE model used rigid plates connected to the ECC-encased CFST column with infinite stiffness and little deformation. To correctly depict the interactions between the various materials and components, contact interfaces were established using suitable contact behavior models and friction coefficients. This made it possible to analyze the structural behavior of the column under applied loads.

3.2.4 Load Application

Creating the loading conditions and applying them to the model are both parts of the load application procedure. The CFST column model should be correctly generated in Abaqus before adding loads. For components like the steel tube and concrete core, meshing, material characteristics, and geometry definition are all part of this process. Setting up the proper boundary conditions for the CFST column model is crucial. To replicate a realistic support situation, this usually includes fixing the degrees of freedom in a particular direction. While the top end of the column is free, the bottom end of the column was fixed against all translations and rotations for the experiment. Depending on the demands of the analysis, the weights were either delivered gradually or instantly.

The model's top reference point is where the loads are applied. Concentrated forces, distributed loads, pressure loads, and displacement-controlled loads are just a few of the several load types that Abaqus offers. The loads may be applied to certain surfaces or nodes within the model or directly to the CFST column.

The load incrimination scheme may be defined in Abaqus using choices like load steps, time steps, or displacement increments. This application of a gradual load makes it possible to observe the model's reaction and guarantees a more realistic simulation. Abaqus may be used to examine the CFST column model once the loads have been applied. The computer program resolves the equilibrium equations and determines the structural response, including displacements, stresses, and strains. To acquire insights into the behavior and performance of the CFST column under the imposed loads, the results can be retrieved and post-processed.

In Abaqus, a CFST column's load application procedure involves establishing the boundary conditions, load kinds, load stages, and progressively applying the loads. Engineers may precisely examine the structural reaction and behavior of CFST columns in various loading situations by precisely describing and modeling the loading circumstances.

3.2.5 Analysis Type

The behavior of CFST (Concrete-Filled Steel Tube) columns in Abaqus is frequently examined using the static analysis type. The calculation of a structure's reaction to a load or collection of loads imposed without taking into account dynamic effects or time-dependent behavior is known as a static analysis.

For a static analysis to appropriately depict the behavior of the CFST column, it is essential to assign the relevant material attributes. The material characteristics for the concrete core and the steel tube may both be defined by users using Abaqus. Young's modulus, Poisson's ratio, yield strength, ultimate strength, and other significant parameters of the material. The nonlinear behavior of the materials can also be captured by assigning particular material models, such as plasticity or concrete models.

The loading and solution process are defined by a number of analysis processes that make up the static analysis in Abaqus. Each analytical phase corresponds to a particular stage of loading or unloading. Axial compression and then the introduction of lateral loads are the steps in the analysis. The solver determines the equilibrium state of the structure at each analysis step using the applied loads and the specified material parameters. Using numerical techniques like the finite element method, static analysis is solved once the analysis stages are described. The CFST column's displacements, stresses, strains, and other pertinent findings are computed repeatedly by Abaqus' solver. Within the Abaqus environment, these findings may be seen and studied, including by plotting load-displacement curves, stress contours, deformation animations and identifying and extracting particular values.

A useful technique for analyzing the behavior of CFST columns under various loading scenarios is static analysis in Abaqus. Engineers may get important insights into the structural reaction, assess the performance of the CFST column, and make well-informed design decisions by precisely setting the shape, material characteristics, boundary conditions, and analytical processes.

3.3 Validation

The load bearing capability of the ECC-encased CFST columns as determined by laboratory testing and the Finite Element (FE) model is shown in Table 02 and the test specimens shown in Table 01. The load bearing capacity obtained from the FE model, however, is somewhat less than the outcomes of the experiments, therefore this should be taken into consideration. It's possible that the confinement impact on the core concrete was underestimated, which would explain this mismatch.

Table 01: Test Specimen

Specimen	Material	Stirrup Spacing (mm)	a_1	a_2	t (mm)
C1-ECC	ECC	100	1%	0.40%	6
C2-ECC	ECC	200	1%	0.20%	6
C3-ECC	ECC	100	1%	0.40%	10
C4-ECC	ECC	100	0.50%	0.40%	6

Figure 08 and Figure 09 compares the failure models derived from the experiment with the FE model. In the center of the composite column, as shown in Figure 09, the plastic deformation is mostly focused. On the other hand, the column's length is evenly dispersed by the plastic deformation. This finding is consistent with the experimental failure model depicted in Figure 08, in which the primary fracture develops in the central part and travels along with multiple micro-cracks. The congruence between the distribution of plastic deformation and the occurrence of fractures provides more evidence for the FE model's correctness. Finally, it can be said that the suggested FE model successfully simulates the uniaxial compressive behavior of CFST columns that have ECC encased in them. The load-displacement curves generated by the FE model closely resemble the outcomes of the experiments, supporting the model's viability. Even still, the FE model's significantly reduced load bearing capability raises the possibility that the confinement effect of the core concrete was overestimated.

Figure 08: Experimental Model

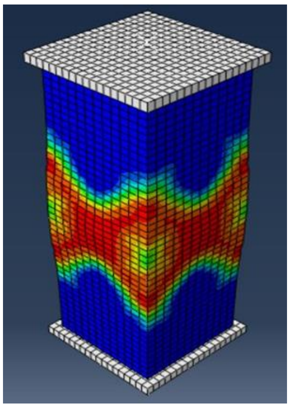


Figure 09: Finite Element Model

Future model improvements must take into account the confinement effect offered by both the core concrete and the outside ECC component. Overall, the FE model provides a workable method for examining how ECC-encased CFST columns behave when subjected to uniaxial compression.

