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REPUBLIC OF TURKEY
UNIVERSITY OF GAZIANTEP
GRADUATE SCHOOL OF
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IMPROVING THE DUCTILITY AND TOUGHNESS BEHAVIOR OF CONCRETE FILLED STEEL TUBE COLUMNS

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IN

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BY

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Supervisor

Assoc. Prof. Dr. Talha EKMEKYAPAR

By

Ali Khalaf DAHAM

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This is to certify that we have read this thesis and that in our consensus opinion it is fully adequate, in scope and quality, as a thesis for of the degree of consensus or majority Master of Science.

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Ali Khalaf DAHAM

ABSTRACT

IMPROVING THE DUCTILITY AND TOUGHNESS BEHAVIOR OF CONCRETE FILLED STEEL TUBE COLUMNS

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M.Sc. in Civil Engineering

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This thesis investigates the performance of reinforced concrete-filled steel tube (RCFST) stub columns and steel fiber reinforced concrete-filled steel tube (SFRCFST) and compared with CFST column under axial compressive loading. Two groups are used in this experimental work, first one was (RCFST) used five circular hollow steel tube specimens with an outer diameter of 114.3 mm, wall thickness of 6.11 mm and length of 310 mm filled with concrete with a compressive strength of 37.60 MPa and second group used six circular hollow steel tube with an outer diameter of 114.3mm, wall thickness of 5.97mm and different length (173, 463 and 916.5 mm) filled with concrete and steel fiber reinforced concrete. For (RCFST) the main variations are the steel bar diameters (8 mm and 12 mm) and the number of tied stirrups (2 and 6) and For SFRCFST, the main variation was steel fiber and different lengths. The test results are given in terms of the compression loading versus end shortening curves, and modes of failure of the specimens were compared and discussed. The results showed that the RCFST columns have better structural performance compared to CFST column, where the RCFST columns have more compression capacity, ductility, and further enhanced the post-peak behavior and for SFRCFST columns have more compression capacity and ductility. The design specifications of AISC 360-16 and EC4 predictions were employed and compared to test results to confirm the behavior of design specifications formulations in predicting the capacity of RCFST columns.

Keywords: Compression capacity, Design codes, Ductility, RCFST column, SFRCFST columns, Steel-bar reinforcement.

ÖZET

İÇİ BETON DOLDURULMUŞ ÇELİK TÜP KOLONLARIN SÜNEKLİK VE TOKLUK DAVRANIŞLARININ İYİLEŞTİRİLMESİ

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Bu tez, eksenel basınç yüklemesi altında içi donatılı beton ve çelik fiberli beton doldurulmuş kolonların klasik beton doldurulmuş çelik tüp kolonlara göre performanslarını incelemektedir.Bu deneysel çalışmada iki grup test edilmiştir. İlk grupta beş adet 114.3 mm çapına ve 6.11 mm et kalınlığına sahip 310 mm uzunluğunda çelik tüpler 37.60 MPa basınç mukavemetine sahip beton ile doldurulmuştur. İkinci grupta ise 114.3 mm çapında 5.97 mm et kalınlığında ve farklı uzunluklarda (173, 463 ve 916.5 mm) içi çelik fiberli beton doldurulmuş altı adet numune kullanılmıştır. Çelik donatılı beton doldurulmuş kolonlar için araştırılan parametreler çelik donate çapı (8 mm ve 12 mm) ve etriye sayısıdır (2 ve 6). Çelik fiberli beton doldurulmuş kolonlar için ise parametreler çelik fiber ve kolon uzunluğudur. Test sonuçları basınç yüklemesine karşı kolon kısalması grafikleri ile verilip numunelerin çökme şekilleri karşılaştırılmıştır. Test sonuçları donatılı beton doldurulmuş kolonların daha fazla basınç kapasitesine, sünekliğe ve daha iyi çökme sonrası davranışa sahip olduğunu göstermiştir. Ayrıca çelik fiberli beton doldurulmuş kolonlar da iyileştirlmiş basınç kapasitesine ve sünekliğe sahiptir. AISC 360-16 ve EC4 tasarım şartnemelerinin hesap metotları kullanılıp donatılı beton doldurulmuş kolonların test sonuçları ile karşılaştırılmıştır. Yapılan karşılaştırmalar ile tasarım şartnamelerininm değerlendirilmeside yapılmıştır.

Anahtar kelimeler: Basınç kapasitesi, Tasarım şartnameleri, Süneklik, İçi donatılı beton doldurulmuş çelik tüp kolon, İçi çelik fiberli beton doldurulmuş çelik tüp kolon, Çelik donatı.

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LIST OF SYMBOLS/ABBREVIATIONS

A_a	Area of steel (mm2).
A_c	Area of concrete (mm2).
ACI	American concrete institute
ASIC	The American Institute of Steel Construction
C_3	The coefficient for calculation of effective rigidity
CC	Composite Column
CFST	Concrete filled steel tubes
D	The diameter of the steel tube section in (mm)
DI	Ductility Index
EC4	The European Code
E	Modulus of elasticity
E_c	Modulus of elasticity of concrete
E_s	Modulus of elasticity of steel tube = 210000 N/mm^2
EI_{eff}	Effective stiffness of composite section (N.mm2)
FA	Fly Ash
F_{cr}	The critical buckling stress
$f_{c'}$	Compressive strength of concrete (MPa).
f_y	Yield strength of steel tube (MPa).
f_{yr}	Yield strength of steel bar (MPa).
I_a	Moment of inertia of the steel section (mm4)
I_c	Moment of inertia of the concrete section (mm4)
I_s	moment of inertia of steel bar
L	The length of the steel tube section in (mm)
K	Effective length factor
N_{ASIC}	Axial load capacity predicted by AISC 360-2010
$N_{p1,Rd}$	plastic resistance

N_{Sd}	The design axial force
N_{cr}	Elastic critical normal force for the relevant buckling
$M_{\max.Sd}$	The maximum design moment
RE	Retarder
RCFST	Reinforcement concrete filled steel tube
SI	Strength Index
SFRCFST	Steel Fiber Reinforced Concrete-Filled Steel Tube
SP	Superplasticizers
T	The wall thickness of the steel tube section in (mm)
P_y	The yield strength
P_p	Full plastic strength
P_e	Elastic axial load
P_{no}	Nominal axial load
X	Reduction coefficient due to column buckling
Λ	Relative slenderness ratio of the composite column
λ_r	slenderness ratios
η_a	The reduction factor of steel
η_c	The enhancement factor of concrete

CHAPTER 1

INTRODUCTION

1.1 General

In civil engineering concrete columns represent the element of vertical structure made of reinforcement, unreinforced or reinforced concrete. It is a structural element tested mainly to axial loading. Concrete columns perhaps spiral steel and longitudinal bars (spiral-reinforced columns) or with reinforced with ties and longitudinal bars (tied columns), or they perhaps unreinforced. Sometimes the columns perhaps a concrete and the structural steel composite of cast iron. Unreinforced concrete columns are scarcely utilized because of transverse tensile stresses being induced by Unexpected and the prospect of longitudinal tensile stresses bending or buckling. Because tension in concrete is weak, these stresses are Avoid them in general. When utilized plain concrete in columns, they commonly are limited to the least thickness in height to five or six times. Under axial loading, under axial load, the measured load on the cross-section of the concrete must not override the acceptable unit compressive stress for the concrete.

On the other hand, the concrete column has some disadvantages like Reinforced concrete has a tensile strength of approximately ten times its compressive strength. The main steps used in the production of reinforced concrete are mixing, casting and curing. As the materials used and their quality mainly affects the final strength of the concrete. It is noted that the steel section for the multi-story buildings is smaller than the RCC column due to the strength and the development of a crack in compressive strength in the case of shrinkage.

(Kilpatrick, 1999), a present of studies available empirical demonstrate that the fundamental parameters influence the strength and behavior of concrete-filled columns are: the parameters geometrical, as the D/t ratio the initial geometry and the slenderness of the column; the parameters of mechanical, like the strength of the steel and concrete, the boundary conditions, loading and the concrete confinement (Wang, 1997), the load carrying capacity reduces with improving the load eccentricity and the column length, whilst the branch of the descending of the load-displacement curve is developing at a smaller rate. In the case of double curvature bending for columns, there is little empirical information in this area where the load capacity of the columns is compared with the loads for single curvature bending.

Steel concrete composite systems (also called hybrid systems or mixed) have utilized diffuse in latest years because of the usefulness of mix the two construction materials. Since Concrete is, inexpensive, stiff and massive whilst steel elements are lightweight, easy to assemble and strong. For the column elements design, there are two systems of the composite, (CFSTs) and steel reinforced concrete (SRC) are usually used. Over last decades, concrete-filled steel tubular structures have quite applied in the construction buildings and bridges that have a high rise, particularly in areas with large seismic preventative intensity.

1.2 Background of the study

In recent years, the CFST system has been used to complete buildings and residential buildings in many parts of Asia and Europe, especially for low or medium-rise buildings. In the experiments conducted, the strength of the short column CFST was compared with the square or rectangular sections, there exists an improvement in the composite suction strength relative to its uniaxial capacity. The reason for this improvement is the strength of the CFST, which provides a lateral confinement (Clark, 1994). Concrete and steel are the most widely used materials in high rise buildings. Because steel is relatively lightweight and fast-building, most high-rise buildings are made of steel, and the weight of steel reduces the size and foundations of structural structures. These steel columns can have a larger cross-section with 25% that can weigh 80% of concrete sections for tall buildings (Griffis, 1987).

(Pires et al., 2012), composite columns made of structural hollow sections are called Concrete-filled steel tubes (CFST). The concrete core is covered by a steel tube. Diameter, breadth, tube thickness, Length, and depth of CFST columns are denoted by D, b, t, L, and d, respectively. Benefits of such columns begin at the construction stage, as CFST are relative, removable formwork and simple to fabricate becomes unnecessary. During its service life, the steel tube protects concrete from adverse environmental agents. Otherwise, concrete increases fire resistance of the column by acting as a heat sink, (Moliner et al., 2013).

Over the past few years, steel-concrete composite structures have become a popular system in tall buildings construction due to their higher load-carrying capacity and stiffness which results from mix structural steel sections with the rigidity of reinforced concrete. The use of composite structures has become widespread in the Middle East, in China and Japan, with Dubai today housing some of the highest buildings in the world. Also, Composite systems have become very important in the design of seismic resistance (Al-bdoor, 2013).

(Han and Li., 2014), concrete offers steel provides high ductility, energy absorption properties, and significant compression capacity. The most effective way of composite compression member application is concrete-filled steel tube columns. In such applications, outer steel tube gives a confinement effect for core concrete. Since the steel material is deployed to the outermost location of the column, core concrete is protected from environmental effects and moment carrying capacity of the member increases significantly.

E. T. (2016), high compression capacity, energy absorption capacity and ductility of CFST columns led such members to use in high-rise buildings, bridges and underground tunnels.

(Kwan and Chung, 1996), comparing with steel structure or traditional concrete, composite steel-concrete construction has gained more advantages from being a system with admirable structural integrity, excellent structural, dimensional stability and high load carrying capacity, etc. When Concrete-filled steel tubular members designed correctly, can take advantage of both components strengths and behave as a single unit. The shell is typically the steel element, which is then infilled with concrete. The steel shell works as formwork for the concrete and because of the location of the steel, typically there is no need for longitudinal reinforcement. Also, the steel shell provides a confining pressure to the concrete, which can improve the compressive strength of the concrete to a much higher level (Baig et al., 2006).

1.3 The Advantage of Composite Column (CC)

The composite column has a lot of advantage (Morino and Tsuda, 2002). of the important advantages, it can offer is here:

(1) The interaction between steel tube and concrete:
Local buckling of the steel tube is delayed, and the strength deterioration after the local buckling is moderated, both due to the concrete restraining influence. Furthermore, steel tube worked to provide a good confining in concrete and due to that concrete strength is improving and the strength of degradation is

not too big because of concrete spelling blocked by the tube. Creep and drying shrinkage and of ordinary reinforced concrete are much bigger than in concrete.

(2) properties of Cross-sectional:

The ratio of steel in cross-sections of concrete-encased steel and reinforced concrete is much smaller than in the cross section of CFT. The steel is reinforced in the tubular CFT submerged section because it is mostly located outside the section.

(3) Fire resistance:

Concrete increases resistance of fire, for this reason, the anti-fire material can be deleted or reduced.

(4) Cost performance:

Due to the features recorded overhead, best cost behavior is gained by substituting a CFT structure with structured steel.

(5) Ecology:

The use of high-performance concrete with rubble that has been recycled and placed in steel pipes reduces the environmental burden.

1.4 Object of Study

The aims of this thesis study are:

- Determine the effect of bar diameter of steel and stirrups number on the concrete infilled in steel tube columns
- To investigate compression performance of (RCFST) columns under compressive strength.
- Determine the influence of (SFRCFST) columns filled in different length.
- To investigate ductility and compression performance of (SFRCFST) columns under compressive strength.

1.5 Outline of Thesis

This thesis mentioned is split into six major chapter.

Chapter One - Introduction: this includes a general overview of CFST, the background of the study, the advantage of composite column and object of study.

Chapter Two – Literature Review: This chapter offers a comprehensive text review of theoretical or experimental works of CFST columns.

Chapter Three - Design Codes Specifications: Design codes specifications for CFST columns are presented in this chapter, where, concentrated on The European Standard and the American Institute of Steel Construction (AISC); Design of composite steel and concrete structures (Eurocode-4).

Chapter Four – experimental Study: the American Institute of Steel Construction (AISC) and the experimental program are presented in this chapter.

Chapter Five - Experimental Results and Discussion: reports experimental axial load-axial shortening, failure modes, axial capacities and characteristics for tested CFST columns. Experimental results that obtained from steel tubes filled with normal concrete were compared with respect to SCC filled steel tube columns. Moreover, Experimental results of ultimate axial load capacities were compared with theoretical results that obtained from AISC 360-10 and EC-4 1-1 1994 codes.

Chapter Six – Conclusion and Recommendations: Main conclusions of this study are presented based on experimental and theoretical results, along with recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

This part offers a previous review of CFST columns, and how previous researchers have understood their behavior under compressive strength. The development and characteristics of modern high-performance concrete are presented. How these concretes studied in composite CFST columns is also discussed.

2.1 Introduction

CFST is one of the kinds of columns that are utilized frequently in all types of constructions due to its many advantages like high strength/hardness, attractive appearance, high energy absorption, high fire resistance (Ding and Wang, 2008) & (Hu et al., 2003). Moreover, the concrete core confinement of the steel tube improves the concrete core strength. Under fire exposure, also there is another advantage of a steel tube which prevents the core of concrete from spelling (Hu et al., 2005).

Last decades, The (CFST) were studied under compressive strength, but the knowledge gap is not fully filled. The use of CFST columns began when the buildings and several bridges were built by CFST columns. The CFST concrete utilized in the structures offers different advantages on conventional normal weight concrete, as long as the strength/weight ratio, fire resistance characteristics enhance thermal insulation. This part presents the most important basic information that specializes in the performance of concrete, which is poured into steel pipes and check the characteristics of strength, and performance and compare them with the American and European codes.

2.2 Experimental and Analytical Studies

Analytical and experimental studies on (CFST) were widespread ongoing since the early 20th century the researchers have made significant contributions, in Australia, Europe, and Asia, especially in China.

M. N. Baig, J. Fan, and J. Nie. (2006), tested the CFST strength. Presents an empirical research on the CFST columns performance under compressive strength until failure. Twenty-eight samples with various cross sections were subjected to examine axial load capacity. , tubes shape and D / t ratio, represent parameters in this study. The results show that it has a large role on the concrete, where the percentage increase to 60% in some condition. Furthermore, it also proposes an equation to expect the final capacity of samples for concrete square steel tubes.

