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

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To my family and people who inspired me,

"Courage is going from failure to failure without losing enthusiasm." , *Winston Churchill.*

Thank you for everything!

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ABSTRACT

Conventional pad footing foundations are built using traditional method of reinforced concrete and utilising wooden formwork. This wooden formwork often encounters problems such as the formation of rectangular shape which is not consistent, the use of timber which is not environmental friendly and not contributing to the strength, the excessive use of labour to construct, and the difficulty to cast during rainy season. As a result, this method tends to slow down the construction time and affect the quality of the product. Thus, an approach to apply the concept of pre-fabrication and composite construction into the construction of pad footing foundation has been introduced by using cold-formed steel (CFS) lipped channel sections to replace both the timber as formwork and steel bars as reinforcement. Currently, the conventional type of foundation is still widely used in local construction, and prefabricated composite pad footing concept is yet to be seen as an alternative usage in foundation systems. In order to investigate the structural behaviours of the pre-fabricated composite pad footing foundation, 18 specimens were tested consisting of 6 specimens of conventional footings, 4 specimens of CFS with A10 wire mesh as reinforcement, and 8 specimens of fully CFS with thickness varies from 150 mm to 200 mm, and length varies from 1000 mm to 1750 mm. All specimens were checked for punching shear, longitudinal shear, and bending moment. The experimental and theoretical calculations were carried out and comparisons were made. The results show good agreement between the experimental works and theoretical values with flexural and shear strength are much higher than the conventional pad footing. Therefore, it can be concluded that the proposed pre-fabricated composite pad footing foundation using CFS lipped channel sections is suitable to be used as pad footing.

ABSTRAK

Asas penapak tunggal lazim dibina secara tradisi dengan menggunakan konkrit bertetulang dan acuan kayu. Acuan kayu ini kerap kali mengalami masalah-masalah seperti pembuatan bentuk segi empat yang tidak seragam, penggunaan kayu yang tidak mesra alam dan tidak menyumbang kepada kekuatan penapak, keperluan tenaga buruh yang berlebihan untuk menyediakan acuan kayu serta kesukaran menuang ketika musim hujan. Akibatnya, kaedah tradisi membina penapak berkecenderungan melambatkan masa pembinaan dan menjejaskan kualiti produk yang dihasilkan. Oleh itu, suatu pendekatan untuk mengaplikasikan konsep pra-fabrikasi dan pembinaan komposit ke dalam pembinaan penapak tunggal diperkenalkan, dengan menggunakan keluli terbentuk sejuk dengan keratan berbibir sebagai kerangka acuan bagi menggantikan acuan kayu, dan sebagai tetulang penapak bagi menggantikan tetulang besi. Buat masa ini, penapak lazim masih digunakan secara meluas oleh industri pembinaan tempatan, dan konsep penapak tunggal komposit pra-fabrikasi masih belum dilihat sebagai suatu alternatif untuk diguna pakai dalam sistem pembinaan penapak. Untuk menyiasat kelakuan struktur penapak tersebut, 18 contoh telah diuji, yang terdiri daripada 6 penapak biasa, 4 penapak keluli terbentuk sejuk dengan tetulang jejaring dawai A10, dan 8 penapak keluli terbentuk sejuk sepenuhnya, dengan sela ketebalan daripada 150 mm ke 200 mm, dan sela panjang daripada 1000 mm ke 1750 mm. Semua contoh telah disemak terhadap ricihan tebuk, ricihan berbujur, serta momen lenturan. Kerja-kerja ujikaji dan pengiraan teori telah dijalankan dan perbandingan telah dibuat. Keputusannya menunjukkan kesamaan yang baik di antara nilai daripada ujikaji dan nilai daripada pengiraan teori dengan kekuatan lenturan dan ricihan yang jauh lebih tinggi daripada penapak tunggal biasa. Oleh itu, boleh disimpulkan bahawa penapak tunggal komposit pra-fabrikasi menggunakan keluli terbentuk sejuk dengan keratan berbibir yang dicadangkan adalah sesuai digunakan sebagai penapak tunggal.

