STRUCTURAL PERFORMANCE OF COLD-FORMED STEEL WITH SELF-COMPACTING CONCRETE IN A COMPOSITE BEAM SYSTEM

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Dedicated to

To my Parents

Late Alhaji Muhammad Lawan and Hajiya Hauwa Muhammad Lawan

My immediate family

Amina Ali Umar (Wife), Safiyya Al-Mustapha Muhammad (Daughter), Fadimatu Al-Mustapha Muhammad (Daughter), Zainab Al-Mustapha Muhammad (Daughter) and Al-Mustapha Muhammad Al-Mustapha (Son)

And my entire family

My brothers, Sisters, Nephews and Nieces

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ABSTRACT

The use of composite systems comprising of concrete and hot-rolled steel (HRS) sections is well established as observed in current design codes. But, there is limited technical information available about the use of composite systems that incorporates the use of light gauge steel sections, despite the potentials of the system in residential and light industrial constructions. Therefore, this research work investigated the structural performance of cold-formed steel (CFS) section with Self-Compacting Concrete (SCC) as a composite beam system, by means of shear connection mechanism of bolted shear connectors. The study comprised two components; experimental and theoretical works. The experimental work consisted of two phases; push-out and full-scale experimental tests. The push-out specimens were of the same dimension (800 mm x 600 mm x 75 mm). In push-out test, strength capability and ductility of the proposed bolted shear connectors were determined. Bolted shear connectors of M16, M14 and M12 of grade 8.8 were installed on the flanges of I-beam section of CFS using single nut and washer above and beneath through bolt holes of 17 mm, 15 mm and 13 mm diameters at a designated longitudinal interval of 150 mm, 250 mm and 300 mm respectively, and spaced laterally at 75 mm. The specimens were cast with SCC of grade 40 N/ mm^2. Shear connector size and longitudinal spacing were the varied parameters, and their influence on the ultimate load capacity was investigated. The results showed that the size and the longitudinal spacing of the shear connectors had significantly influenced the ultimate load capacity. Ductility of the shear connectors was determined to be acceptable as an average characteristic slip capacity above 6 mm as recommended by Eurocode 4 was achieved by all shear connectors. Close agreement was recorded between experimental and theoretical values based on Eurocode 4 equations. In full-scale test program, longitudinal spacing employed was 250 mm and 300 mm excluding 150 mm spacing due to overlapping of stress fields as established in push-out test that led to strength reduction. The full-scale specimens were of the same dimension (4500 mm x 1500 mm x 75 mm) and were tested using a four-point bending test. The results showed that the ultimate load and ultimate moment capacities were influenced by the studied parameters as established in push-out test. Results of comparison between experimental and theoretical values revealed good agreement. In conclusion, the CFS-SCC composite beam system can be employed in small and medium size buildings, and in light weight construction industry.