(Baig et al., 2006), present an empirical research on the short (CFT) columns conduct axially loaded. A total of 16 specimens of circular and twenty-eight specimens of the square which have been filled with concrete and twelve hollow specimens with various cross sections have been subjected to investigate the capacity load. The ratios of (L/D) of these columns have been varied between four and nıne. Test parameters were (D/t) ratio and tube shape. Some concrete filled columns were preparing the internal of the distorted bars. The results of the experience were compared with the theoretic research results. The results offered that the confinement influence on concrete plays a role in developing the compressive strengths to almost 60% in some cases. The experiments have been offered that improve of strength in square columns is much less than in circular columns. Develop in the circular columns strength of one series was more than 60%. Local buckling was offered in square columns both hollow and filled. The strength improves perhaps due to the pretty quality of the concrete.

(Aly et al., 2010). Offers the analytical study of modeling (CFST) columns conduct tested to Variable Repeated Loading (VRL) and Static Loading (SL). The variables studıed in this paper are load eccentricity and concrete strength. Mathematical samples simple are improved and utilized in the analyzing. The results of analytical offered that the incremental collapse (IC) occurs in high load domains in instability failure happen under SL and CFST columns under VRL. The columns of CFST with big end eccentricity of loading were offered to failure at a little upper boundary load grade than which with the small eccentricity of the load.

It has been found that IC failure was not influenced by the force of concrete filling. The (HST) columns provided similar behavior under the VRL and SL protocols. The study offered that the analyses theoretic model acceptable models the effective behavior of the columns beneath VRL and SL protocols.

(Han et al., 2011), shows the CFST behavior under axial tension. Eighteen samples were examined. The major factors were the concrete kind, the ratio of steel and unbonded or connection between the core of concrete and steel tube. According to the tests of results in this research, it can be the conclusion these points:

(1) In the empirical work, it was found that CFST filled by concrete increases the tensile strength by 11% compared to the HST.

(2) The bonding and non-bonding between the concrete core and the steel have effects on tensile strength in shafts. As the tensile strength of the elements that are filled with concrete from kind SCC is little lower than those elements that are filled with concrete from kind SFRC.

(3) A (FEM) has been improved, and the sample can be utilized for parametric studies and perform mechanism analysis for CFST beneath axial tension.

(4) An easy form for prophesying the CFST strength of axial tensile has been suggested in this experience, where the results of the work were acceptable compared to the results that can be predicted.

(Ghannam et al.,2011), investigated an experimental research on (LWCFST) columns and studied the columns behavior under axial loadings. Tests of steel columns circular and a rectangular section infilled with LWC and NC Implemented for comparing (LWCFST) columns and (NCFST) columns for cross-sections various of columns. Also using (EC-4, 1994) and (BS 5400) codes were taken into consideration. Conclusions of this research are an offer that (LWCFST) and (NCFST) columns had failed according to buckling; whilst columns hollow steel be unsuccessful depending on local buckling at the bottom of the column. Dimensions with larger column sections offered higher load 14 carrying capacity. For these results, it is best to use LWC instead of regular concrete due to thermal conductivity and low gravity. Moreover, the LWCFST showed reasonable strength under axial load when compared depending on calculations of design.

(Shiming and Huifen , 2012), showed the CFST compressive behavior circular section with a saving of the gap of separation between steel pipe and inner concrete core. This testing was done with varying parameters like yield stress (fy), the steel pipe thickness (t), the strength of concrete, load eccentricity (e), and depth of gap. ABAQUS software utilized to increase the FEM and compared experimental examine results with the results that got from ABAQUS software. The results concluded that reduced depth of the gap and of the load eccentricity with improves the strength of CFST section. Moreover, the noted of researchers that there is an upper strength of CFST section with an increased steel tube thickness because increasing confinement influence.

Moreover, (Dundu., 2012), conducted an experimental research to check the (CFST) columns behavior, which the test consists of twenty-four Specimens loaded concentrically in compression until failure. In this research, the material strength and slenderness ratio were considered as major variables. The results have presented that the columns having larger slenderness ratio failed by overall flexural buckling. Whilst the composite columns that have lower slenderness ratio failed by yielding of the steel pipe and overwhelming the concrete. Furthermore, the test outcomes compared with the South African code AND Eurocode 4, so the conclusion was drawn that the codes are conservative.

(Xue et al., 2012), Examine the effect of the confinement on the concrete core for columns under pressure effect. Nevertheless, this is a useful composite work can weaken even destroyed by debonding, Where it represents a vast phenomenon that is nearly inevitable for CFST columns and has not been convincingly reviewed in relation to the existing design codes. According to the tests of results in this research, it can be the conclusion these points:

(1) In this experiment, the effect of the debonding on the short circular CFST stub columns was verified. Where the pattern of failure of these samples was almost similar to the rest of the samples of short lengths. Where the pattern of failure of axial deformation for models without debonding was less serious than for models with debonding.

(2) It can be utilized the model of a finite element to investigate the behavior of mechanical of circular CFST stub columns with debonding is checked by the results of the test.

(3) For the samples examined under the axially loaded and after the pregnancy reaches the maximum, the loading is faster than any other sample without debonding to reach a certain value. In addition, it was observed that the displacement curves were almost the same as the central load samples without or with the debonding of both samples.
(4) Analyses of parametric outcome demonstrate that with an increment of the factor of confinement, debonding thickness or debonding ratio of arc-length, the factor of reduction of maximum load capability reduces. When a critical value is more than debonding thickness or debonding ratio of arc-length, the coefficient of reduction of maximum load capability reduces fast. Otherwise, the coefficient of reduction of maximum load capability reduces slowly. Furthermore, with an increment of the coefficient of confinement, the worth critical of debonding thickness develops.
(5) Depend on analyses of parametric, an easy form is suggested for the reduction factor of the maximum load power of circular debonding CFST short columns tested to small eccentric load or axial load.
(6) The research concentrates on the debonding influence on the circular CFST stub columns tested to tiny eccentric load or axial load. Nevertheless, a recent study was conducted to research the debonding effect on circular CFST short columns tested to the circular CFST long columns and large eccentric load.

(Abed et al.,2013), investigated the compressive behavior of circular CFST column filled with various ratios of D/t and varying grades of concrete. Analytical method obtained by many codes namely AS, EC-4, AISC-2005, and ACI-318, were discussed with the empirical results of the experiment. From this investigation, researchers found that occurred a depression in the compressive strength of the CFST section by using upper D/t ratio, because of less confinement. The research also concluded which there is less deviation happen in results for the higher D/t ratio. The experiments results were confirmed using ABAQUS software and there was a good correlation between analytical and empirical results

(Ismail et al., 2013), this research focused on the ultimate behavior of (LWHCFST), the study showed the behavior of static nonlinear of (LWHCFST). This research had two aims of major specific. The first aim was to verify the effect of confinement on the elasticity factor in the LWHCFST. The other aim the other goal is to locate the final behavior of the LWHCFST bridge and to develop the performance of the computer program component of FE the nonlinear determination. The program is a finite element nonlinear were utilized and developed to demonstrate the static nonlinear behavior of LWHCFST when the failure happened. Three cases were studied; hollow steel tube (HST), high strength concrete (HSC), and (NC) and (LWC) were subjected under the influence of progressive uniformity divided load even achieving of maximum strength when the failure happened. The compression results conclusions of this research demonstrate that systems of a bridge with the geometry of bridge and the same transverse zone and the same compressive force of the concrete of the deck, for the special information utilized in this experiment. With the same compressive strength, the LWHCFST resists a failure load of 13% more than the NCFST. As well, the LWHCFST failure loads percentages are 64% with consider to dead load and the upper of which of NCFST.

(Lai et al., 2014), (CFST) columns showed the ductility and strength performance of superior due to composite work. Nevertheless, it was found that in advanced stages it is not possible to see a complete improvement because the expansion in steel is more than in the concrete, and therefore the durability and hardness decrease due to the lack of close bonding between concrete and steel. According to the tests of results in this research, it can be the conclusion these points: (1) Rings could develop the stiffness, reduce the rate of the strength degradation and axial load-carrying capacity. (2) The critical confinement index (NCR) has been diverse with the concrete degree. (3) The lateral deformation of steel tube and concrete can be reduced by using loops for its effective role to reduce deformation. Depend on a results obtained analysis of the effect of the result of the laying of reinforced concrete by loops in steel tubes for three samples of CFST columns by the authors are suggested to assess the ring-confined CFST columns and axial load-carrying capacity of unconfined. A result was suggested for the models by comparing the results of the theoretical strength and the strength generated by the tests by other researchers.

(Kalingarani et al., 2014), investigated the compressive behavior of CFST slender columns analytically utilizing three codes, namely, (EC-4 1-1, 2004), (ACI-318, 2011) and (AISC, 2004). The study was shown by a ratio of (D/t) and the ratio of (L/D). Results of Analytical conducted on by utilized the codes method indicates which for an improved ratio (D/t) ratio but without a change in dimension of diameter, because of fewer confinements, the strength compressive of CFST section was reduced. In the end, due to improving ratio of L/D, low of compressive strength happen because of the effect of slenderness ratio.

(Evirgen et al., 2014), studied the compressive conduct of (CFST) section with different cross-section forms such as rectangular, hexagonal square, and circular. A study of experimental was obtained by concrete grades and varying (B/t) ratio. The results which obtained from a research of the experiment were compared with software outcomes calculated by the FEM using software of ABAQUS. In this experimental where it is noted that the importance of concrete in CFST columns in their resistance to the buckling occurring within the steel tube, while the steel tube works to increase the amount of concrete confinement and thus gives the column strength resistance higher, for these features the CFST strength section has been improved. In the end, the investigation concluded that the CFST rectangular square and hexagonal, had ductility is less than, circular CFST sections.

(H. and T., 2015), investigated a study of experimental on CFST columns utilizing various materials of steel under compressive strength. Twelve samples were utilized and examined. Four samples of cold-formed steel, four specimens for stainless steel and four samples of mild steel, were subjected under compressive strength. The major parameters used in the research are;

1. The wall thickness of the tubes (t) was (3 mm), and (2 mm).

2. The steel materials that utilized are Cold-formed steel, Stainless steel, and Mild steel.

3. The ratio of L/D was 4.

4. The ratio of D/t were 75 and 50.

5. The compressive strength of the concrete cube (fc′) has been 30 MPa.

The research of experimental has been completed for casting and examining the cube, cylinders, and CFST samples. Additional stability of the tube walls versus the influence of mechanisms of local buckling has been because of the existence of concrete infill. In the columns it was observed that most types of failure appear of local buckling, in addition to the failure of welding occurs during the examination of the CFST columns. Cost of Analysis presents that the stainless steel concrete filled tubular columns is more expensive than the mild steel and rate of cold-formed steel. Nevertheless, taking into consideration the economic aspect, it was noted that the cost of mild steel and cold steel is less than the cost of stainless steel. In addition, the strength of the column containing the stainless steel is greater than the strength of the column that contains cold steel and mild steel. Also, in the status of high-performance requirement, it is a good potential for utilizing stainless steel columns.

(Faxing et al., 2015), this study shows, 22 CFST samples were carried with axial load and four circular samples of CFT were performed and compared with the purpose of determining the effect of the papers in the concrete. In addition, a further analysis was depended on the FEM. According to the tests of results in this research, it can be the conclusion these points:

(1) According to the results obtained, it is noted that the typical pattern of failure in the steel columns is the local buckling. The torsion in the columns is associated with the shear in the filled concrete for the steel pipe. As for the CFST column, it was observed that there is a decrease in durability whenever the width of wall thickness is increased. The results showed that the effect of the in confinement in the CFST columns is extinct, which has a large wall thickness width that is insufficient on the concrete core inside.

(2) For columns loaded with axial loaded and analyzed by FE, it was observed that the results obtained were consistent with experimental results. In addition, the results of FE modeling obtained indicate that the effect of the confinement improves the width of the thickness of the wall. It was found that the samples with the lowest fish give more confinement.

(Aghdamy, 2015), in this study, it was verified that CFST columns were subjected to a lateral impact load. The technical and numerical modeling work of this type of column, which was subjected to lateral impact load and axial compressive strength, as compared to the results obtained with the empirical results obtained from previous research. Where a numerical model was introduced through the impact event and predicted satisfactorily. The sensitivity analysis was then performed to verify the effect of the load parameters and the effect of these parameters on the conduct of CFST columns. From the results obtained from the parametric sensitivity tests, the following points can be inferred:

1- The ratio (t/D) that is followed by the speed of the effect and the contact area is more sensitive to the initial peak strength. Where changes in the strength of concrete pressure can be observed for the sensitivity obtained at the initial peak strength. Which can be considered as related to the changes that can be made in slenderness ratio, a location of impact, impactor's mass, and configurations of column section.

2- The initial sensitivity change depends on the t / D ratio of the fixed line to the remaining strength. There are some parameters that have a significant impact, from these site impact parameters, the location of impact, contact area, axial load level, the compressive strength of concrete, and the velocity of impact and section configurations. The period of impact shows high sensitivity to changes in impactor's mass, impact velocity, (t/D) and slenderness ratio.

3- The duration of impact shows high sensitivity to changes in impactor's mass, impact velocity, the ratio of (t/D) and slenderness ratio. while the effective period has a clear sensitivity to change the location of the impact of columns, while we note that the impact is less on the configurations of the section of columns, the strength of compression in concrete, and the level of load axial, in addition to the contact area of influence.

4- The impact positions in the composition of the large column vary with the maximum sensitivity of the collision speed followed by (t/D) and the ratio of tenderness, impact mass, and a maximum sensitivity of the deviation. However, the sensitivity appears to be minimal due to differences in the contact area, the compressive strength of the concrete, and the level of axial load.

5- The sensitivity of the remaining column deflection is big for the change in the speed of the impact followed by t / D, by the rate of slenderness and the mass of impact. While the maximum sensitivity of reflection can be observed for the composition of the columns and the impact sites, the compressive strength of concrete, axial load level, and contact impact areas. In general, it is possible to say that the ratio of tenderness is clearly significant in the response to CFST columns, which is considered to be the most influential parameter. While the maximum sensitivity is observed for impact, column formation, contact effect areas, compressive strength in concrete as well as axial load level.

(L et al., 2016), this study show behavior of bending of LWC spatial truss beam under a bending load. By strains and the deviation analysis of the beam, the behavior has been studied. The results present that the suppositions were made to achieve a method of bearing capacity calculation. The LWACFST spatial after excessive deflection had been failed. Analysis of Finite element with various chord matched test evidence with only a 3% variance between the two. Analysis of finite element analysis with various chord dimensions presents that the ultimate 19 bearing capacity reduced as the chord dimensions' reduce; furthermore, it still almost unchanged.

(Tao et al., 2016), in this research, the conduct of connecting between steel pipe and concrete in (CFST) is examined. A chain of push-out experiences on square and circular CFST samples were carried out, and among the major parameters taken into account are: (a) kind of steel (carbon and stainless steels); (b) concrete kind (expansive concretes, recycled and normal aggregate); (c) concrete age (31–1176 days); (d) dimension cross-sectional (120–600 mm); and (e) interface kind (shear studs with interface, normal interface and an internal ring with interface). An investigation of experimental was studied to examine the strong connection between the steel tube and concrete CFST. Depending on the results of this work, the following can be inferred:
(1) The results showed that the use of stainless steel has reduced bond strength by between 32% and 69%, which replaced carbon steel. This, in turn, works to reduce in roughness stainless steel surface.
(2) For columns with the same cross-sectional dimension, it was observed that the columns with the circular section could improve bond strength more easily than the square cross-section. It can be seen that improving cross-sectional dimension in both types of columns reduces the bond strength between the steel pipe and the concrete.
(3) Bond strength is significantly affected by the concrete age. The lower the strength of the bond, the longer the age of concrete. For full-scale samples subjected at an age of concrete of over three years, when utılızed NC the strength of bond reduced to a negligible value. Subsequently, in view of the long service periods of the buildings, the art of designing large columns is handled by the strength of the bonds in addition to the need to transfer the load. Especially when steel or concrete is subject to axial loads.
(4) The most effective way to improve bond strength is by welding the inner rings on the inner surface of the tube.
(Thumrongvut et al., 2016), presented the axial load conduct of (CLWCFT) columns tested to concentric axial compression. In this experimental, the ultimate compressive loads of the test were found with compared the values considered utilized the IK-4, 1994 design equation. The square column samples dimension was 150×750 mm. Ultimate compressive strengths of the steel tubes and the effect of the thicknesses of

the wall have been disclosed. Where the experience includes, 18 CLWCFT columns and 6 references (CLWC) columns, under monotonic axial compression, has been subjected. Results of the test present that the curves of the response of the CLWCFT columns have a performance of linear elastic up to around 80-90% of their ultimate compressive load. The performance of nonlinear has a ductile like with type of strain softening. In addition, ductility and the ultimate compressive load of the CLWCFT columns are clearly improved compared to the columns of reference, depending majorly on the maximum the thick wall of the concrete and compressive strength of the steel tube. Finally, the results that were predicted using EC were more consistent with the results with the results obtained in the experiment.