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LIST OF SYMBOLS

A_c	-	Cross section area of concrete
A_{cc}	-	Column Area
A_{pad}	-	Pad Area
A_{sb}	-	Cross section area of steel at major axis
A_{sc}	-	Cross section area of steel reinforcement in compression
A_{sca}	-	Cross section area of CFS used as reinforcement
A_{scb}	-	Cross section area of CFS used as formwork
A_{sw}	-	Cross section area of steel at minor axis
A_s	-	Cross section area of steel reinforcement in tension
b	-	Pad Breadth
b_v	-	Section breath of the pad
c	-	Thickness of concrete nominal cover
cc_x	-	Breadth of column
cc_y	-	Width of column
c_{sc}	-	Centroid of CFS
c_{sca}	-	Centroid of CFS used as formwork
c_{scb}	-	Centroid of CFS used as reinforcement
d	-	Effective depth of the pad
D	-	Height of CFS
D_a	-	Height of CFS section used as formwork
D_b	-	Height of CFS section used as reinforcement
d_c or d_{CFS}	-	Effective depth of outer CFS
F	-	Flange measurement of CFS
F_{ya}	-	Force act on left resulted from applied axial load
F_{yb}	-	Force act on right resulted from applied axial load
f_{cu}	-	Characteristic strength of concrete
f_y	-	Characteristic strength of steel

f_{yc}	-	Characteristic strength of CFS
G_k	-	Characteristic dead load
h	-	Pad Height
K	-	Factor based on simplified stress block
L	-	Pad Length
M	-	Moment
M_x	-	Moment acting on major axis
M_y	-	Moment acting on minor axis
N	-	Axial load
P	-	Pressure
p_y	-	Design strength of steel
Q_k	-	Characteristic imposed load
S_v	-	Spacing between link bars placement for stump/column
t	-	Steel Thickness
U	-	Critical parameter, 1.5d away from the stump/column
U_o	-	Stump/Column perimeter
w	-	Pad Width
V	-	Design shear force due to ultimate loads
v_c	-	Design concrete shear stress
v_{max}	-	Maximum design shear stress
z	-	Lever arm
%	-	Percent
=	-	Equals to
+	-	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
π	-	*Pi* = 3.14159
γ_m	-	Partial safety factor for concrete
$Ø_{bar}$	-	Diameter of steel bar reinforcement
$Ø_{min}$	-	Minimum required diameter of steel reinforcement.

LIST OF NOTATION

A10	-	Wire mesh, diameter 10 mm and spacing 200 mm × 200 mm
A.1510	-	Case 2 specimen label. A indicating A10 wire mesh; first and second digits reflect thickness of pad,15 = 150 mm; third and fourth digits reflect breadth of pad, 10 = 1000 mm
C.1510	-	Case 3 specimen label. C indicating fully CFS; first and second digits reflect thickness of pad,15 = 150 mm; third and fourth digits reflect breadth of pad, 10 = 1000 mm
C25	-	Grade of concrete: 25 N/mm^2 characteristic strength
C35	-	Grade of concrete: 35 N/mm^2 characteristic strength
$F_{V\ 1.0d}$	-	Loading when shear failure happens at 1.0*d* away from stump/column face
$F_{V\ 1.5d}$	-	Loading when punch failure happens at 1.5*d* perimeter away from column face
$F_{V\ max}$	-	Loading when punch failure happens at stump/column Perimeter
$F_{Mx\ max}$	-	Loading when failure happens due to bending moment
KS10016C	-	Name of CFS section, refer to Table 3.1 and Table 3.2
KS15016C	-	Name of CFS section, refer to Table 3.1 and Table 3.2
KS20016C	-	Name of CFS section, refer to Table 3.1 and Table 3.2
R6	-	Stump/Column link bars with 6 mm diameter
T10	-	Stump/Column reinforcement bar with 10 mm diameter
T.1510	-	Case 1 specimen label. T indicating conventional; first and second digits reflect thickness of pad,15 = 150 mm; third and fourth digits reflect breadth of pad, 10 = 1000 mm

LIST OF ABBREVIATION

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
mm^2	-	Unit of measurement: millimeter square
MPa	-	Unit of measurement: Mega Pascal, equivalent to N/mm^2
N	-	Unit of measurement: Newton
N/mm^2	-	Unit of measurement: Newton per millimeter square, equivalent to MPa
vs	-	Versus

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The on-going demands of construction industry for faster construction process, economical viability, better quality, higher performance and standardised construction method are enhancing the prefabrication concept and gaining in popularity. Being one amongst the prefabrication concept, composite construction has becoming popular in both research and practical aspects. As the concept is commonly understood within the context of building and other civil engineering structures, composite construction implies the use of steel and concrete formed together into a component resulting an arrangement functioned as a single item (Nethercot, 2003).

