UNIVERSITI PUTRA MALAYSIA

STRENGTH OF REDUCED SIZE MORTARLESS INTERLOCKING PUTRA LOAD BEARING HOLLOW BLOCK SYSTEM

MUNIRAH MOHD RAMLY

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By

MUNIRAH MOHD RAMLY

Thesis submitted to the School of Graduate Studies, Universiti Putra Malaysia, in fulfillment the requirement for the Degree of Master of Science

August 2015

To my dearest husband, Faidhil

And

To all my family members

Abstract of thesis presented to the senate of Universiti Putra Malaysia
in fulfillment of the requirement for the degree of Master of Science

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August 2015

Chairman : Professor Abang Abdullah Abang Ali, Ir.
Faculty : Engineering

Industrialized building systems (IBS) was first introduced in Malaysia in the early 60's as a prefabricated building systems. One of the five categories of IBS is the block wall building system. A mortarless interlocking hollow block (MIHB) wall system was developed in Malaysia by the Housing Research Centre of Universiti Putra Malaysia in 2001. The block system was named as Putra Block and it consists of three different units of block known as stretcher, corner and half block. Weight and strength of MIHB units are the most important properties that contribute to the strength of the block system. For Putra Block units, the average weight and strength of each block unit are 12 kg, 14 kg and 8 kg, and 17.2 N/mm^2, 19.2 N/mm^2, 17.0 N/mm^2 respectively for stretcher, corner and half blocks. Based on these properties, the blocks have been considered as heavy; thus it leads to a higher strength capacity than the minimum requirement of load bearing walls for low rise housing. Subsequently, it leads to a higher overall construction cost for a building. There were number of previous researches that have been carried out in order to produce lighter blocks. However, it was found that none of the previous relevant research has been conducted on MIHB. In this study, the aim was to develop a lighter and more suitable MIHB for applications of load bearing walls in low rise housing while conforming to minimum strength requirement according to BS 5628. Therefore, one of the objectives is to optimize the materials content of MIHB concrete and to reduce the bearing area of MIHB in order to achieve the aim of this research. The concrete materials content to be optimized were the ungraded quarry dust content and cement content. The number of joints in the masonry wall was maintained during the reduction of bearing area size due to the fact that the joints are the weakest part in a masonry wall. The important parameters have been considered were the minimum width of block shell and slenderness of a typical concrete wall. The theoretical and experimental work have covered the design of masonry block, selection of optimum concrete mix for new size block, testing of individual block subjected to compressive load and testing of MIHB wall panel under vertical compressive load. The reduced size MIHB with optimum concrete mix design has been found to perform sufficient required strength for load bearing walls of low rise housing. As a result, material contents optimization has contributed to a reduction of 4% in weight with 27% reduction in strength of MIHB. Furthermore, a significant weight reduction has been attained by bearing size reduction which is 20% in weight with smaller losses of 5%

in block strength. In summary, the combination of material contents optimization and bearing size reduction has significantly reduced the block weight meanwhile maintaining a sufficient strength capacity as load bearing blocks.

Abstrak tesis yang dikemukakan kepada senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Sarjana Sains

