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

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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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f_{yc}	-	Characteristic strength of CFS
Gk	-	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
My	-	Moment acting on minor axis
N	-	Axial load
P	-	Pressure
p_y	-	Design strength of steel
Qk	-	Characteristic imposed load
S_v	-	Spacing between link bars placement for stump/column
t	-	Steel Thickness
U	-	Critical parameter, 1.5*d* away from the stump/column
U_0	-	Stump/Column perimeter
w	-	Pad Width
V	-	Design shear force due to ultimate loads
v_c	-	Design concrete shear stress
Vmax	-	Maximum design shear stress
z	-	Lever arm
%	-	Percent
=	-	Equals to
+	-	Plus, or Mathematical operator: plus
-	-	Dash, or Mathematical operator: minus
x	-	Mathematical operator: multiply
-5- or /	-	Mathematical operator: divide
A	-	Mathematical operator: to the power of
V	-	Mathematical operator: square root of
7i	-	*Pi* = 3.14159
y_m	-	Partial safety factor for concrete
0bar	-	Diameter of steel bar reinforcement
0_{mm}	-	Minimum required diameter of steel reinforcement.

LIST OF NOTATION

A10	Wire mesh, diameter 10 mm and spacing 200 mm x 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
Fvi.Od	Loading when shear failure happens at 1.0d away from stump/column face
Fvi.5d	Loading when punch failure happens at 1.5d perimeter away from column face
Fv max	Loading when punch failure happens at stump/column Perimeter
Fmx 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/mra^2
N	-	Unit of measurement: Newton
N/mm	-	Unit of measurement: Newton per millimeter square, equivalent to MPa
vs	-	Versus

LIST OF APPENDICES

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.

CHAPTER 2

LITERATURE REVIEW

2.1 Background on Composite Construction

The use of composite construction in buildings has known to increase the loading capacity and stiffness of the composite construction. The benefits of using composite construction in composite beams can provide significant economy through reduced steel weight, reduced floor depths and quicker construction (Wright, 2003). These advantages of composite beam have contributed to the dominance of composite beam in the commercial building in steel construction industry.

To enhance further the advantages of composite construction, this thesis has extended the research work to composite pad footing. The composite action in pad footing is due to the interaction of cold-formed steel section (CFS) lipped C-channel sections with normal concrete. The proposed composite pad footing is expected to enhance further the moment resistance and the shear capacity. However, the moment resistance and the stiffness of the footing can only be understood by carry out full scale testing for both the conventional reinforced concrete pad footing and the proposed composite pad footing. Six specimens for the conventional reinforced concrete pad footing, four specimens for the proposed composite pad footing with wire mesh reinforcement and CFS permanent formwork, and eight specimens for the proposed composite pad footing with fully CFS configuration were fabricated and tested. The results of moment resistance, shear, and axial load capacity of the specimens were compared and discussed in this thesis.

Nethercot (2003) reviewed that application of composite construction as early as 1894 which concrete encased beams were used in a bridge in Iowa and a building in Pittsburgh. Later on, other places such as Japan and Europe were seen of such practice in their construction. Documentation to govern the composite construction practice were documented since 1948 in BS 449 code and further extended in CP 117 code, and later replaced by BS 5950-3:1990.

Composite construction in Malaysia is currently being popularised under government effort by introducing comprehensive national Industrialised Building System (IBS) by the Construction Industry Development Board Malaysia (CIDB). Badir-Razali building system classified composite construction system as shown in Figure 2.1 (Badir *etal.,* 1998).