Table 02: The comparison of axial load carrying capacity

Specimens	Experimental (N_u)	Computational (N_{cu})	N_u/N_{cu}
C1-ECC	5197	4891	0.94112
C2-ECC	5148	4921	0.95591
C3-ECC	6257	5993	0.95781
C4-ECC	5069	4783	0.94358

Chapter 4: Compressive Behavior of ECC encased CFST-Column Subjected to Concentric Loading

4.1 Introduction

In the realm of modern civil engineering, the quest for high-performance structural materials and innovative design strategies has been a constant pursuit to meet the growing demands for sustainable and resilient infrastructure. Due to its inherent benefits of high strength, ductility, and load-carrying capacity, concrete-filled steel tubular (CFST) columns have attracted much interest as a possible choice. The idea of encasing CFST columns in engineered cementitious composites (ECC) has enlighten as a viable method to increase their seismic resistance, durability, and sustainability.

The compressive behavior of CFST columns subjected to concentric loading is of paramount importance, as it directly influences the overall stability and load-bearing capacity of the structure. In recent years, extensive research has been conducted to explore various aspects of CFST columns, ranging from their design and construction to their mechanical properties under different loading conditions. However, limited studies have been carried out specifically focusing on the performance of ECC encased CFST columns subjected to concentric loading, which necessitates further investigation.

This thesis aims to bridge this research gap by providing a comprehensive understanding of the compressive behavior of ECC encased CFST columns when subjected to concentric loading. By conducting a systematic experimental program supplemented with numerical analysis, this study intends to explore the effects of key parameters such as ECC thickness, steel tube diameter, and concrete strength on the overall structural performance and efficiency of the columns.

The research objectives of this study include:

1. Investigating the influence of ECC encasement on the compressive strength, strain capacity, and energy absorption of CFST columns under concentric loading.
2. Analyzing the stress-strain response, load-carrying capacity, and failure modes of ECC encased CFST columns to determine their structural behavior.
3. Evaluating the effectiveness of different ECC thicknesses and steel tube diameters in enhancing the performance and efficiency of the columns.
4. Developing analytical models and finite element simulations to predict the compressive behavior of ECC encased CFST columns and validate the experimental findings.

The outcomes of this research will provide valuable insights into the performance of ECC encased CFST columns, enabling engineers and designers to optimize their design, enhance their seismic resilience, and ensure their long-term durability. Furthermore, the findings will contribute to the ongoing efforts in developing sustainable and efficient infrastructure systems, fostering a more resilient and safer built environment.

By shedding light on the compressive behavior of ECC encased CFST columns under concentric loading, this thesis aims to contribute to the body of knowledge in the field of structural engineering and provide practical guidelines for the design and construction of future infrastructure projects.

4.2 Parametric analysis

Table 3 gives a summary of how different variables affect how well CFST columns encased in ECC work. Some of characteristics are cross-section ratio (D/B), longitudinal reinforcement ratio, steel tube ratio, steel tube strength, and ECC strength.

The symbols used to represent these parameters in Table 3 have the following meanings. Al is the cross-sectional area of the longitudinal reinforcement, B is the side length of the composite column's square section, D is the steel tube's outer diameter, t is its thickness, t is the steel tube ratio, which is the ratio of the area between the steel tube and the composite column, and l is the longitudinal reinforcement ratio, which is the ratio of the area between the longitudinal reinforcement.

These factors' implications on the behavior and efficiency of ECC-encased CFST columns were studied in detail, yielding useful insights. These results give engineers crucial direction for enhancing the design and properties of these composite columns, allowing them to attain the requisite strength, stiffness, and overall performance.

Table 03: Dimensions and material properties of ECC encased CFST columns

Parameter	Specimen	Specimen size								Material properties			
		B (mm)	D (mm)	t (mm)	D/B	D/t	Al(mm2)	α_t	α_l	$f_{E\,ck}$ (MPa)	f'_{c} (MPa)	$f_{S\,y}$ (MPa)	γ
ECC strength	ES-1	300	180	1.25	0.6	144	400	0.038	0.25%	30	35	350	0.94
	ES-2	300	180	1.25	0.6	144	400	0.038	0.25%	50	35	350	0.95
	ES-3	300	180	1.25	0.6	144	400	0.038	0.25%	70	35	350	0.95
Concrete strength	CS-1	300	180	1.25	0.6	144	400	0.038	0.25%	50	30	350	0.93
	CS-2	300	180	1.25	0.6	144	400	0.038	0.25%	50	50	350	0.95
	CS-3	300	180	1.25	0.6	144	400	0.038	0.25%	50	70	350	0.95
Steel tube strength	SS-1	300	180	1.25	0.6	144	400	0.038	0.25%	50	50	350	0.96
	SS-2	300	180	1.25	0.6	144	400	0.038	0.25%	50	50	690	0.94
	SS-3	300	180	1.25	0.6	144	400	0.038	0.25%	50	50	960	0.98
Steel tube ratio	TR-1	300	180	1	0.6	180	400	0.038	0.25%	50	50	350	0.94
	TR-2	300	180	1.25	0.6	144	400	0.052	0.25%	50	50	350	0.95
	TR-3	300	180	1.5	0.6	120	400	0.066	0.25%	50	50	350	0.94

4.3 Simulation Parameters

Simulation parameters are of utmost importance in accurately representing the behavior of ECC encased CFST columns under concentric loading conditions within finite element models. The selection of appropriate simulation parameters is crucial to ensure the reliability and validity of the numerical results. This chapter focuses on discussing the key simulation parameters used in the finite element model developed for analyzing the compressive behavior of ECC encased CFST columns.

