STRUCTURAL BEHAVIOUR OF PRE-FABRICATED COMPOSITE PAD FOOTING FOUNDATION USING COLD-FORMED STEEL OF LIPPED CHANNEL SECTIONS

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To my late grandmother whom I deeply respect,

You will be fondly remembered and will be sorely missed by us.

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ABSTRACT

Pad footing foundations are traditionally made of concrete reinforced by high tensile steel bars moulded by timber formwork. This type of fabrication has three main disadvantages, which are large deviation of intended geometry due to weak structural integrity of used timber formworks, wastage of timber material as temporary timber formwork does not contribute to the strength of pad footing and as to be disposed after a certain number of usage, and longer construction time due to the need to remove the timber formwork after the concrete has hardened. Due to these disadvantages, the traditional method of constructing pad footing can cause an increase in construction cost and time, uncertainty in the quality of the final product and also environmental issues from the disposal of used timber formwork. To overcome the existing flaws of pad footing construction, the concept of pre-fabrication construction of pad footing foundation has been introduced using cold-formed steel lipped channel sections to replace timber as permanent formwork, and to replace high tensile steel bars as reinforcement in the pad footing foundation. However, such practice of using cold-formed steels in pre-fabricated pad footing foundation is still uncommon and no design guide has been established yet. This thesis investigates the moment and shear resistances and the failure modes of such pre-fabricated pad footing foundation designed to BS EN 1992-1. A total of 9 specimens were tested, which consisted of six 1000 mm x 1000 mm x 150 mm footings, and three 1000 mm x 1750 mm x 150 mm footings. The experimental result and theoretical calculation was on good agreement and the use of cold-formed steel increased the structural resistance of the footing due to composite effects. As a result, the proposed pre-fabricated pad footing foundation using cold-formed steel lipped channel sections is proved to be feasible in actual construction practice and can be reliably designed by using the existing code in BS EN 1992-1.

ABSTRAK

Penapak tunggal yang tradisional diperbuat daripada konkrit bertetulang dengan bar keluli tegangan tinggi dan dibentuk oleh acuan kayu. Jenis pembinaan tersebut mempunyai tiga kelemahan utama, iaitu sisihan besar dari geometri bertujuan disebabkan oleh integriti struktur lemah kayu terpakai, pembaziran bahan kayu sebagai acuan kayu kerana tidak menyumbang kepada kekuatan penapak tunggal dan perlu dilupuskan selepas sebilangan penggunaan, dan masa pembinaan lebih panjang kerana acuan kayu perlu ditanggalkan selepas konkrit telah keras. Oleh kerana kelemahan ini, kaedah tradisional membina penapak tunggal boleh menyebabkan peningkatan dalam kos pembinaan dan masa, kualiti produk akhir rendah dan juga isu-isu alam sekitar daripada pelupusan acuan kayu yang digunakan. Untuk mengatasi masalah pembinaan penapak tunggal, konsep pembinaan pra-fabrikasi telah diperkenalkan dengan menggunakan keluli terguling sejuk dengan keratan berbibir untuk menggantikan kayu sebagai acuan kekal, dan untuk menggantikan bar keluli tegangan tinggi sebagai tetulang dalam penapak tunggal. Walau bagaimanapun, amalan menggunakan keluli terguling sejuk dalam penapak tunggal yang dibina secara pra-fabrikasi masih lagi luar biasa dan tiada panduan reka bentuk lagi yang telah ditubuhkan. Tesis ini mengkaji rintangan momen dan ricih, dan juga mod kegagalan penapak tunggal pra-fabrikasi tersebut direkakan dengan menggunakan BS EN 1992-1. Sebanyak 9 spesimen yang terdiri daripada enam 1000 mm x 1000 mm x 150 mm penapak tunggal dan tiga 1000 mm x 1750 mm x 150 mm penapak tunggal telah diujikan. Keputusan eksperimen dan pengiraan teori menunjukkan kesamaan yang baik dan penggunaan keluli terguling sejuk meningkat rintangan struktur penapak tunggal disebabkan oleh kesan komposit. Oleh itu, boleh disimpulkan bahawa penapak tunggal yang dicadangkan menggunakan keluli terguling sejuk dengan keratan berbibir dibuktikan dapat dilaksanakan dalam pembinaan sebenar dan direka dengan menggunakan kod yang sedia ada di BS EN 1992-1