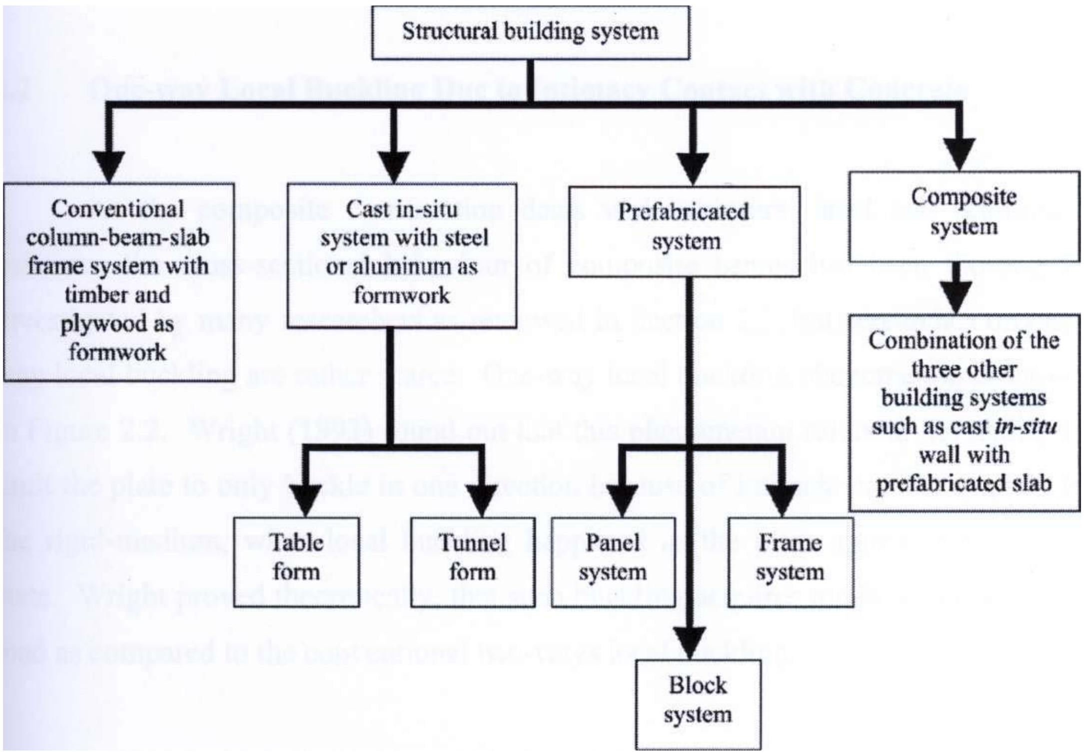


Figure 2.1 Badir-Razali building system classification

Various efforts have been made to benefit the composite construction in Malaysia. Abdul Kadir *et al.* (2006) found significant improvement in labour productivity using IBS rather than conventional building system by up to 70%. Badir *et al.* (2002) found that quality, speed of construction, and cost savings are the main advantages of IBS. However, Abdul Kadir *et al.* (2006) pointed out that IBS is still not preferred because of cost factors, and this is further supported by of Haron *et al.* (2005) which reported cost per gross floor area (m^2) of conventional construction system is lower as compared to composite construction system of single storey low cost house.

According to the Industrialised Building Systems (IBS) Roadmap 2003-2010, IBS is a construction process that utilises techniques, products, components, or building systems which involve pre-fabricated components and on-site installation. The composite pad footing is good to fit into two of the five IBS main groups identified in Malaysia, namely the pre-cast concrete systems and the steel formwork system.

2.2 One-way Local Buckling Due to Intimacy Contact with Concrete

As the composite construction deals with structural steel and reinforced concrete, the cross-sectional behaviour of composite beams has been thoroughly investigated by many researchers as reviewed in Section 2.3, but researches on one-way local buckling are rather scarce. One-way local buckling phenomenon is shown in Figure 2.2. Wright (1993) found out that this phenomenon refers to the ability to limit the plate to only buckle in one direction because of intimate contact of plate to the rigid-medium, when local buckling happened as the plate approaching failure state. Wright proved theoretically, that such buckling acquires much larger buckling load as compared to the conventional two-ways local buckling.

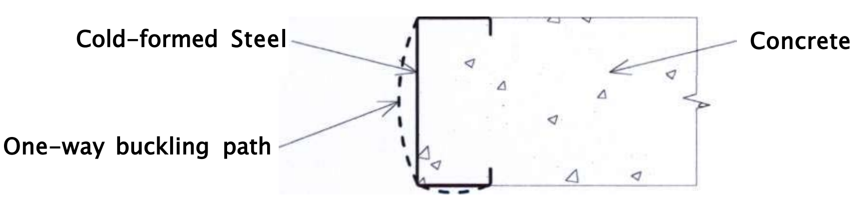


Figure 2.2 One-way local buckling due to intimate contact with rigid medium

Wright (1993) also stated that steel sections could be comprised of two main plate types namely plates supported on both sides (internal elements) and plates supported on one side only (external or outstand elements). Generally, the length of the plates is assumed much longer than their width and once compressed the plates will deform into a free wave. Wright (1995) also formulated the approximate mathematical expressions to illustrate such one-way local buckling phenomenon. The assumed plate buckling shapes is shown in Figure 2.3. As the plates connected to rigid medium, buckle can no longer develop into a simple, sinusoidal wave form. There are two possible wave patterns for the buckled plate to deform. The first occurs when the connection is staggered, and the second occurs when the connection is uniformly spaced.