KEKUATAN SISTEM BLOK PUTRA BERONGGA TAHAN BEBAN SALING MENGUNCI TANPA MORTAR BERKURANG SAIZ

Oleh

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Ogos 2015

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Sekitar tahun 60an, sistem bangunan perindustrian (IBS) telah pertama kali diperkenalkan di Malaysia sebagai sistem pembinaan bangunan pasang siap. Salah satu kategori di bawah IBS adalah sistem dinding kerja blok. Suatu sistem dinding blok berongga saling mengunci tanpa mortar di Malaysia telah pertama kali dibangunkan oleh Pusat Penyelidikan Perumahan di Universiti Putra Malaysia pada tahun 2001. Sistem blok tersebut dikenali sebagai Blok Putra di mana ia terdiri daripada tiga unit blok yang berbeza dikenali sebagai *stretcher, corner* dan *half*. Berat dan kekuatan unit blok berongga saling mengunci tanpa mortar merupakan ciri paling penting yang menyumbang kepada kekuatan sistem blok tersebut. Bagi Blok Putra, secara puratanya berat dan kekuatan setiap unit blok adalah 12 kg, 14 kg dan 8 kg, dan juga 17.2 N/mm^2, 19.2 N/mm^2 dan 17.0 N/mm^2 masing-masing bagi unit *stretcher, corner* dan *half*. Berdasarkan ciri-ciri ini, blok tersebut dianggap sebagai blok berat seterusnya membawa kepada kapasiti berkekuatan lebih terutamanya bagi keperluan dinding tanggung beban untuk bangunan berketinggian rendah. Seterusnya, hal ini akan mengakibatkan kos pembinaan secara keseluruhan yang lebih tinggi bagi sesebuah bangunan. Terdapat beberapa penyelidikan terdahulu yang telah dijalankan bagi meningkatkan ciri keringanan sesuatu konkrit dan produk yang terhasil daripadanya. Walau bagaimanapun, tiada penyelidikan terdahulu yang dilaporkan yang mana berkaitan dengan topik ini telah dijalankan ke atas blok berongga saling mengunci tanpa mortar. Dalam kajian ini, tujuannya adalah untuk membangunkan sebuah blok berongga saling mengunci tanpa mortar yang lebih ringan dan lebih sesuai bagi aplikasi dinding rumah tanggung beban yang menepati keperluan kekuatan minima berdasarkan kepada BS 5628. Oleh itu, salah satu objektifnya adalah untuk mengoptimakan kandungan bahan-bahan bagi konkrit blok berongga saling mengunci tanpa mortar dan untuk mengurangkan keluasan tanggung beban blok berongga saling mengunci tanpa mortar bagi mencapai sasaran penyelidikan ini. Kandungan bahan-bahan konkrit tersebut yang akan dioptimakan adalah kandungan debu kuari tidak digredkan dan kandungan simen daripada segi per meter kiub. Di samping itu, jumlah sambungan dalam dinding kerja batu tersebut dikekalkan semasa pengurangan keluasan tanggung beban oleh kerana sambungan merupakan bahagian yang paling lemah bagi suatu dinding kerja batu. Parameter penting yang perlu diambil kira semasa proses pengubahsuaian saiz adalah kelebaran minima cengkerang blok, rongga blok dan kelangsingan dinding. Beberapa kaedah

kajian berdasarkan kiraan secara teori dan kerja eksprimen telah dijalankan. Ia meliputi pertimbangan rekabentuk bagi blok kerja batu, pemilihan campuran konkrit yang optimum bagi blok bersaiz baru, ujian blok individu yang dikenakan beban mampatan dan ujian beban mampatan secara menegak ke atas panel dinding blok berongga saling mengunci tanpa mortar. Kajian ini disimpulkan dengan penemuan blok berongga saling mengunci tanpa mortar yang diubah saiz beserta dengan campuran konkrit optimum yang mempunyai kekuatan mencukupi yang diperlukan bagi dinding tanggung beban untuk perumahan berketinggian rendah. Lantaran itu, pengoptimisan kandungan bahan-bahan telah menyumbang kepada 4% pengurangan dalam berat beserta 27% pengurangan dalam kekuatan bagi blok berongga saling mengunci tanpa mortar. Tambahan pula, suatu pengurangan berat yang ketara telah dicapai melalui pengurangan saiz tanggung beban di mana ianya adalah 20% pengurangan dalam berat beserta pengurangan yang lebih kecil sebanyak 5% dalam kekuatan blok. Secara keseluruhannya, kombinasi antara pengoptimisan kandungan bahan-bahan konkrit dan pengurangan saiz tanggung beban telah mengurangkan berat blok dengan ketara seterusnya kekuatan blok namun mengekalkan kapasiti kekuatan sebagai unit blok tanggung beban.

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Thank you!

I certify that a Thesis Examination Committee has met on 13 August 2015 to conduct the final examination of Munirah binti Mohd Ramly on her thesis entitled "Strength of Reduced-Size Mortarless Interlocking Putra Load Bearing Hollow Block System" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