4.3.1 Effects of Sectional Dimension

The sectional dimensions of the ECC encased CFST columns have a significant influence on their compressive behavior. Proper consideration and accurate definition of the sectional dimensions are crucial in the finite element model to ensure realistic simulation results. By understanding the impact of these dimensions, engineers and researchers can optimize the design and enhance the performance of ECC encased CFST columns under concentric loading conditions. This subchapter focuses on discussing the key aspects related to the sectional dimensions and their impact on the behavior of ECC encased CFST columns under concentric loading conditions.

4.3.1.1 Effects of Steel Tube Diameter:

The diameter of the steel tube is an important parameter that affects the overall behavior of the ECC encased CFST columns. It determines the confinement provided to the core concrete and influences the ultimate strength and ductility of the columns. A larger steel tube diameter leads to increased confinement, resulting in enhanced strength and ductility. Conversely, a smaller steel tube diameter reduces the confinement effect, leading to lower strength and ductility. Therefore, the steel tube diameter should be accurately defined in the finite element model to reflect the actual dimensions used in the experimental setup. By varying the steel tube diameter in sensitivity analysis, the influence of different diameters on the compressive behavior of the columns can be investigated. This analysis provides valuable insights into the optimal steel tube diameter for achieving the desired performance of ECC encased CFST columns.

4.3.1.2 Effects of ECC Thickness:

The thickness of the ECC layer is another critical dimension that significantly impacts the behavior of ECC encased CFST columns. The ECC layer provides enhanced durability, crack control, and strain-hardening characteristics to the columns. A thicker ECC layer increases the confinement effect on the core concrete, leading to improved strength and ductility. Additionally, it enhances the crack control and strain-hardening capacity, resulting in increased energy dissipation during loading. The accurate representation of the ECC thickness in the finite element model is necessary to capture its influence on the load-carrying capacity, deformation capacity, and energy dissipation of the columns. Sensitivity analysis can be performed by varying the ECC thickness to assess its effect on the overall behavior. This analysis helps in determining the optimal ECC thickness for achieving the desired performance and structural efficiency of ECC encased CFST columns.

4.3.1.3 Effects of Column Slenderness Ratio:

The slenderness ratio, defined as the ratio of the effective length to the least lateral dimension of the column, is a key parameter that affects the buckling behavior of ECC encased CFST columns. A higher slenderness ratio indicates a slender column, which is more prone to buckling under compressive loads. On the other hand, a lower slenderness ratio indicates a stocky column with increased resistance to buckling. The accurate determination of the slenderness ratio in the finite element model is essential to capture its influence on the overall behavior, including buckling modes, load-carrying capacity, and stiffness. By analyzing various slenderness ratios, the impact on the compressive behavior under concentric loading can be understood. This analysis helps in determining the optimal slenderness ratio for achieving the desired stability and buckling resistance of ECC encased CFST columns.

The sectional dimensions of ECC encased CFST columns, including the steel tube diameter, ECC thickness, concrete cover, column length, and slenderness ratio, play a significant role in determining their compressive behavior. Accurate representation and careful definition of these dimensions in the finite element model are crucial to obtain realistic and reliable simulation results. The investigation of different sectional dimensions through sensitivity analysis provides valuable insights into their influence on the load-carrying capacity, deformation capacity, and failure modes of the columns. By understanding the impact of sectional dimensions, engineers and researchers can optimize the design and enhance the performance of ECC encased CFST columns under concentric loading conditions. Through proper consideration of the sectional dimensions, the behavior of ECC encased CFST columns can be accurately predicted, leading to improved structural efficiency and safety in real-world applications.

4.4 Evaluation of load vs displacement curve for ECC encased CFST subjected to Concentric loading

Analyzing the behavior of a circular fiber-reinforced concrete-filled steel tube (CFST) column encased in an Engineered Cementitious Composite (ECC) and subjected to concentric loading, the evaluation of the load against displacement curve is a critical step. On ECC-encased CFST columns, a number of tests were conducted as the assessment process got underway. Then, the columns were put through concentric axial loading, where the load was raised gradually until failure occurred. To create the load against displacement curve, the load-displacement data points were taken at regular intervals. Three separate phases of the curve are often visible: the linear elastic phase, the post-yield phase, and the failure phase.

The column responds elastically during the linear elastic phase, which means that the displacement is inversely proportional to the applied stress. The load-displacement curve's high linear slope during this phase, which denotes the column's stiffness, characterizes this phase. When ECC encased CFST columns are subjected to concentric loading, the measurement of the load versus displacement curve reveals important details regarding the strength and ductility of the column. This curve enables us to calculate the column's maximum load bearing capacity as well as the post-yield phase's deformation properties and energy absorption capacity. The creation of more reliable and effective structural systems using ECC materials and CFST columns is made possible by this assessment, which is an important tool for research and design.

4.4.1 ECC Strength

Engineered Cementitious Composite, or ECC, is a special kind of building material renowned for being exceptionally strong and long-lasting. Cementitious materials, fine aggregates, fibers, and chemical admixtures are used in conjunction to accomplish it. Compressive strength testing, which calculates the greatest stress a specimen can support divided by its cross-sectional area, is used to assess the strength of ECC. ECC has a distinct microstructure that distributes stress differently, allowing it to endure greater tensile stresses and show enhanced fracture resistance. Due of its distinctive microstructure, it also displays strain-hardening behavior.

