BEHAVIOUR OF COLD-FORMED LIPPED C-CHANNEL WITH FERROCEMENT JACKET COMPOSITE COLUMN UNDER AXIAL COMPRESSION

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To My Parents
Haji Khudair Alenezi & Asia Husain
And
My Wife and Children
Ghadeer, Shahad Khaled, Fajer Khaled & Hoor Khaled

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ABSTRACT

One of the major challenges for strengthening or upgrading steel structures is to increase column capacity to withstand large expected loads. The main objective of the present study was to investigate the behaviour of build-up lipped Cold Formed steel (CFS) C-channel column assembled with ferrocement jacket. Generally the data and information are limited on the behaviour and performance of CFS column in composite construction.. One of the limiting features of CFS is the thinness of its section that makes it susceptible to torsional, distortional, lateral-torsional, lateral-distortional and local buckling. Hence, a reasonable solution was to propose a composite construction of structural CFS section and ferrocement jacket, which would minimize the buckling of the web and reduce the distortion of CFS sections. This study comprised of three major components, i.e. experimental, theoretical and finite element analysis through ANSYS (version 11). Experimental work involved small-scale and full-scale laboratory testing. The first phase comprised of push-out test specimens while the second phase focussed on full-scale testing of eighteen CFS-ferrocement composite column specimens. All eighteen full-scale axially loaded column specimens with variable parameters were tested till failure. The experimental test results show good agreement with the predicted value calculated from AISI S100 (2007). It was found that the capacity of shear connector with 12 mm diameter bolts was the best in transferring shear force into steel section-ferrocement jacket interface. The strength capacity of CFS-ferrocement composite columns were improved by 245% than that of bare steel columns. Also it was found that axial load capacity of CFS-ferrocement jacket composite columns (CFFCC) increased with the increased thickness of CFS. The results of the finite element model agreed well with the experimental results based on the graphs plotted for load versus axial shortening of the proposed composite column system relationships.

ABSTRAK

Salah satu cabaran utama untuk menguatkan atau menaik taraf struktur keluli adalah untuk meningkatkan keupayaan tiang bagi menahan beban jangkaan yang besar. Untuk itu, objektif utama kajian ini adalah untuk menyiasat kelakuan bebibir besi tergelek sejuk (CFS) yang terbina bagi tiang saluran-C yang dipasang pada jaket simen-ferro. Pada umumnya, data dan maklumat mengenai tingkah laku dan prestasi tiang CFS dalam pembinaan komposit adalah terbatas. Salah satu ciri yang menghadkan CFS adalah seksyen yang tipis menjadikan ia mudah terdedah kepada kilasan, perubahan, sisi-kilasan, sisi-perubahan dan lengkokan tempatan. Oleh itu, penyelesaian yang munasabah adalah dengan memcadangkan pembinaan komposit dengan struktur CFS dan jaket simen-ferro, bagi mengurangkan lengkokan web dan mengurangkan mampatan tegasan lenturan dalam syeksyen CFS. Pengajaran disini terdiri daripada tiga komponen utama iaitu uji kaji eksperimen, teori dan analisa unsur terhingga menggunakan ANSYS(verse 1.1). Kerja eksperimen melibatkan ujian berskala kecil dan ujian berskala besar di makmal ujikaji. Fasa pertama yang mengandungi lapan spesimen ujikaji tolak keluar manakala fasa kedua yang mengandungi lapan belas spesimen berskala penuh CFS-simen-ferro tiang komposit diuji dalam makmal. Kesemua lapanbelas spesimen tiang dikenakan beban paksi berskala penuh dengan parameter yang berbeza telah diuji. Ujian ini telah menunjukkan bahawa kapasiti sambungan ricih bolt bersaiz 12mm adalah yang terbaik untuk digunakan untuk memindahkan daya ricihan pada permukaan seksyen keluli-ferrocement jaket. Kekuatan kapasiti bagi jaket telah diperbaiki lebih daripada 245% lebih besar daripada tiang yang tidak ada jaket. Ia juga telah ditemui bahawa kapasiti beban paksi bagi CFS-ferrocement jaket untuk tiang rencam(CFFCC) telah meningkat dengan peningkatan ketebalan CFS. Keputusan model unsur terhingga menunjukkan persetujuan yang sangat baik bila dibandingkan dengan keputusan ujian makmal berpandukan kepada graf yang dilukis bagi hubungan antara beban lawan pemendekan paksi bagi tiang rencam yang dicadangkan.