MIHB	mortarless interlocking hollow block
f_{cb}	compressive strength of individual block
f_{cp}	compressive strength of individual prism panel
f_{cw}	compressive strength of individual wall panel
σ	value of instantaneous stress
ε	values of corresponding strain to instantenous stress
σ_o	values of ultimate stress
ε_o	values of corresponding strain to ultimate stress
p	material parameter
CFRC	coconut fibre reinforced concrete
LECA	lightweight expanded clay aggregate
A/C	aggregate to cement ratio
FEM	finite element method
F_k	characteristic load
G_k	dead load
Q_k	imposed live load
N_R	design vertical load resistance of wall
N	ultimate design load
γ_f	partial safety factor of loads
β	capacity reduction factor
f_k	characteristic strength of masonry
t	thickness of wall
γ_m	partial safety factor for material subject compression
CB	control block
RSB	reduced size block
OPC	ordinary Portland cement
F/C	fine to coarse sand ratio

w/c	water to cement ratio
UTM	universal testing machine
CB-W	control block wall panel
RSB-W	reduced size block wall panel
MC	control concrete mix
M5	optimum concrete mix (final)
L	length of wall panel
H	height of wall panel
LVDT	linear variable differential transducers
t_s	width of shell
t_{hk}	width of horizontal interlock key
t_w	width of web/vertical interlock key
A_b	bearing area
SR	slenderness ratio
h_{ef}	effective height of wall
t_{ef}	effective thickness of wall
CFRC	coconut fibre reinforced concrete
FBA	furnace bottom ash
NAC	normal aggregate concrete
WFW	wood fiber waste
RHA	rice husk ash
LPW	limestone powder waste

CHAPTER 1

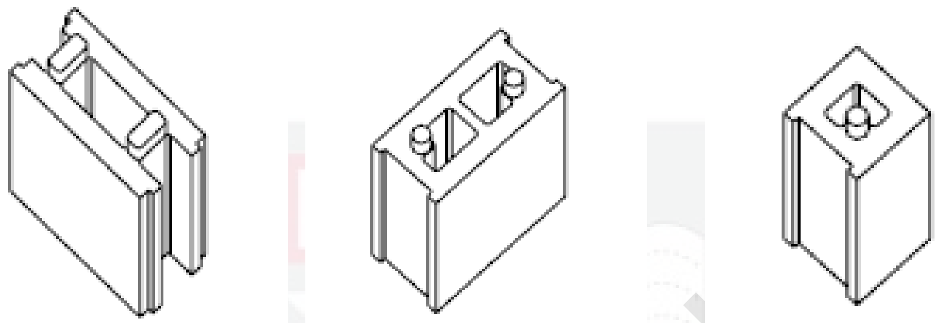
INTRODUCTION

1.1 Introduction

Masonry has been known as one of the oldest construction materials that parallel to human civilization. Masonry is categorized according to their types, application, strength, and structural performance. Masonry is also categorized as load bearing or non-load bearing units. In recent years, mortarless or dry stack masonry systems have been developed for use in the building construction industry. Mortarless masonry is a masonry system which the use of mortar as a binder between units has been eliminated. Instead, the mortarless masonry system uses an interlocking keys system in order to join the masonry units together. The interlocking keys can be placed in horizontal, vertical, or a combination of both directions. Due to the mortar elimination, some promising advantages have been achieved by this masonry system such as speedier construction time and reduction in the overall construction cost. Besides mortarless, other added value properties of masonry are hollow and load bearing. According to BS 6073, Part 1 (1981), hollowness of masonry units is defined as blocks or bricks having holes which pass through the units more than 25%. Despite being a solid block, hollow block has a better weight value and is more practical during construction practice and will result in a shorter construction period. Meanwhile, load bearing masonry has been defined in Eurocode 6, Part 1-1 (2005) as a masonry system which is primarily designed to take a certain amount of imposed load other than its own weight. Although the hollowness property has resulted in lightweight block, the structural performance of the hollow block system to act as load bearing units has scientifically proved.

Amongst all masonry systems, one of the most important masonry developments is the mortarless interlocking hollow block, hereinafter denoted as MIHB, which offer some advantages such as hollowness, mortarless, and being lightweight. In Malaysia, a MIHB system known as Putra Block has been invented by the Housing Research Centre of Putra Malaysia University. Several studies related to the Putra Block system have been reported since 2001 (Jaafar et al., 2006) (Thanoon et al., 2004) (Thanoon et al., 2008) (Safiee et al., 2009). Disparate to the mortared masonry, the Putra Block system had been designed with interlocking keys in order to connect adjacent units or between two successive layers of block units. In contrast to the solid block, the block had been optimized with voids which subsequently reduced the weight of the hollow block unit. The hollow block also provides a better sound insulation and good thermal conductivity.