(Chen et al., 2017), in this study, a chain of experiences on (CFSTs) with angles or reinforcing bars under axial tension were examined. The strengths and behavior of CFSTs with angles or reinforcing bars under axial tension were examined. Through the results, it was observed that the tensile strength is not affected by the connection of the edge between the steel pipes and the angles, while the effect is shown on the flexible tensile strength. The recent equations of AISC design supply conservative predictions and safe on the tensile strengths of axially loaded CFST specimens with angles or reinforcing bars. Depending on the full-scale test outcomes, equations were suggested to predict the elastic tensile stiffness and tensile strength of CFST samples with angles or reinforcing bars, and an overall good agreement was achieved between the examine outcomes and predictions.

(Lacki and Derlatka, 2017), Purpose of work has been analyses of the numerical of a steel column and a steel-concrete composite column. Depending on this work can be conclusions:

1– Due to the way of loading and boundary conditions, the stresses concentration in the composite columns and steel are at the base and the head of the column.

2– Change the steel column structure is proposed because after loading this column, the stresses of 321 MPa will override the strength of yield of 235 MPa.

3– Pregnancy load capacity is calculated analytically for steel reinforced concrete column arrived at 90%.

4– Based on the numerical analysis, in the composite column showed the stresses have been 201 MPa in the cross section, that Compatible with 86% of the strength of yield.

5– The model of numerical takes into consideration the stretch of concrete. The stresses of tensile in the concrete in the base and the head of the column override the strength of tensile resulting in the scratches appearance.

6– The steel reinforced concrete column is subjected to further displacement (Δlx=1.2 mm, Δlz=1.3 mm) and more solid than one steel.

(Tang et al., 2017), study a performance of Seismic of recycled aggregate CFST columns, load tests of Low cyclic were conducted on 2 steel tube columns filled with NC and 9 seamless steel tube columns filled with Recycling of aggregate concrete (RAC) to analysis their mechanism of damage and performance of seismic. The coefficient of ductility, the stiffness degradation, capacity of energy dissipation, the curve of the skeleton, and behavior of hysteresis of the columns of steel tube was studied. The strength of steel, the ratio of axial compressive, and the effect of the steel thickness on the seismic performance of the columns of steel tube were studied. The results showed that there was a complete slowdown for the columns filled with RCA. In addition, the ratio of energy dissipation coefficient in this experiment was between 2.617 to 3.595 while the results showed that the equivalent coefficient of viscosity from 0.402 to 0.572. The results showed that there is a correlation between these two types in terms of seismic performance of the NCFST columns are bigger than columns of RAC-filled steel tube and that the RAC-filled steel tube columns are even much better ductility, little lower ability of energy dissipation and better bearing capacity of lateral at the same level of displacement. These results are constantly remembered that conduct of eligible seismic is accomplished, and they avail as structural design in areas of seismic and consider the application of RAC components as a possible reference.

(Ozbakkaloglu et al., 2016), shows a new style of design-oriented for predicting the ultimate failure provisions of the concrete in fiber-reinforced polymer (FRP)–concrete–steel double-skin tubular columns (DSTCs). In this type of study, hollow concrete and concrete-filled FRP–concrete– steel DSTCs with concrete and steel were used in addition to square and circle cross-sections where a new pattern of maximum concrete provisions. The model was improved depending on Test database assembled carefully Consisting of all reported results to date on concentrically loaded DSTCs. This is the first style that applies to a concrete-filled DSTCs. The results have shown, through careful research, that the behavior of DSTCs compression is influenced by the plastic deformation of the internal steel tube. Depending on this noting, failure ways of inner steel tube has been included into the suggested model to represent the internal steel tube condition within sample fail. Through the results of the test and compared with the existing models, there is a close agreement showing the advanced performance of the predicted model.

(E et al., 2012), this research demonstrated an experimental investigation of eccentrically and axially loaded plain and (FR) concrete-filled stainless steel circular tubular columns. Where the results showed that there is a great improvement, especially in the softness of the column, especially for (FR) concrete-filled stainless steel circular tubular columns, which is made of stainless steel material. The maximum loads of examining were compared with the EC4 utilizing for calculating the maximum load design for composite columns. Usually, it was demonstrated that the EC4 strictly predicted the eventual loads of axially loaded concrete-filled stainless steel circular tubular columns, but were quite conservative for predicting the ultimate loads of the eccentrically loaded columns.It also seems to maintain expectations that EC4 is increasing with the deviation increasing. The results of the test provide beneficial information concerning the FR concrete-filled stainless steel columns.

(T et al., 2016), presents the experimental results research into the behavior of large-scale FRP-confined CFT and (CFST) columns under combined lateral loading and compressive strength. The factors of the test included the scenario of loading and the FRP jacket stiffness. The outcomes of the test demonstrated that the FRP jacket Can be efficient delayed or even prohibit local sprains to the outside at the end of a cantilevered CFT column, resulting in a significant improvement in performance of structures under combined cyclic lateral loading and constant axial compression. Compared to cyclic lateral loading, single side load a more severe localized distortion was found near the end of the column and could lead to earlier rupture of the fibrillation within that area.

2.3 Concluding Remarks

A investigate of obtainable analytical and empirical research studies presents that there are various major parameters affecting the performance of RCFST columns, these characteristics are; the geometrical factors, like the slenderness ratio (L/D), (D/t) ratio, and the mechanical parameters; like the strength of the steel and concrete, the loading and the concrete confinement degree and boundary conditions.

Also, the previous works on composite columns found that there is a lack of information about the RCFST columns studies and have been reported concerning the performance of CFST columns.

In view of the insufficiency in the experimental works on RCFST columns, a comprehensive study is required to provide a database for the strength of such 20 columns. This database requires further testing of steel tube columns having a aspect ratios, different tube thickness and concrete properties to identify the behavior under axial compressive loading So, the current research will study the performance of RCFST Columns under axial load and treat these gaps and then checked the design approach of such RCFST columns in accordance with formulas codes will be helpful for civil engineer for civil engineers, designers and future studies in this field.

CHAPTER 3
DESIGN CODES SPECIFICATIONS

3.1 Introduction

The international design codes have been proposed various formulas So as to determine the axial capacity of CFST, like the American Institute of Steel Construction (AISC 360, 2016) depending on the structural steel. But the Eurocode-4 (EC-4-1-1, 1994) depending on the composite members. However, all codes considering that the confinement effect but only (EC-4) have been providing some details for this refereeing. In addition, the codes that mentioned above, have many limitations in strengths of materials and the cross-section geometry of (CFST) members. By these presents, last studies concentrated on improving new equations to interpret the value capacity of (CFST) element taking into consideration the concrete confinement due to the steel tube presence.

In this chapter, (AISC 360, 2010) and (EC-4 1-1, 1994) will be demonstrating and utilizing different formulas and provisions of the codes that adapt to predicting the axial capacity of CFST columns.

3.2 Design Codes Formulations

3.2.1 AISC 360, 2016

(A. 360-16, 2016), have been assumed the plastic stress distribution to determine the nominal strength of composite sections. For a composite section, the interaction diagram for axial force and moment adopted on distribution of plastic stress, for compression members, the plastic stress assumes that does not happen any slipping between the steel tube parts and concrete, and the sufficient D/t ratio prevent local buckling from happening unto crushing of concrete and yielding have taken place in composite column (CFST).

3.2.1.1Concrete and Steel Reinforcement

Standard (ACI.,2008), refers to concrete provisions reinforcement part of detail and composite design, like splice lengths and anchorage, reinforcing spirals, sprain provisions, shear and intermediate column ties The minimum of longitudinal reinforcement in reinforcement in the reinforced concrete of compressed members is 0.01Ag in ACI reinforcement in the reinforced concrete of compressed members is 0.01Ag in ACI 318 where it depends on the phenomenon of stress transmission under levels of service load from the concrete to the reinforcement because of creep shrinkage. Provisions, shear and intermediate column ties. The minimum of longitudinal reinforcement in the reinforced concrete of compressed members is 0.01Ag in ACI 318 where it depends on the phenomenon of stress transmission under levels of service load from the concrete to the reinforcement because of creep shrinkage.

3.2.1.2 Nominal Strength of Composite Sections

There are two approaches shall be used to compute the strength of the composite section. The first part is called strain compatibility, which is represented by a general calculation method. The second part is called the plastic stress distribution part which represents a subset of the strain compatibility approach

3.2.1.3 Material Limitations

For steel structure and concrete in composite systems, the following restriction must be achieved in (CFST) according to (A. 360-16, 2016), unless that test or analysis is justified:

- The compressive strength of normal strength concrete between 21-70 MPa.
- The minimum yield strength of steel tubs ≤ 525 MPa.

3.2.1.4 Classification of Filled Composite Sections for Local Buckling

The steel members performance is fundamentally various of the filled composite member performance. The concrete presence infill has a large effect on the strength, toughness, and flexibility of composite members. Also, by reducing of steel section area, the contribution of concrete shall be more important. The concrete filling is strongly influenced by the elastic local buckling of the steel tube. However, the buckling mode of the steel tube has influenced by concrete infill (both and along the member length and within cross-section), by Prevent steel tubes from deformation inside.

Figures 3.1 and 3.2 shows the development in cross-sectional buckling mode and Changes in buckling mode with length because of concrete infill.

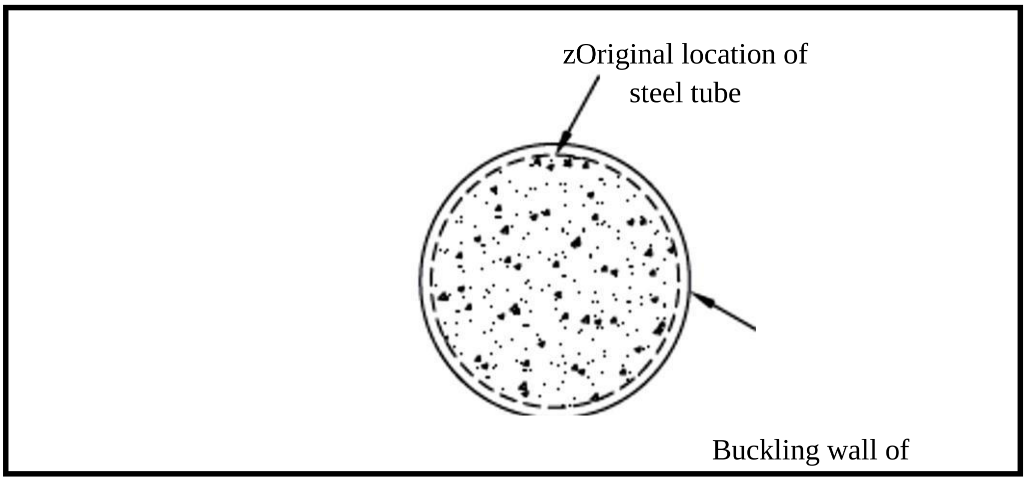


Figure 3.1 Changes in cross-sectional buckling style because of concrete. (A. 360-16, 2016)

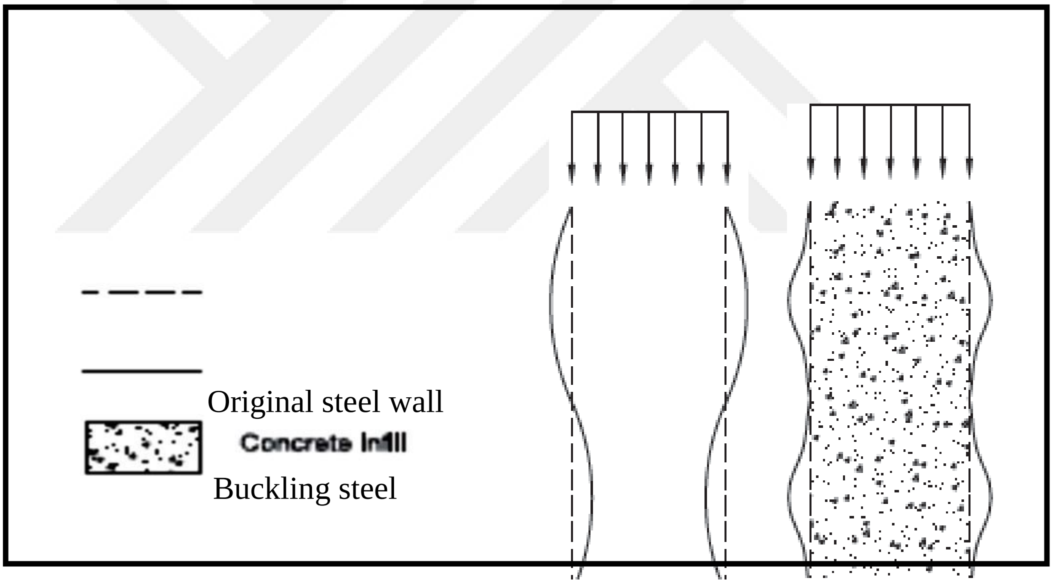


Figure 3.2 Changes in buckling style with length because of the presence of concrete infill. (A. 360-16, 2016).

In general, for filled composite sections, compression elements are assorted like;

1. Compact.
2. Non-compact.
3. Slender.

This classification depending on the (D/t) ratio, and the limits above-mentioned in Table 3.1 as offered below

Table 3.1 Limitation of D/t ratios for compression steel members in composite elements.

Description of Element	Width-to-thickness ratio	λ_p Compact / Non-compact	λ_r Slender / Non-compact	Maximum permitted
Round HSS (Circular)	D⁄t	$\frac{0.15\,E}{f_y}$	$\frac{0.19\,E}{f_y}$	$\frac{0.31\,E}{f_y}$

From this Table 3.1 above, for a compact section, the maximum ratio of width-to-thickness (D/t) of its compression steel members that the ratio of D/t limit shall not override (λ_p). For non-compact section, the maximum ratio of D/t of steel members override (λ_p), but shall not override (λ_r) from Table 3.1. And if the maximum ratio of D/t of any steel member compression override (λ_r), the section should be called slender.

A compact section has enough thickness of steel tube to enhance yielding in compression longitudinal of the steel tube and to obtain concrete infill confinement which leads to improving the compressive strength of 0.85 or 0.95 percent.

Non-compact section has an adequate tube thickness (t) to improve yielding of HSS or the circular steel tube in the direction of longitudinal, But after it arrives 0.70 of compressive strength of concrete, it cannot enough to confine the concrete infill and starts to enter in the large dilation of volumetric and elasticity phase, subsequently, The stresses will begin to push against the steel tube. A slender section, in the longitudinal direction, there is no enhancing in confine the concrete infill and yield strength of steel tube, and before 0.7 of concrete compressive strength. And starts to entering in inelastic strains and the significant dilation of volumetric, subsequently, the stresses will begin to push against the steel tube.

Figure 3.3, shows the nominal axial compressive strength, P_{no}, of the composite section of the HSS slenderness. Nevertheless, full plastic strength (P_p) with compact sections progress, in compression. For non-compact sections, the nominal axial strength can be determined (P_{no}), by an interpolation quadratic between, (Pp) and the yield strength (Py), for regarding the tube slenderness. The steel tube restricts the concrete, passes a throw inelasticity stages and the volumetric dilation improve quickly with slenderness of HSS, for these cases, the interpolation is quadric.

In the end, slender sections are stated as developing 0.7 MPa, of ($\acute{f_c}$) of the concrete infill and the critical buckling stress (F_{cr}) of the steel HSS.

