Faculty of Engineering

INVESTIGATION ON THE FLEXURAL BEHAVIOUR OF CFST BEAM WITH DIFFERENT CONFIGURATION OF STEEL PLATE REINFORCEMENTS

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INVESTIGATION ON THE FLEXURAL BEHAVIOUR OF CFST BEAM WITH DIFFERENT CONFIGURATION OF STEEL PLATE REINFORCEMENTS

NUR JASMIN BINTI AZRI

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To my beloved family and friends.

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ABSTRACT

Concrete filled steel tubes (CFST) are composite structural members consist of hollow steel tubes and concrete as infill. The CFST members are progressively used in the development due to its excellent durability and earthquake-resistant properties. The objectives of this project are to evaluate the improvements made by embedding steel plates into the tensile zone of the concrete core of CFST beams subjected to bending in terms of flexural capacity, stiffness and ductility through experimental works. A total of eight specimens with height of 200 mm and width of 100 mm will be embedded with various quantities, height and thickness of steel plates and the specimens will be tested to study the flexural behaviour of CFST beam with embedded steel plates. Additionally, a total of fourteen coupons were cut from the steel plates and prepared in accordance to BS EN ISO689-1:2016 will be tested under a direct tensile load. Throughout this study, the behaviour of CFST beams with embedded steel plates through its characteristics point such as elastic limit, elastic-plastic range, plasticity, yielding and buckling of steel tubes by generating the moment-curvature relationship will be assessed. The result thus concludes that the CFST beams with higher quantity of steel plates possessed the highest strength and stiffness followed by the thickness and then the height of steel plates given that the steel plates reinforcement area is similar.

ABSTRAK

Tiub Keluli Terisi Konkrit (TKTK) adalah struktur komposit yang terdiri daripada tiub keluli berlubang yang dipenuhi oleh konkrit. Tiub Keluli Terisi Konkrit digunakan secara progresif dalam pembangunan kerana ketahanan yang sangat baik dan sifat rintangan gempa bumi yang tinggi. Objektif projek ini adalah untuk menilai penambahbaikan yang dilakukan dengan memasukkan plat keluli ke zon tegangan teras konkrit di dalam Tiub Keluli Terisi Konkrit yang mengalami lenturan dari segi kapasiti lenturan, beban dan keupayaan bahan untuk mengalami ubah bentuk plastik melalui kerja eksperimen. Sebanyak lapan spesimen dengan ketinggian 200 mm dan lebar 100 mm akan ditanamkan dengan pelbagai kuantiti, ketinggian dan ketebalan plat keluli dan spesimen akan diuji untuk mengkaji tingkah laku lenturan beban TKTK dengan plat keluli tertanam. Selain itu, sejumlah empat belas kupon dipotong dari plat keluli dan disediakan mengikut BS EN ISO689-1: 2016 akan diuji di bawah beban tegangan langsung. Sepanjang kajian ini, tingkah laku TKTK dengan plat keluli tertanam melalui beberapa ciri-ciri seperti had elastik, julat elastik-plastik, keplastikan, penghasilan dan lengkungan tiub keluli dengan menghasilkan hubungan kelengkungan momen akan dinilai. Kesimpulannya dibuat bahawa TKTK dengan jumlah plat keluli yang lebih tinggi mempunyai kekuatan dan kekakuan tertinggi diikuti oleh ketebalan dan kemudian ketinggian plat keluli memandangkan kawasan tetulang plat keluli serupa.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

SYMBOL	DEFINITION
m	Metre
mm	Millimetre
kg	Kilogram
M	Moment
P	Load
L_e	Effective length
M_{max}	Maximum moment
P_{max}	Maximum load
L	Length
kN	Kilonewton
kNm	Kilonewton metre
Ki	Initial stiffness
Ks	Serviceability stiffness
U_{max}	Maximum deflection
κ	Curvature
μ	Ductility index
Δ_y	Yield deflection
MPa	Mega Pascal

LIST OF ABBREVIATIONS

CFST	Concrete Filled Steel Tube
CHS	Circular Hollow Section
SHS	Square Hollow Section
RHS	Rectangular Hollow Section
SCC	Self Consolidating Concrete
SSC	Self Stressing Concrete
CFAT	Concrete Filled Aluminium Tubes
CFDST	Concrete Filled Double Skin Tubes
BS	British Standard
EN	European Standard
ISO	International Organization for Standardization
W/C	Water-Cement Ratio
LVDT	Linear Variable Displacement Transducer