ABSTRAK

Penggunaan sistem komposit yang terdiri daripada keluli konkrit dan keratan tergelek panas (HRS) telah mantap sepertimana yang dilihat didalam kod rekabentuk terkini. Bagaimanapun, terdapat maklumat teknikal yang terhad tentang penggunaan sistem komposit yang menggabungkan penggunaan keratan keluli tolok ringan, walaupun terdapat potensi dalam pembinaan industri perumahan dan pembinaan struktur ringan. Oleh itu, kerja-kerja penyelidikan ini mengkaji prestasi struktur keluli sejuk terbentuk (CFS) dengan pemadatan konkrit sendiri (SCC) sebagai sistem rasuk komposit, melalui cara yang inovatif dengan mekanisme sambungan ricih menggunakan penyambung bolt. Kajian ini terdiri daripada dua komponen; kerja-kerja uji kaji dan teori. Kerja-kerja eksperimen dibahagikan kepada dua fasa; menolak keluar dan ujian eksperimen skala penuh. Spesimen tolak keluar menggunakan dimensi yang sama (800 mm x 600 mm x 75 mm). Dalam ujian tolakan-keluar, keupayaan kekuatan dan kemuluran penyambung ricih diperketatkan yang dicadangkan telah ditentukan. Penyambung bolt ricihan dari M16, M14 dan M12 Gred 8.8 telah dipasang pada bebibir atas dan bawah keratan I pada rasuk CFS menggunakan mur tunggal dan cincin penutup melalui lubang bolt 17 mm, 15 mm dan 13 mm diameter pada ketetapan selang membujur 150 mm, 250 mm dan 300 mm masing-masing dan jarak sisi pada 75 mm. Spesimen-specimens ini dituang bersama keratan CFS menggunakan SCC gred 40 N/ mm^2. Saiz penyambung ricih dan jarak membujur adalah parameter yang diubah, dan pengaruh mereka pada kapasiti beban muktamad telah dikaji. Keputusan, mendapati bahawa, saiz dan jarak membujur penyambung ricih yang dicadangkan telah dipengaruhi dengan ketara kapasiti beban muktamad penyambung ricih. Kemuluran penyambung ricih juga didapati tidak memuaskan kerana kapasiti tergelincir pada ciri di atas rata-rata 6 mm seperti yang disyorkan oleh Eurocode 4 telah dapat dicapai untuk semua spesimen. Persefahaman yang rapat dapat dicapai antara nilai-nilai eksperimen dan ramalan berdasarkan Eurocode 4 persamaan. Dalam program ujian berskala penuh, jarak tanaman membujur bekerja ialah 250 mm dan 300 mm tidak termasuk 150 mm jarak pertindihan pada lapangan tekanan sepertimana yang ditetapkan dalam ujian tolakan keluar yang membawa kepada pengurangan kekuatan. Panjang spesimen berskala penuh dengan ukuran yang sama (4500 mm, lebar 1500 mm dan ketebalan 75 mm) dan telah diuji menggunakan ujian lenturan empat titik. Keputusan menunjukkan bahawa beban dan momen muktamad kapasiti muktamad bagi kedua-duanya dipengaruhi secara signifikan oleh parameter dikaji seperti yang disaksikan dalam ujian tolakan keluar. Keputusan perbandingan antara nilai-nilai eksperimen dan teori mendedahkan persefahaman yang baik. Kesimpulannya, CFS-SCC sistem rasuk komposit yang dicadangkan boleh digunakan dalam pembinaan bangunan-bangunan kecil dan sederhana, dan juga dalam pembinaan industri ringan.

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LIST OF ABBREVIATIONS

ACI	-	American Concrete Institute
AISC	-	American Institute of Steel Construction
AISI	-	American Iron and Steel Institute
ASCE	-	American Society of Civil Engineers
BS	-	British Standard
BTTST	-	Bent-up Triangular Tab Shear Transfer
CAN/CSA	-	Canadian Standard Association
CFS	-	Cold-Formed Steel
CS	-	Closed Section
EC2	-	Eurocode 2
EC3	-	Eurocode 3
EC4	-	Eurocode 4
FEM	-	Finite Element Modelling
FS	-	Full-Scale Specimen
HRS	-	Hot Rolled Steel
HSS	-	High Strength Steel
HTHHB	-	High Tensile Hexagon Head Bolt
IBS	-	Industrialized Building Systems
LVDT	-	Linear Variable Displacement Transducer
M10	-	Bolt with 10 mm diameter
M12	-	Bolt with 12 mm diameter
M14	-	Bolt with 14 mm diameter
M16	-	Bolt with 16 mm diameter
NVC	-	Normal Vibrated Concrete
OS	-	Open box Section
PNA	-	Plastic Neutral Axis

PS	-	Push-out Specimen
RC	-	Reinforced Concrete
SCC	-	Self-Compacting Concrete
SC	-	Screwed Channel
SD	-	Screwed Deck
SF	-	Slump Flow
SG	-	Strain Gauge
USA	-	United States of America
WC	-	Welded Channel
WE	-	Welded Extension
WER	-	Welded Extension and Rod

LIST OF SYMBOLS

A	-	Numerical coefficient (0.5 for beams)
A	-	Area of stud shank
A_{eff}	-	Effective area
A_{cc}	-	Shear area of concrete per connector
A_c	-	Concrete pull-out failure surface area
A_c	-	Area of concrete
$A_{concrete}$	-	Cross-sectional area of concrete
A_g	-	Gross cross-sectional area
$A_{g,sh}$	-	Gross cross-sectional area with sharp corners
A_s	-	Cross-sectional area of the stud shear connector
A_s	-	CFS cross-sectional area
A_{st}	-	Tensile stress area of the bolt connector
A_{steel}	-	Cross-sectional area of steel
A_{tr}	-	Total area of transverse reinforcement
b	-	Slab thickness
b_{eff}	-	Concrete slab effective breadth
b_f	-	Steel flange width
b_o	-	Average rib width
$b_{p,i}$	-	Notional flat width of plane element i for a cross-section with sharp corners
d	-	Diameter of rib holes
d	-	Diameter of stud or bolt
d	-	Concrete dowel diameter
d	-	Effective depth of web
d_o	-	Diameter of stud or bolt