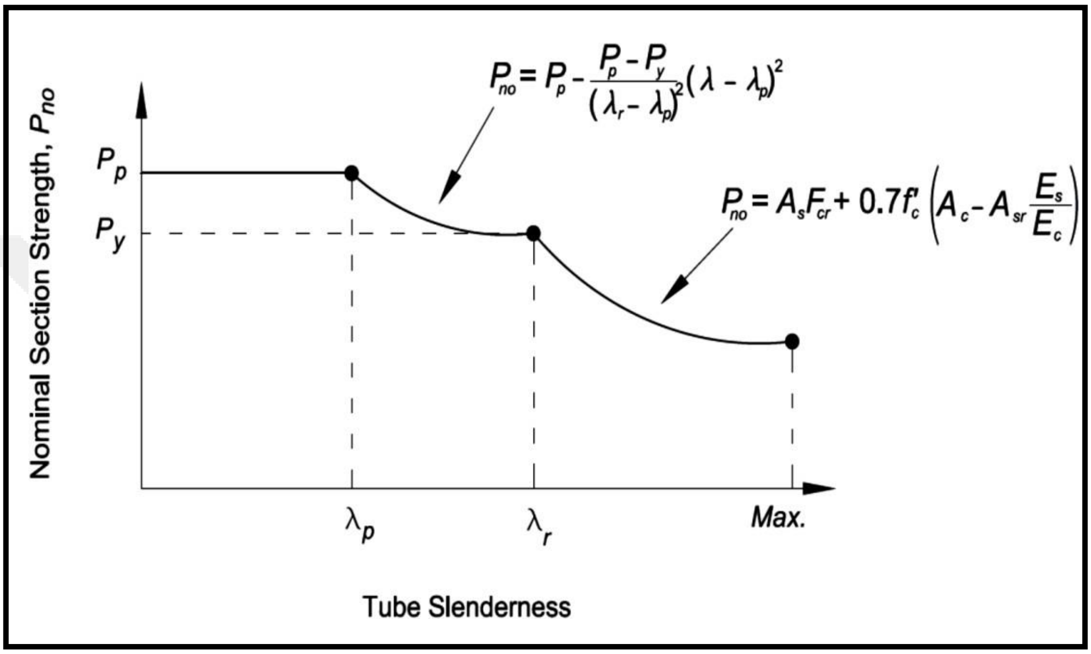


Figure 3.3 Nominal axial strength (P_{no}) vs. HSS slenderness (ANSI/AISC 360, 2010).

3.2.1.5 Axial Capacity of CFST Columns

The cross-sectional area of the steel tube shall comprise at least 1% of the total composite cross-section of concrete filled steel tube, the available compressive strength of axially loaded doubly symmetric filled composite members:

1. When ($\frac{pno}{pe}$ > 2.25):

   Pn= [(0.658)$^{\frac{\text{pno}}{pe}}$] ……. (3.1)

2. When ($\frac{pno}{pe}$ > 2.25):

   Pn=0.877 P ……… (3.2)

- For compact sections:

  Pno=PP ………. (3.3)

- PP=$fyAs$+$C2f'$ (Ac+$AsEsEc$) ……. (3.4)

Where, ($C2$ = 0.95) for round section.

- For non-compact sections:

$$Pno=PP-\frac{PP-Py}{(\lambda r-\lambda P)^2}(\lambda-\lambda r)^2 \quad \ldots\ldots (3.5)$$

Where; and λr are slenderness ratios can be determine in Table 3.1.

$$Py=fy\ As+0.7\ f'\ (Ac+As\ \frac{Es}{Ec}\ ) \ldots\ldots (3.6)$$

- For slender sections:

$$Pno=Fcr\ As+0.7\ f'\ (Ac+\frac{Es}{Ec}) \quad \ldots (3.7)$$

- For round section:

$$Fcr=\frac{0.72fy}{\left(\left(\frac{D}{t}\right)\frac{fy}{Es}\right)^{0.2}} \quad \ldots\ldots\ldots (3.8)$$

$$Pe=\frac{\pi 2\ EIeff}{(KL)^2} \quad \ldots\ldots\ldots (3.9)$$

$$EIeff=EsIs+C3EcIc \quad \ldots\ldots\ldots (3.10)$$

$$C3=0.6+2\left[\frac{As}{Ac+As}\right] \quad \ldots\ldots\ldots (3.11)$$

$$Ec=4700\sqrt{fc'} \quad \ldots\ldots\ldots (3.12)$$

Where Es=210000 MPa

3.2.2 The European Code EC4

EC4 offers a method of design to both of partially encased and encased concrete steel sections and concrete filled tube without or with reinforcement. This code depends on the design of limit state that utilizes some factors of safety to loading and features of the material to present the safety and usability. EC4 applies to composite columns with steel have yield strengths 235 MPa to 460 MPa and strength of classes concrete of C20/25 to C50/60.

There are two methods general method and the simplified method used by the EC4 for design the axial capacity of CFST columns. Both approaches are depended on the following major presumptions:

a) Plane sections stay plane, though the column is deformed because of the load.

b) The steel and concrete reacted completely to each other until the breaking point.

c) Tolerances must be tolerated for defects that are consistent with those adopted to assess the strength of bare steel columns.

The general method takes into account the influence of defects. Analysis of Numerical methods is necessary to investigate. This method applies to symmetrical and axial non-prismatic sections. The curves European buckling for steel columns is using in the simplified method. The member's flaws are implicitly included. Don't prefer the general method, the simplified method applies only to prismatic composite axial members with uniform sections. Because of the simplified method of application on the samples subject to simple calculation, it will be utilized in this experiment.

3.2.2.1 Local Buckling

Both approaches assume that there is no local buckling of the steel parts of the cross-section until strengths of material are achieved.

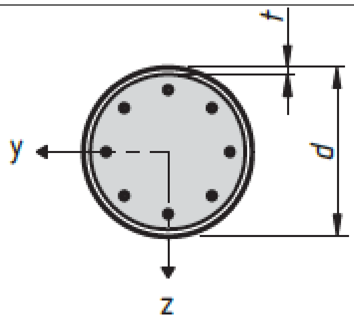
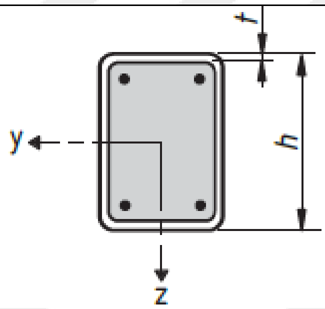
The maximum (w/t) ratios for the steel tube compression is required to meet the following values to prevent buckling:

3.2.2.2 The Simplified Method

The composite column, designed in this way, must meet the following limitations:

- A composite column must have a uniform cross-section along the whole column and a double symmetry.
  The relative slenderness $\bar{\lambda}$ must fulfill the condition $\bar{\lambda} \leq 2.0$, as mention in table 3.2.

Table 3.2 Values of Width-to-Thickness Ratio with f_y in N/mm^2.

<table>
<tr><td>Type of cross section</td><td></td><td>Width-to-thickness ratio</td></tr>
<tr><td>Circular hollow steel sections</td><td>
</td><td>$\frac{d}{t} \leq 90\,\frac{235}{f_y}$</td></tr>
<tr><td>Rectangular hollow steel sections</td><td>
</td><td>$\frac{h}{t} \leq 52\sqrt{\frac{235}{f_y}}$</td></tr>
</table>

- The longitudinal reinforcement ratio is between 0.3% and 6% that may be utilized in calculating.
- 1The CFST member should have a ratio of steel contributionδ between 0.2 and 0.9; it can be calculated as follow:

$$\delta = \frac{A_a f_{yd}}{N_{p1,Rd}} \qquad \text{...... (3.13)}$$

Where $N_{p1,Rd}$: the plastic resistance.

- The slenderness ratio of the composite cross-section should be between 0.2 and 5.

3.2.2.3 Composite Cross-Sections Resistance to Axial Loads

A composite cross-section resistance to compression $N_{p1,Rd}$ should be evaluated by:

$$N_{p1,Rd} = A_a f_{yd} + A_c f_{cd} + A_s f_{sd} \qquad \text{......(3.14)}$$

Where:

A_a, A_s and A_c are areas of the steel tube, the reinforcement bars and the concrete respectively

f_{yd}, f_{cd} and f_{sd} steel, concrete and reinforcement design strength, respectively

For circular CFST cross-section, the eccentricity of the axial force (e) must be less than the value $d/10$ and relative slenderness $\bar{\lambda}$ of the member does not exceed 0.5 corresponds to (l⁄d) ratio of nearly 12. Where d is the external diameter of the circular steel section. The eccentricity is defined by:

$$e = \frac{M_{\max Sd}}{N_{Sd}} \qquad \text{....... (3.14)}$$

Where:

$M_{\max Sd}$ is the maximum design moment
N_{Sd} is the design axial force

The plastic resistance composite members may then be calculated by:

$$N_{p1,Rd} = \eta_a\, A_a f_{yd} + A_c f_{cd}\left(1 + \eta_c \frac{t}{d}\frac{f_y}{f_{ck}}\right) + A_s f_{sd} \qquad \text{...... (3.15)}$$

in which η_a is the factor of reduction of steel and η_c is the factor of enhancement of concrete. When the central difference is not exceed 10% of the outside steel tube diameter, η_a and η_c factors are calculated as follows:

$$\eta_a = 0.25(3 + 2\bar{\lambda}) \leq 1 \qquad \text{......(3.16)}$$

$$\eta_c = 4.9 - 18.5\bar{\lambda} + 17\bar{\lambda}^2 \geq 0 \qquad \text{......(3.17)}$$

The relative slenderness ration can be calculated by the following expression:

$$\bar{\lambda} = \sqrt{\frac{N_{p1,Rd}}{N_{cr}}} \qquad \text{......(3.18)}$$

N_{cr} is a composite column elastic critical load and it can be evaluated using the conventional Euler buckling formula:

$$N_{cr} = \frac{\pi^2 (EI)_{eff}}{L^2} \qquad \text{......(3.19)}$$

in which L refer to the effective length and $(EI)_{eff}$ refer to effective the flexural stiffness of composite column cross section and can be calculated from:

$$(EI)_{eff} = E_a I_a + E_s I_s + K_e I_c E_c \qquad \text{......(3.20)}$$

Where :

$K_e = 0.6$

I_a, I_s and I_c is moment of inertia of steel tub, steel bar and the uncracked concrete section, respectively.

E_c is the elastic modulus of concrete, which is defined by:

$$E_c = 22000 \left(\frac{f_{cm}}{10}\right)^{0.3} \text{ MPa}$$

$$f_{cm} = f_c + 8 \text{ MPa} \qquad \text{......(3.21)}$$

$$N_{Sd} \leq x. N_{p1,Rd}$$

Where x is the relevant buckling mode reduction factor and given in term:

$$x = \frac{1}{\emptyset + [\emptyset^2 - \bar{\lambda}^2]} \leq 1 \qquad \text{......(3.22)}$$

Where

$$\emptyset = 0.5[1 + \alpha(\bar{\lambda} - 0.2) + \bar{\lambda}^2] \qquad \text{......(3.23)}$$

α = 0.21 for circular-cross section of CFST columns.

3.2.2.4 Summary

The AISC 360-16 allows design CFST columns with either the allowable stress or limit state design formula. The Eurocode 4 is representing the code only that deals with the influences of long-term loading separately and using limit state and setting a factor of partial safety to loading and material features concepts to realize the goals of safety and serviceability. The fields of application for two codes are mentioned in Table 3.3 clearly. Resistance models of the European code supply detailed tolerance for concrete confinement by the steel tube and it is can to predict mean resistance of column. In contrast to the AISC code, the concrete confinement has a fixed and continuous allowance, especially for short columns where it has become overly conservative (up to 30%, in the mean for $\lambda \leq 0.1$). Column performance is fundamentally elastic, and samples of resistance of the two codes become a little conservative for large slenderness ratios and the concrete confinement is a bit. However, the AISC 360-16 is forecast reliable for all parameters component. Beyond the limitations, EC4 can be expanded to cover wide properties of CFST columns (Beck et al., 2009).

Table 3.3 Scope of application for AISC and EC4 building codes relevant to CFST columns.

<table>
<tr><td colspan="2">Content</td><td>AISC 360-16</td><td>EC4</td></tr>
<tr><td colspan="2">Cross-sectional type</td><td>Circular, Rectangular</td><td>Circular, Rectangular</td></tr>
<tr><td colspan="2">Concrete specimen type</td><td>Cylinder</td><td>Cylinder, Cube</td></tr>
<tr><td rowspan="5">Physical parameters</td><td>Concrete strength (N/mm^2)</td><td>21–41(lightweight)</td><td>C20/25–C60/75</td></tr>
<tr><td>Elastic modulus of concrete, E_c (N/mm^2)</td><td>$4700\sqrt{\acute{f}_c}$</td><td>$E_c = 22000\left(\frac{f_{cm}}{10}\right)^{0.3}$</td></tr>
<tr><td>Yield strength of steel, f_y (N/mm^2)</td><td>≤525</td><td>≤460</td></tr>
<tr><td>Elastic modulus of steel, E_s (N/mm^2)</td><td>200000</td><td>210000</td></tr>
<tr><td>Flexural stiffness, *EI*</td><td>$E_sI_s + E_sI_{sr} + C_3E_cI_c$</td><td>$E_sI_s + E_aI_a + 0.6E_{cm}I_c$</td></tr>
<tr><td rowspan="2">Geometric parameters</td><td>*D/t* (Circular)</td><td>$\leq 0.31E_s/f_y$</td><td>$\leq 90\frac{235}{f_y}$</td></tr>
<tr><td>Steel ratio, or confinement ratio, or steel contribution ratio</td><td>α ≥ 1% (steel ratio)</td><td>$0.2 \leq \delta \leq 0.9$ *(steel contribution ratio)*</td></tr>
<tr><td></td><td>Column Slenderness</td><td>$KL/r \leq 200$</td><td>$\bar{\lambda} \leq 2$</td></tr>
</table>

CHAPTER 4
EXPERIMENTAL PROGRAM

4.1 General

Experimental techniques were utilized to investigate the performance of RCFST columns under axial load. A total of five specimens of RCFST and four concrete cylinders were tested in a laboratory environment at Gaziantep University. In this research utilized steel tube member with two different reinforcement steel bar were filled with normal concrete. Moreover, the specimens of RCFST were performed and tested under compressive strength load until failure. The objectives of the investigative work were explained by the specimen's composition in this chapter. The specimens divided into two-part, each part takes two specimens depending on the diameter of the reinforcement bar and a number of stirrups with normal concrete. Hence, all experiments were completed and examined by the Civil Engineering Department Laboratory, Gaziantep University. Through the tests of RCFS columns, the relations between loading the displacement column and ultimate load were recorded accurately for all experimental samples.

4.2 Steel Bar Reinforced concrete

4.2.1 Material

4.2.1.1 Steel Tube

The cross sections of the steel tubes are chosen according to the nominal wall slenderness ratio, the possible shape and the length irregularities due to the manufacturing processes and the transfer from the manufacturing workshops to the laboratory of the University of Gaziantep. In addition, each model shall be examined with high precision and its dimensions shall be checked and confirmed to the required engineering specifications such as the thickness of the wall and straightening of the pipe and make sure that it is free of defects after the cutting process. After that, samples of these pipes shall be taken for the purpose of checking the tensile strain for the tensile strength and compatibility We take these models and cut them according to the lengths required in the pilot program, taking into account the need to smooth the sense of the cut part and the specifications of the steel pipes used in this study. The specification of the steel tube is shown in table 4.1.

Table 4.1 Specification of steel tube

D (mm)	**L (mm)**	**t (mm)**	**L/D**	**D/t**	f_y (MPa)
114.3	310	6.11	2.71	18.707	535

4.2.1.2 Steel Bars

In the engineering buildings, steel bars are the main materials used in construction with concrete for their ease of operation and the relatively simple cleverness required in concrete buildings. In addition, the concrete is weak in tensile strength, cracks develop when loaded and tensile stresses increase with shrinkage. The cases resist stress and reduce shrinkage and crawling behavior.

In addition to improving the seismic performance, durability and toughness, reinforcing steel should be used with normal concrete to improve performance it.