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A_c	=	The cross-section area of core concrete
A_s	=	Cross-sectional area of steel
$A_{s,s}$	=	Cross –sectional area of steel stiffeners
$A_{s,t}$	=	Cross –sectional area of steel tube
B/t	=	Width thickness ratio
B	=	The width of the plate
b_{eff}	=	Effective width
b_s	=	Width of the steel stiffener
d_w	=	Diameter of wire mesh
D_s	=	Diameter of steel bar
E_c	=	Concrete modulus of elasticity
E_m	=	Mortar modulus of elasticity
E_s	=	Steel modulus of elasticity
E_{co}	=	The tangent elastic modulus of unconfined concrete
$\frac{E_t}{E}$	=	The ratio of tangent modulus of elasticity
ε	=	Strain
ε_{cc}	=	Axial strain of confined concrete
$\acute{\varepsilon}_{cc}$	=	The strain at peak strength
ε_y	=	The axial strain when the composite section is at yield
$\varepsilon_{85\%}$	=	The axial strain when the load falls to 85% of the ultimate load
$\varepsilon_{95\%}$	=	The axial strain when the load falls to 95% of the ultimate load
ξ	=	Confinement factor
$\acute{f}_{cc}$	=	Incremental increase in peak compressive stress

f'_c	=	The peak axial compressive stress
f_{2A}	=	The hydrostatic confining stress
f_{cc}	=	Axial stress of confined concrete
$f_{y,t}$	=	Yield strength of steel tube
$f_{y,c}$	=	Yield strength of cold-formed steel
$f_{y,st}$	=	Yield strength of steels' stiffeners
f_{cu}	=	Cube crushing strength
f_{cm}	=	Cube crushing strength of mortar
f_{my}	=	Yield strength of wire mesh
f_s	=	Yield strength of steel bar
$f_{s,c}$	=	Yield strength of cold-formed steel
I_s	=	Stiffeners stiffness
I_c	=	The moment of inertia of un-cracked concrete core
$I_{s,re}$	=	Requirement on stiffener rigidity
K	=	The elastic buckling coefficient
L	=	Length of column
N_u	=	The ultimate strength capacity of the CFFCC column
N	=	Axial load
$N_{u,e}$	=	Experimental ultimate strength
σ	=	Stress
σ_R	=	Constant confining pressure
σ_{cr}	=	Critical buckling stress
σ_y	=	Material yield stress
P_o	=	The perimeter of concrete-steel interface
P_{cr}	=	The local buckling stress of the element
P_u	=	Ultimate load in compression
R_r	=	The strength reduction radio
t	=	Wall thickness of the steel
t_s	=	Thickness of the steel stiffeners
V_f	=	Volume fraction of wire mesh
υ	=	The Poisson's ratio

w	=	The width of the sup-panel plate, taken approximately as b/2
F_y	=	specified minimum yield stress of steel section
F_{yr}	=	specified minimum yield stress of reinforcing bars
EI_{eff}	=	Effective stiffness of composite section
R_{se}	=	The allowable horizontal load
A_{sc}	=	Cross-sectional area of stud connector
F_{ys}	=	The yield stress of stud shear connectors

LIST OF ABBREVIATIONS

ACI	American Concrete Institute
ASCE	American Society of Civil Engineers
AISI	American Iron and Steel Institute
ASTM	American Standards for Testing of materials
BS	British Standards
BTTST	Bent-up Triangular Tab Shear Transfer
CFS	Cold-Formed Steel
CFFCC	Cold-formed Steel /Ferrocement Composite Column
CFST	Concrete Filled Steel Tube
DSM	Direct Strength Method
FC	Ferrocement
FRP	Fiber Reinforced Polymer
IFS	International Ferrocement Society
IBS	Industrialized Building System
LYLB	Lakkavalli and Liu Bent-up Tab
LVDT	Displacement Transducers
OPC	Ordinary Portland Cement
RC	Reinforced Concrete
SP	Superplasticizer
UTM	University Technology Malaysia
W/C	Water-Cement Ratio
W-web	With web-stiffener (column cross-section)
N-web	No web-stiffener (column cross-section)
NAS	North American Specification
PNA	Plastic Neutral Axis
EC 4	Euro code 4