dp	-	Depth of plastic neutral axis
E_c or E_{cm}	-	Modulus of elasticity of concrete
$E_{concrete}$	-	Modulus of elasticity of concrete element
E_{steel}	-	Modulus of elasticity of steel element
E_s	-	Modulus of elasticity of steel material
F_1 and F_2	-	Non-dimensional modifying factors
f_{bv}	-	Shear buckling strength
$F_{b,Rd}$	-	Bearing resistance of bolt
f_{ck}	-	Concrete cylinder compressive strength
$f_{ck,mean}$	-	Average concrete cylinder strength of all specimens
f_c' or f_{cu}	-	Concrete cube compressive strength
$F_{concrete}$	-	Longitudinal resultant in concrete element
$f_{y,mean}$	-	Average steel strength of all specimens
F_y or f_y	-	Yield strength steel element
f_{yb}	-	Basic yield strength
f_{yr}	-	Reinforcement yield strength
F_{shear}	-	Connection force
F_{steel}	-	Longitudinal resultant in steel element
F_u or f_u	-	Tensile strength of steel material
f_{ub}	-	Ultimate tensile strength of bolt
$F_{v,Rd}$	-	Shear resistance of bolt
H	-	Height of the channel shear connector
h or h_p	-	Height of rib
h	-	Slab height downward the connector
h	-	Depth of CFS section
h_c	-	Concrete slab height
h_{sc}	-	Height of shear connector
h_w	-	Height of web between the mid-lines of flanges

$I_{concrete}$	-	Moments of inertia of concrete
I_{steel}	-	Moments of inertia of steel
k	-	Experimental stiffness
k_i	-	Reduction factor
K_{Norm}	-	Normalized stiffness
L_c	-	Contact length between the concrete and steel flange
L_c	-	Length of channel connector
L_f	-	Collar length of BTTST
L_s	-	Span length of BTTST
M	-	Resisting moment
m	-	Number of plane elements
$M_{concrete}$	-	Moment in concrete element
M_{cr}	-	Elastic critical moment for lateral torsional buckling
$M_{c,Rd}$	-	Design moment resistance
M_{Ed}	-	Applied bending moment
M_{steel}	-	Moment in steel element
$M_{u,exp}$	-	Experimental ultimate moment
$M_{u,theory}$	-	Theoretical ultimate moment
N	-	Number of shear connectors provided over the relevant part of the span
N_f	-	Number of shear connectors for full shear connection
n	-	Number of studs subjected to similar displacement
n	-	Number of rib holes
n	-	Number of concrete dowels
n	-	Number of curved elements
n	-	Modular ratio
n_r	-	Number of studs per rib
Pe	-	Elastic load
$P_{e,exp}$	-	Experimental elastic load

P_{Rd}	-	Shear connector design resistance
Pu	-	Ultimate load
$P_{u,exp}$	-	Experimental ultimate load
$P_{u,pre}$	-	Predicted ultimate load
P_{tab}	-	Ultimate load per shear tab
Q_n	-	Nominal strength per channel shear connector
Q_p	-	Static shank failure load of stud
Q_{rib}	-	Strength of shear connector in a rib
Q_{sol}	-	Strength of shear connector in a solid slab
Q_u	-	Resistance of stud connector
q	-	Shear capacity per perfobond shear connector
q_u	-	Capacity per perfobond connector
q_u	-	Strength capacity of channel shear connector
R_n	-	Capacity of channel shear connector
R_q	-	Total shear force transferred by shear connectors
R_{CFS}	-	Resistance of CFS element
R_{SCC}	-	Resistance of concrete element
$R_{w,Rd}$	-	Resistance of web crippling
r_j	-	Internal radius of curved elements *j*
S_s	-	Nominal length of stiff bearing, taken as the distance over which the applied load is effectively distributed at a slope of 1:1
t	-	Thickness of CFS
t	-	Thickness of connected part
t	-	Web thickness
t_f	-	Flange thickness of channel connector
t_{sc}	-	Thickness of connector
t_w	-	Web thickness of channel connector
$V_{b,Rd}$	-	Design shear resistance
$V_{bw,Rd}$	-	Shear resistance of the CFS section