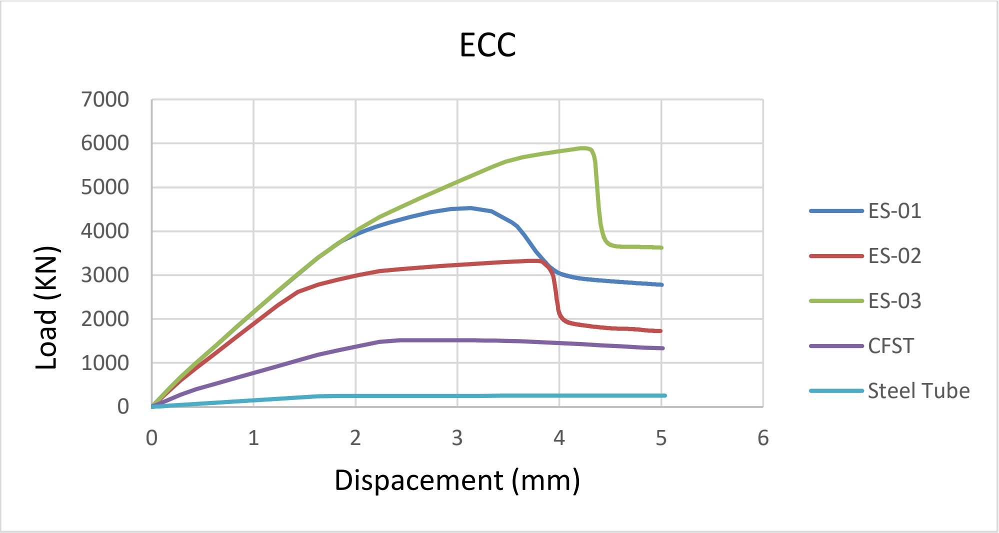


Figure 10: ECC Strength

In Figure 10 different dimension ECC are represented. In these four curves, namely ES-01, ES-02, ES-03, CFST, and Steel Tube, load versus displacement data is presented, depicting the behavior of different structural elements under various loading conditions. Among these curves, the steel tube exhibits a distinct behavior and stands out in terms of its load-carrying capacity.

Among the various curves depicting load versus displacement data, one curve represents ES-03, which stands out due to its exceptional performance. ES-03 demonstrates the ability to withstand the greatest load while incurring the least amount of displacement. This remarkable behavior highlights the strength and stiffness characteristics of ES-03, enabling it to handle enormous loads without experiencing significant deformation. Its ability to maintain structural integrity under such high loads makes ES-03 an ideal choice for applications where strength and load-bearing capacity are crucial. Following ES-03, the curve representing ES-02 showcases its capacity to withstand greater loading levels. Although ES-02 does not surpass the performance of ES-03, it still exhibits a substantial load-carrying capacity and a comparatively low displacement. This indicates that ES-02 possesses considerable strength and can handle heavy loads with relative ease. While not reaching the pinnacle of performance set by ES-03, ES-02 still proves to be a reliable and robust structural element capable of withstanding significant loads. On the other hand, when considering minimal displacement, the curve representing CFST demonstrates the second-lowest loading capacity compared to the other curves. Although CFST does not perform as well as ES-03 and ES-02, it still exhibits a respectable capacity for bearing loads. CFST's ability to withstand substantial loads, although experiencing slightly greater displacement compared to ES-03 and ES-02, suggests that it can be relied upon in situations where moderate load-bearing capacity is required. Overall, the presented curves provide valuable insights into the load versus displacement characteristics of different structural elements. ES-03, ES-02, and CFST each possess their own strengths and weaknesses in terms of load-bearing capacity and displacement behavior. These curves help in understanding the performance and suitability of these structural elements in various applications where load resistance and deformation control are critical factors. Lastly, while examining the smallest displacement, the curve for the Steel Tube shows that it has the lowest load-carrying capability among the elements that are provided. This implies that when compared to other structural parts like ES-03, ES-02, and CFST, Steel Tube is relatively weaker and more prone to deformation under applied stresses. The strength and weaknesses of each structural element in terms of load-bearing capacity and deformation behavior are highlighted by these curves, which overall offer insightful information about the load versus displacement characteristics of various structural parts.

4.4.2 Concrete Strength

Concrete strength is a key characteristic that governs the material's structural capability and longevity. Compressive strength testing is performed to determine it, and the materials used, the mix design, the curing circumstances, and the testing processes all have an impact. Compressive strength is expressed in units of pressure and is defined in terms of force per unit area. The ability of concrete constructions to sustain loads and endure over time depends critically on their concrete strength. The needed design strength for a specific application, which is attained by careful mix design, quality control throughout construction, and suitable testing processes, determines what it is. To withstand tensile pressures and enhance overall structural performance, reinforcement in the form of steel bars or fibers is frequently included into concrete constructions.

Here different dimension CS is represented. In these four curves, namely CS-01, CS-02, CS-03, CFST, and Steel Tube, load versus displacement data is presented, depicting the behavior of different structural elements under various loading conditions shown in Figure 11. Among these curves, the steel tube exhibits a distinct behavior and stands out in terms of its load-carrying capacity.