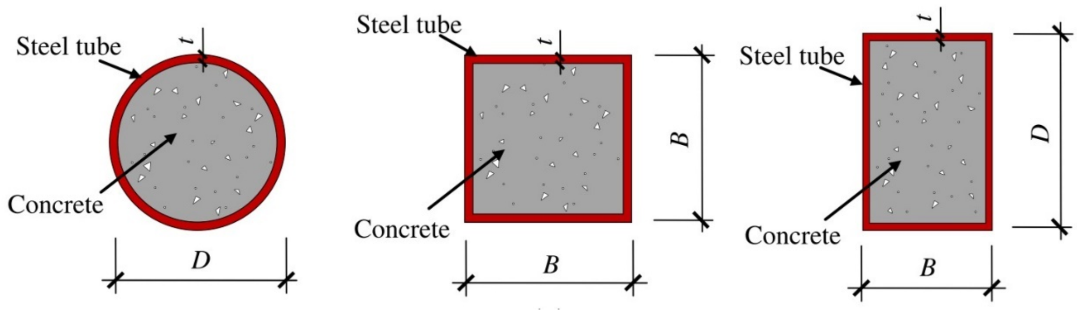
CHAPTER 1

INTRODUCTION

1.1 Background of Study

The concept of concrete-filled steel tubes (CFST) composite structural members consists of hollow steel tubes and concrete as its infill. Due to its excellent performance, concrete-filled steel tube is mainly used as columns as it can support high compressive load and is broadly used for building, bridge and foundation structures. Figure 1.1 shows the typically used cross-sections of steel tube columns typically used for the concrete-filled are sections with circular hollow (CHS), a square hollow (SHS) or a rectangular hollow (RHS) (Han, Li, & Bjorhovde, 2014). The importance of knowing that concrete has high compressive strength compared to structural steel is known by many. In contrast, structural steel has higher tensile strength than concrete however the structural steel could easily buckle when it is subjected to compression.

Hence, concrete-filled steel tube is an application that develops the strength of both concrete and steel and simultaneously will counteract its weakness by composite action. A great interest of concrete-filled steel tube has culminated among past researchers as CFST members are better in strength and ductility compared to conventional reinforced concrete and structural steel (Han et al., 2014; Nakamura & Momiyama, 2002). The benefits of using concrete-filled steel tubes besides providing high ductility and strength is, it possesses high fire resistances. Besides that, the time of construction may be shortened with the application of concrete filled steel tube members which the use of formwork and the erection of structural steel frame during the curing of concrete is eliminated.



Source: Han, Li, & Bjorhovde (2014)

Figure 1.1 Typical Steel Tube Columns

1.2 Statement of Problem

Hollow steel tubes with concrete infill are widely used in constructions given that the ductility, rigidity and strength is greater than reinforced concrete and conventional structural steel. This is because the hollow steel tube acts will be able to confined the concrete infill which is due to the longitudinal and transverse confinement and simultaneously, the concrete core will reinforce and strengthen the steel tube to prolong the local buckling (Lu et al., 2017). The combination of both materials affects the full performance of the strength of materials, high bearing capacity, members stiffness and ductility, together with excellent structural characteristics resistant to earthquake.

Concrete-filled steel tube beams when subjected to flexural load will experience both tension and compression hence, the tensile stresses will affect the concrete core as well. Referring to Wheeler and Bridge (2004) as cited in Zhan et al (2016), the cracking of the concrete in the tension zone area occurred in the early stage of the loading. Therefore, this occurrence leads to a reduction of the ultimate capacity and stiffness of CFST beams when it is subjected to pure bending to a bare steel tube. Around 5% of the ultimate moment was reported to be the cracking moment.

Besides that, the moment capacity of the CFST does not enhance greatly even by increasing the strength of the concrete in relation to the thickness of the tube (Chitawadagi & Narasimhan, 2009). This will result in the decrease of stiffness, ductility and strength of CFST beams where the cracking may cause the degradation of confinement.

The aim of this research study, therefore, to resolve this discrepancy by proposing embedded steel plates in concrete-filled steel tube beams, additionally providing a more comprehensive understanding in which concrete-filled steel tube beam could enhance the stiffness, ductility and moment capacity.

1.3 Research Objective

The objective of the study is:

1. To evaluate the improvements made by embedding steel plates into the tensile zone of the concrete core of CFST beams subjected to bending in terms of flexural capacity, stiffness and ductility through experimental investigation.
2. To assess the behaviour of CFST beams with embedded steel plates through its characteristic's points such as elastic limit, elastic-plastic range, plasticity, yielding and buckling of steel tubes and cracking of the concrete by generating its moment-curvature relationship.

1.4 Hypothesis

By introducing a new method where steel plates embedded in the tension zone of the concrete core of the CFST beams, the tensile stress will be supported by the steel plates thus, will improve the behaviour of the moment capacity, ductility and stiffness.

1.5 Scope of Work

The scope of work in this research involves with the difference of quantity, height and thickness of embedded steel plates in CFST beams. The cross-sectional shape, span, width-to-depth ration and width-to-thickness are all the same for each specimen.