V_c	-	Shear strength due to concrete pull-out failure
V_{Ed}	-	Applied vertical shear
$V_{u,exp}$	-	Experimental shear
$V_{u,theory}$	-	Theoretical shear
w	-	Average rib width
W_{eff}	-	Effective section modulus
$y_{concrete}$ and y_{steel}	-	Distance of the lowest and upper most fiber of the concrete and steel element, measured from the neutral axis
Z	-	Distance between the centroids of the concrete and steel element
L/d	-	Span-to-depth ratio of the specimen in consideration
$\left(L/d\right)_{mean}$	-	Average span-to-depth ratio of the specimens in comparison
ρ	-	Reduction factor for plate buckling
δ	-	Factor considering the rounded corner effect
δ_u	-	Slip at ultimate load
δ_{uk}	-	Characteristic slip capacity
γ_v	-	Partial factor of safety
γ_{mo}	-	Partial safety factor
γ_{m1}	-	Safety factor taken
γ_{M2}	-	Factor of safety
α	-	Dimensional coefficient
α_{LT}	-	Imperfection factor
θ	-	Angle of BTTST
$\varepsilon_{concrete}$	-	Concrete strain
ε_{steel}	-	Steel strain
χ_{LT}	-	Reduction factor of lateral torsional buckling
λ_1	-	Factor dependent upon concrete type (0.75 for low density concrete, 0.85 for semi-low density concrete, 1.0 for normal density concrete)

ϕ_j	-	Angle between two plane elements
ϕ	-	Slope of the web relative to the flanges
ϕ_{sc}	-	Resistance factor for shear connector

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In steel and construction industry, hot-rolled steel (HRS) section and cold-formed steel (CFS) section are two distinguished steel sections that are used. However, among the two steel sections, HRS is the most familiar among building contractors and engineers. The use and application of CFS sections started in the United States of America (USA) and Great Britain for decades, mainly for non-structural purposes only. Though, the use of CFS is expanding in the present era of building constructions (Irwan, 2010; Kibert, 2012). However, in the mid- 20th century, the structural use of CFS sections began especially for commercial and industrial building constructions (Hancock *et al.*, 2001; Riley and Cotgrave, 2014). Recently, the use of CFS sections as an alternative material for roof structure keep increasing due to the quality assurance of steel structures (Yu, 2000).

CFS sections are lightweight material produced by bending a flat steel sheet at room temperature (Hancock, *et al.*, 2001; Lee *et al.*, 2014) into a desired shape that can withstand more load than the flat sheet itself; and are suitable for building construction owing to their high structural performance (Yu and LaBoube, 2010). The most common sections of CFS are channel lipped C and Z sections (Figure 1.1), and the typical thickness ranged from 1.2 to 6.4 mm with a depth range of 51 mm to 305 mm (Yu, 2000; Lee, *et al.*, 2014).

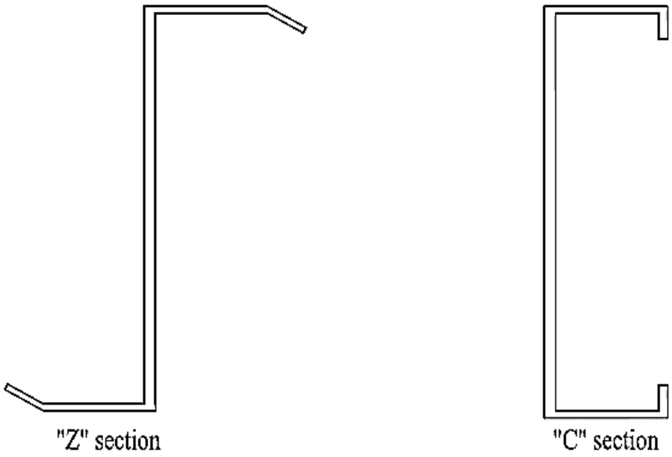

Figure 1.1: Typical cold formed steel sections

Composite construction using CFS section and concrete began in Europe in mid-1940s was used as floor system (Allen, 2006; Talal, 2014). Composite action is categorized by an interactive behaviour between structural steel and the concrete designed to utilize the best load resistance capability. An illustrative steel-concrete composite cross-section usually used in composite beam construction is depicted in Figure 1.2. For the components (i.e. steel-concrete) to act compositely, a mechanical means of shear connection must be provided (Prakash *et al.*, 2012). The most generally used shear connectors are the headed studs shear connectors which are commonly provided at the interface between the concrete and the steel to resist the longitudinal shear (Kim *et al.*, 2001). However, in composite structure, the key element for achieving the composite action is the effectiveness of the shear connectors.