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LIST OF SYMBOLS

Ac	-	Cross section area of concrete
A_s	-	Area of steel reinforcement required
A_{sl}	-	Area of steel reinforcement provided
b_w	-	Breadth of the pad
c	-	Thickness of concrete cover
d	-	Effective depth of the pad
D	-	Height of CFS
F	-	Flange measurement of CFS
L	-	Lip measurement of CFS
fcu	-	Characteristic strength of concrete
fy	-	Characteristic strength of steel
fyc	-	Characteristic strength of CFS
K	-	Factor based on simplified stress block
M	-	Moment
t	-	Thickness of CFS
U	-	Critical perimeter, 1.5*d* away from the stump/column
Uo	-	Stump/Column perimeter
V	-	Design shear force due to ultimate loads
$\mathrm{V_{Rd,c}}$	-	Concrete shear resistance
$\mathrm{V_{min}}$	-	Minimum concrete shear resistance
z	-	Lever arm of section
%	-	Percent
=	-	Equals
+	-	Plus, or Mathematical operator: plus
−	-	Dash, or Mathematical operator: minus
×	-	Mathematical operator: multiply
÷ or /	-	Mathematical operator: divide

^	-	Mathematical operator: to the power of
√	-	Mathematical operator: square root of

LIST OF NOTATIONS

F1010	-	Case 1 specimen label. F indicating expected failure mode in flexure; first two and second two digits reflect width and length of pad respectively, 10 = 1000 mm
S1010	-	Case 2 specimen label. S indicating expected failure mode in shear; first two and second two digits reflect width and length of pad respectively, 10 = 1000 mm
F1017	-	Case 3 specimen label. F indicating expected failure mode in shear; first two and second two digits reflect width and length of pad respectively, 10 = 1000 mm, 17 = 1750 mm.
C35	-	Grade of concrete: 35 N/mm2 characteristic strength at 28 days.
KS15016C	-	Name of CFS section, refer to Table 3.1
R6	-	Stump/Column link bars with 6 mm diameter.
T10	-	Stump/Column reinforcement bar with 10 mm diameter.

LIST OF ABBREVIATIONS

BS	-	British Standard
BSI	-	British Standard Institution
CFS	-	Cold-formed Steel
CIDB	-	Construction Industry Development Board Malaysia
IBS	-	Industrialised Building System
kN	-	Unit of measurement: kilo Newton
max	-	maximum
min	-	minimum
mm	-	Unit of measurement: millimeter
mm2	-	Unit of measurement: millimeter square
MPa	-	Unit of measurement: Mega Pascal, equivalent to N/mm2
N	-	Unit of measurement: Newton
N/mm2	-	Unit of measurement: Newton per millimeter
vs	-	Versus

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Waste generated from construction can cause many problems in terms of waste of materials, loss of profit, waste management and environmental pollutions. In construction industry, one of the most prominent wastage is the use of timber formwork for containment of freshly poured concrete. These temporary timber formworks contribute no structural strength to the structure as they have to be removed after the concrete has hardened and gained sufficient strength to support itself and other loadings. Different structural members may have different sizes, thus many of these formworks may only be used once and have to be modified to be used again in other areas of the building. Modification and stripping of the formworks can be time consuming and have no real value to the building itself. After being used multiple times, timber formwork could deteriorate and loses its geometrical and structural strength integrity, thus need to be replaced by new formworks. Replacements can increase the construction cost and there is also wastage from the old formworks that needed to be properly managed. Many irresponsible contractors discard the old formworks through open air burning, which contributed to air pollution.

As construction industry is booming, there are more demand for faster and better quality construction methods, which should also generate less wastage. One of the method for fast and quality construction is through prefabrication in the controlled environment of a plant. Precast concrete production eliminates the use of temporary timber formwork, as they are produced by using steel or aluminum formworks in the plant. Steel or aluminum formworks do not deteriorate like timber after being used multiple times and they can be recycled, thus resulting in no wastage. Although there is no wastage, construction time is still similar to the conventional method as the metal formworks needed to be stripped off after the concrete has hardened. To further shorten the construction time in concrete buildings, permanent formworks are therefore more advantageous to be used compared to temporary formworks.