Cold-Formed Steel (CFS) is commonly used in prefabrication and composite construction for structural application. However, the use of thin plate should be considered with precautious. The thin plate is normally associated with the failure of local buckling before the section reaches yielding point. It tends to buckle elastically under low compressive stress, and also has low torsional stiffness. CFS sections which are braced against lateral or torsional-fllexural buckling may undergo distortional buckling.

In composite construction, formworks are used to provide support and containment for fresh concrete, without exception. Formworks mold the concrete to the desired shape and size, and control its position and alignment. Besides, formworks are functioned to support load of fresh concrete, construction materials, equipment, workers and various impacts loading (Hanna, 1999). Functioning as a structure that transfers loads to the ground, foundations can be generally divided into two categories, namely shallow foundations and deep foundations, depending on depth of load-transfer member and type of load transfer mechanism. Shallow foundation construction is by far the most popular for residential and light commercial building.

Currently, the conventional type of foundation known as pad footing is still widely used in local construction, and prefabrication concept is yet to be seen as an alternative used in foundation systems. Similar to other construction, prefabricated foundations also need to use mold or formwork to provide support and containment for fresh concrete before it is hardened. However, a permanent formwork is functioned not only as formwork but also contributes to strength.

The use of CFS in pad footing to act as permanent formwork seems more beneficial provided that the composite reaction could contribute to the strength. The practice of integrating CFS into pad footing is yet to be established and issues related to the design method, materials saving, time saving, and workability need to be addressed. Furthermore, the advantages of using CFS as permanent formwork as compared to conventional wood and reinforced concrete construction in pad footing structure needs to be investigated. The results derived from the study could be used as a standardised design for the newly proposed foundation system of pre-fabricated composite pad footing.

1.2 Problem Statement

The use of prefabrication for the construction of foundation structures is still low compared to conventional footing method. Therefore, there is a need to encourage local builders and designers to implement this concept in order to speed up the construction time, reduce material usage, and also to guarantee the quality of the construction. The use of prefabricated pad footing is hoped to enhance the global competitiveness of local builders and designers while the dependency of foreign labours could be reduced. This can be achieved by conducting full scale testing and developed design guide for typical soil bearing for footing design.

1.3 Research Objectives

Research objectives of the proposed composite pad footing are listed as follows:

i. To propose a new construction method for composite pad footing system using CFS lipped channel sections.

ii. To analyse and evaluate the performance of the proposed pre-fabricated composite pad footing by carried out analytical studies and experimental tests.

iii. To validate the performance of the proposed construction method for pre-fabricated composite pad footing foundation by comparing experimental results with the design requirements as stated in British Standard BS 8110-1:1997.

iv. To prepare the standardised table for the proposed pre-fabricated composite pad footing according to the typical soil bearing capacity.

1.4 Research Significance

The use of composite construction in buildings has known to increase the loading capacity and stiffness. With reduced materials usage resulting more slender floor depths and quicker construction (Wright, 2003), these advantages of composite structures have contributed to the dominance of composite beams in commercial building construction. Studies conducted on composite construction have proven the savings in material usage while achieving the required strength. By utilising cold-formed steel in pre-fabricated configuration, faster construction time and shape uniformity could be achieved. Based on these assumptions, this study intends to look into the structural behaviour of pre-fabricated pad footing foundation constructed using cold-formed steel lipped channel section, which could be an alternative to replace the conventional pad footings currently used.

1.5 Research Scope

The scope of the study is limited to the analysis of construction method using cold-formed steel section for foundation system by taking into account of the structural performance. The structural performance is focused on the shear and bending failure. Maximum load derived from these failure loads will determine the load capacity of the proposed footing. The proposed foundation system is only limited to square and rectangular pad footings. Experimental tests and analytical studies are to be carried out to evaluate the performance of the proposed steel section by comparing experimental results with the design requirements, as stated in British Standard BS 8110-1:1997, BS 5950-3:1990 and BS 5950-5:1998. The study carried out experimental tests on 18 specimens divided into 3 cases. Details of the specimens are further elaborated in Chapter 3. At the date of this writing, British Standards and Eurocodes are still in coexistence period (BSI, 2004), and hence only British Standard Codes are considered in the design.

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 available information regarding composite construction background which lead to ideas of the proposed pre-fabricated composite pad footing. Chapter 3 covers on the experimental and theoretical aspects for conducting the research work. Chapter 4 presents results and discussion on the data acquired from the experimental works, and how standardized table is prepared. Chapter 5 concludes the finding of the research work.