Putra Block system is a precast system consisting of three different units, namely stretcher, corner, and half as shown in Figure 1.1. Each unit has different characteristics in terms of geometrical feature and function in a wall system. In general, the stretcher unit is the main unit to be used in the construction of masonry walls. It also plays a major role in resisting loads subjected to a wall. The other two units also have their specific functions. The corner unit has the function of connecting two or more cross walls at a junction, while the half unit has the function of a complementary unit prior to the completion of a wall course. The unique feature of this block system is the use of interlocking keys comprising of a couple of protrusions and grooves in order to eliminate the use of mortar. The interlocking keys were designed to govern the shear area parallel to z-axis and it also provides the horizontal interlock parts that govern the shear area parallel to the y-axis as shown in Figure 1.2.



(a) Stretcher unit (b) Corner unit (c) Half unit

Figure 1.1 Putra block units (Thanoon et al., 2008)

The MIHB block system has been designed as a load bearing masonry unit complying to MS 7.2 (1971) (Thanoon et al., 2004). The strength and weight of the stretcher, corner and half units are 17.2 N/mm^2, 19.2 N/mm^2 and 17.0 N/mm^2, and 12 kg, 14 kg and 8 kg respectively (Jaafar et al., 2006, Fares, 2005). This block wall system can be applied as exterior wall as well as interior wall. According to Trikha and Abang Abdullah (2004), this wall system was structurally designed and analyzed to sustain loadings of up to a five storey building.

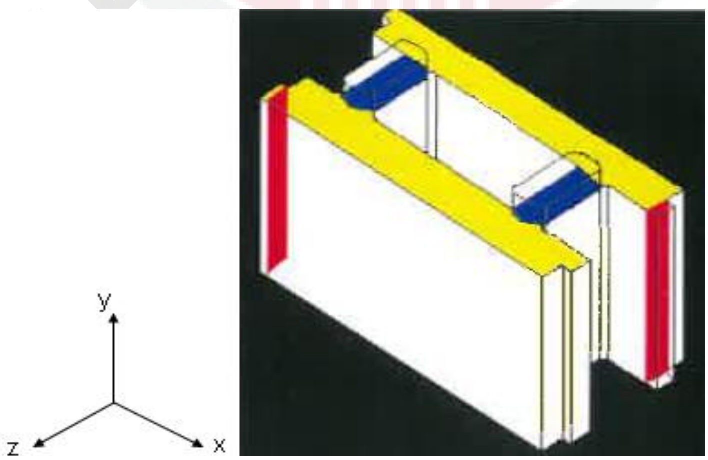


Figure 1.2 Shear areas of stretcher Putra block (Final Report of Interlocking Load Bearing Hollow Block Building System, 2004)

Apart from the development of MIHB, the concept of reduced weight concrete block was also studied. The idea of reduced weight concrete block has been proposed and studied in the related research works due to the benefit of overall weight reduction of a building, ergonomic construction, and cost-effectiveness. However people might misunderstand the difference between lightweight and reduced-weight concrete block, which is either by its density or size. According to Co et. al, (2011) and Arya, (2009), there are two potential methods in order to reduce weight of masonry block. This can be achieved by (i) the modification of material, or (ii) the modification of the shape or size of the block. Thus, these two potential methods will be further investigated in order to reduce the weight of MIHB. Hence further investigation on the behavior of MIHB with reduced-weight masonry blocks is necessary.

1.2 Problem statement

In recent years, various methods of reduced-weight concrete masonry block have been proposed. Generally there are two methods to reduce the weight of the concrete masonry block. It can be achieved by modifying the block material or modifying the block size or shape. Various investigations on the behavior of masonry block incorporated with material modification have been reported by Amato et al., (2011), Farah et al., (2011), Kumar, (2003), Tang et al., (2011), Xiao et al., (2011) Demirdag & Gunduz, (2008), Nafeth et al., (2009), and Soutsos et al., (2011). Material modification can be carried out either by adding or replacing lightweight materials in the mixes. The selection of the lightweight materials is based on the low density of the material, its suitability as the block material, and its availability in the local market. It was found that the concrete masonry block incorporated with lightweight materials can contribute to a significant weight reduction ranging from 10% to 40% compared to the masonry block using normal weight concrete (Amato et al., 2011), (Farah et al., 2011), (Kumar, 2003), (Tang et al., 2011), (Xiao et al., 2011) (Demirdag & Gunduz, 2008), (Nafeth et al., 2009) and (Soutsos et al., 2011).