In this experiment, the bars are deformed so as er to make the mechanical interlock between the steel and concrete, which helps to keep bonds between the two. Four main reinforcing bars of 8 mm and 12 mm diameter were cut with 470 MPa and 534 MPa yield strength respectively to the length of the tube. Square stirrups have been used with various elements of stirrups and various spacing. In the first case, two stirrups were used with an 8 mm diameter of reinforcing bar. The distance between the two rings was 275 mm. In the second case, 6 rings were used with an 8 mm diameter of reinforcing bar, the distance between the stirrups was 55mm. The same stirrups and distance were also used with the reinforcing bar diameter 12 mm the reinforced samples offered in Figure 4.1.

(a) **(b)**

Figure 4.1 Reinforcing bar 8 mm and 12 mm with (a) two stirrups (b) six stirrups.

4.2.1.3 Concrete

Normal aggregate (gravel and sand) was utilized for working NC to infill steel tubes. The coarse aggregate has a farthest volume of 12 mm. Concrete mixtures consist of different materials and different percentages to obtain them. Ordinary Portland cement grade 42.5 (CEM I 42.5) were used. The value 42.5 refers to the compressive strength of the cement mortar cube at age 28 days. Table 4.2 offered The proportions of mix that utilized to work NC.

Table 4.2 The mix proportions of the normal concrete.

Mix proportion	C	FA	W	SP	GA	S	CA total	CA (2-0.3mm)	CA (< 0.3mm)
30lt ($0.030m^3$)	8.55	8.55	5.64	0.08	21.29	19.5	6.1	4.338	2.17

4.2.1.3.1 Normal Aggregate

Aggregate (GA) is usually represented inert filler, accounting between (70 - 85) percent of the weight of the concrete and 60 to 80 percent of the volume. Also, the aggregate is represented as an inert filler, it is a necessary element that determines the elastic of concrete and properties of thermal and stability of dimensional. There are two types of aggregate, fine and coarse types. The fine aggregate less than 4.75mm and passing from sieve 4, while aggregate is more than 4.75 mm (maintained on sieve 4), the coarse aggregate of the sieve 12 is used and the fine (S) (river sand) in this mixture. Compressive aggregation is an important factor in selecting aggregates. When NC strength is setting, other components in concrete will be weaker multi times than most concrete aggregates, and subsequently are not an agent in the strength of ordinary concrete.

Other mineralogical and physical features of the aggregate should be examined before starting mixing concrete to gain a good mixture. These properties include texture, shape, reactivity, soundness, bulk unit weight, specific gravity, soundness, size gradation and moisture content. These features along with the ratio of water/cement material appear the durability of concrete, strength, and workability.

The surface textile of aggregate is offered either rough or smooth. A coarse surface gives a good connect bond between aggregate and the paste that ıs creating perfect bond strength, but. A smooth surface can increase workability.

The distribution or volume of aggregates is a paramount feature due to it appears the requirements of workability for concrete. Since cement is considered to be the most expensive component, it is the paste that controls the cost. It is subsequently advisable to reduce the quantity of paste with the output of concrete that can a treat, pressured on it, and completed whilst supply the important strength and durability. The necessary quantity of paste of cement depends on the full area of the surface that should cover and the quantity of void space that should be filled. The spacing is the biggest when the particle volume is regular, but when a Collection of volumes has utilized the spaces of the void are the paste and filled wanted is reduced. The less workable the concrete becomes, the more these voids are filled, subsequently, a compromise between economy and workability is necessary.

4.2.1.3.2 Cement

The hydraulic cement, which is obtained by grinding the soft clinker resulting from calcification to the initial fusion, is a mixture of clay and similar materials or limestone. An ordinary Portland cement (CEM I 42.5) was utilized for producing all concrete mixtures with reinforcement bars had been used during the mixes of concrete infill (RCFST).

4.2.1.3.3 Fly Ash (FA)

Fly ash can be classified as carefully separated sediments from coal burning, where ash is transported from the burning rooms by exhaust gases. Steam and coal represent the fuel used in the power plants used to produce this ash. Usually, coal is milled and Bloat into the air in a boiler burning room where it constantly burning, creates heat and produces molten metal residues.

The boiler pipes produce heat and cool the flue gas from boilers and leave the residue of the metal that melts as a result of the heat through which the dust is produced. These particles can be defined as ash or slag below the bottom of the burning rooms, while fly ash remains aligned with flue gas. The flue gas is separated from the ash by special control devices, such as electrostatic precipitators or filter cloth bags.

Every year fly ash is used in various fields in civil engineering applications. In addition, it enters into the industry of ordinary cement, roads, asphalt fillings and other fields.

4.2.1.3.4 Superplasticizers (SP)

Superplasticizers can also be known as high-volume water reducers, it is a chemical material used with concrete to reduce the amount of water, as it suspends the particles in the concrete, as well as it increases the workability of the concrete and increases the strength of the concrete. Nevertheless, this improvement is not retained for more than 30–60 min I. Papayianni, G. Tsohos, N. Oikonomou, and P. Mavria. (2005), Aly, T and Thayalan, P and Elchalakani, M and Patnaikuni, I. (2010). Reducing the amount of mixing water decreases the water-cement ratio, which in turn, develops the strength of hardened concrete. Superplasticizers can be utilized when:

1. Cast concrete around densely spaced steel bars
2. A low water-cement ratio is beneficial (e.g., high-strength concrete, early strength gain, and reduced porosity)
3. Casting concrete underwater
4. Pouring concrete in thin sections
5. Consolidating the concrete is difficult
6. Placing concrete by pumping.

4.2.1.3.5 Crush stone

Crushed stone is a kind of aggregate used in construction and concrete, which is created by mining rocks to different sizes and then the use of the crusher to crack the rocks to the appropriate crushing according to the type of purpose to be used. The crushed stone differs from the gravel, where the gravel is shaped more round than the crushed stone as a result of erosion and weathering.

Crushed stone can give high concrete strength in more adequate compared to natural sand and gravel. Furthermore, the crushed stone can use to develop the properties of fresh and hardened concretes (Celik et al.,1996). In this experiment, the crushed stone passing through a sieve (< 0.3) and size between (0.3 – 2) mm had been used in (RCFST) mixes with the specific percentages.

4.2.2 Fabrication of RCFST Columns

Four reinforced normal concrete filled steel tube with different steel bar (Ø8 and Ø12) and a different number of stirrups (2 and 6) and one specimen is controlled were used and tested in this experimental. The hollow steel tubes mentioned above were used to make RCFST samples. To offer, a better connection between the normal concrete (NC) and steel pipe, the inner surfaces of the hollow tubes was well cleaned. The bottom ends of the tubes are placed on clean, smooth surface plastic sheets for the purpose of obtaining a soft surface after casting. These tubes are then fixed on a thick layer of silicon to prevent the movement of the tubes during the casting process and to keep the concrete water from leakage. Four specimens were filled with NC with reinforcement and the control was filled with normal concrete without reinforcement.

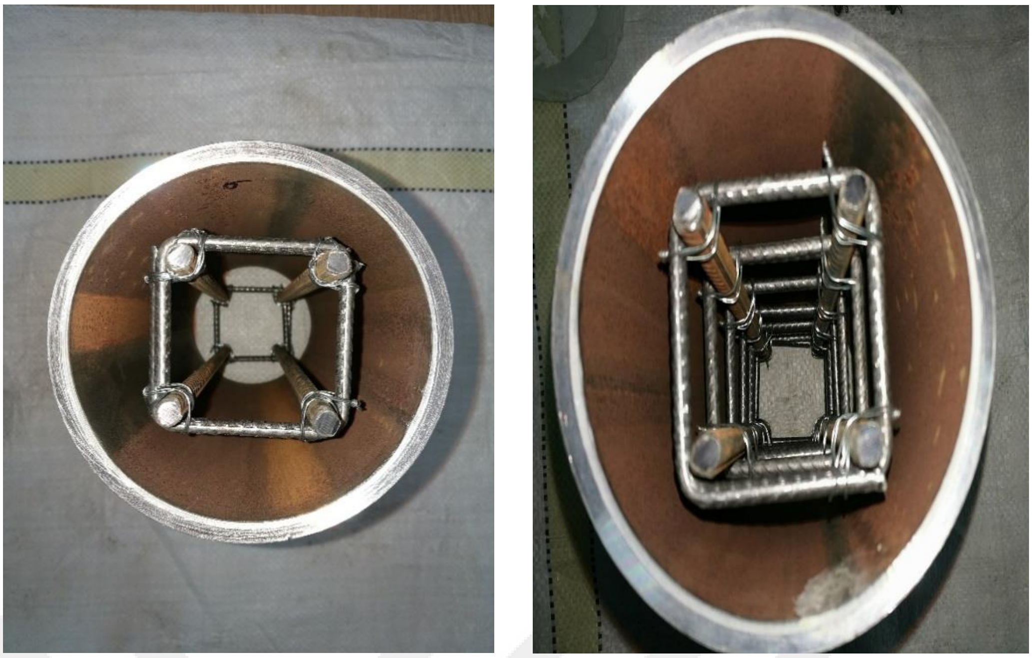
Naming and properties and system of RCFST column specimens are presented in

Table 4.3. Naming system includes tube thickness (1), reinforcement bar diameter (Ø) and stirrups number respectively. For example, 1-2-Ø8 represents an RCFST column with 6.11 tube thickness, 2 stirrups, and Ø8 reinforced bar diameter. While C refer to control specimen (columns without reinforcement). The steel bars were taken to the industrial workshop at Gaziantep University, where they were cut to the required length and then brought to the laboratory. Square stirrups were manufactured with width 60 mm and tied to longitudinal bars by using tie wire with 60 mm spacing along the column. The reinforcement has been installed in the steel tube and centered carefully with approximately 20 mm cover between circular tube and square stirrups corner. Figure 4.2 presents the illustration of the formation of the RCFST specimens.

Table 4.3 Properties and naming system of RCFST column specimens.

No	**Specimen**	**D (mm)**	**t (mm)**	**L (mm)**	**D/t**	**L/D**	**fy (MPa) tubes**	**fyr (MPa) reinf.**	**fy (Mpa) stirrups**
1	Control	114.3	6.11	310	18.707	2.71	535	0	520
2	6S-12mm	114.3	6.11	310	18.707	2.71	535	470	520
3	2S-12mm	114.3	6.11	310	18.707	2.71	535	470	520
4	6S-8mm	114.3	6.11	310	18.707	2.71	535	534	520
5	2S-8mm	114.3	6.11	310	18.707	2.71	535	534	520

A single mix of ordinary concrete was prepared to cast these five models simultaneously.



(a)Reinforced bar with two stirrups (b) Reinforced bar with six stirrups

Figure 4.2 Formation of the RCFST specimens.

The normal concrete was filled inside the steel tubes without a compact. Then the top left 10 mm of empty steel tubes and covered with plastic sheets for 24 hours to prevent evaporation of concrete water. The specimens were taken out to be dried at chamber temperature after 28 days of curing, the inevitable water loss of concrete mix and drying shrinkage took place and it appears clearly in column specimens without reinforcement compared with column specimens with reinforcement, as shown in Figure 4.3. After removing of mica plates, the columns were cleaned from silicone residues and all top ends of samples were covered with high strength epoxy to achieve flat surfaces of the columns as well before the test, as mention in Figure 4.4.

(a) (b)

Figure 4.3 Shrinkage of Columns (a) without reinforcement (b) with reinforcement

Figure 4.4 Columns specimens

4.3 Steel Fiber Reinforced Concrete Filled Steel Tube (SFRCFST)

(SFRC) can be defined as a composite material, which involves the mixing of regular concrete with short steel fibers and in various forms where it is added to the concrete because it is less expensive and more economical in terms of construction compared with conventional construction. This type of concrete was used in the early 1960s. In addition, it contains many useful features including high hardness, lightweight, better behavior in terms of fracture and dynamic, high ductility, and the cost of repair less (Al-lami, 2015).

4.3.1 Material

4.3.1.1 Steel tube

Steel tube explains previously in this chapter and the specification of the steel tube is shown in table 4.4.

Table 4.4 Specification of steel tube

No.	D(mm)	t(mm)	L(mm)	D/t	L/D
1	114.3	5.97	916.5	19.5	8.01
2	114.3	5.97	463	19.5	4.05
3	114.3	5.97	173	19.5	1.51

4.3.1.2 Fiber Steel

Steel fiber considered one of the reinforcement types using in concrete, fiber steel utilized to develop the features of mechanical in concrete, particularly the post-cracking, improve structural strength, improve impact– and abrasion–resistance, and decrease the width of crack and control the widths of crack, thus developıng toughness. Hooked end fiber steel used with normal concrete, table 4.5 explain some properties of the steel fiber that used in this experimental, figure 4.5 shows Typical hooked-end steel fiber.

Figure 4.5 hooked-end steel fiber

Table .4.5 Properties of Steel Fiber.

Product type	DRAMIX® 3D 40/30BG
Fiber shape	Hooked ends
Length (mm)	30
Diameter (mm)	0,75
Aspect Ratio	40
Modulus of elasticity (GPa)	200

4.3.2 Concrete

In this experimental used two mix of concrete one of them without fiber steel and the second with fiber steel each mix. Ordinary Portland cement grade 42.5 (CEM I 42.5) were used. The value 42.5 refers to the compressive strength of the cement mortar cube at age 28 days. The mix proportions of concrete without fiber steel are mentıon in Table 4.6, and The mix proportions of with fiber steel are mentıon in Table 4.7.

Table 4.6. The concrete mix proportions of concrete without fiber steel.

Mix proportions	C	FA	CA	W	SP	RE
Ratio	1	1.5761	2.7056	0.3319	0.019	0.008
Kg/m3	445	701.36	1204	147.7	8.455	3.56
75	lt					
0.075	33.375	52.602	90.298	11.077	0.6341	0.267

Table 4.7. The mix proportions of concrete without fiber steel

Mix proportions	C	FA	CA	W	SP	RE	Fiber %
Ratio	1	1.5761	2.7056	0.3319	0.019	0.008	0.015
Kg/m3	445	701.36	1204	147.7	8.455	3.56	117.75
75	Lt						
0.075	33.375	52.602	90.298	11.077	0.6341	0.267	8.8313

4.3.2.1 Cement

Cement explained clearly previously in this chapter in 4.2.1.3.2**.**

4.3.2.2 Fly Ash

Fly Ash explained clearly previously in this chapter in 4.2.1.3.3**.**

4.3.2.3. Coarse Aggregate

Coarse Aggregate (gravel) explained clearly previously in this chapter in 4.2.1.3.1**.**

4.3.2.4 Superplasticizers (SP)

Superplasticizers explained clearly previously in this chapter in 4.2.1.3.4**.**

4.3.2.5 Retarder (RE)

Is a chemical material added to the concrete to delay the time hardening of concrete, the purpose of the use of this article sometimes is: (1) Reduce the effect of weather temperature on concrete; (2) It works to retard the initial settıng tıme of the concrete in the presence of a difficult or unusual during castings, such as pouring a large area of pavements or foundations; or (3) Can be used with special finishing techniques like detected aggregate surface.

4.3.3 Fabrication of SFRCFST Columns

In this experimental used two mix concrete (without and with fiber steel) filled steel tube with different length (173, 463and 916.5 mm) utilized to prepared specimens, for each mix of concrete used 3 specimens, one specimen for each length. To offer, a better connection between concrete and steel tube, the internal surfaces of the hollow tubes have been cleaned well. The bottom ends of the tubes are placed on clean, smooth surface plastic sheets for the purpose of obtaining a soft surface after casting. These tubes are then fixed on a thick layer of silicon to prevent the movement of the tubes during the casting process and to keep the concrete water from leakage. Two concrete mixes were used (without and with the fiber) filled with steel tubes. Six specimens were used for each mixture 3 specimens length (175,463 and 916) were used. The process of casting the concrete without fiber steel (CFST) was carried out at the University of Gaziantep on the first day, The materials were mixed together for a few minutes to ensure uniformity of the material with each other and then the water was added with Superplasticizers mixer by mixing materials up to 3 minutes and then the concrete is filled in the tube steel

Naming and properties and system of SFRCFST column specimens are presented in Table 4.8. The naming system includes tube without and with fiber steel (W and F), (L/D) ratio and compressive strength respectively. For example, W-1.5-92.22 represents an SFRCFST column W means without fiber and 1.5 mean (L/D) ratio and 92.22 mean compressive strength equal to 92.22MPa. Then the top left 10 mm of empty steel tubes and covered with plastic sheets for 24 hours to prevent evaporation of concrete water. The specimens were taken out to be dried at room temperature after 28 days of curing, after removing of mica plates, the columns were cleaned from silicone residues and all top ends of samples were covered with high strength epoxy to achieve flat surfaces of the columns as well before the test, as shown in Figure 4.6.