1.2 Problem Statement

Conventional cast in-situ pad footings require timber formwork. This method of construction generate waste as timber formwork could deteriorate after a certain amount of usage. When timber formwork loses its geometry and strength integrity, the resulting pad footing also could have undesired geometry and size. Conventional cast in-situ pad footings also require longer construction time as the timber formwork need to be stripped off after the concrete has hardened. A new method of construction is needed to eliminate the use of timber formwork for time, cost and environmental benefits.

Although it is widely acknowledged that composite construction can speed up construction time and have better structural performance compared to traditional reinforced concrete and steel, there are still comparably very few construction projects that utilize composite construction that consists of thin-walled steel skin with infilled concrete. One of the main reasons is that these type of structures have not been researched extensively and there are no well-established design codes dedicated to designing concrete infilled thin-walled steel structural elements for current practicing engineers as a guide. Most of the research done on concrete infilled thin-walled steel have been focused on application in column, beam and slab construction. As a result, some infilled thin-walled steel construction can be found applied to column, beam and slab construction in certain countries, where high structural performance and fast construction time are highly valued.

Application of infilled thin-walled steel in foundation structure construction has not been reported before the research of Wong (2009), which focused on the structural behaviour of the composite pad footing with cold-formed lipped steel section (CFS) as both permanent formwork and reinforcement. After the research shows promising results in this type of construction, where the composite footing performed better than the theoretical calculations based on BS8110, a prototype building was constructed in the compound of Universiti Teknologi Malaysia (UTM), Skudai with this novel type of composite pad footing as its foundation structure. However, Wong's study did not include the stumps using CFS as permanent formwork and reinforcements. Also, the study was done in accordance to the requirements of BS 8110-1:1997, which is now superseded by the BS EN 1992-1. Thus, a new study of pre-fabricated pad footing using cold-formed lipped steel section designed to the requirements of BS EN 1992-1 is required.

1.3 Research Objectives

The objectives of this research are:

1. To study the structural behaviour of the square and rectangular pad footings together with its stump, using CFS as permanent formwork and reinforcement through experimental tests.
2. To validate the behaviour of the proposed construction method through comparison of the experiments results and the design requirements of BS EN 1992-1.

1.4 Research Significance

The importance of this research are:

1. Validation of the suitability of a well-established design code such as BS EN 1992-1 in predicting the most relevant structural resistances, such as moment and shear resistances of CFS pad footing.
2. Allow practicing engineers to design CFS pad footing conventionally as a reinforced concrete in accordance to BS EN 1992-1 confidently.

3. Improve construction cost and time through the usage of CFS composite pad footing in the building industry.
4. Reduce material wastage and contribute to environmental friendly construction through the application of CFS composite pad footing by eliminating timber formwork.

1.5 Research Scope

The main focus of this research is on the two structural resistances of pad footing most relevant to structural design for industrial application, which are the moment and shear resistance. Thus, the scope of this research is:

1. Analyze the bending and shear resistances of CFS composite square 1m x 1m x 0.15m square pad footing and 1m x 1.75m x 0.15m rectangular pad footing through experiment which tests the footings to failure.
2. Compare experimental results to theoretical calculations based on the requirements of BS EN 1992-1, and establish the relationships between the two.

1.6 Organisation of the Writing and Terminologies

This section provides the general overview on how the research work has been carried out and also the presentation of the obtained result in this writing. Chapter 1 and Chapter 2 consist of the available information regarding composite construction background and information which lead to the idea of proposing a prefabricated pad footing. Chapter 3 covers on the experimental and theoretical aspects of pad footing, and related methodology to conduct the research work. Chapter 4 extended the works and presented results and discussion on the data acquired and analysed from the experimental works, and standardized table is prepared. Chapter 5 concludes the writing and the research work. While efforts have been made to present the research work and the results as clearly as possible, it is the writer’s concern that undefined terms might cause confusion. Therefore, all symbols, abbreviations, and notations used in this writing can be referred as listed in the front of this thesis.

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