FLEXURAL BEHAVIOR OF STEEL REINFORCED BRICK BEAM UTILIZING INTERLOCKING BRICK SYSTEM

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TO MY BELOVED FAMILY

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ABSTRACT

The Interlocking Hollow Brick System (IHBS) was recently used in the construction of load bearing beam and walls. The concepts behind an IHBS include the elimination of the mortar layer. The interlocking brick system investigated in this study was a load bearing brick system relied on U-shaped hollow bricks in the bed row and hollow voids in the beam that allowed the addition of reinforced concrete grout stiffeners in vertical and horizontal directions to enhance the stability and integrity of the beams. Both Normal Concrete (NC) and Self Compacting Concrete (SCC) were and concrete, grout, and mortar used as infill material. Generally, in this research, twelve specimens are prepared for full scale testing with different parameters. The size of hollow brick was 250mm x 1250 x100 and the number of rebar was 12 mm diameter. The dimensions of beam make with hollow brick and horizontal and vertical rebar was 3000mm length, 125 mm width, and 300mm height. It was found that addition of super plasticizer in beam with SCC performed better under flexural loading than NC. This behavior also allows the concrete to have a more homogeneous mix, resulting to better bonding between bricks, grout, and steel reinforcement. Different arrangement of hollow interlocking brick in bed row causes a very ductile behavior because of the horizontal reinforcement surrounded by concrete between two layers of hollow brick which it has better interaction among the rebar, brick, and grout.

ABSTRAK

Sistem bata saling Hollow (IHBS) baru-baru ini digunakan dalam pembinaan rasuk dan dinding galas beban. Konsep sebalik sebuah IHBS termasuk penghapusan lapisan mortar. Sistem bata saling disiasat dalam kajian ini adalah bata galas beban sistem bergantung pada bata berongga berbentuk-U di barisan katil dan lompang kosong dalam rasuk yang membenarkan penambahan pengukuh grout konkrit bertetulang dalam arah menegak dan mendatar untuk meningkatkan kestabilan dan integriti rasuk. Kedua-dua Konkrit Biasa (NC) dan Konkrit Membuka Diri (SCC) dan konkrit, grout, dan mortar yang digunakan sebagai bahan pengisi. Secara umumnya, dalam kajian ini, dua belas spesimen disediakan untuk ujian skala penuh dengan parameter yang berbeza. Saiz bata berongga adalah 250mm x 1250 x100 dan bilangan rebar adalah 12 mm. Dimensi rasuk membuat dengan bata berongga dan rebar mendatar dan menegak adalah 3000mm panjang, 125 mm lebar, dan ketinggian 300mm. Ia telah mendapati bahawa penambahan super plasticizer dalam rasuk dengan SCC prestasi yang lebih baik di bawah pembebanan lenturan daripada NC. Tingkah laku ini juga membolehkan konkrit untuk mempunyai campuran lebih homogen, disebabkan ikatan yang lebih baik antara bata, grout dan tetulang keluli. Susunan yang berbeza bata berongga saling berturut-turut tidur menyebabkan tingkah laku yang sangat mulur kerana tetulang melintang dikelilingi oleh konkrit antara dua lapisan bata berongga yang ia mempunyai interaksi yang lebih baik di kalangan rebar, bata dan grout.

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CHAPTER1

INTRODUCTION

1.1 General

Originally, brick was formed by placing moist clay in a mold by hand. As modern industrial methods were implemented in the brick manufacturing process, the majority of production was changed from a molded process to an extrusion process. Extrusion more easily accommodates the inclusion of holes in a brick unit, which in turn can make the manufacture and use of brick more cost-effective and material-efficient. Traditionally, the size and number of holes in a brick unit have varied based on manufacturer capabilities, type of clay being extruded, type of firing process, and intended use of the product. As part of the evolution of brick unit manufacture and classification, these various hole patterns were categorized into two basic designations: solid brick and hollow brick. Solid brick are defined as having holes (or voids) not greater than 25 percent of the unit's bed area. Hollow brick are defined as having greater than 25 percent and at most 60 percent void areas. Hollow brick are further classified into those with a void area not greater than 40 percent and those with greater than 40 percent voids. [1]

In today's construction, majority of hollow brick are used in two basic applications. The first is in reinforced or unreinforced single-Wythe structural walls. Hollow brick units provide both the structural component and the brick finish without the need for additional materials. Hollow brick for this type of use generally

range in size from 4 to 8 in. (102 to 203 mm) in nominal thickness with void areas in the range of 35 to 60 percent. Typical single-Wythe applications of hollow brick include commercial, retail and residential buildings; hotels; schools; noise barrier walls; and retaining walls. The second application of hollow brick is as veneer units. These brick are generally 3 to 4 in. (76 to 102 mm) in nominal thickness with void areas in the range between 26 and35 percent.