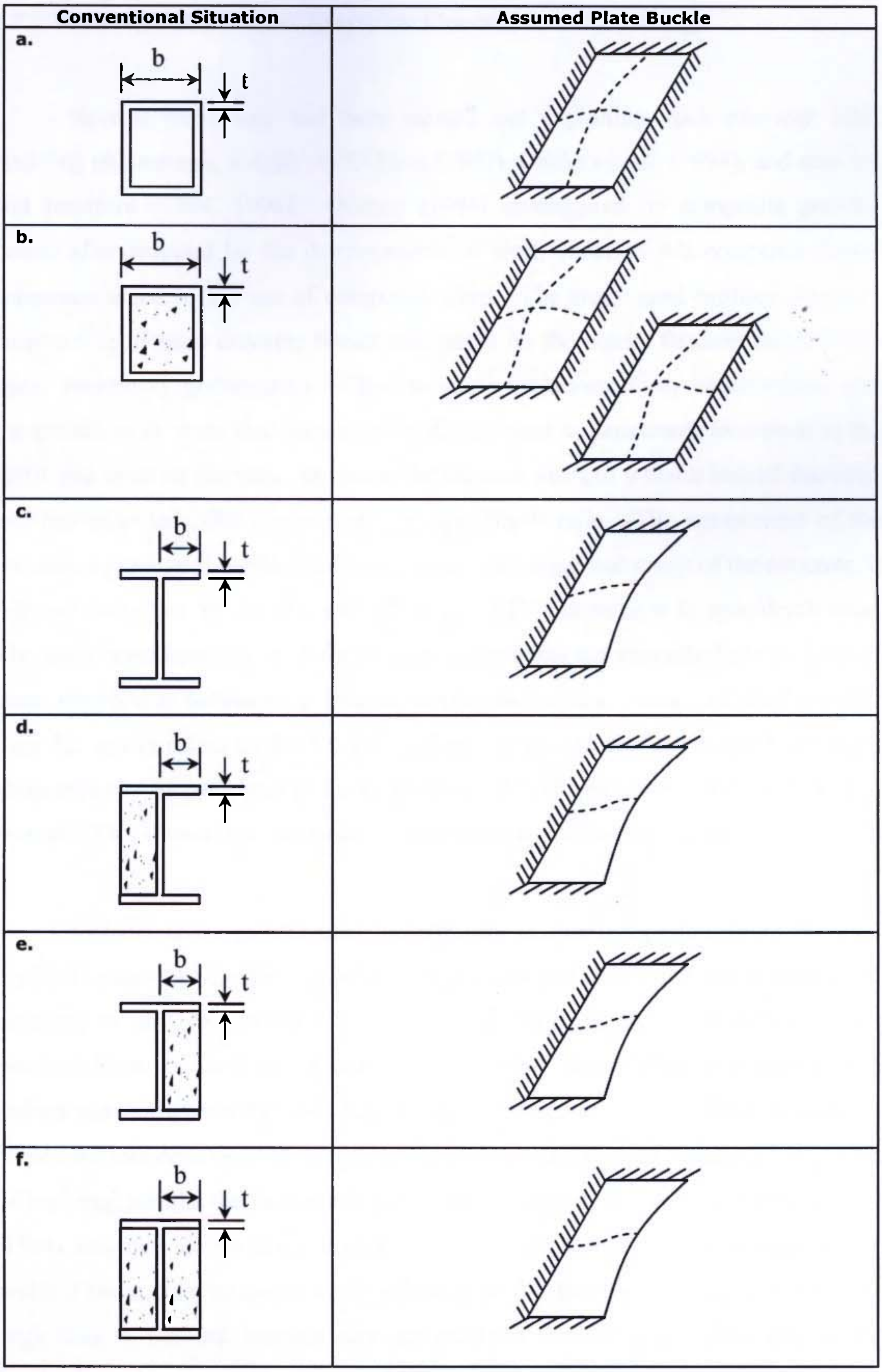


Figure 2.3 Assumed buckling shapes for outstanding flanges subject to uniform compression formulated by Wright (1995)

2.2.1 Previous Researches Related to One-way Local Buckling

Several researches had been carried out exploiting such one-way local buckling phenomena, notably by Oehlers (1993), Oehlers *et al.* (1994), and also Uy and Bradford (1994, 1996). Oehlers (1993) investigated on composite profiled beams after inspired by the developments of steel, concrete and composite frame construction led to the use of composite slabs. The study used profiled sheets to construct reinforced concrete beams and tested on the beams flexural strength and shear resistance performance. The conclusions drawn from experimental and theoretical work were that the use of profiled sheets as permanent formwork to the soffit and sides of the beam increased the flexural strength without loss of ductility, and has recorded 30% improvement in span/depth ratio. The encasement of the concrete by the steel profiled decking reduces shrinkage and creep of the concrete, it reduced deflection up to 40% and allow up to 20% increment in span/depth ratio. The shear bond however were found to only increased the strength slightly. Loss of shear connection between the internal reinforced concrete beam and steel profiled sheet has minor effect on the flexural strength. Thus, the profiled beams have larger shear capacity as compared to the reinforced concrete beams with the same flexural strength. This shows that composite action benefited the profiled beams.

Oehlers *et al.* (1994) tried to formulate simple design procedure for their profiled beams. As the flexural behaviour of composite profiled beams is unique, the buckling of the profiled sheet in composite profiled beams is not behave as the standard forms of buckling of thin-plate elements. The steel plate is restricted to deform outwards from the concrete, and the fold lines act as fully fixed support. A procedure was developed to determine the onset of this type of buckling. This form of buckling permits the increase in the width of the plate up to 70%. Oehlers *et al.* (1994) also had shown that complete loss of the longitudinal shear strength of the profiled beam only causes a small reduction in the flexural capacity in contrast to large loss in flexural strength that occurs when there is a complete loss in the longitudinal shear strength of standard form of composite steel and concrete beams.

Uy and Bradford (1993) continued their effort to carry out experimental and theoretical study on local buckling of thin steel plates in composite construction based on their previous finite strip model (Uy and Bradford, 1996), to derive the design of composite profiled slabs, beams, walls and other composite steel-concrete structural elements. The comparison of theoretical model based on the finite strip method and experimental test results gave good accuracy.

De Andrade *et al.* (2002) carried out structural assessment of cold-formed composite structures, which consist of a full-scale experimental investigation to study the structural behaviour of composite steel beams made of CFS section shapes filled with reinforced concrete. They found out that the presence of reinforced concrete increased the inertia of the beam which has resulted to the increase in stiffer and consequently leading to smaller deflections than a non-composite solution.

Hossain (2005) presented his design on thin-walled composite-filled beams, which comprised of cold-formed open steel box sections with an infill of concrete. The study found out that strength of thin-walled composite beams was limited by compression buckling capacity of steel plate at the top of the open box section. Such strength can be enhanced by stiffening the compression steel plates at the open end of the box section.

Helena and Knight (2005) studied about hollow and concrete-filled CFS section subjected to axial and bending forces. They found out from their experiment that the provision of in-fill substantially increases one and a half to two times of the ultimate load carrying capacity using low grade concrete of C25, and one and a half times of the ultimate load carrying capacity by using high grade concrete of C35.