CDAS	Control and Data Acquisition System
ENA	Elastic Neutral Axis
FEM	Finite Element Method
HRWR	High Range Water Range
SCM	Self-Compacting Mortar

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CHAPTER 1

INTRODUCTION

1.1 General Appraisal

Compression members are the key elements of all skeletal structures, and the study of their behavior is usually based on testing of concentrically loaded columns. Compression members, or columns, may be defined as members that carry axial compressive loads, and whose length is considerably greater than cross-sectional dimensions. Such members may carry other types of loadings, and may have end conditions and end moment of different kinds *(Saadon ,2010).*

In construction industry, different materials can be integrated together in an optimum geometric configuration, aimed at utilizing only the desirable property of each material by virtue of its designated position. The structure is then known as a composite construction.

Composite construction is ***a*** combination of two or more materials in a unit structure to provide tangible benefits and a versatile solution to suit different applications. A composite system reduces the unnecessary and unwanted material properties, such as weight and cost, without sacrificing required capacity (*Yardim, Y et al., 2008*).

A structure can be considered composite only as long as various components are connected to act as a single unit. The structural performance depends upon the extent to which composite action can be achieved. Also, it has a higher stiffness and higher load bearing capacity when compared with their non-composite counterparts. Hence the size of the composite section could be reduced at the expense of greater stiffness and strength (*Baig et al., 2006*).

Composite action is characterized by an interactive behaviour between structural steel and concrete components designed to use the best load-resisting characteristics of each material. The steel and concrete composite system, which together resists the entire set of loads imposed on the structure, are generally more efficient in resisting the applied loads. Composite construction systems first appeared in the construction industry in the early 1900s (*Viest et al., 1997*). Continuous research and development all around the world over the past 100 years has made composite construction increasingly popular in bridges as well as residential and commercial high-rise buildings. (*Akram ,2010*).

The general term "composite column" refers to any compression member in which a steel element acts compositely with a concrete element, so that both elements resist compressive force. There is a wide variety of composite columns of varying cross-section in today's construction. In contrast to the encased composite column, the concrete-filled column has the advantage that it does not need any formwork or reinforcement as shown in Figure 1.1. The concrete-filled column offers several advantages, related to its structural behaviour over pure steel, reinforced concrete or encased composite column. The location of the steel and the concrete in the cross-section optimizes the strength and stiffness of the section. The steel lies at the outer perimeter where it performs most effectively in tension and in resisting bending moments (*Baig et al., 2006*).

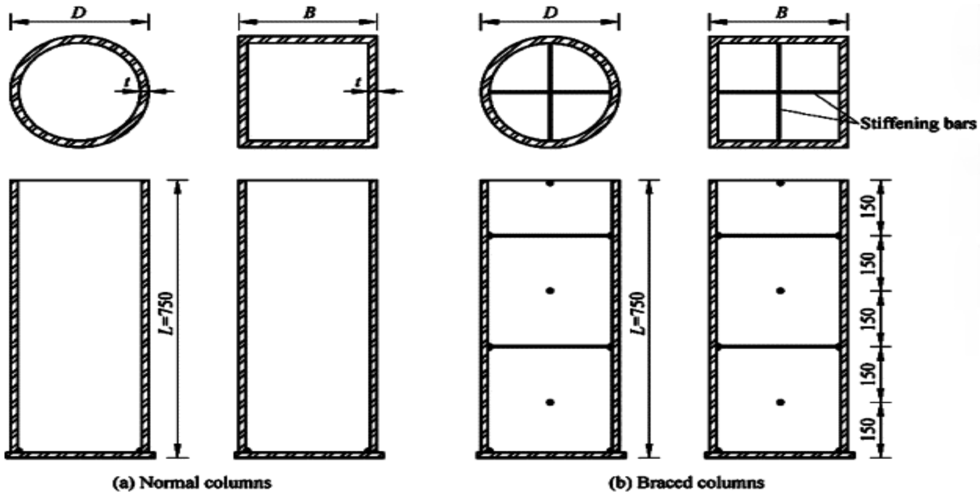

Figure 1.1 Details of concrete-filled steel tubular columns

Ferrocement is a form of thin reinforced concrete structure in which a brittle cement-sand mortar matrix is reinforced with closely spaced multiple layers of thin wire mesh and /or small diameter rods, uniformly dispersed throughout the matrix of the composite (*Naaman, 2000*).