The experimental works will be conducted in the concrete and heavy structure laboratory of Civil Engineering Department. Experimental works which include standard coupons are needed for tensile tests to determine the yield stress and strain together with its ultimate stress and strain. Hollow steel tubes and cylindrical mold will be used to cast the concrete in which it will be cured in the same conditions. Hence, cylindrical compression test will be conducted to determine the actual strength of the concrete. Four points bending test is used due to the middle one-third of the beam subjected to pure bending.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

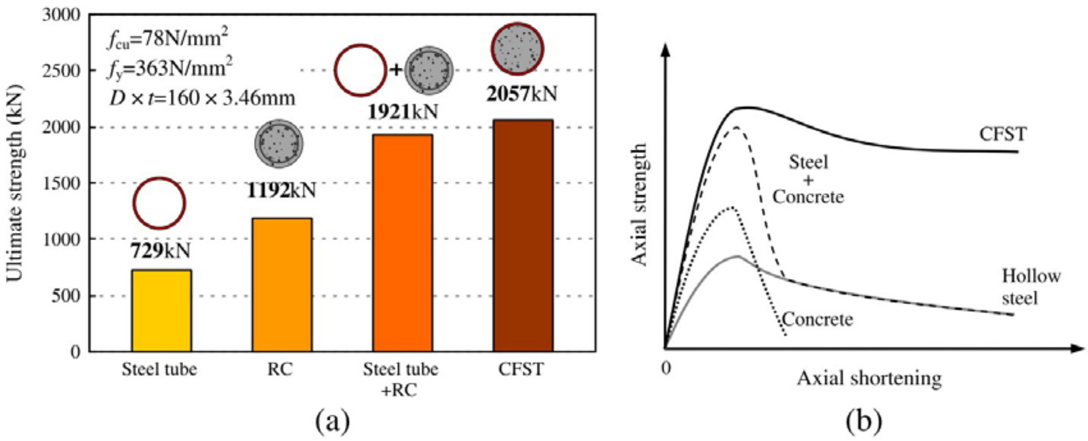
This chapter discusses the importance of CFST and the methods that has been done by past researchers which influences the flexural capacity, stiffness, ductility and the mechanical behaviour of CFST beams.

2.2 Advantages of Concrete-Filled Steel Tubes

In China, few buildings were using CFST column to prevent the use of columns with bigger sizes. This is because CFST was typically used as a compressive load resistant component and is generally will form a composite frame structure when it is attached to steel or reinforced concrete beams and also with other lateral resistant systems such as RC core tubes or steel shear walls. Using CFST columns, the structure combines both high rigidity and ductility which fits well in hybrid structures with the core tubes and shear walls.

The use of CFST in bridges, specifically arch bridges, shows that the hollow steel tubes can act as a formwork for casting the concrete during the erection phase, which decreases the construction costs. In addition, the composite arch can be built without temporary bridging due to the tubular structure’s characteristic in stability. To transform the structure into a composite frame, concrete can be filled into the hollow steel tubes. It is possible to use simpler construction technology for erection due to the hollow steel tubes weight which are relatively lower. Cantilever launching methods, and vertically or horizontally swing methods, which allows respective partial arch to be rotated horizontally in place are the common methods used (Han et al., 2014).

Figure 2.1(a) shows the comparisons of the ultimate strength for different type of columns used. It is reported that same geometric dimensions of column with fixed yield strength of steel and fixed compressive strength of steel gives different ultimate strength where the ultimate strength of CFST column is higher with the value of 2075 kN than the strength of steel tube column, reinforce concrete column together with both steel tube and reinforced concrete column respectively. Besides ultimate strength, ductility of the CFST are also improved as shown in Figure 2.1(b).



Source: Han, Li, & Bjorhovde (2014)

Figure 2.1 Ultimate Strength and Axial Compressive Behaviour of CFST Column

2.3 Past Findings of CFST

2.3.1 Concrete

It is known that concrete has been used widely in structures nowadays. Concrete has high compressive strength than its tensile strength which makes it suitable to be the infill of the hollow steel tubes. Researchers have proposed different types of concrete that can be used as the infill in CFST structures which is concrete with normal weight and concrete with high strength properties (Han et al., 2014). The author suggested that to enhance the structural performance of both combinations of concrete and steel tubes, it must be appropriately matched. For example, combinations of steel and concrete with higher strengths is suitable to improve the performance and vice versa. The properties of the materials of concrete is shown in Figure 2.2.

However, several researchers took a strong interest in self consolidating concrete (SCC) and discussed the importance role of self-consolidating concrete. In modern construction practice, the usage of self-consolidating concrete has been increased due to its advantages that can shorten the time of construction and decrease the cost of labour. The cast structures and the structural durability can be improved with self-consolidating concrete as well given that the use of shuttering is eliminate in the construction process.

According to Han et al. (2014), SCC can be used as a way to improve the quality of construction of the core concrete. This is because the sealed tube cannot drain the excess water hence, the concrete's water-to-cement ratio must be strictly controlled. Of normal weight concrete, a water-to-cement ratio above 0.4 is unacceptable. As mentioned above, SCC can be filled without the usage of vibration due to its high fluidity where it can give an advantage to the connection zone area.

Nevertheless, Zhu et al. (2016) stated that due to the improved consumption of cement, the shrinkage occur in SCC increases than the vibrated concrete. This occurrence will weaken the confinement between the concrete filled and steel tube which simultaneously will affect the structure in terms of durability. To solve the shrinkage issue, Lu et al. (2017) proposed a self-stressing concrete (SSC) which has a behaviour of self-expansion. The conduct of self-expansion is produced as a compensation for the shrinkage by chemical process within SSC. Using expansive additives may reduce the