Prabhavathy and Knight (2006) also studied on behaviour of CFS concrete infilled rectangular hollow sections connections and frames. Similarly, they found out that provision of concrete infill increases the stiffness and the ultimate moment carrying capacity substantially, irrespective of the axis of loading of the column.

Many previous researches clearly identified the advantage of composite action with coverage given to beams, columns and slabs as basic structure of building components. It should be interesting to implement such concept into foundation structure.

2.3 Foundation

Mosley *et al.* (1999) stated that foundations are used to transfer and spread the loads from a structure's columns and walls into the ground without exceeding safe bearing capacity of the soil. Although foundations exist in considerable variety, BS 8004:1986 broadly grouped them into three main types: shallow foundations; subaqueous and deep foundations/pile foundations.

Das (1999) stated that individual square or rectangular footings which support columns, and strip footings which support walls and other similar structures are generally referred to as shallow foundations. Mat foundations, also considered shallow foundations, are reinforced concrete slabs of considerable structural rigidity which support a number of columns and wall loads. Piles and drilled shafts, which are considered deep foundations, are used when the soil located immediately below a given structure is weak.

Chai (2003) defined shallow foundation as one in which the foundation depth is less than or on the order of its least width. Common types of shallow foundations include spread footings, strap footings, combined footings, and mat or raft footings. Shallow foundations or footings provide their support entirely from their bases, whereas deep foundations derive the capacity from two parts, skin friction and base support, or one of these two.

Arumugasaamy (2006) classified structural foundations into 6 types: the isolated spread footings; wall footings; combined footings; cantilever footings; mat, raft, or continuous footings, and also pile foundations. Pad footing foundation is a simple yet important shallow foundation structure, consisting of rectangular or square pad and a column sitting on the middle of the pad's top. Figure 2.4 shows some examples of shallow foundations.

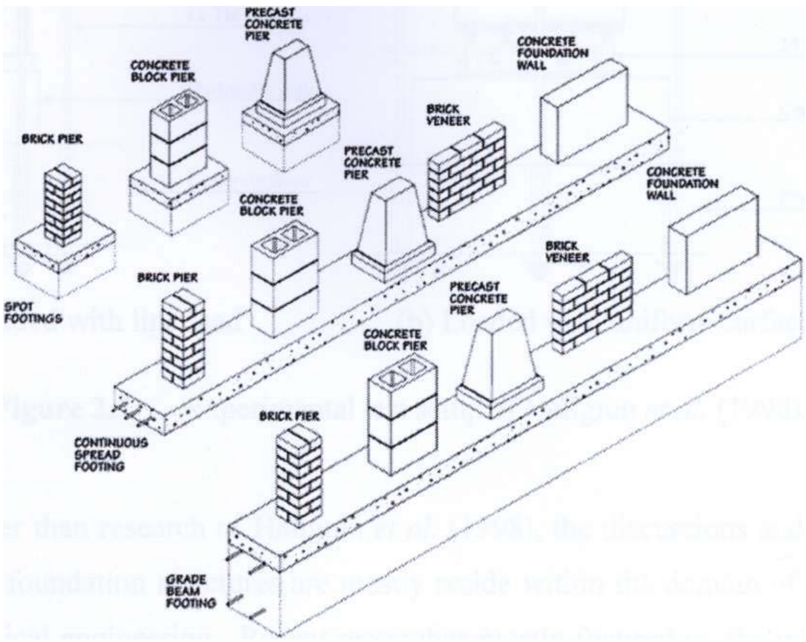
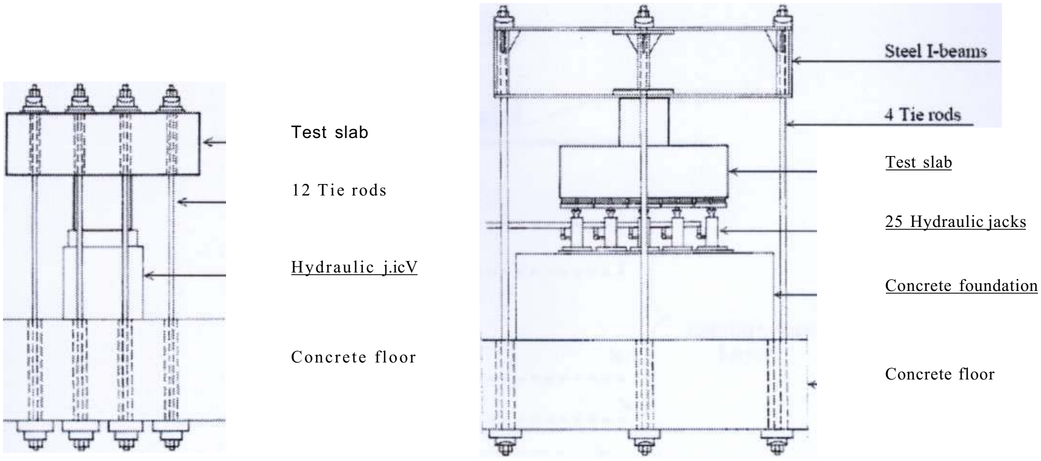


Figure 2.4 Types of shallow foundation

2.3.1 Previous Researches Related to Pad Footing

Hallgren *et al.* (1998) carried out research of punching shear tests on column footings in structural approach. They reported about 14 column footings of reinforced concrete considering main variables of concrete strength, ratio of flexural reinforcement, type of anchorage of the reinforcement and type of shear reinforcement. Their tests showed that concrete strength had a strong influence on the punching shear strength. Ratio of flexural reinforcement only slightly influenced the punching shear strength, and type of anchorage did not influence the punching shear strength. Figure 2.5 shows their experimental test setup.



