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JUDUL: **STRENGTHENING OF BOLTED SHEAR JOINT IN FERROCEMENT CONSTRUCTION**

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# STRENGTHENING OF BOLTED SHEAR JOINT IN FERROCEMENT CONSTRUCTION

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A project report submitted in a partial fulfillment of the
requirement for the award of degree of
Master of Engineering (Civil – Structure)

Faculty of Civil Engineering
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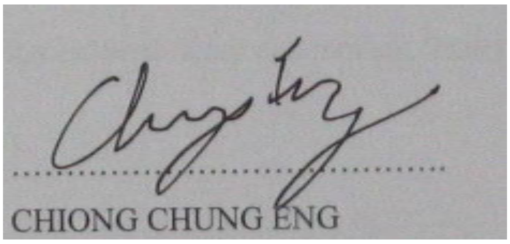
JULY, 2007

"I declare that this project report entitled "Strengthening of Bolted Shear Joint in Ferrocement Construction" is the result of my own study except as cited in the references. This thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree."

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To my beloved father and mother, family and dear friends.

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# ABSTRACT

This study deals with strengthening of bolted shear joint in thin-walled ferrocement construction. Such a joint is attractive because it provides faster and neat means of assembling precast elements into a complete structure. Steel wires, bent into O-Shape and U-shape with or without extra straight wire, are considered as simple inserts around the bolt hole to enhance the joint strength. The parameters investigated include the number of layers of wire mesh (or volume fraction of reinforcement), edge distance of bolt hole and the effectiveness of different types of the steel inserts. Test results have shown that for small edge distance, failure occurs either in cleavage or shearing mode, and the strength of the joint increases with an increase in the edge distance. This continues up to an upper limit set by either tension or bearing failure. For a given edge distance and details of connected members, the strength of a joint can be significantly enhanced by using steel insert, while U-insert is most cost-effective. Available equations for predicting the joint strength in ferrocement composites can be slightly modified to include the effects of these inserts with a good level of accuracy. Since the cleavage failure equation is quite conservative, removing it from consideration or modifying it to reflect test data can improve the accuracy of the predictions of joint strength. As an alternative, strut-and-tie model, herein can predict the joint strength in ferrocement composite as proposed. However it does not perform that well if steel insert is included in the ferrocement plate, as the process to determine volume fraction of reinforcement becomes more complex.

# ABSTRAK

Kajian ini adalah berkenaan sambungan ricih bolt dalam pembinaan dinding nipis ferrocement. Sambungan bolt sesuai kerana ia adalah cepat dan tersusun semasa menyambungkan elemen precast kepada suatu struktur yang menyeluruh. Dawai besi, yang dibengkokkan kepada bentuk O dan U yang ditambah atau tidak ditambah dengan dawai lurus, telah digunakan sebagai tetulang tambahan disekeliling bolt untuk meningkatkan kekuatan sambungan. Parameter yang dikaji termasuk bilangan lapisan jejaring dawai (atau peratus isipadu tetulang), jarak ke tepi dari lubang bolt dan kesesuaian tetulang tambahan besi yang berlainan. Keputusan ujian menunjukkan untuk jarak tepi yang kecil, kegagalan dalam "cleavage" atau rich berlaku. Kekuatan sambungan meningkat apabila jarak tepi bertambah. Ini berterusan sehingga satu tahap apabila kegagalan tegangan atau galas berlaku. Untuk jarak tepi dan keadaan sambungan yang ditetapkan, kekuatan sambungan boleh ditingkatkan keberkesannya dengan penggunaan tetulang tambahan besi, manakala tetulang tambahan bentuk U adalah paling kos-efektif. Formula yang ada untuk menjangka kekuatan komposit ferrocement boleh diubah sedikit untuk menambahkan kesan tetulang tambahan dengan ketepatan yang baik. Oleh kerana formula untuk kegagalan "cleavage" sangat konservatif, pengeluaran formula "cleavage" dalam pertimbangan atau pengubahsuaian formula tersebut dapat meningkatkan ketepatan jangkaan kekuatan sambungan. Modal strut-and-tie merupakan satu cara lain untuk menjangka kekuatan sambungan komposit ferrocement. Tetapi keputusannya menjadi kurang tepat jika tetulang tambahan digunakan dalam komposit ferrocement. Ini disebabkan pengiraan peratus isipadu tetulang untuknya adalah sukar.

# TABLE OF CONTENTS

# LIST OF TABLES

# LISTS OF FIGURES

# LISTS OF APPENDICES

# CHAPTER 1

# INTRODUCTION

Ferrocement is a type of thin reinforced-concrete construction where instead of reinforcing bars, larger amount of smaller diameter wire meshes are used uniformly throughout the cross section and, instead of concrete, mortar is used (Surendra & Naaman, 1978). The ferrocement technique was invented about 160 years ago by Joseph Lambot when he constructed the first ferrocement boat at Brignoles, France in 1848.