Table 4.8 Properties and naming system of SFRCFST column specimens

No	Specimen	L (mm)	D (mm)	t (mm)	$\frac{D}{t}$	$\frac{L}{D}$	f_y (MPa)	f_c (MPa)
1	2-W-916.5	916.5	114.3	5.97	19.5	8	235	92.22
2	2-F-916.5							86.53
3	2-W-463	463	114.3	5.97	19.5	4	235	92.22
4	2-F-463							86.53
5	2-W-173	173	114.3	5.97	19.5	1.5	235	92.22
6	2-F-173							86.53

Figure 4.6 Columns specimens

4.4 Concrete Control Specimens Preparation

Well known that concrete control specimens are prepared to obtain the basic materials' properties that affect the performance of the tested specimens. Three mixes of concrete filled steel tube in this experimental. Concrete cylinders were prepared and cast using standard mold size of a 200 mm height and100 mm diameter from the same mix of normal concrete that filled the steel tubes.

The molds were filled with concrete and the top face of the concrete cylinders was then leveled and covered with plastic sheeting for 24 hours to prevent the concrete water from evaporation. The samples are then removed from plastic molds and placed in a water basin for 28 days to complete the curing process. After the curing process is completed, the concrete cylinders are removed from the water and left them to dry at chamber temperature. In order to make sure that the top and bottom surfaces of the concrete cylinders are levels, they are covered with a layer of sulfur using a sulfur leveling mortar. The capping process is complying with ASTM C617/ C617M-15 (Astm, 2012). Figure 4.7 shows concrete cylinder samples with capping, which are ready for testing.

Figure 4.7 Concrete cylinder specimen after capping.

4.5 Compression Testing Machines and Measuring devices

To test the ultimate compression load of RCFST, SFRCFST columns and concrete specimens, universal testing machines were used for each one over the testing program. One of them is used for the testing of the RLWCFST columns, while the other is used for the concrete cylinder tests. The RLWCFST were subjected to compressive load by a 3000 kN universal testing machine in the laboratory of the civil engineering department, Gaziantep University. To terminate the possibility of loading eccentricity, columns were accurately concentrated in the machine of testing. In order to measure the shortening of the specimen. To minimize the effect of unevenness and looseness at the upper end and to avoid the stress concentration of the specimens, before the final loading, all the columns have been subjected to preloaded with 30kN, then subjected to compressive loading at an initial load rate of 0.1kN/min till the end of the test. All testing data for compression loading versus axial deformation of columns were collected to be able to discuss in chapter five.

Compression tests of the concrete control cylinder were accomplished utilizing a 3000 kN capacity universal testing machine. Just like the RCFST columns, concrete cylinders were centered carefully in the universal machine and subjected to axial compressive loading to failure, as shown in Figure 5.1. The compressive strength was recorded and will be discussed in the next chapter.

CHAPTER 5

EXPERIMENTAL RESULTS AND DISCUSSION

5.1 General

In this part presents the behavior of test for two types of reinforcement RCFST and SFRCFST columns under axial compression loading where the load was Sheded to both steel and concrete. To check the result of column parameters and confinement effect, in this experimental used different parameters according to kind of reinforcement, the RCFST parameters were bar diameter and number of stirrups, while the SFRCFST was the effect of steel fiber in the three different lengths. Results for RCFST and SFRCFST columns are presented and discussed. Then, the performance of RCFST and SFRCFST columns infilled with concrete and reinforced bars is compared with respect to RCFST and SFRCFST columns.

5.2 Concrete Cylinder Test Results

Twelve-cylinder specimens (100*200mm) for 3 mixes concrete (RCFST and SFRCFST and CFST) were utilized in this experimental 4 cylinders prepare for each mix. These cylinders were examined after 28 days from the casting day. The cylinders were prepared and examined depending on the ASTM C39/C39M (C., 2005), as shown in Figure 5.1. The concrete specimens were undergone to compressive load to investigate the compressive strengths. Depending on the cylinders test, the average compressive strength for RCFST, SFRCFST, and CFST were (37.6, 86.53and 92.22 Mpa) respectively.

5.3 Columns Test Results

5.3.1 RCFST COLUMNS

Five (RCFST) columns were examined to an axial compression load. Details of the columns that have been checked are given in Table 5.1. To test the effect of confinement and to compare column performance, use (*SI*) to indicate the effect of confinement and to measure the composite procedure of CFST columns. End shortening versus compression loading curves delineates hardness, flexibility, and behaviors of the stiffness of columns. In addition, by observing the load-shortening curves, the behavior of the core of concrete can be determined. Where the performance of columns can be compared by the strength index (*SI*). Where the SI was used in previous research and the SI can be defined as a beneficial measure used in CFST columns for and confinement assessments and composite work (Han et al., 2005), (Ding et al., Tao 2015). *SI* is defined by this equation:

$$SI = \frac{N_u}{A_s f_y + A_r f_{yr} + 0.85 A_c f_c} \tag{5.1}$$

Figure 5.1 Concrete Cylinder test.

in which N_{ue} is the experiment or design specifications compression strength of a CFST section, calculated by:

$$N_{uo} = A_s F_y + A_{sr} F_{yr} + 0.85 \acute{f}_c A_c$$
(5.2)

Compression load capacities of columns and The strength index (*SI*) are mention in Table 5.1.

Table 5.1 Properties and naming system of RCFST column specimens.

No	Specimen	D (mm)	t (mm)	L (mm)	f_c (MPa)	f_y (MPa)	(ξ)	*P* (kN)	*SI*
1	Control	114.3	6.11	310	37.60	535	3.601	1665	1.214
2	2S-8mm	114.3	6.11	310	37.60	535	3.694	1753.6	1.190
3	6S-8mm	114.3	6.11	310	37.60	535	3.694	1826	1.239
4	2S-12mm	114.3	6.11	310	37.60	535	3.814	1872	1.191
5	6S-12mm	114.3	6.11	310	37.60	535	3.814	1985	1.263

In this experimental, the stub columns were prepared and tested. In this type of column, the typical failure mechanism is the crushing of the concrete and the yielding in the steel. A local curvature can also be observed for all the tubes examined. Where Figure 5.2 shows a model of samples failure and Figure 5.3 presents load-shortening curves of five stub columns.

(a) **(b)** **(c)** **(d)**

Figure 5.2 Failure modes (a) 2S-8mm (b) 6S-8mm (c) 2S-12mm (d) 6S-12mm

The ultimate load of column specimen 2S-8mm was arrived to be 1753.6 KN. the load-shorting curve in this column is so seamless, as mention in Figure 5.3. It is important to note that the modes of the failure are greatly affected by using of reinforcing steel compared with control specimen that was recorded capacity of 1665 KN. this specimen has SI equal to 1.191, this value represents a good confinement influence was provided in this sample configuration. Sample 6S-8mm arrived a compression capability of 1862 KN and the load- shortening curve of this sample has also a Seamless conduct, as mention in Figure 5.3. This increasing of a number of stirrups has also given a good SI of this sample is equal to 1.241. This value of SI implies that the 6S-8mm sample exhibits a slightly upper performance of confinement compared to 2S-8mm sample. The ultimate load of Specimen 2S-12mm was arrived to be 1872 KN. the load-shorting curve in this sample is so seamless compared with the control sample, and this specimen has SI equal to 1.192, which means this value represents a good confinement influence was provided in this sample configuration. While sample 6S-12mm gave 1985 kN, it was large than control and 2S-12mm specimens and the also the load-shorting curve in this specimen was very smooth caused by confinement in the steel tube and The SI of this specimen is 1.265, as shown in Figure 5.3.

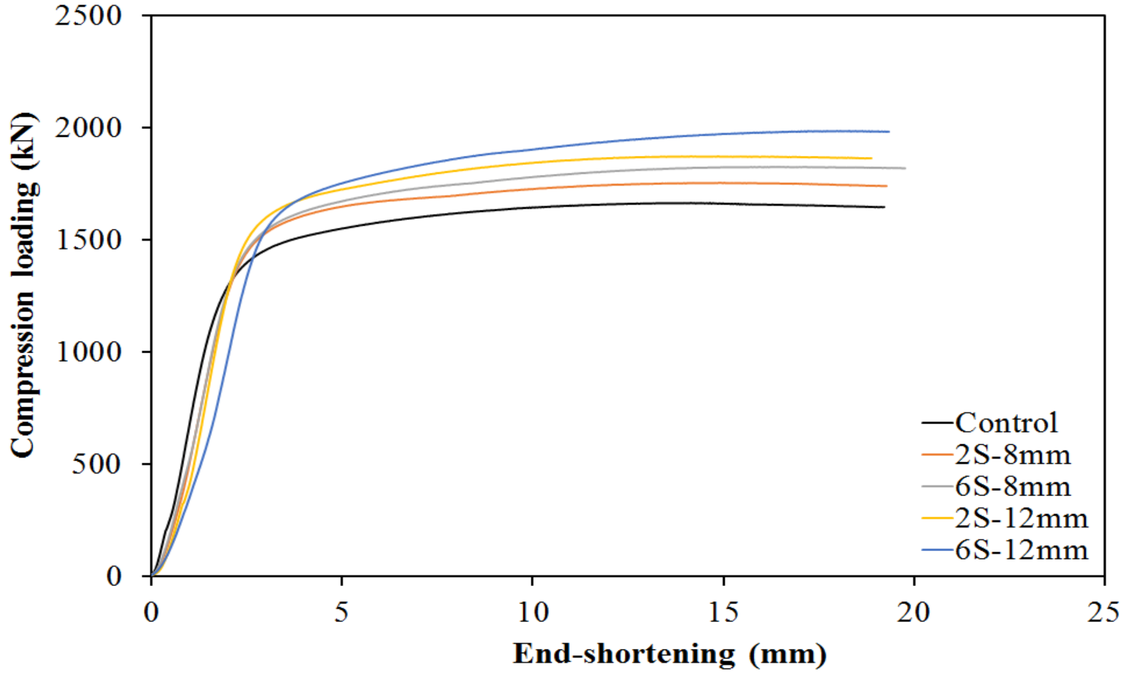


Figure 5.3. Compression load versus end-shortening curves of specimens

Also, when the comparison between specimens has the same stirrups and different steel bar like between 2S-8mm, 2S-12mm, 6S-8mm, and 6S-12mm, (*SI*) were 1.190, 1.239, 1.191, and 1.263 respectively. It can be noted that the *SI*, It can be clearly seen that increment in a number of stirrups increases toughness, ductility, and stiffness. Figure 5.4 and Figure 5.5 showed effect number of stirrups and bar diameter on the (*SI*) and load capacity respectively.

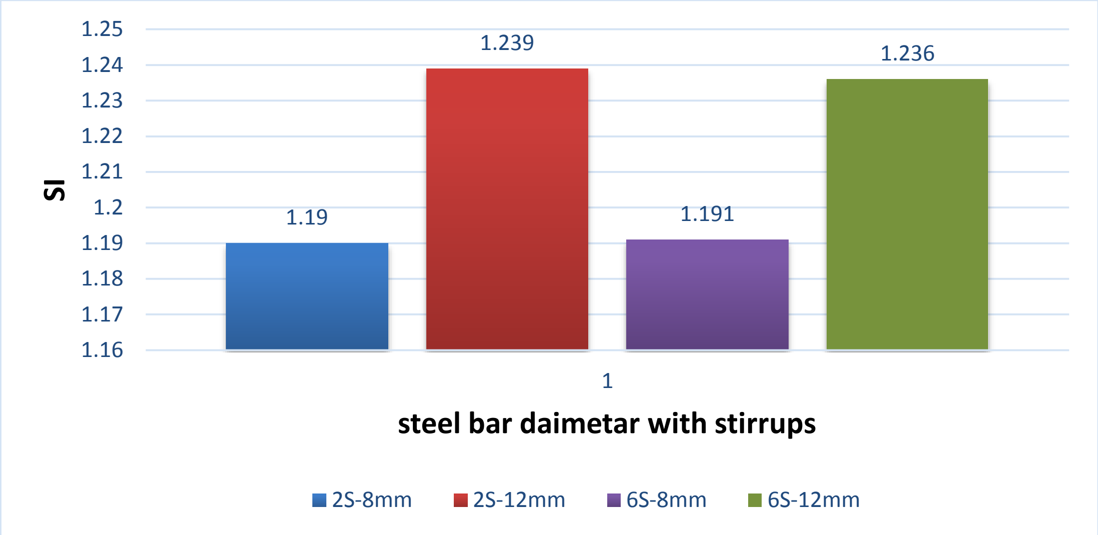


Figure 5.4 Effect of a number of stirrups and bar diameter on SI.

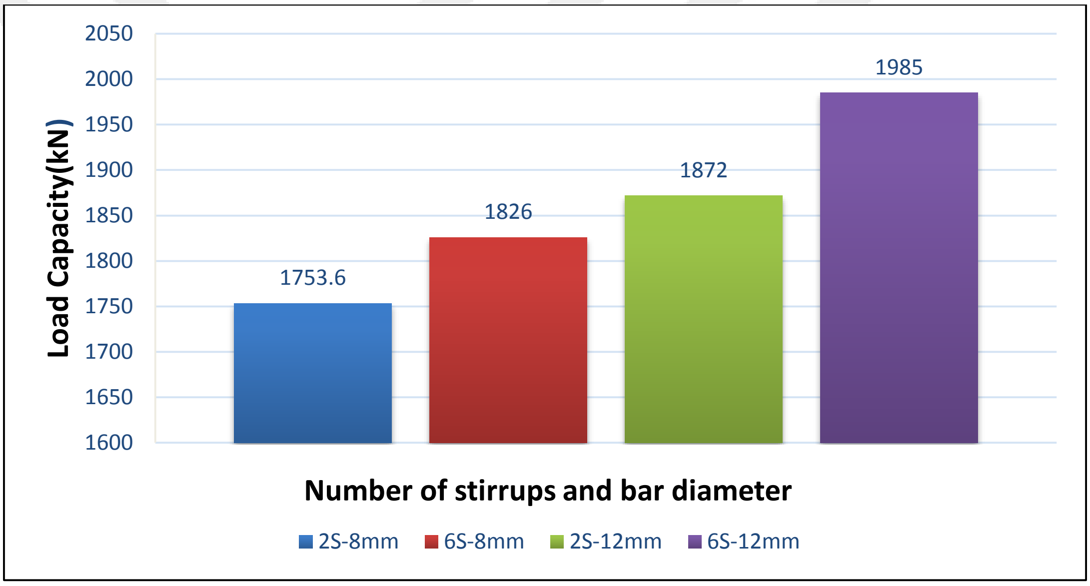


Figure 5.5 Effect of a number of stirrups and bar diameter on load capacity.

5.3.1.1 Comparison Test Results with Design Specification

(EC4 2004) EN1994-1-1Eurocode4. (2004) and (AISC360-10) (AISC360-10, 2010) are the design specification methods which are utilized in this paper to perform some assessments. The EC4 is the European symbol of the design of composite structures and the AISC 360-16 is the specification of steel structures in the United States.

If the experimental results ratio to specifications predictions smaller than unity that means the prediction is unconservative, otherwise, when the ratio is greater than unity, it indicates that the prediction is conservative.

The experimental results ratios to ASIC 360-10 predictions are between 1.1926 and 1.2709, as mention in Table 3. The average of the ratios for the entire empirical set is equal to 1.2195. Subsequently, it can be concluded in general that ASIC 36-10 leads to conservative predictions that are on the safe side for design purposes. By examining AISC 360-16 performance for RCFST columns, it can be noted that the average of the ratios for RCFST columns are equal to1.2195. These results propose that the prediction of ASIC 360-10 correspond satisfactorily to the RCFST columns with a 22% difference in the safe side.