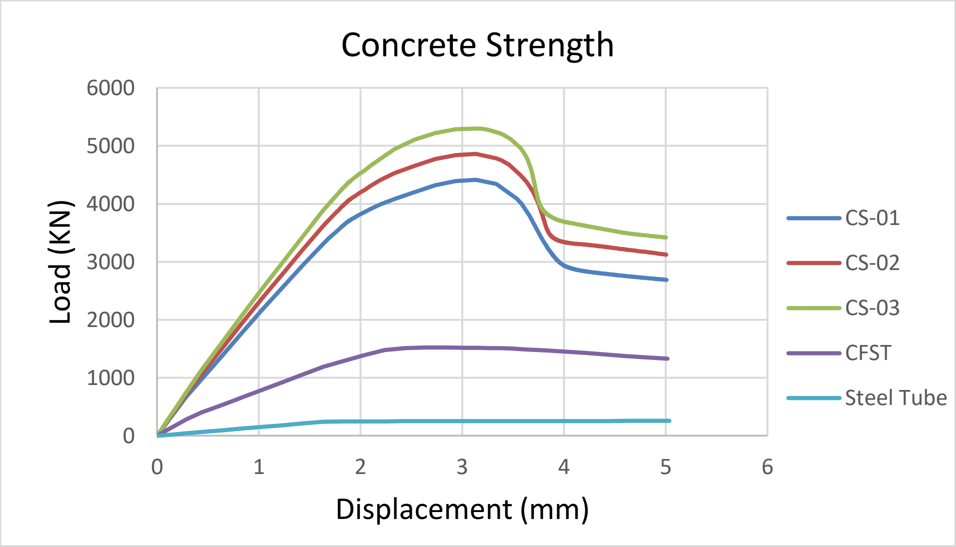


Figure 11: Concrete Strength

Among the various curves depicting load versus displacement data, one curve represents CS-03, which stands out due to its exceptional performance. CS-03 demonstrates the ability to withstand the greatest load while incurring the least amount of displacement. This remarkable behavior highlights the strength and stiffness characteristics of CS-03, enabling it to handle enormous loads without experiencing significant deformation. Its ability to maintain structural integrity under such high loads makes CS-03 an ideal choice for applications where strength and load-bearing capacity are crucial. Following CS-03, the curve representing CS-02 showcases its capacity to withstand greater loading levels. Although CS-02 does not surpass the performance of CS-03, it still exhibits a substantial load-carrying capacity and a comparatively low displacement. This indicates that CS-02 possesses considerable strength and can handle heavy loads with relative ease. While not reaching the pinnacle of performance set by CS-03, CS-02 still proves to be a reliable and robust structural element capable of withstanding significant loads. On the other hand, when considering minimal displacement, the curve representing CFST demonstrates the second-lowest loading capacity compared to the other curves. Although CFST does not perform as well as CS-03 and CS-02, it still exhibits a respectable capacity for bearing loads. CFST's ability to withstand substantial loads, although experiencing slightly greater displacement compared to CS-03 and CS-02, suggests that it can be relied upon in situations where moderate load-bearing capacity is required. Overall, the presented curves provide valuable insights into the load versus displacement characteristics of different structural elements. CS-03, CS-02, and CFST each possess their own strengths and weaknesses in terms of load-bearing capacity and displacement behavior. These curves help in understanding the performance and suitability of these structural elements in various applications where load resistance and deformation control are critical factors. Lastly, while examining the smallest displacement, the curve for the Steel Tube shows that it has the lowest load-carrying capability among the elements that are provided. This implies that when compared to other structural parts like CS-03, CS-02, and CFST, Steel Tube is relatively weaker and more prone to deformation under applied stresses.

4.4.3 Steel Tube Strength

The capacity of a steel tube to bear applied loads without breaking down is known as steel tube strength. It is impacted by a number of elements, including the make-up of the material, the manufacturing process, the dimensions, and the geometry. The two most popular ways to gauge steel tube strength are yield strength and ultimate tensile strength. Carbon steel, alloy steel, and stainless steel are frequently used steel types for tubes. The ability of steel tubes to carry loads and maintain their structural integrity is largely dependent on their strength.

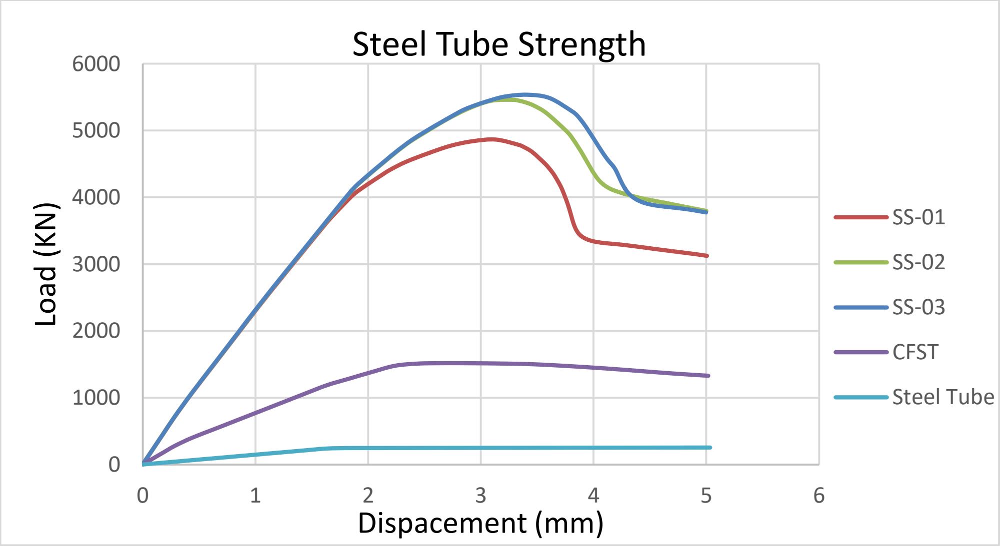


Figure 12: Steel Tube Strength

Here, several SS dimensions are displayed. These four curves—SS-01, SS-02, SS-03, CFST, and Steel Tube display data on load versus displacement and show how various structural parts behave under various loading scenarios as shown in Figure 12. The steel tube stands out in terms of its ability to bear loads along various curves and displays a unique behavior.