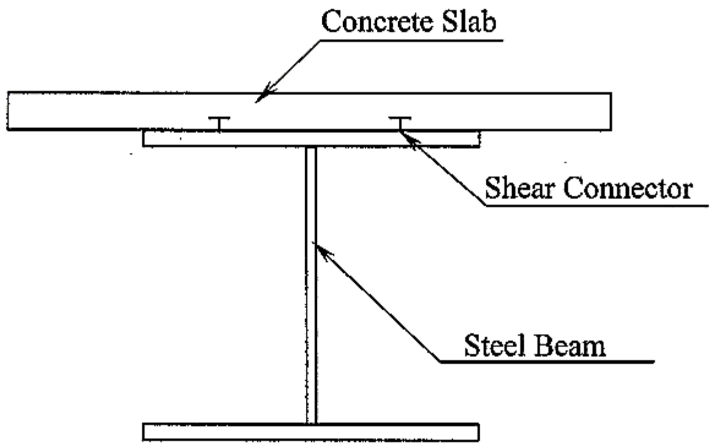

Figure 1.2: Typical composite section

Composite construction is the combination of steel and concrete to form a single unit (Nethercot, 2003). But the use of steel structures especially the CFS sections not compositely lead to a buckling problem which reduces the strength, especially when used as compression members. Therefore, steel beams without lateral restrain are subjected to lateral torsional buckling and twisting (Irwan *et al.*, 2008; Irwan *et al.*, 2009; Irwan *et al.*, 2011). However, a quick development in technology, leads to the use of CFS section in the Industrialization of Building Systems (IBS) and it has become more popular and well accepted in developed and developing countries in the globe respectively. CFS sections are used with concrete as composite structural component and the resulting performances were found to be encouraging. Due to the thinness of the CFS section and its susceptibility to lateral torsional buckling, twisting and web crippling, significant number of research studies (Lau and Hancock, 1987; LaBoube, 1994; Rogers and Hancock, 1997; Wang and Li, 1999; Wilkinson and Hancock, 2000; Schafer, 2002; Holesapple and LaBoube, 2003; Stephens and LaBoube, 2003; Yu and Schafer, 2003; Young, 2004; Young and Ellobody, 2005; Yu and Schafer, 2006; Dubina, 2008; Ranawaka and Mahendran, 2009; Macdonald and Heiyantuduwa, 2012) were conducted to study the stability complications and to improve the performance of the CFS members.

However, with the advantages demonstrated by CFS for use in composite construction, welding of the conventional headed shear studs is not feasible (Hanaor, 2000). Therefore, the development of feasible shear connector for use with the CFS and the concrete as a composite entity is of paramount significance, and hence, required further investigation in order to explore more of its advantages. CFS structural members have several benefits over their conventional counterpart HRS, such as lightness, reduced thickness, high strength and stiffness, accurate detailing, non-shrinking and non-creeping at ambient temperature, non-combustibility, fast and easy erection, ease of fabrication and mass production and easy to install (Yu and LaBoube, 2010). The use of CFS members in composite with concrete is still rarely reported; this could be due to the non-availability of standard specifications made for CFS sections as composite members.

Therefore, this research investigated the structural performance of CFS with Self-Compacting Concrete (SCC) as a composite beam system. In the study, an innovative shear enhancement suitable for CFS section is proposed to accomplish the composite action between the concrete slab and the CFS section. The proposed system of shear connection provided was using bolted shear connectors instead of the conventional headed studs shear connectors as welding of the studs is not feasible with the CFS section. However, the study also proposed the use of SCC instead of the normal vibrated concrete (NVC) as lack of proper vibration leads to creation of air voids thus, leading to the weakening of the concrete slab. The proposed SCC does not require any external vibration thus, compaction is achieved by its own self weight and its homogeneity is maintained even in the presence of congested reinforcement. The findings from this study may magnify the use of CFS in the construction industries of developed and the developing countries. And may also promote the use of the proposed bolted shear connection enhancement as an alternative shear mechanism in composite construction, for small and medium size buildings as well as light weight industrial constructions.