Recently, due to increasing labour cost and the need for producing high quality construction material, Industrialized Building System (IBS) is introduced. The system encourages structural components to be manufactured in the factory in mass quantity and assemble them on site by using suitable connections. Ferrocement can be fabricated into any desired shape and, being a thin-walled composite, the components will be lighter for handling and transportation. Assembling these components by using bolted joints will eliminate the requirement for messy wet connection on site and greatly expedite the construction process. The ACI Committee 549 had provided design guide for the fabrication of ferrocement, but there is still a lack of information on bolted connections in precast ferrocement panels.

Since 1994, a number of research programs on the behaviour and strength of bolted joint in ferrocement has been conducted at the National University of Singapore (Mansur et. al., 1994, 2001, Abdullah and Mansur, 1995, Tan, 1999). These investigations identified four different modes of failure for a shear joint and attempted to develop analytical models for predicting the ultimate strength of such a joint. A careful review of the resulting expressions reveal that, for a given geometry and connected member details, joint strength may be enhanced significantly by incorporating simple steel insert of desired shape at suitable location. The focus of this study has therefore been directed toward strengthening of bolted shear joint in ferrocement construction.

## 1.1 Research Problem

This study concentrates mainly on the problem of identifying the effect of steel inserts on bolted shear joint and their effectiveness in strengthening bolted shear joint.

## 1.2 Objectives

The objectives of the study are:-

a) To propose suitable ways to strengthen bolted shear joint using steel insert by investigating the available mechanistic models and modifying the models for incorporation of inserts.

b) To verify experimentally the effectiveness of the strengthening method by designing and conducting a series of tests and comparing with the analytical predictions.

## 1.3 Scope of Project

This research was aimed to propose suitable way to strengthen bolted shear joint. To archive that, some literature study had been done and the equations of four mode of failure were analyzed to see the relationship of the parameters involved. A strut-and-tie model was also constructed to achieve that purpose. From the analysis, steel inserts could significantly increase the strength of the joint. Furthermore, tests on the steel inserts on bolted shear were conducted to verify its effectiveness.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Ferrocement and Its Application

Ferrocement is a type of thin-wall reinforced concrete commonly constructed of cement-sand mortar with closely spaced layers of continuous and small diameter mesh bound together. The ferrocement technique was first used by Joseph Lambot when he constructed his first ferrocement boat at Brignoles, France in 1848. Fig. 2.1 showed the production of ferrocement. Fig. 2.2 showed the first ferrocement boat constructed by Joseph Lambot.

Ferrocement was used for boat building in Bangladesh, China, India, Indonesia and Thailand due to timber shortages and the availability of cheap labour (Shah and Naaman, 1978). Being efficient in the crack arresting property, ferrocement was suitable to be used in water resource applications, such as water tank, casing for well and sedimentation tank. Besides, ferrocement was considered as a suitable construction material for housing in developing countries (Naaman, 1998). It was used as precast elements for roofing, wall panels, fences and sunshades. These precast elements were chosen for its low self-weight, avoidance of formwork and availability of cheap labour. In 1987, large scale application of ferrocement was held in Singapore (Mansur et. al., 1987). Ferrocement was used to build sunscreens for modern multi-storey apartment blocks. Fig. 2.3 shows innovative application of ferrocement while Fig. 2.4 shows ferrocement sunscreens for apartment block in Singapore.

## 2.2 Industrialized Ferrocement Housing System

An industrialized two-storey housing system proposed in the literature consists of precast ferrocement panels of different sizes (Naaman, 2000). They are wall panel, corner panel, window panel, floor panel, ceiling panel and window panel. These panels can be easily manufactured in a precasting yard under strict quality control and sent to the site for assembling. In order to avoid messy and slow wet connection on site, bolted joints was proposed to assemble the precast panels into complete structure. Fig. 2.5 showed diagram of the precast ferrocement panels. Assembly of panels using bolted joints are shown in Fig. 2.6 and Fig. 2.7.

A careful review of joints in such a housing system reveals that the forces transmitted through the joints consists of shear force, axial force and bending moment, and accordingly, the joint are classified as shear joint, axial joint and moment joint, as shown in Fig.2.8. This study deals with shear joints only as it is one of the most common type of joints in such a structural system.

## 2.3 Basic Failure Modes and Equations in Bolted Shear Joint

When a bolted shear joint is subjected to tensile load, four modes of failure have been identified by previous researchers (Mansur et. al., 1994, 2001, Abdullah and Mansur, 1995, Tan, 1999). These are (refer to Fig. 2.9):-

a) Shear Failure
b) Tension Failure
c) Cleavage Failure
d) Bearing Failure

### 2.3.1 Shear Failure Mode

Shear mode of failure occurs when formation of inclined cracks radiating from the bolt hole leads to the failure. It causes by the interaction of both steel and concrete failure. The ultimate shear failure load, $P_s$, was predicted from Equation 1, which was proposed by Mansur (1994):-

$$P_s = eh(f_t f_c{}^*)^{0.5} \qquad (1)$$

where $e$ = The edge distance of the bolt hole

$h$ = The thickness of the specimens

$f_t$ = The tensile strength of ferrocement in any orthogonal direction

= $(A_s f_y)/wh$

$f_c{}^*$ = The reduced compression capacity of the cement mortar

= $v\, f_c$

$A_s$ = The effective area of mesh reinforced in the direction of loading.