The curve for SS-03 stands out among the other curves showing load versus displacement data because of its excellent performance. The SS-03 has the maximum load capacity with the least displacement, proving its superiority. This exceptional behavior demonstrates the SS-03's strength and stiffness properties, which enable it to support heavy loads without suffering appreciable deformation. The SS-03 is a great option for situations where strength and load-bearing capability are essential because of its propensity to preserve structural integrity under such high loads. The curve for SS-02, which comes after SS-03, shows off its ability to handle higher loading levels. Although SS-02 does not surpass the performance of SS-03, it still exhibits a substantial load-carrying capacity and a comparatively low displacement. This indicates that SS-02 possesses considerable strength and can handle heavy loads with relative ease. While not reaching the pinnacle of performance set by SS-03, SS-02 still proves to be a reliable and robust structural element capable of withstanding significant loads. On the other hand, when considering minimal displacement, the curve representing CFST demonstrates the second-lowest loading capacity compared to the other curves. Although CFST does not perform as well as SS-03 and SS-02, it still exhibits a respectable capacity for bearing loads. CFST's ability to withstand substantial loads, although experiencing slightly greater displacement compared to SS-03 and SS-02, suggests that it can be relied upon in situations where moderate load-bearing capacity is required. Overall, the presented curves provide valuable insights into the load versus displacement characteristics of different structural elements. SS-03, SS-02, and CFST each possess their own strengths and weaknesses in terms of load-bearing capacity and displacement behavior. These curves help in understanding the performance and suitability of these structural elements in various applications where load resistance and deformation control are critical factors. Lastly, while examining the smallest displacement, the curve for the Steel Tube shows that it has the lowest load-carrying capability among the elements that are provided. This implies that when compared to other structural parts like SS-03, SS-02, and CFST, Steel Tube is relatively weaker and more prone to deformation under applied stresses.

4.4.4 Steel Tube Ratio Strength

The steel tube ratio strength is a crucial factor in determining the steel tubes' performance and ability to carry loads in structural applications. The formula for this is R = UTS / YS, where UTS and YS stand for ultimate tensile strength and yield strength, respectively. A stronger ability to withstand bigger loads before failing is indicated by a higher ratio strength. In structural engineering, the ratio strength is a crucial factor since it affects how safe and effective steel tube constructions are. The kind and quality of steel used, as well as the production method, can all affect it. When choosing steel tubes for structural purposes, designers and engineers take the ratio strength into consideration since it denotes a more durable and dependable tube.

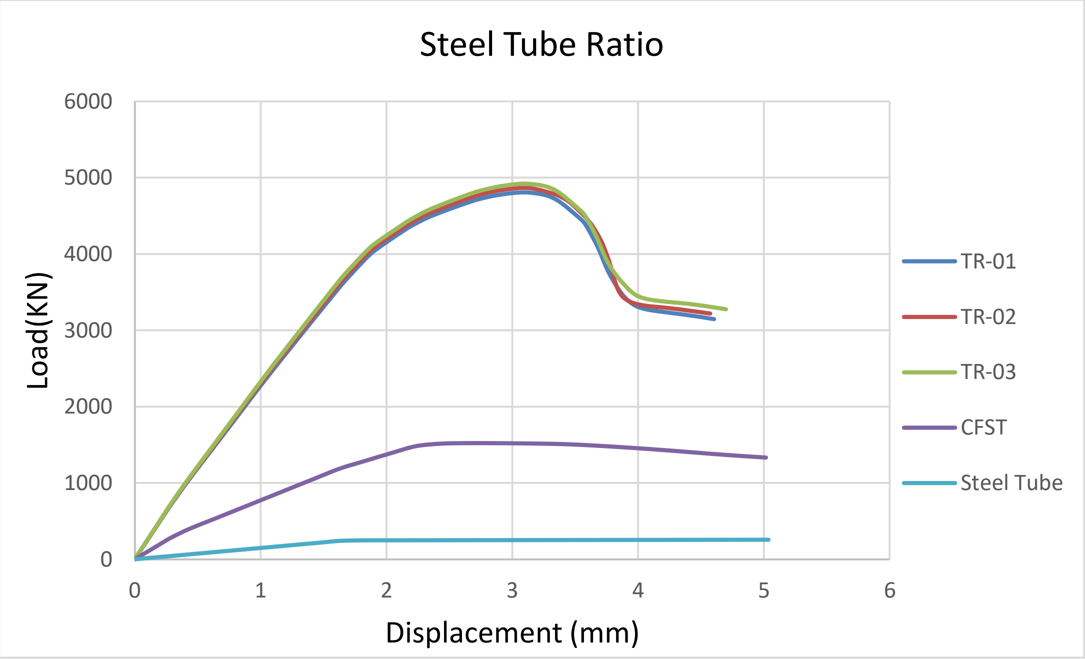


Figure 13: Steel Tube Ratio

In Figure 13 four curves, namely TR-01, TR-02, TR-03, CFST, and Steel Tube, load versus displacement data is presented, depicting the behavior of different structural elements under various loading conditions. Among these curves, the steel tube exhibits a distinct behavior and stands out in terms of its load-carrying capacity.