Considering the EC4 method, the experimental results ratio to design specification predictions lie between 0.8721 and 0.9455 with an average of 0.9 for the entire experimental set. Generally, it can be concluded that EC4 leads to the unconsevative prediction on average by 1%.

Table 5.2 Compared between the strength load experimental and the predicted load ASIC (360-10) and EC4 codes

Specimens	**P(kN)**	$\mathbf{P/P_{ASIC}}$	$\mathbf{P/P_{EC4}}$
Control	1665	1.1926	0.8721
2S-8mm	1753.6	1.1932	0.8747
6S-8mm	1826	1.2424	0.9108
2S-12mm	1872	1.1987	0.8918
6S-12mm	1985	1.2709	0.9455
Average		1.22	0.9

5.3.2 CFST and SFRCFST Columns

three CFST and 3 SFRCFST were examined to an axial compression load. In this experimental used three lengths (916.5, 463 and 173mm) for each mix to investigate the effect of steel fiber in CFST. Details of the columns that have been checked are given in Table 5.2. To test the effect of confinement and to compare column performance, use (SI) to indicate the effect of confinement and to measure the composite procedure of CFST columns. For determining the flexibility of columns, a ductility index (DI) was utilized in (Han, 2002) & (Tao et al., Y. Lu, N. Li, S. Li, and H. Liang 2005) and can be represented by:

$$DI = \frac{\varepsilon_{85}}{\varepsilon_u} \tag{5.3}$$

where ε_u is the strain at the maximum load Nu, and ε_{85} is represent the strain when the load arrives at 0.85 Nu. Where the local deformation of the steel tube represents the series of values obtained as a result of the use of strain gauges, especially after the yielding of the steel tube a perversion between the values of the measured strain and distortion of the actual sample (Cai, 2003). In this research, the DI is can be represented by:

$$DI = \frac{\delta_u}{\delta_{85}} \tag{5.4}$$

where $\delta_u$is the axial shortening at N_u, and δ_{85} when the axial shortening arrives at of 0.85 N_u in the descending section of the axial load-axial shortening curve. The strength index (*SI*) and compression load capacities of columns are mention in Table 5.3.

Table 5.3 Properties and naming system of CFST and SFRCFST column specimens

No	Specimen	L (mm)	D/t	$\frac{L}{D}$	f_c (MPa)	f_y (MPa)	*P* (kN)	SI	DI
1	W-8-92.22	916.5	19.15	8	92.22	235	1581.3	1.41	2.8
2	F-8-86.53				86.53	235	1598.5	1.47	2.4
3	W-4-92.22	463	19.15	4	92.22	235	1546.4	1.37	5.1
4	F-4-86.53				86.53	235	1623.3	1.49	3.9
5	W-1.5-92.22	173	19.15	1.5	92.22	235	1625.4	1.44	2.4
6	F-1.5-86.53				86.53	235	1607.8	1.48	1.8

5.3.2.1 W-8-86.53 and F-8-92.22Columns

In this experimental used two columns, one of them was CFST and other SFRCFS to assess the performance of the CFST and SFRCFST columns It is important to investigate the failure conduct of the columns. Two specimens of W-8-92.22 and F-8-86.53 columns were a failure with the local buckling in the top and overall buckling near the center of columns. The typical failure mode of CFST columns is mentıon in

Figure 5.6.

(a)

(b)

Figure 5.6 Failure modes of 916.5 mm columns (a) F-8-86.53 (b) W-8-92.22.

Curves of compression load versus deformation of two 916.5 mm columns are displayed in Figure 5.7. Specimens W-8-92.22 and F-8-86.53 achieved compression load capacities of 1581.3(kN) and 1598.5(kN) respectively, as shown in Figure 5.6. On the other hand, SI of the specimens are 1.41 and 1.47 and the DI of the samples are 2.4 and 1.8 respectively. Shortening curves of specimens have smooth behaviours. The results show the increase in load capacity and SI was small when used fiber steel and DI results are 2.8 for F-8-86.53 specimen and 2.4 for W-8-92.22 specimen that means decrease ductility and the reason for small increase in load capacity and SI and decrease DI due to weak concrete used with fiber in this experimental, It can be noted the result of compressive strength with fiber steel was 86.53MPa less than 92.22MPa compressive strength without fiber. Figure 5.8, Figure 5.9 and Figure 5.10 showed effect steel fiber on the load capacity, SI, and DI respectively.

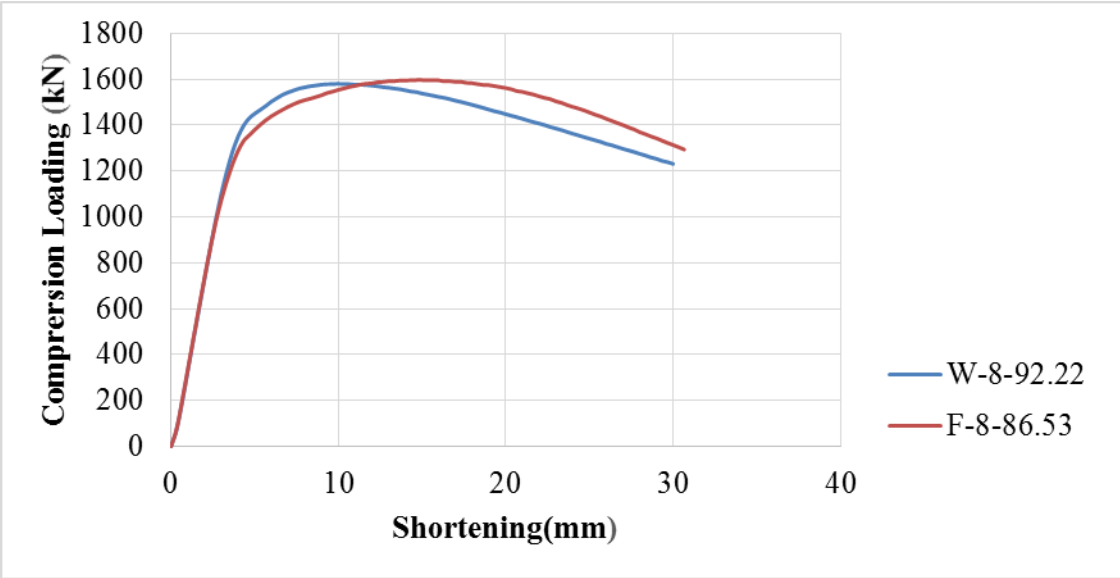


Figure 5.7 Load versus deformation curves of W-8-92.22 and F-8-86.53 columns

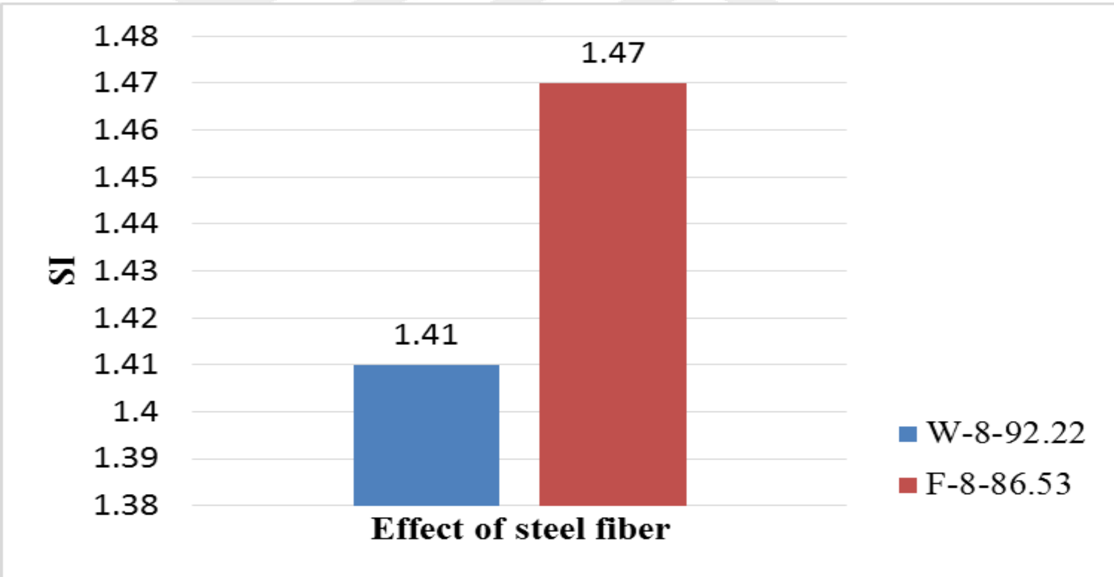


Figure 5.8 Effect of steel fiber on SI

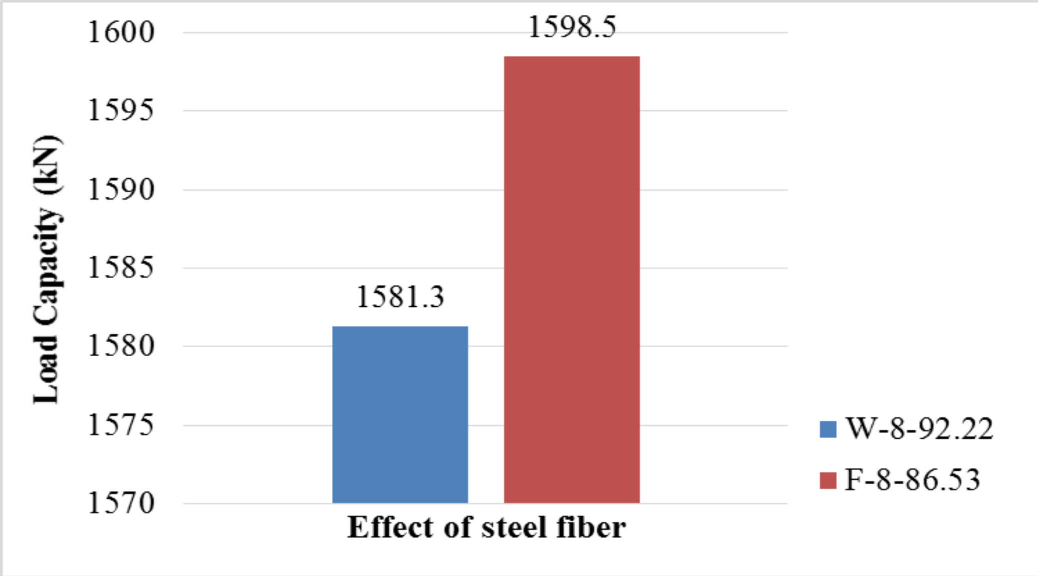


Figure 5.9 Effect of steel fiber on load capacity

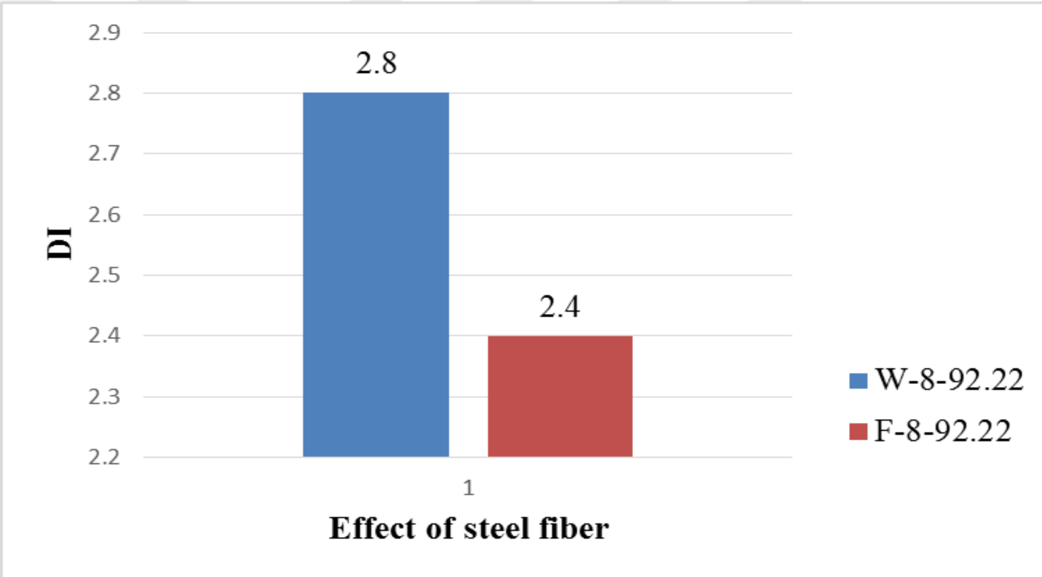


Figure 5.10 Effect of Fiber Steel on DI.

5.3.2.2 W-4-92.22 and F-4-86.53 Columns

One cylindrical specimen for each batch of CFST and SFRCFST have demonstrated interaction failure modes between local and global with SFRCFST and CFST, as shown in Figure 5.11. Specimen W-4-92.22 reach a compression load of 1546.4 kN, while specimen F-4-86.53 mm reach a compression load of 1623.3 kN and SI with W-4-92.22 and F-4-86.53 was 1.37 and 1.49, as shown in Figure5.12 and Figure 5.13 respectively. It can be noted that increment in steel fiber give a small increase in load capacity and SI, for columns with concrete of high strength, Showed an abrupt loss of and CFST specimens offered a similar response of axial load-axial shortening, where the ascending section pursued a descending section. in a different way Somewhat, the tendency of the increased load capacity parts for the STRCFST samples was bigger than that for the CFST samples, As the addition of fiber to the concrete to develop the behavior of the post-peak, due to the presence of pressure confining across the faces of cracking and this improves the ability to transfer the story and then works to delay the occurrence of a failure.

(a) (b)

Figure 5.11 Failure modes columns (a) F-4-86.53 (b) W-4-92.22

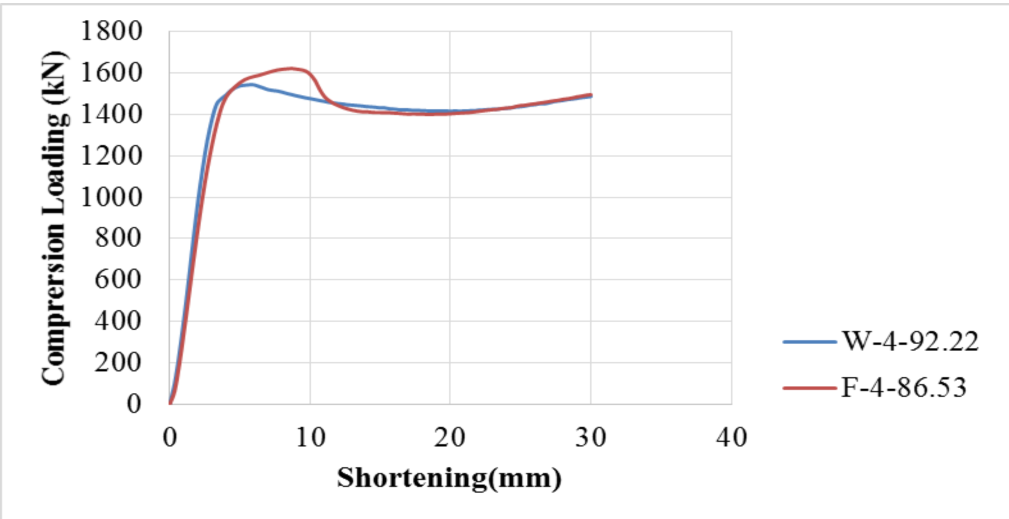


Figure 5.12 Load versus deformation curves of W-4-92.22 and F-4-86.53 columns.

Results of test showed the increase in load capacity and SI was small when used fiber steel and DI results are 5.1 for F-4-86.53 specimen and 3.9 for W-4-92.22 specimen that means decrease ductility and the reason for small increase in load capacity, SI and decrease DI due to weak concrete used with fiber in this experimental, It can be noted the result of compressive strength with fiber steel was 86.53MPa less than 92.22MPa compressive strength without fiber, Figure 5.13 showed effect steel fiber on DI .