Apart from modifying the material, another method to reduce the weight of the masonry block is by modifying the masonry block size or shape. There are a limited number of studies that focused on this method. Coz et al. (2011) had conducted a study on the weight minimization of masonry hollow concrete block using topological optimization and finite element analysis. The geometrical properties of the hollow concrete block has been modified and resulted in a significant weight reduction of 45%. The result obtained was comparable to the ones that incorporated lightweight materials.

It was found that Putra Block has redundant strength of about 50% higher than the required strength (Jaafar et. al, 2006), and consequently it has lead to an over-design of the building. For unreinforced masonry, it was known that the weight and strength of masonry block is closely related to each other (Jaafar et al., 2006). Hence the aim of this research work is to reduce the weight of the Putra block which may subsequently reduce the strength of the block. This is to improve its benefits, such as more efficient masonry construction activity, lighter building materials, cost-saving enhancement, and environmental friendly design. Gunduz (2008) also agreed that the size and weight of masonry block has influenced the productivity of mason works as well as the impact on the building foundation by the dead load. Therefore it is important to investigate the effect of size and material modification in order to reduce the weight of MIHB.

On the other hand, as a mortarless interlocking load bearing hollow block, more detailed consideration on the geometrical properties of the block is required in order to modify the size of the block. This is to ensure that the interlocking parts that govern the shear strength of the MIHB are sufficient and efficient. Hence, in modifying the size of the block only, the width of the shell will be optimized in order to reduce the weight of the block. As a consequence, there will be a reduction in the strength of the block due to its smaller bearing area. Hence, the effect of the reduced width of MIHB on the structural performance of the wall system will also be studied.

1.3 Objective

The main objectives of this research are:

1. To develop a lightweight Putra block through modification of size and material selection.
2. To determine the masonry design calculation of single and double storey load bearing hollow block wall system.
3. To determine the structural performance of the reduced size mortarless interlocking Putra block as load bearing wall panel.

1.4 Scope of study

This research work was based on a theoretical and experimental study. In the theoretical study, the design aspect of MIHB was studied according to BS 5628 (1992) and BS 6073 (1981) in order to propose a new size block. Based on BS 5628 (1992), the design strength of the block was calculated and compared with the theoretical loads for typical single and double storey houses. The size of block has been reduced based on the original size of Putra Block but shall conform to the BS 6073 (1981). The proposed new size block was then assessed in terms of the physical features and compared to the original size block.

Apart from the block size modification, the material content of the original concrete mix had been optimized in order to enhance the weight reduction and economical aspect of the block. The cement content was decreased along with the increase of the aggregate to cement ratio.

The experimental study covered the material content of the concrete block, individual block test and wall panel test. For individual block, a total of 180 block units consisted of stretcher, corner and half unit were prepared and tested for compressive strength test. The total block samples were categorized into three groups which is original size block with original concrete mix, new size block with original concrete and new size block with new concrete mix.

The three wall panel specimens having dimension of 900 mm in length and 1000 mm in height were prepared and tested for structural performance. The width of wall panels were followed the width of block used. The wall panel specimens were constructed using stretcher and half block units. The wall panel specimens were then subjected to vertical compressive load only.

1.5 Significance of study

This research work was carried out to reduce the weight of Putra block by size and material modification. Many research works were conducted throughout the world to encourage the development of lightweight block units. Due to weight and density of Putra block, it has been considered as heavy block units. Therefore this research work attempts to develop a lighter MIHB by size and material modifications of the masonry block in an attempt to produce MIHB that is more cost effective.

1.6 Thesis outline

Chapter 1: this chapter outlines the introduction of this research, the research objectives, problem statement, scope and significance of study.

Chapter 2: this chapter summarizes the related literatures of this study including the design aspect of conventional and non-conventional masonry system and the development of lightweight block.

Chapter 3: this chapter explains the research methodology that covers the theoretical study and experimental study.

Chapter 4: this chapter discusses the theoretical findings including the size modification of mortarless interlocking hollow block (MIHB) and the design compressive strength of MIHB wall. This chapter also discusses in details the experimental results of concrete cube samples, individual block test and wall panel test subjected to vertical compressive load.

Chapter 5: this chapter outlines several conclusions made from the research and recommendations for future research.

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