Ferrocement has taken a significant place among components used for construction, due to its durability, strength, and its lean thickness, which makes it a component suitable for constructing many lightweight structures. From the architectural stand-point, ferrocement is very useful, since it can be molded into different shapes for different designs. These facts point out its feasibility for future use in the construction industry.

Recent researches (*Billah, 2011*) have indicated that ferrocement jacketing may be used as an alternative technique to strengthen RC columns with inadequate shear strength. The external confinement using ferrocement has resulted in enhanced stiffness, ductility, strength, and energy dissipation capacity as shown in Figure 1.2. The mode of failure could be changed from brittle shear failure to ductile flexural failure by the use of ferrocement jacket. The axial loads influence the response of columns and the energy absorption capacity. The effect of axial compression on column response was the acceleration of strength and stiffness degradation under repeated inelastic load cycles (*Rathish Kumar et al, 2007*).

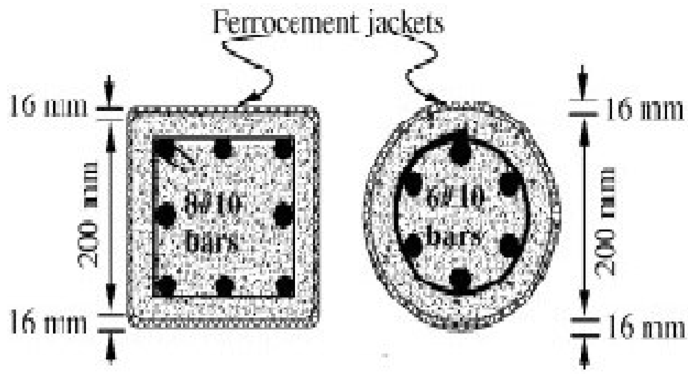

Figure 1.2 Details of Ferrocement Jacketing

Cold-formed steel (CFS) structural members are made by cold-forming steel sheets, strips, plates or flat bars in roll forming machines or by press brake operations. The typical thickness of cold-formed steel products ranged from 0.373 mm to 6.35 mm (*AISI, 2007b*). Presently, cold-formed steel sections are being extensively used in airplanes, automobiles, grain storage structures, and building structures *(Yu, W.W, 1999).*

CFS is currently being used widely in residential and light commercial building constructions instead of wood framing because of the decreasing supply of quality lumber (*Wei-Wen et al., 2000*). Besides, cold-formed steel has high strength-to weight ratio of any building material used in construction today. Cold-formed steel sections are economical, light weight, non-combustible and also recyclable (*Gregory et al., 2001*).

Usually, the nominal yield strength of steel ranges from 250 to 550 MPa, while thickness less than 1 mm is normally used. Nowadays, significant improvements in manufacturing technologies and development of thin, high strength steels are used therefore CFS structures have increased quickly in recent times (*Narayanan et al, 2003*).

Structural stability problems are not observed in hot-rolled steel sections, but such troubles have clearly been seen in cold-formed steel sections. Three structural unsteady modes namely local, distortional and flexural / flexural–torsional buckling are likely to happen in steel compression members, as shown in Figure 1.3. Distortional buckling usually occurs in the flanges of channel at the flange/web junction if the lip stiffener is inadequate. It prevents the normal movement of the flange's plane that it supports (*Schafer, 2000*).