(a) Loaded with line load (b) Loaded with uniform surface load

Figure 2.5 Experimental test setup of Hallgren *et al.* (1998).

Other than research of Hallgren *et al.* (1998), the discussions and researches concerning foundation structures are mostly reside within the domain of knowledge in geotechnical engineering. Recent researches mostly focused on the interaction of foundation structure to soil, its load transfer mechanism and ground improvement technique using geotextile to improve the performance of the foundation structure.

Research carried out by Das and Sivakugan (2007) on the settlements of shallow foundations on granular soils reviewed the current state-of-the-art for predicting settlements of shallow foundations in granular soils and also critically reviewed the traditional settlement prediction methods. They found that uncertainty in settlement prediction is due to designers' inability to quantify the soil stiffness correctly.

Experimental and numerical study by Chung and Cascante (2007) found that the effect of location and number of soil reinforcement was inter-related and by increased the number of reinforcement layers, the bearing capacity and low-strain soil stiffness could be improved significantly. Figure 2.6 shows their experimental tests setup.

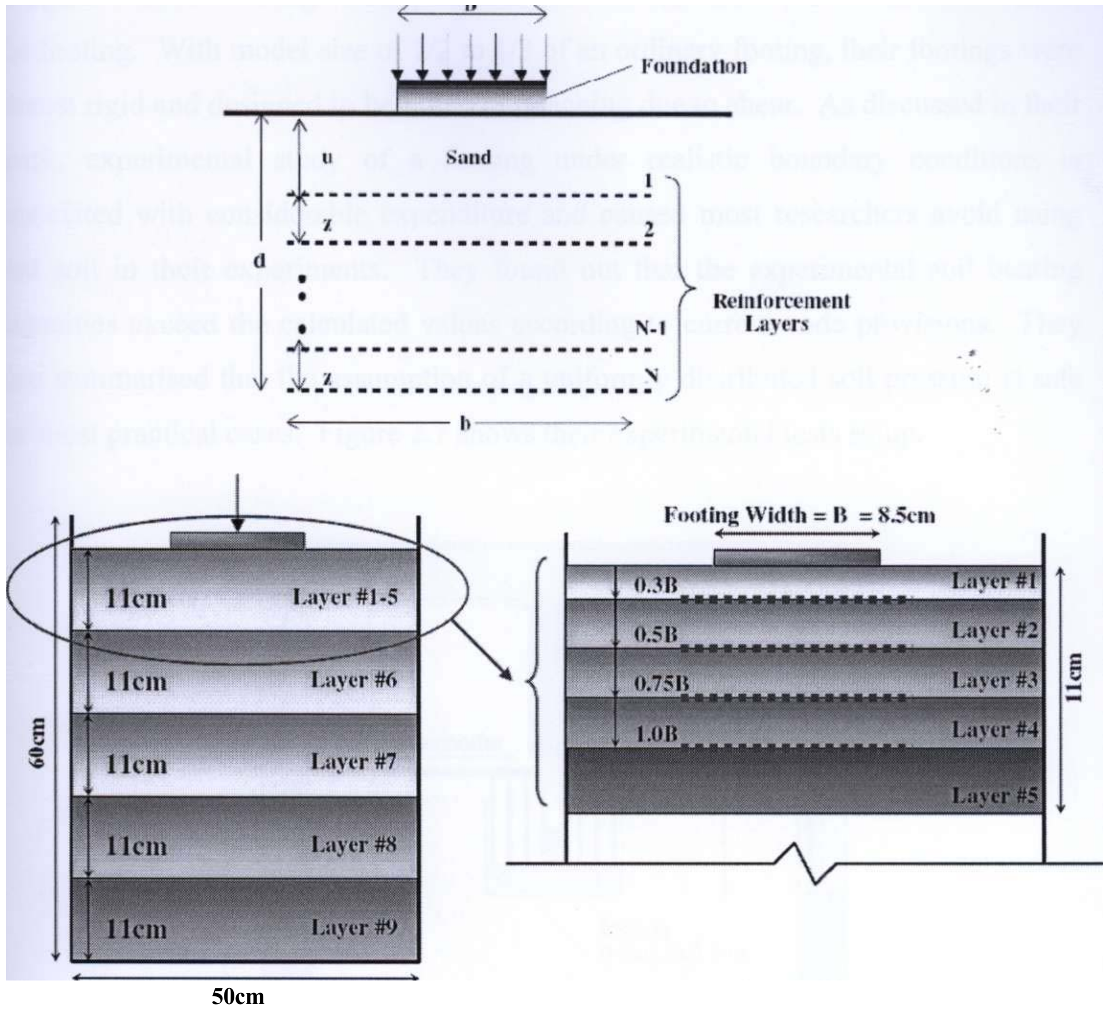
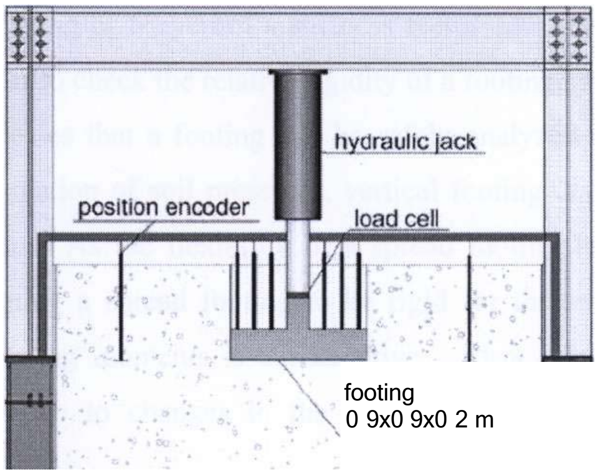


Figure 2.6 Test setup of rigid footing by Chung and Cascante (2007).