One of the curves represents TR-03, which exhibits outstanding performance by withstanding the highest load while undergoing the least amount of displacement. This shows that TR-03 has exceptional stiffness and strength properties, enabling it to support heavy loads without suffering considerable deformation. The curve for TR-02, which comes after TR-03, demonstrates its ability to tolerate higher loading levels. Although it does not surpass the performance of TR-03, TR-02 still exhibits a considerable load-carrying capacity and a relatively low displacement, indicating its strength and ability to withstand substantial loads. In contrast, CFST, represented by its own curve, displays the second lowest loading capacity in relation to the other curves when considering the minimum displacement. While CFST does not match the performance of TR-03 and TR-02, it still demonstrates a reasonable load-bearing capability, although it undergoes slightly more displacement under similar loading conditions.

Lastly, while examining the smallest displacement, the curve for the Steel Tube shows that it has the lowest load-carrying capability among the elements that are provided. This implies that when compared to other structural parts like TR-03, TR-02, and CFST, Steel Tube is relatively weaker and more prone to deformation under applied stresses. The strength and weaknesses of each structural element in terms of load-bearing capacity and deformation behavior are highlighted by these curves, which overall offer insightful information about the load versus displacement characteristics of various structural parts.

4.5 The Ultimate Strength of ECC-encased CFST Column

By taking into account the combined behavior of the steel tube, concrete core, and ECC (Engineered Cementitious Composite) material, the ultimate strength of an ECC-encased CFST (Concrete-Filled Steel Tube) column is established shown in Table 04.

The steel tube adds to the overall strength of the column by providing structural support. The material qualities, cross-sectional geometry, and pertinent design norms or standards are often used to calculate the steel tube's ultimate strength. The ability of the steel tube to withstand axial and bending loads is assessed while taking into account elements like its yield strength, moment of inertia, and cross-sectional area.

The steel tube's internal concrete core increases the CFST column's strength and stiffness. Based on the concrete core's compressive strength and confinement offered by the steel tube, the concrete core's overall strength is determined. Utilizing pertinent design regulations or standards, the axial load resistance of the concrete core is assessed while taking into account elements like concrete strength, cross-sectional area, and effective height.

The CFST column's strength, ductility, and fracture resistance are all improved by the ECC, a cutting-edge cementitious material. Usually, experimental results or analytical models that are tailored to the characteristics of the ECC material are used to assess the ECC material's contribution to ultimate strength. The ECC's ability to support axial and bending loads is determined by considering its strain-hardening tendency and enhanced fracture resistance.

To evaluate the ultimate strength of the ECC-encased CFST column, the interaction effect between axial load and bending moment is taken into account. To analyze the combined impact of axial load and bending moment, interaction diagrams are employed, making sure that both axial and bending capabilities are taken into account concurrently. The behavior of the column and its ultimate strength under combined loading circumstances are assessed using these diagrams.

Table 04: Load Carrying Capacity of FEM Models

Parameter	Specimen	Ultimate load from FEM, $P_{ECC-CFST}$ KN	Ultimate load for CFST column, $P_{CFST,}$ KN	Ultimate load for Steel, KN	$P_{ECC-CFST}/P_{CFST}$	Load Carrying Capacity (%)
ECC strength	ES-1	4528.39	1513.09	256.25	2.99	66.58
	ES-2	3306.68			2.18	54.24
	ES-3	5839.56			3.85	74.08
Concrete strength	CS-1	4416.09			2.91	65.73
	CS-2	4863.93			3.21	68.89
	CS-3	5118.48			3.38	70.43
Steel tube strength	SS-1	4863.51			3.21	68.88
	SS-2	5447.03			3.59	72.22
	SS-3	5537.57			3.65	72.67
Steel tube ratio	TR-1	4804.33			3.17	68.50
	TR-2	4863.51			3.21	68.88
	TR-3	4920.37			3.25	69.24

The concrete core is contained by the ECC-encasement, which increases the concrete's strength and ductility. The stress distribution and strain characteristics inside the ECC-encased zone are frequently taken into consideration in the calculations to account for the confinement effect. Increased confinement improves the column's resistance to axial stresses and delays early failure.

It is significant to highlight that determining an ECC-encased CFST column's ultimate strength can be challenging and calls for knowledge of structural analysis, material behavior, and design concerns. Specific formulae and procedures are provided by engineering regulations, design standards, and research articles to evaluate the ultimate strength of ECC-encased CFST columns. For precise calculations for particular column designs, it is advised to examine pertinent references and work with skilled structural engineers.

4.6 Summary

The compressive behavior of ECC (Engineered Cementitious Composite) encased CFST (Concrete-Filled Steel Tube) columns subjected to concentric loading is a topic of significant interest in structural engineering. This summary provides an overview of the key aspects and findings related to this topic.

ECC encased CFST columns have gained attention due to their enhanced performance in terms of strength, ductility, and durability compared to conventional reinforced concrete columns. The combination of the high-strength steel tube and the ECC layer provides a composite system that exhibits improved structural performance under compressive loading.