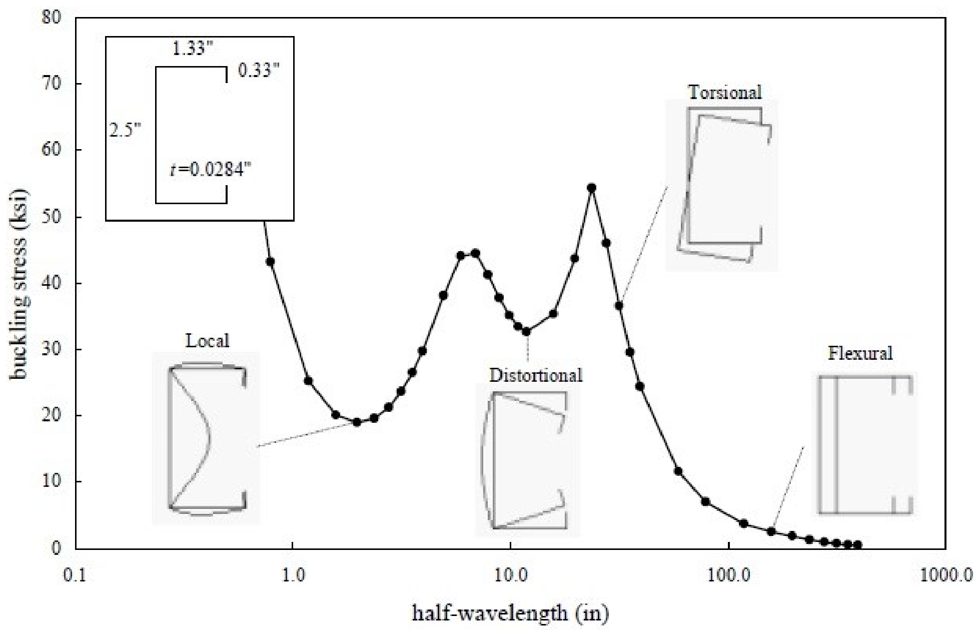

Figure 1.3 Details of different buckling modes that occur for lipped C-channel

In the past, different buckling modes have been investigated by researchers who frequently used cold-formed steel sections. Past developments were designed at deriving simple calculation procedures using manual calculations or worksheet. This is however difficult as some aspects of behavior observed in cold-formed steel sections are very difficult *(Narayanan et al, 2003*).

It is thus noted that local buckling and flexural / flexural- torsional buckling behavior of cold-formed steel sections have been widely studied in the past. Recently, the focus has been extended to distortional buckling as well. (*Schafer, 2000*).

Hence this study aimed to combine the benefits of cold formed sections with those of ferrocement jacketing so as to utilize the betterment of both materials' composite action. It is hoped that the proposed study could be of value if a composite column is used in typical buildings, such as residential and commercial buildings.

1.2 Background and Rationale

The development of lightweight, industrialized and sustainable housing system is the need of our time all over the world. In Kuwait, development and construction activity is one of the most important economic activities needed for both the citizens and the huge foreign labor in the state. It has spurred the demand for fast, cost-effective and quality residential buildings. The supply of houses by both the public and private sectors is far from meeting their demand. Rising cost of both building materials and labor is another issue which makes it imperative to study the economic and systematic application of new construction materials and systems.

Industrialization of building system by developing efficient prefabricated composite structural elements may deal with the issue reasonably well. Fabrication of the elements takes place in the factory or workshops and the elements are installed with minimum time period and labor needed at the site. This may also lead to the reduction in foreign labor engaged by the country's construction industry resulting in economical and expertise problems for the country which hires foreign labor will face economic and training issues,

1.3 Statement of the Problem

Cold-formed steel columns have distinct structural stability problems. Buckling remains as the main issue. . The cross-section of cold-formed steel developed from connecting the C-channel section as an I-section has not improved the axial capacity of the section. This is due to the formation of a weak axis which has a low degree of stiffness. As a result, researchers must overcome this problem to reap the benefits of cold formed sections, if used as columns or compression members (*Gregory et al., 2001*).

On the other hand, ferrocement was examined by some researchers as a method of jacketing to strengthen RC columns. Results showed promise and were inspiring (*Kondraivendhan & Pradhan , 2009*). The problem of weak axis as mentioned earlier can be solved by the formation of rectangular section. The integration of ferrocement as encased column in the C-channel connected back-to-back to form an I-section, positioned at the centre of the proposed composite column, has enhanced the stiffness as well as the axial capacity of the column.

Hence, cold-formed steel/ferrocement jacket composite columns (CFFCC) seem to represent a promising combination. This study aimed to integrate the benefits of cold formed sections and those of ferrocement cold formed composite column. It was hoped that the information gained from the study could be used to establish an alternative composite column construction for the actual buildings, such as residential and commercial buildings. The use of self-compacting concrete (SCC) was proposed instead of the normal concrete as the SCC would reduce the problem of developing "honey comb" usually occurring in normal concrete.