Finding of di Prisco *et al.* (2001) in their work of numerical analysis of rigid shallow foundations on geo-reinforced soil strata was that the use of geo-reinforcements seems to be more promising for foundations with inclined or eccentric loads.

Researches of Chung and Cascante (2007) and di Prisco *et al* (2001) assumed a rigid footing condition for their work. They used model footings fabricated from metal such as aluminium or steel plates in their laboratory scale tests.

Hegger et al. (2007) carried out investigations on the punching behaviour of reinforced concrete footing on top of a reasonably homogeneous sand bed to derive a design model for footings taking into account the soil stress distribution underneath the footing. With model size of 1/2 to 1/3 of an ordinary footing, their footings were almost rigid and designed to be failed in punching due to shear. As discussed in their work, experimental study of a footing under realistic boundary conditions is associated with considerable expenditure and caused most researchers avoid using real soil in their experiments. They found out that the experimental soil bearing capacities exceed the calculated values according to current code provisions. They also summarised that the assumption of a uniformly distributed soil pressure is safe for most practical cases. Figure 2.7 shows their experimental tests setup.



3.25

Figure 2.7 Test setup of Hegger et al. (2007).

2.3.2 Design Situation and Failure Mode of Pad Footing

Goldsworthy *et al.* (2004) stressed on the importance of site investigations on the design of pad footings. They found that the reduction of failure and over-design probability for site investigations with additional tests is more evident for increasingly random soils.

However, Tabsh and Al-Shawa (2005) mentioned that experience has shown the assumption of a linear pressure distribution is satisfactory for most cases because of the conservative load estimates and ample factors of safety in materials and soil. Due to some shortcoming of Meyerhofs stiffness factor equation, they proposed a relative stiffness factor to check the relative rigidity of a footing. A factor equal to or greater than 1.0 indicates that a footing can be safely analyzed as a rigid footing, including the determination of soil pressures, vertical footing displacements, shear, and bending moments. As the flexibility of a spread footing leads to lower load effects; hence, assuming a spread footing to be rigid for the sake of determining shear forces and bending moments is conservative. Also, they found that shear forces are less sensitive to changes in the stiffness of a footing than bending moments.

As governed in the standard code for foundation structure BS 8004:1986, the thickness of pad footing foundations should not be less than 150 mm, and they should be designed in accordance with the code of practice appropriate to the loading assumptions such as BS 8110. Also, footings resides on top of non-cohesive soils should have width of not less than 1 m.

According to Webster and Brooker (2006), foundations should be designed so that the soil safely resists the actions applied to the structure. The design of any foundation consists of two components; the geotechnical design and the structural design of the foundation itself. However, for some foundations such as flexible rafts, the effect of the interaction between the soil and structure may be critical and must also be considered.

Eurocode 7 recommends three Geotechnical Categories to assist in establishing the geotechnical design requirements for a structure. Firstly, for small and relatively simple structures, structural engineers can take sole responsibility of the geotechnical design. Secondly, conventional types of structures and foundations with no difficult ground or loading condition may undertake by members of either profession of structural or geotechnical engineers for the geotechnical design. Lastly, the geotechnical engineers have to take responsibility for structures other than these two.

According to review by Webster and Brooker (2006) on the Geotechnical Categories of Eurocode 7, risk of geotechnical failure is negligible for small and relatively simple structure. Also, there is no exceptional risk of geotechnical failure for conventional types of structure and foundation with no difficult ground or loading condition. Hence it is generally safe to assume a uniform distribution of soil pressure under simple pad footing.

Bond and Harris (2008) mentioned that spread foundations must be designed to withstand loss of stability owing to an applied moment, bearing failure, and sliding owing to an applied horizontal action; and structural failure of the foundation base and combined failure in the structure and the ground.

Nevertheless, as reviewed in previous section, researches assumed a rigid footing condition even though it is not necessarily so. The pad of a footing might still fail to withstand the applied load and suffer structural failure if not appropriately designed according to structural design codes, especially for a newly proposed configuration.

2.4 Development of Pre-fabricated Pad Footing

Researches in composite constructions were mainly concerning the basic component of a building like beams, columns, slabs, connections, and frames; but yet not extended into foundation structures. Researches in shallow foundations mainly assumed a rigid footing condition.

These relevant previous studies could be served as valuable guides to develop research work on structural performance of pre-fabricated pad footing. Given the scope of this research is on the structural performance, hence, only the structural aspects of the pad footing foundation will be considered for the research work, and it is covered in Chapter 3 Section 3.2 of this writing.

BS 8110-1:1997 covers design of reinforced concrete for structural elements of beam, slab, column, wall, staircase, and base. The code provisions the design shear strength and other design aspects for the pad footing to share the same calculation method. For the purpose of structural analysis, it could be generalised that pad footing can be simplified as a slab with a short column on its top.