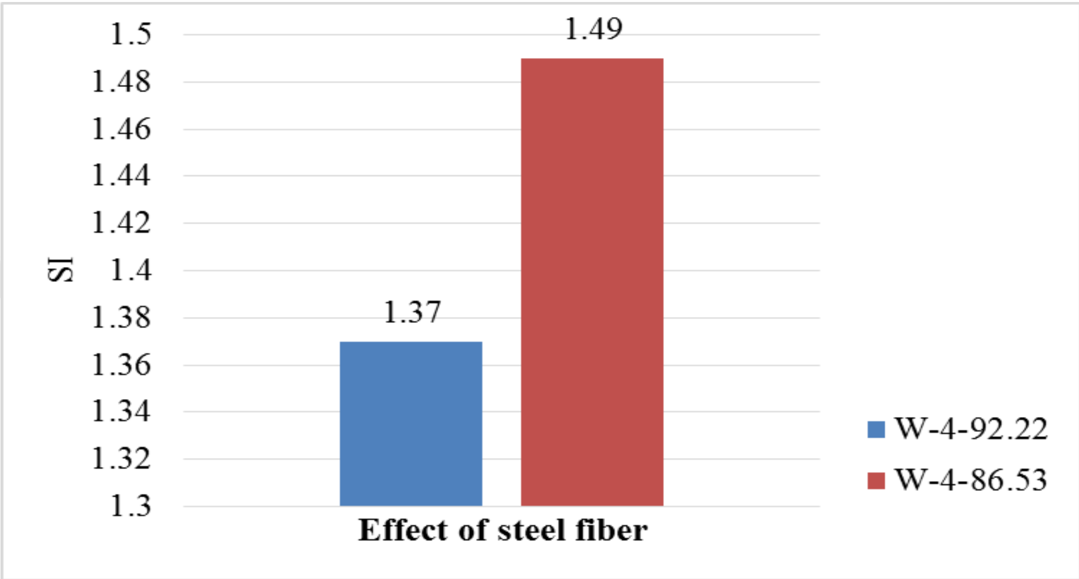


Figure 5.13 Effect of steel fiber on SI

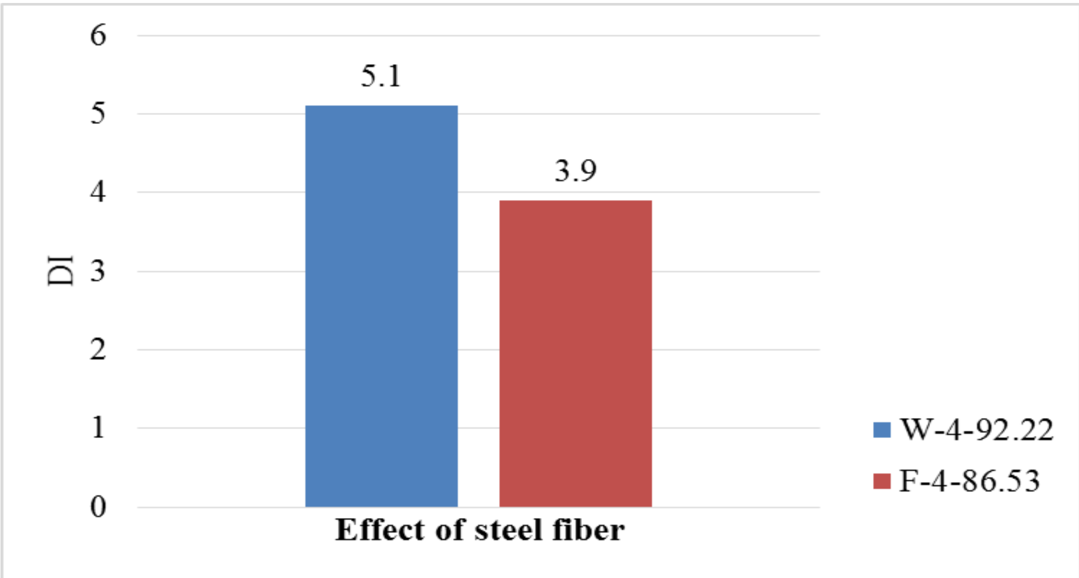


Figure 5.14 Effect of steel fiber on DI

5.3.2.3 W-1.5-92.22 and F-1.5-86.53 Columns

Two stub columns were prepared and tested. It can be said that in this type of columns was the mechanism of failure is the crushıng of concrete inside the steel tubes and the arrival of steel to the stage of yielding. The appearance of lateral deformity in this group of columns also shows the so-called local buckling. Modes of failure of two samples in this set are mention in Figure 5.14 and Figure 5.15 presents load-shortening curves for these stub columns. Specimen W-1.5-92.22mm reach a compression load of 1625.4 kN, while specimen F-1.5-86.53 reach a compression load of 1607.8kN and SI with W-1.5-92.22 and F-1.5-86.53 are 1.44 and 1.48 as shown in Figure 5.16. For columns with concrete of high strength, Showed an abrupt lack of axial load, as mentıon in Figure 5.10 illustrates the influence of the strength of concrete on the conduct of the SFRCFST and CFST samples. In the linear period, Showed that the slope of the samples was deeper with high strength concrete, giving the columns higher hardness. With the softening period, parts diminishing samples with upper concrete of strength demonstrated an increaser drop, and the axial shortening at 85% of the maximum strength diminished with the improvement of the concrete of strength. It can be concluded that the deformation and durability of STRCFST samples decrease with increasing strength of concrete (Lu etal., (2015).

(a) **(b)**

Figure 5.15 Failure modes columns (a) F-1.5-86.53 (b) W-1.5-92.22

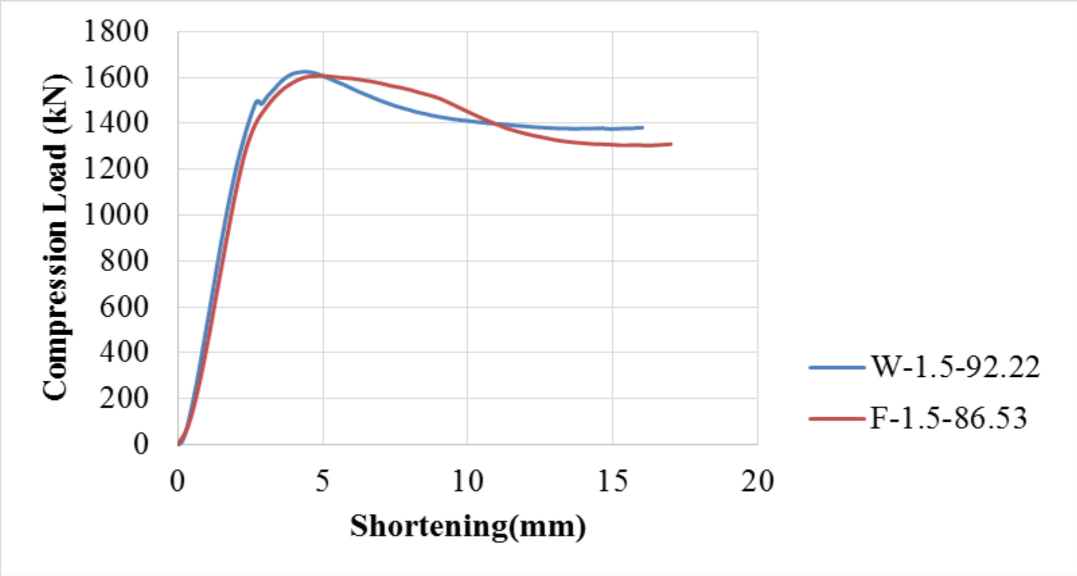


Figure 5.16 Load versus deformation curves W-1.5-92.22 and F-1.5-86.53 columns.

Results of test showed the increase in load capacity and SI was small when used fiber steel and DI results are 2.4 for F-1.5-86.53 specimen and 1.8 for W-1.5-92.22 specimen that means decrease ductility and the reason for small increase in load capacity, SI and decrease DI due to weak concrete used with fiber in this experimental, It can be noted the result of compressive strength with fiber steel was 86.763MPa less than 92.22MPa compressive strength without fiber, Figure 5.16 showed effect steel fiber on DI .

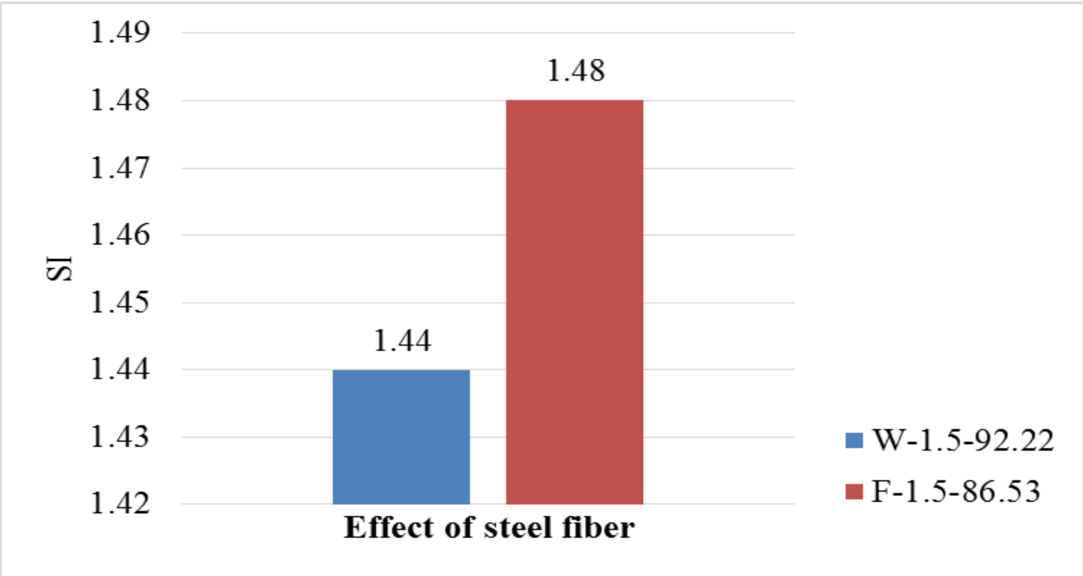


Figure 5.17 Effect of steel fiber on SI.

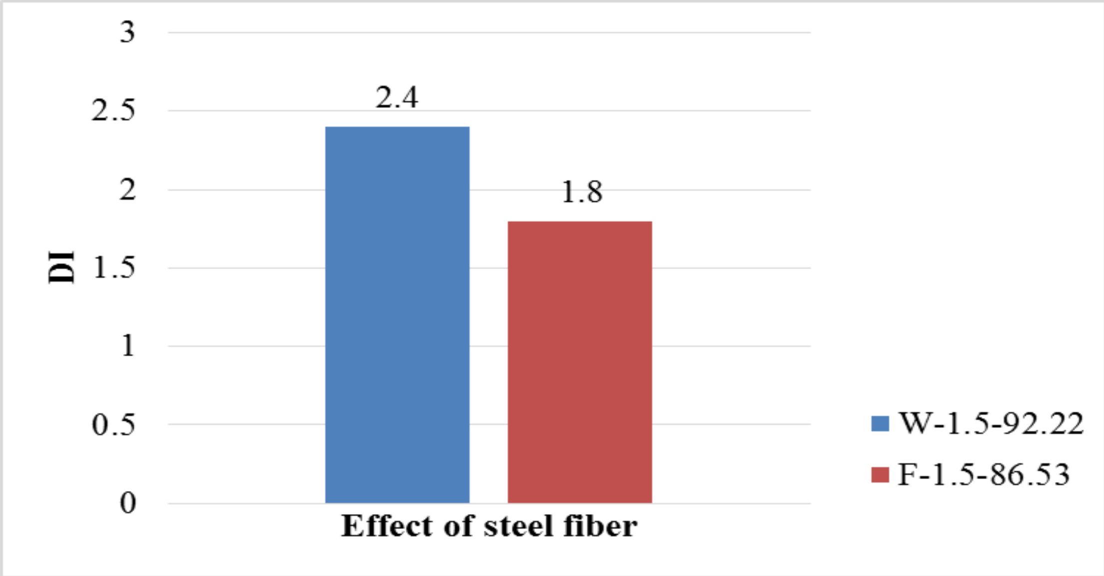


Figure 5.17 Effect of steel fiber on DI.

5.3.3 Comparison Test Results with Design Specification

(EC4 2004) and (AISC360-16 2016) 16 2016) are the design specification methods which are utilized in this paper to perform some assessments. The EC4 is the European symbol of the design of composite structures and the AISC 360-16 is the specification of steel structures in the United States.

If the experimental results ratio to specifications predictions smaller than unity that means the prediction is unconservative, otherwise, when the ratio is greater than unity, it indicates that the prediction is conservative.

The experimental results ratios to ASIC 360-10 predictions are between 1.39 and 1.52, as mention in Table 5.4. The average of the ratios for the entire experimental set is equal to 1.47. Subsequently, it can be concluded in general that ASIC 36-10 leads to conservative predictions that are in the safe side for design purposes. By examining AISC 360-16 performance for SFRCFST and CFST columns, it can obvious that the average of the ratios for SFRCFST columns are equal to1.47. These results propose that the prediction of ASIC 360-10 correspond satisfactorily to the RCFST columns with a 47% difference in the safe side.

Considering the EC4 method, the experimental results ratio to design specification predictions lie between 1.24 and 1.37 with an average of 1.31 for the entire experimental set. Generally, it can be concluded that EC4 leads to the conservative prediction on average by 31%.

Table 5.4 Compared between the strength loads experimental and the predicted load ASIC (360-10) and EC4 codes for SFRCFST

Specimens	P(kN)	$\mathbf{P/P_{ASIC}}$	$\mathbf{P/P_{EC4}}$
2-W-173	1623.385	1.45	1.33
2-F-173	1607.383	1.48	1.37
2-W-463	1546.362	1.39	1.24
2-F-463	1623.315	1.51	1.35
2-W-916.5	1581.261	1.45	1.24
2-F-916.5	1598.493	1.52	1.35
Average		1.47	1.31

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 General

In this part of the research shows the compression performance of RCFST columns and SFRCFST. To provide a unitary structure to the thesis, an introduction of CFST columns and its application and advantages is firstly presented. Then in a detailed review of the CFST columns, comprehensive mechanical features, applications, axial load design, past empirical, researchers and design codes formulation is presented. Then, five samples with two steel reinforcing bars diameter and different stirrups and sex specimens 3 with steel fiber (SFRCFST) and 3 without fiber are fabricated and tested under axial load. For the RCFST columns, the effects of two main parameters; steel reinforcing bar diameter and a number of stirrups, and with SFRCFST and CFST the effect parameter was the length-to-thickness (L⁄D) ratio are investigated in this study. The axial load performance, such as failure mechanism, ductility, and strength of test specimens are analyzed.

6.2 Conclusion

According to the tests of results in this research, it can be the conclusion these points:

6.2.1 RCFST COLUMNS

- Increasing diameter of the steel bar and the number of stirrups showed an increase in the confinement of steel tube on the concrete core.

- The result in this experimentally demonstrated concrete have a good deformation capacity and ductility depending on increasing in diameter of steel bar and a number of stirrups, (6-12mm) specimen have higher strength in the test.

- The typical failure in this experimental was local buckling for all specimens and variation of bar diameter and number of stirrups don’t have a significant influence on the failure styles.

- Increasing the diameter of the steel bar in concrete led to increasing of compressive load and using the steel reinforcement reduce form occurs shrinkage in concrete.
- The results of the tests presented that the EC4 predictions were more agreement with the results of tests for columns that have properties that exceed the limits of application. ASIC 360-16 the results proved to be conservative in terms of properties within and beyond the limits of application.

6.2.2 SFRCFST and CFST Columns

- Steel fiber with concrete filled with steel tube gave a small enhance with loading capacity compared with CFST.
- In this experimental, used steel fiber with concrete led to decrease of ductility index (DI) compared with CFST.
- The results of this experimentally used fiber steel with concrete demonstrated a small improvement in strength index (SI) and confinement factor compared with CFST.
- The results of the tests revealed that the EC4 predictions were more agreement with the results of tests for columns that have properties that exceed the limits of application. ASIC 360-16 the results proved to be conservative in terms of properties within and beyond the limits of application.

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