1.2 SCC Brief History

The idea of ‘self-compaction’ largely antedates that of modern SCC. In practical situations, there were important applications for concrete where compaction is an issue or physically not feasible (Bartos, 2013). For instance, such applications could be found in construction works underwater, foundation works consisting of large diameter concrete piles, very deep concrete diaphragm walling etc. However, the concrete mix required for such kind of applications therefore had to be self-compacting (De Schutter *et al.*, 2008).

The development of present SCC was initiated in Japan in 1980s in which researchers were pursued for paving the way for the introduction of SCC as it is now known (Bartos and Cleland, 1993; Bartos *et al.*, 2004; Bartos, 2013). In 1950s and 1960s during the postwar reconstruction of Japan, it was noticed that the reinforced concrete structures constructed begins to deteriorate after a decade or two. As a result of that, a team of investigation was set up which was headed by Okamura of Tokyo University (De Schutter, *et al.*, 2008). During the course of the investigations they found out that lack of insufficient compaction was the cause of the structural deteriorations. The team proposed a solution by suggesting on increasing the workability (flow) of the fresh concrete mix such that compaction was no longer an issue and the mix would be ‘self-compacting’ (Kuroiva *et al.*, 1993). In the early 1990s, demonstrations and full-scale trials were conducted and the SCC was first used in significant practical application in Japan (De Schutter, *et al.*, 2008).

Due to the advantages of SCC demonstrated since the time of its discovery to date therefore, in this study it’s proposed to be use in composite construction as this is yet to be explored.

1.3 Problem Statement

In steel industries, HRS is more versatile in use both by the engineers and the building contractors as compared with CFS. The use of CFS is limited in the construction industries in which its application is mainly in roof trusses and bridge rails. But, significant number of research studies (Abdullah *et al.*, 1999; Hanaor, 2000; Nakamura, 2002; Hossain, 2003; Lakkavalli and Liu, 2006; Airil and Nethercot, 2007;

Wehbe *et al.*, 2011; Bamaga and Tahir, 2013; Alenezi *et al.*, 2013; Lee *et al.*, 2013) carried out had pointed the potentials of using CFS as a structural member. But the main limiting feature of CFS is the thinness of the section that makes it susceptible to torsional, distortional, lateral-torsional, lateral-distortional and local buckling problems (Irwan, *et al.*, 2011) and its inability to be weld. Therefore, orienting two CFS lipped channel sections back-to-back to form an I-section restores symmetricity and minimizes lateral-torsional and to a slighter extent, lateral-distortional buckling. These two advantages possesses by the system, promote the use of CFS sections in a wider range of structural applications (Irwan, *et al.*, 2009; Irwan, *et al.*, 2011). But, conventional method of using HRS sections with headed studs shear connectors to act as composite entity are adopted in the construction of small and medium size buildings, in which the practice leads to a tremendous costs of construction, labor and construction delay etc. But, the emergence of using CFS sections to replace HRS sections in the construction of small and medium rise buildings with an innovative way of shear enhancement of bolted shear connectors installed with a nut and washer, may lead to a significant reduction in construction cost, construction time and labor cost. Also ductility and strength capabilities could be better achieved when compared with the conventional method. On the other hand, the use of conventional NVC in composite construction may lead to an inadequate compaction and insufficient passage of the concrete to a desired position as the flow is controlled by vibration. Therefore, using innovative way of concreting with a flowable and cohesive concrete known as SCC will eliminate the inability of the concrete passage to a required position as it compacts by its own self weight while its homogeneity is maintained been a self-compacting.

Using CFS section with SCC to be integrated compositely is by providing such devices that could generate the composite action, increase strength capabilities and also meet the ductility requirements of the shear connection. Therefore, an innovative way of shear connection is devised in this research that will suitably fit with the CFS as a composite system. The shear connection proposed is of bolted shear connector with single nut and washer to be installed on CFS flanges and beneath, because of their ease of demounting and dismantling advantage.

1.4 Aim and Objectives of Study

The aim of this research is to investigate the structural performance of CFS with SCC as composite beam system. Three specific objectives were considered in this study to achieve the above aim as follows:

1) To propose a bolted type shear connector and evaluate its performance by push-out test.