BS EN 1990:2002 points out that in order to provide a structure that corresponds to the requirements and to the assumptions made in the design, appropriate quality management measures should be in placed. Thus, BS EN 14991:2007 provides evaluation of conformity to the completed precast foundation elements which are supplied to the market and covers all the production operations carried out in the factory with the design rules referred to BS EN 1990:2002.

2.5 Concluding Remarks

After review, it can be concluded that the concept of IBS and composite construction practise are becoming popular in Malaysia. However, the application of composite construction in building using cold-formed steel sections as pad footing foundation is very new and with the development of standardised table, the popularity of this system can be enhanced. By assuming a load applied at the column stump with the end of the footing is simply supported, the proposed pre-fabricated composite pad footing can be tested with relatively easier method for assessment of structural behaviour on bending and punching shear.

CHAPTER 3

EXPERIMENTAL AND THEORETICAL ASPECTS OF PAD FOOTING

This chapter discusses the experimental works carried out to investigate the performance of the proposed pad footing using cold-formed steel section (CFS) sections and the conventional reinforced concrete pad footing. The theoretical aspects for both the proposed and the conventional pad footings by considering moment, shear and axial capacities are also considered. The experimental and theoretical results are compared and discussed in details. The experimental works in the laboratory is divided into three cases which are Case 1, Case 2 and Case 3. The Case 1 specimens consists of 6 conventional reinforced concrete pad footing, the Case 2 specimens consists of 4 specimens with formwork using CFS and using A10 wire mesh as reinforcement bars, and the Case 3 specimens consists of 8 specimens with both the formwork and the reinforcement bars are from the CFS section. Figure 3.1 shows the illustration of the specimens for all the three cases. Tensile tests and cube tests are also carried out to investigate the material properties.

3.1 Specimens and Materials Details

A total of eighteen pad footing specimens were tested until failure and the results were recorded together with failure mode. Prior to commencement of the tests, several tests were carried out to investigate the material properties of concrete and steels. These were done so that the correct design mixture for concrete strength could be established and also the actual strength of steel could be achieved. Preparation of all specimens is covered in Section 3.3 of this thesis.

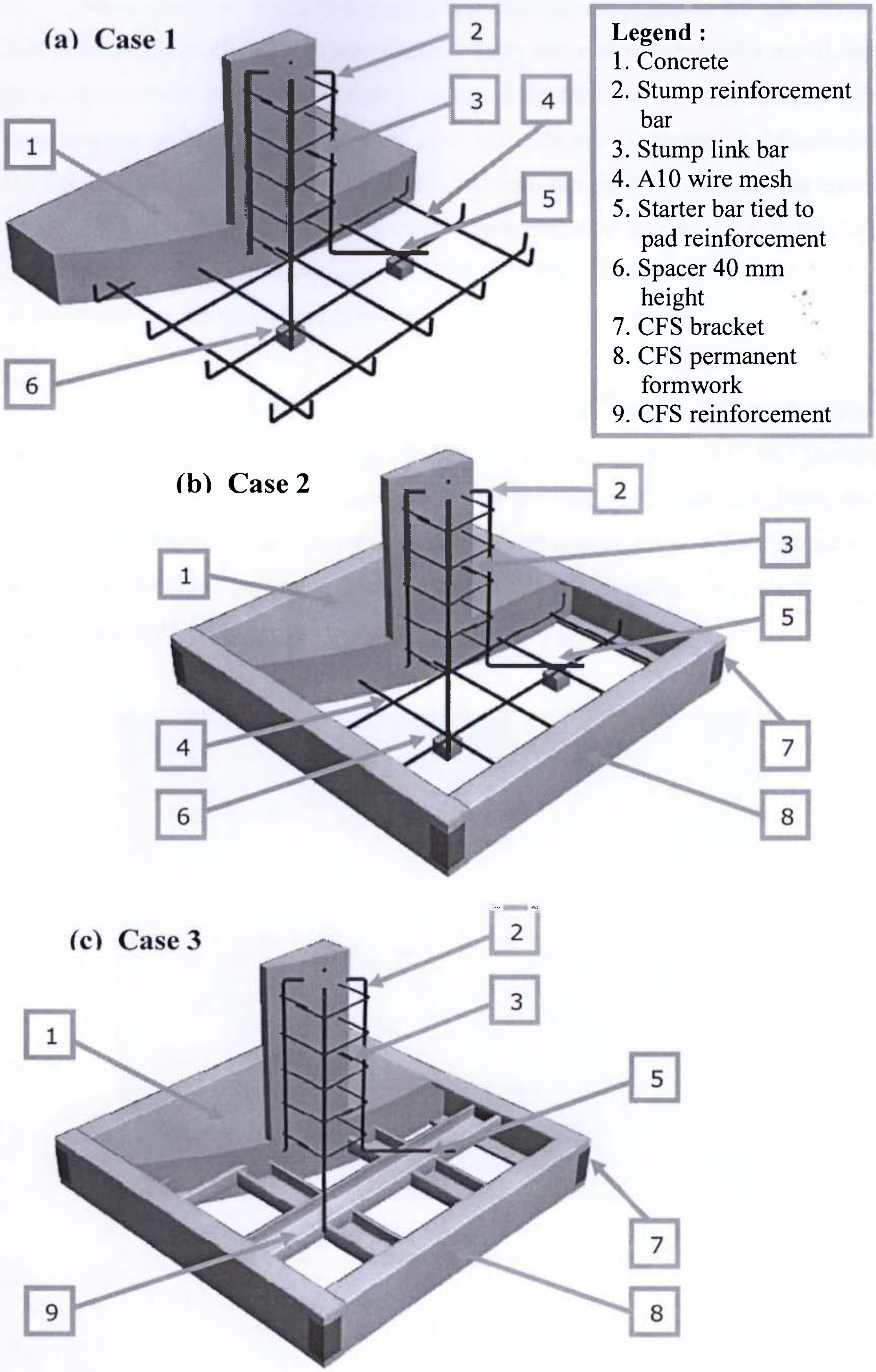


Figure 3.1 Illustration of (a) Case 1 specimen, (b) Case 2 specimen, (c) Case 3 specimen