1.4 Objectives of the Study

The chief aim of this research was to manufacture and study the behavior and properties of cold formed assembled with ferrocement jacket composite column (CFFCC) structural system. Hence, an extensive analytical and experimental study was required as follows:

1. To propose new viable shear connectors for ferrocement jackets and cold formed steel column that can function as composite column.
2. To model the behavior of the proposed composite column by Finite Element Analysis using ANSYS software

3. To validate the experimental results of the proposed composite column with AISI-S100 (2007) that can predict the strength load capacity of the proposed ferrocement jacket/cold formed steel column system.

1.5 Scope of the Study

The scope of the study consisted of intensive experimental work on the proposed composite column by integrating together CFS with ferrocement. The experimental program was designed to provide a better understanding of the behavior and properties of CFS with ferrocement jacket as composite column .The proposed column focused on the strength capacity of the axial load by introducing a new stiffening system of longitudinal ferrocement jacket stiffeners. The experimental program comprised of two phases:

1.5.1 Push out Test

The main scope of this phase focused on the shear strength of (CFFCC) with the proposed shear connector system. Push out test was used to determine the ultimate slip and strength of shear connector with large diameter, for connecting ferrocement jacket and cold-formed steel column. The main aim was to investigate the strength characteristics of the proposed shear connectors embedded in the ferrocement slab and connected to the cold-formed lipped C-channel section. The bond strength between ferrocement and the cold-formed column was determined. These tests were meant to determine the design values of the shear connections (stiffness, resistance and ductility) as well to study the effect of connection's stiffness in the performance of the composite system.

Eight push-out specimens of CFS with lipped C-channel sections assembled with ferrocement jacket were prepared and tested. In addition, various types of shear connectors namely, bolts (10 mm and 12mm in diameters), bar angle bolts (10mm in diameter), and self-drilling screw (6.3 mm in diameter x 12 mm long) were evaluated.

The typical welded shear connector such as shear stud was not suitable for use as shear connector due to thinness of CFS section. The objectives of this phase were to study load-slip behaviour and to determine the shear strength and stiffness of the design. The results and discussion are presented by varying the numbers of wire mesh used and types of installed shear connector.

1.5.2 CFS-Ferrocement Composite Column Tests

The second scope was designed to evaluate the behaviour of full scale (CFFCC) that was subjected under axial loads into two systems (column with web stiffener and column without web stiffener). The stiffening of column web was proposed since CFS is known for its slender section making the possibility of web failure very high. This phase was divided into two parts namely; experimental tests and numerical analysis.

The experimental part of shear connector comprised of cold-formed lipped C-channel assembled with ferrocement jacket by using shear connector to form a composite column. The control specimens with two, four and six layers of wire mesh for ferrocement jacketing were tested. Then the best number of wire mesh that had high strength and resistance to the applied axial force was chosen. Finally, it was fixed with different lengths and thicknesses of cold-formed lipped C-channel. The increasing number of wire mesh layers were purposely tested so as to understand the extent of improvement they showed in the axially load column. Wire mesh in ferrocement is known to reduce the formation of cracks in concrete.

The proposed lengths of full scale columns used were 1000 mm, 2000 mm and 3000 mm. Differing lengths of the column were studied so as to understand the relation of length to capacity of the proposed tested columns. The stiffness of column is dependent on the column length as the crushing failure when compared to overall buckling, could result in different values of axial load capacity. Moreover, the use of shear connectors in the proposed column could enhance the stiffening of CFS column designed as composite column. Bare steel column could develop the problem of low axial load due to buckling failure (*Gregory et al., 2001*) as shown in Fig. 1.4. All webs were connected back-to-back and fastened by self-drilling-screws while all surrounding flange and web were strengthened by ferrocement jacket and connected by shear connectors. Eighteen specimens were tested under axial load until failure occurred. .

Figure 1.4 Failure mode of non-composite columns tested under axial load.

Numerical analysis by Finite Element using ANSYS was done to verify the experimental results obtained with different parameters. Details of the research involved were divided into several smaller tasks, which were subsequently organized into relevant chapters as described in section 1.7. A brief methodology and scope of work of the study is illustrated in Figure 1.5.

Investigation of the Behaviour of Composite Columns with built up back-to-back Cold-Formed lipped C-Channel / Ferrocement Jacket

Laboratory Test: Properties of Material:

-Cold-Formed Steel –tensile test

-Mortar-cube compressive

-Wire mesh - tensile test

-Welded wire mesh fabric reinforcement-tensile test

Laboratory Test: Push-out test:

-Materials and specimens preparation:

- Three types of shear connectors,

Instrumentation setup:

-Universal Testing Machine

-Testing: EC4 test procedure

Data Analysis: Analysis of material properties, Failure mechanisms, General Analysis of push-out test results, parametric study: (i) effect of shear connectors (ii) number of layers of wire mesh.