The behavior of ECC encased CFST columns is influenced by various factors, including sectional dimensions, initial imperfections, and the interaction between the concrete core, steel tube, and ECC layer. Accurate representation of these parameters in numerical models is crucial to obtain realistic simulation results and predict the columns' response accurately.

Sectional dimensions, such as the steel tube diameter, ECC thickness, concrete cover, column length, and slenderness ratio, significantly affect the compressive behavior of ECC encased CFST columns. Understanding the impact of these dimensions helps optimize the design and enhance the performance of the columns. Sensitivity analysis is a valuable tool for investigating the influence of sectional dimensions on the columns' load-carrying capacity, deformation capacity, and failure modes.

Initial imperfections, including geometric deviations, out-of-straightness, and eccentricities, are inevitable in real-world structures. These imperfections have a significant impact on the behavior and stability of ECC encased CFST columns. Accurate modeling of initial imperfections in numerical models is essential to capture their influence on the columns' behavior. Sensitivity analysis can be performed to evaluate the effects of different types and magnitudes of initial imperfections.

Sensitivity analysis is a valuable tool for studying CFST columns under concentric loading. By systematically varying parameters such as the steel tube diameter, ECC thickness, concrete strength, steel reinforcement ratio, boundary conditions, and loading rate, researchers can assess the sensitivity of CFST columns and optimize their design. Sensitivity analysis provides insights into the critical parameters that significantly influence the columns' behavior and helps in developing improved design guidelines and structural performance predictions.

Overall, the compressive behavior of ECC encased CFST columns subjected to concentric loading is a complex phenomenon influenced by various parameters and factors. The research and understanding in this area contribute to the development of more reliable, efficient, and durable structural systems. By optimizing the design, accurately modeling sectional dimensions and initial imperfections, and performing sensitivity analysis, engineers can enhance the performance and safety of ECC encased CFST columns, leading to the advancement of sustainable and resilient structures.

Chapter 5: Conclusions and Recommendations

5.1 Summary

This chapter provides a comprehensive summary of the research conducted on the effectiveness of ECC (Engineered Cementitious Composite) encasement on the compressive behavior of slender CFST (Concrete-Filled Steel Tube) columns. It highlights the key findings, significance of the research, and recommendations for future work. The conclusions drawn from the study and the implications of the findings are presented, along with suggestions for further research in this field.

5.2 Conclusions

Based on the findings and analysis presented in the previous chapters, the following conclusions can be drawn:

1. The ECC encasement significantly improves the compressive behavior of slender CFST columns. The confinement effect of the ECC enhances the load-carrying capacity, ductility, and energy absorption capacity of the columns.

2. The thickness and properties of the ECC encasement have a substantial impact on the compressive behavior of the CFST columns. Increasing the thickness of the ECC encasement and utilizing high-performance ECC materials further enhance the performance of the columns.

3. The bond between the ECC encasement and the steel tube plays a critical role in the overall behavior of the CFST columns. Adequate bond strength and compatibility between the ECC and steel surface are essential for achieving optimal performance.

4. The presence of initial imperfections in the CFST columns affects their compressive behavior. Proper consideration of initial imperfections, such as out-of-straightness and eccentricity, is necessary in design and analysis to ensure accurate predictions of the column's response.

5. The load eccentricity with respect to the centroid of the CFST columns influences their compressive behavior. The eccentric loading leads to non-uniform stress distribution and affects the ultimate strength and failure mode of the columns.

6. Numerical simulation using finite element analysis is an effective tool for studying the behavior of slender CFST columns with ECC encasement. It provides valuable insights into the stress distribution, load-deformation response, and failure modes of the columns under different loading conditions.

5.3 Recommendations for Future Work

Based on the findings and limitations of the present study, several recommendations for future research in the field of ECC-encased slender CFST columns are proposed:

1. Experimental Validation: Conduct experimental tests to validate the numerical results and further investigate the behavior of ECC-encased slender CFST columns. Experimental studies will provide more accurate and reliable data, particularly for the bond behavior between the ECC and steel tube.

2. Parametric Studies: Perform parametric studies to explore the effect of various parameters, such as ECC thickness, material properties, steel tube dimensions, and load eccentricity, on the compressive behavior of ECC-encased slender CFST columns. This will help in developing design guidelines and optimizing the column's performance.

3. Long-Term Durability: Investigate the long-term durability and sustainability aspects of ECC-encased slender CFST columns. Assess the effects of environmental factors, such as moisture, temperature variations, and aggressive chemicals, on the performance and service life of the columns.

4. Structural Design Guidelines: Develop comprehensive design guidelines for ECC-encased slender CFST columns, considering various loading conditions and design requirements. These guidelines should incorporate the confinement effect of the ECC, bond characteristics, and consideration of initial imperfections.

5. Performance under Combined Loading: Study the behavior of ECC-encased slender CFST columns under combined axial compression and bending moments. Investigate the interaction between the axial and flexural responses and the effect on the overall behavior and capacity of the columns.

By addressing these recommendations, future research can further enhance the understanding of ECC-encased slender CFST columns and provide valuable insights for their practical application in the construction industry.

In conclusion, the numerical study on the effectiveness of ECC encasement on the compressive behavior of slender CFST columns has demonstrated the significant improvement in their performance. The conclusions drawn from this study contribute to the knowledge base in this field and provide a basis for further research. The recommendations for future work highlight the areas where additional investigation is needed to advance the understanding and application of ECC-encased slender CFST columns. This research has implications for the design and construction of more efficient and sustainable structural systems, promoting the utilization of CFST columns with ECC encasement in various engineering applications.

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