For concrete strength, slump tests were carried according to BS EN 12350-2:2000 to ensure workability of the concrete. Only concrete which yield a true slump (a slump in which the concrete remains substantially intact and symmetrical) with measurement of 50 mm to 80 mm were used. Concrete samplings were conformed to BS EN 12350-1:2000. The mould of size 150 mm was used for cube casting based on BS EN 12390-1:2000. Cube tests were conducted after curing using TONIPAC 300 Testing Machine, in compliance to BS EN 12390-3:2000 for 7-day and 28-day to determine the strength of the concrete.

Figure 3.2 shows the cubes cast in the moulds and Figure 3.3 shows the cubes prepared for cube tests after casting. Figure 3.4 shows the TONIPAC 300 Testing Machine used for cube tests. Figure 3.5 shows the steel reinforcements, links, and CFS lipped channel sections prepared for tensile and coupon tests. Figure 3.6 shows a conventional graph generated from the tensile test to determine the properties and the characteristic values of the specimen.

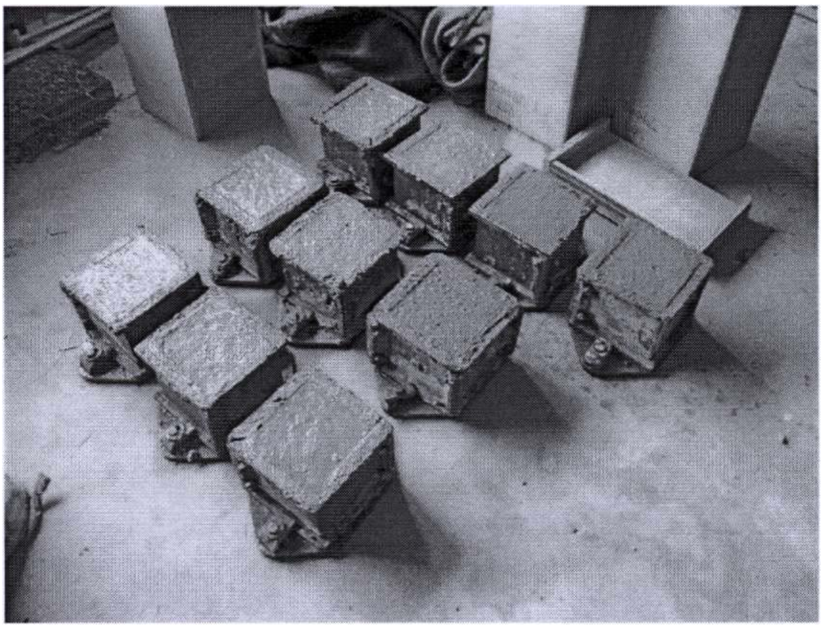


Figure 3.2 The cubes cast for the cube tests

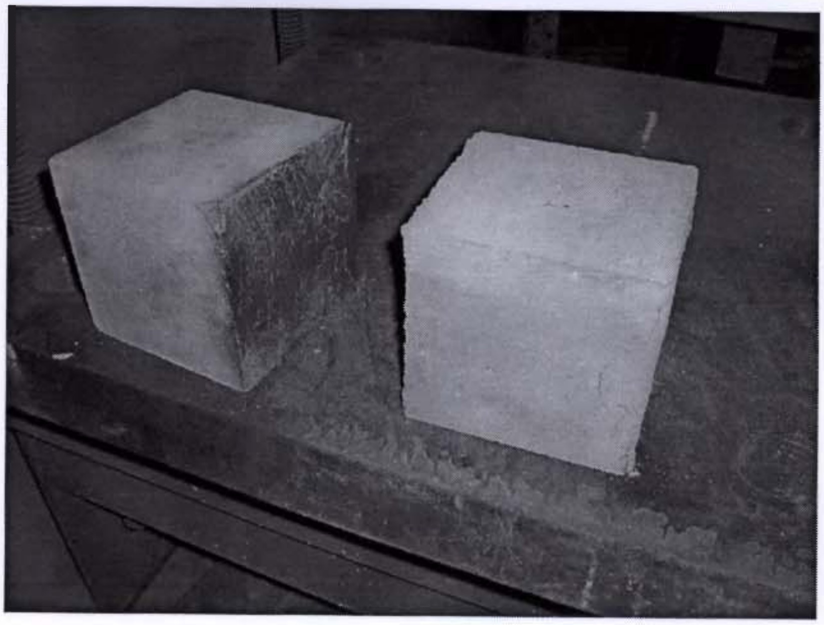


Figure 3.3 The cubes, size 150 mm, prepared for the cube tests

Figure 3.4 The TONIPAC 300 Testing Machine used for cube tests

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