$f_y$ = The yield strength of mesh

$f_c'$ = Cylinder compressive strength of mortar.

$v$ = Effectiveness factor of 0.53

### 2.3.2 Tension Failure Mode

Tension Failure mode is the formation of cracks starting from the hole along the net section and propagates normally to the loading direction, up to the edge of the plate. The ultimate strength, $P_t$, of a joint that fails in tension mode is given as:-

$$P_t = h(w-d)f_t \quad (2)$$

where $w$ = The width of the plate

$d$ = The diameter of the bolt hole

### 2.3.3 Cleavage Failure Mode

Cleavage failure mode is the formation of the splitting cracks paroled to the plate loading direction, from the hole to the plate edge. This type of failure occurred in the steel mesh along the direction of loading and the equation for prediction of ultimate cleavage strength of the joint was recommended by Hammoud and Naaman (1998):-

$$P_{cl} = N(e-d/2)R_{cl}/0.6 = 1.67\ h\ (e-0.5d)\ f_{tcl} \quad (3)$$

where $N$ = The number of layers of reinforcing mesh

$d$ = The diameter of the bolt hole

$R_{cl}$ = The yield resistance per unit width of one layer of reinforcing mesh crossing the cleavage section

### 2.3.4 Bearing Failure Mode

Bearing Failure Mode is the compressive crushing of concrete material around the hole due to high stress caused by the contact between bolt and hole. Normally the value for bearing failure load is the highest among these four modes. The ultimate bearing strength of the joint given by

$$P_b = (\sigma_b)_u \times h \times d = 2 f_c' hd \qquad (4)$$

where $(\sigma_b)_u$ = 2.0 $f_c'$ as proposed by Mansur et al. (2001).

## 2.4 Strengthening of Bolted Shear Joint

A close scrutiny of the equations for the four modes of failure reveals that the strength of the given joint with known geometry and strength properties of the composite that fails in either tension or cleavage modes is governed by tensile strength, $f_t$ of the composite, while that failing in bearing is governed by its compressive strength, $f_c'$. In contrast, the shearing mode of failure is governed by both tensile and compressive strength of the composite. In cement-based composites, the tensile strength is solely provided by the reinforcement. Therefore, the strength of the joint failing in any of three modes – cleavage, shear and tension can be enhanced by using simple steel inserts around the bolt hole. When suitably placed, the insert will contribute to $f_t$, thus improving the capacity and efficiency of the joint without having to change its geometry or details of the members being connected. A previous attempt to strengthen a shear joint by embedding steel pipes to pre-form the bolt hole was not successful (Abdullah and Mansur, 1995). The present investigation on bolted shear joint in ferrocement has been directed towards exploring the extent of strengthening that can be accomplished by incorporating simple U-shaped steel insert at suitable location around the bolted hole.

## 2.5 Strut-and-Tie Model

Besides using equations, strut-and-tie model is an alternative model for estimating the tensile stress resultant for a concrete structure. This model assumes that in a cracked member, concrete in between the cracks carries direct compression and steel carries axial tension. The load-carrying mechanism of the member can then be idealized as that of a truss comprising a series of concrete struts and steel ties. Known as the strut-and-tie model, this concept of idealization has been found to be a simple, but powerful tool dealing with disturbed or discontinuous regions of a concrete structure (MacGregor, 1997).

Strut-and-tie model is a system of forces in equilibrium with a given set of loads. The lower bound theorem of plasticity states that the capacity of such a system of forces is the lower bound on the strength of the structure, provided that no element is loaded beyond its capacity. This assumes that deformation capacity is not exceeded at any point before the assumed system of forces is reached. For this reason, the resultant forces in the members of the strut-and-tie model should be close to the final set of the internal forces.

A simple strut-and-tie model for a deep beam is shown in Fig. 2.10. It consists of concrete compressive struts, reinforcing bars as tension ties, and joints and nodal zones.

(a) Compression Strut

In a strut-and-tie model the strut represent concrete compression stress fields with the prevailing compression in the direction of the strut. Struts are frequently idealized as prismatic or uniformly tampering members, but often vary in cross section along their lengths (Fig. 2.11) because the concrete is wider at midlength of the strut than at the ends.

(b) Tension Ties

The spreading of the compression forces gives rise to transverse tensions, which may cause the strut to crack longitudinally. If the strut has no transverse reinforcement, it may fail after this cracking occurs. If adequate transverse reinforcement is provided, the strut will fail by crushing,

Tension ties represent one or several layers of steel reinforcement which resist these tension forces. Tension ties may fail due to lack of end anchorage. The anchorage of the ties in the nodal zone is a major part of the design of D-region using a strut-and-tie model.

(c) Nodal Zones

Nodal zones are the joints in strut-and-ties model. Here three or more forces meet at a node and these forces must be in equilibrium.