2) To study the structural behavior of the proposed CFS-SCC composite beam by integrating with bolted shear connectors.

3) To validate the performance of the proposed CFS-SCC composite beam system by comparing with theoretical predictions based on Eurocode 4 recommendations.

1.5 Scope of Study

The research focuses on investigating the structural performance of the proposed CFS-SCC composite beam and also the strength capacity and ductility of the proposed bolted shear connectors. A new technique of composite beam system comprising of CFS section with SCC and an innovative shear connection mechanism is proposed. The study is basically on experimental investigation which focuses on strength and ductility of the proposed shear connectors. The proposed connectors are then used in CFS-SCC composite beam system, to get a better understanding on the performance behavior. The scope of the study is designed in two phases. The first phase is designed to investigate the performance of the proposed bolted shear connectors. The second phase is designed to investigate the performance of the proposed CFS-SCC composite beam system. The CFS section is to be oriented back-to-back to form an I-section beam for the proposed composite beam system. Proposed shear connection mechanism suitable for CFS-SCC composite beam is suggested. The proposed shear connectors are M16, M14 and M12 bolts of grade 8.8 with height of 75 mm are to be embedded 60 mm in the concrete slab of 75 mm thick. The push-out specimens comprised of two slabs; slab A and slab B of dimension 800 mm x 600 mm x 75 mm are attached to the CFS I-section. The full-scale composite beam system is a simply supported beam of 4500 mm length spanned 4200 mm between supports is to be tested using four-point loading bending test. This type of system of loading produces a constant region of pure bending moment between the point loads. Therefore, the ultimate flexural capacity of the proposed composite beam system can be determined.

1.6 Significance of Study

Composite beams are widely used in the construction industry due to their ability of being rigid, material savings and efficiency in strength (Nie *et al.*, 2006; Tahir *et al.*, 2009). However, the composite action that is achieved in composite construction between the steel beam and the concrete slab is by using of conventional headed stud shear connectors (Pallarés and Hajjar, 2010). It was reported that, significant tripping effects on working surfaces at site are created with the use of headed stud shear connectors due to welding process (Bamaga, 2013). Therefore, with this at stake, an alternative and innovative shear connection mechanism in composite construction with CFS section needs to be employed. The innovative shear connection to be adopted in this research is the use of bolted shear connectors with a single nut and single washer, because of their dismantling and demountable advantage (Pavlović *et al.*, 2013; Moynihan and Allwood, 2014) which could provide the ease for structural repairs.

On the other hand, CFS sections are designed as non-composite beams (Ghersi *et al.*, 2002; Satpute and Varghese, 2012) which are used as floor beams and joists in light-weight commercial and residential edifice. Therefore, the possibility of such floor beams to fail due to lateral-torsional buckling need to be checked. However, as a result of that conventional large HRS steel sections, NVC and headed stud shear connectors are used in the construction of small and medium size buildings which could resulted to; construction cost, labor cost, waste of materials, waste of space, and construction delay.

Therefore, using CFS sections with bolted shear connectors in SCC as a composite beam system could significantly increase the strength and stiffness capacities required.

1.7 Thesis Structure

In this sub-section, the structure of the thesis is presented according to each chapter.

Chapter 1 presents the general introduction, problem statement, aims and objectives of the study, scope of the study, methodology to be employed, significance of the research and the thesis structure are all described in this chapter.

Chapter 2 presents a comprehensive review of literature survey on the subject of this study.

Chapter 3 describes detailed methodology of this study on the specimens, test set-up and instrumentations used in the experimental works for push-out test and the full-scale flexural test of CFS-SCC composite beams.

Chapter 4 presents and discusses the experimental results of materials properties test for the materials used in the study. Results of push-out test, load-slip responses of all push-out specimens are presented. Strength capacities and ductility of the specimens as well as their modes of failure are also discussed. Comparison between experimental, theoretical and other researches is also conducted.

Chapter 5 presents and discusses the results of the experimental full-scale flexural beam tests. Load-deflection responses of all composite beam test specimens and their modes of failure are also discussed. Theoretical calculations for the CFS section, validation analysis and calculations of the proposed CFS-SCC composite beams using current design codes and methods are presented. Comparison between the experimental and theoretical results is conducted.

Chapter 6 provides summary, conclusions and recommendations for further works.

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