Laboratory Test: Large –: Material and specimens preparation:

Composite Column Specimens, Instrumentation setup:

-Universal Testing Machine

-Strain gauge, testing: Axial load test.

Theoretical Work:

Develop equations that expressed the behavior of the proposed ferrocement jacket/cold formed steel column system, Regression Analysis, Validation of The Prediction Model, study the structural buckling modes of CFS-Ferrocement composite column, Discussion of Theoretical Analysis base on code AISI S100-2007.

Data Analysis: Analysis of material properties, column behavior, Slip and load Analysis, Ferrocement jacket characteristic.

Parametric study: (i) Effect of shear connectors (ii) layers of wire mesh in jacket (iii) Dimension of CFS (different length & fixed height web). Theoretical Analysis and experimental results compared and simulation by Finite Element Analysis through **ANSYS**.

Figure 1.5 Flowchart illustrating the methodology and scope of work

1.6 Significance of Research

In recent years society has begun to re-evaluate built environment with the purpose of achieving higher performance, sustainability specifically to minimize loss attributed to natural hazards. In order to seek sustainable solutions for long-term needs in the built environment, more efficient low-rise structures in general and residential housing in particular, the research being reported was undertaken. In the past, cultural norms largely drove the materials and systems employed for residential housing.

In lightweight residential and commercial buildings cold formed steel members are used as floor and joists, and designed as non-composite columns (Popo-Ola, et al., 2000. Ghersi ,et al.,2002). Most columns need to be checked for buckling and most likely they failed due to local or lateral-torsional buckling for incapability to the attainment of their capacities. Ferrocement is the solution to overcome of this frequent problem.

Ferrocement was examined by some researchers as a method of jacketing to strengthen RC columns. Results were good and inspiring (Kondraivendhan & Pradhan , 2009). Thus, the validation of using cold formed steel sections with ferrocement as a composite column could significantly increase the axial load capacity as well as improve appreciably the stiffness and slenderness of the proposed column. Since such column can be produced as a pre-cast column, commercial value of the column is supposedly high. A mass production of the proposed composite system is possible in the factory. Cost saving could be possible as less labour would be needed and the quality of the product can be controlled. The ferrocement jacket could also provide lateral restrain that prevents the cold formed steel section to fail under lateral-torsional buckling. Furthermore, improvement in the resistance of top flange and reduction of its tendency to buckle under compression can be expected. The proposed composite column could also be an alternative solution in facilitating CFS's fire resistance capacity. But that aspect was not explored in this research.

1.7 Thesis Layout

In this section, a synopsis is provided for each chapter of the thesis

Chapter One presents the general introduction, background of the study and outlines the aim and objectives and scope of this research. Significance of the study and thesis layout is also described in this chapter.

Chapter Two surveys the literature involving the historical development of conventional composite column construction and construction incorporating cold-formed steel tube filled with concrete which describes the background information about concrete filled steel tubes. Also it is followed by details of previous work done for concrete column in terms of confinement and jacketing by ferrocement.

Chapter Three contains a detailed description of the experimental investigation carried out in this study. The chapter also describes the proposed stiffening system for CFS and details of the fabrication method. Details of test specimens, experimental setup and testing procedure according to the actual sequence of each type of experimental investigation are provided.

Chapter Four presents the relationship between the basic finite elements, derived from the governing equilibrium equations, and the mathematical modeling of the materials used in the tested composite column (CFFCC).

Chapter Five presents the observations and discussion of the first phase that describes the results of the experimental work for push-out test. It includes analysis of the push-out test results and evaluates the strength and behaviour of a shear connector's enhancement.

Chapter Six constitutes the result and discussion of the second phase of experimental work based on investigation of the behaviour of full scale specimens of (CFFCC) columns. Observation of the physical failure mechanism and the effect of ferrocement jacket, loading conditions and columns' cross sections to the ultimate strength and ductility are discussed in details. Finally a comparison of all the experimental results with analytical values by using Finite Element analysis using (ANSYS) and (AISI S100-2007) code are included

Chapter Seven present conclusions, recommendations and future work development.

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