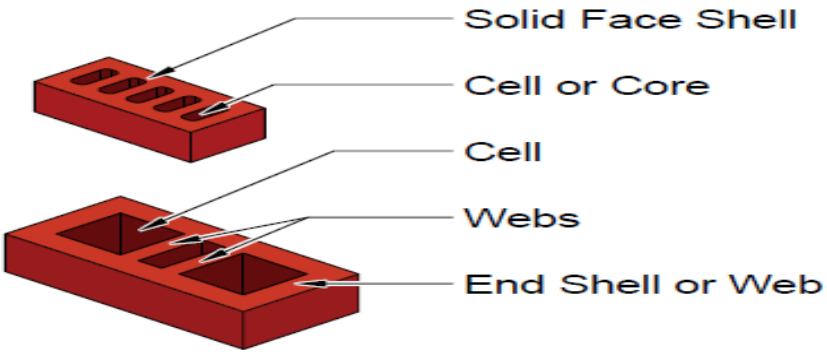
Masonry consists of a variety of materials. Raw materials are made of masonry units of different sizes and shapes, each having specific physical and mechanical properties. Both raw materials and method of manufacture affect masonry unit properties. One of the oldest building products in the world, brick remains a popular and durable wall covering. However, its use has taken on new meaning as design professionals specify and incorporate environmentally responsible construction that considers appropriate use of natural resources. Due to rapid development in the world, there is a need to build different categories of houses within a limited time to meet the increasing demand in the housing sector. Hence, a number of building systems have been developed in the world by different overseas companies. A technology using reinforced hollow concrete brick has been developed all over the world since a while. Its principle is to reinforce the masonry by grouting a concrete into the holes of the blocks where stands a steel rod at the critical locations (Corners, ends, near openings, etc,). Horizontal reinforcements are also cast in blocks with a U shape.

Reinforced horizontally and vertically masonry with Reinforce Cement Concrete (RCC) members is a new proposed method for IBS. The advantage of hollow interlocking, compared to hollow clay bricks, is that they offer keys, which interlock in the other bricks. Thus these beams offer more resistance to shear and flexure behavior of beam. They would better resist earthquakes and without major damages. The building system must satisfy all the normal building construction requirements, such as to be structurally efficient, durable and environmentally friendly. In addition, the building system required for housing construction must be developed fast enough to meet the time limit required for development. The cost is another important factor which everybody is interested in.

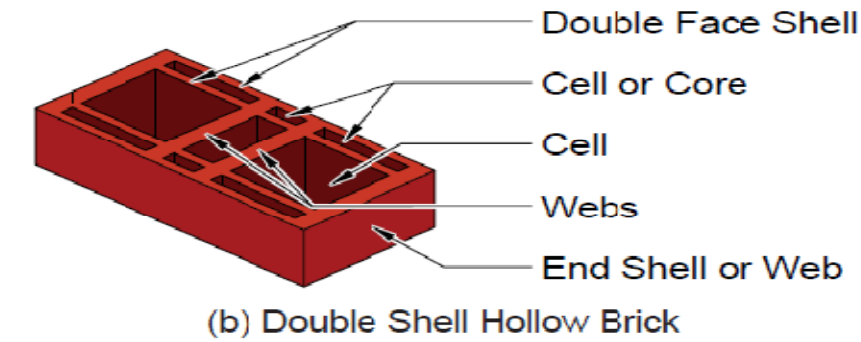
Interlocking Hollow Brick system (IHBS) is recently used in the construction of non-load bearing walls and load bearing walls. The main concepts of IHBS are the elimination of the mortar layers and instead the bricks are interconnected through providing key connection (protrusion and groove). The elimination of the mortar layers in the IHBS will speed up the construction and reduce the number of skilled and unskilled workers required to construct similar mortar bricks constructions.

The stresses developed in the wall due to the applied loads resisted by the connected parts of the bricks. The complex interaction between different parts of the brick under different types of stresses requires more comprehensive investigation in order to provide the designer a clear picture on the mechanism of load transfer. Most of the published researches focus on testing the Interlocking Hollow Brick systems experimentally, Published data are available on the theoretical analysis on normal masonry but no published data are available on the theoretical analysis and design procedures of IHBS. [2]

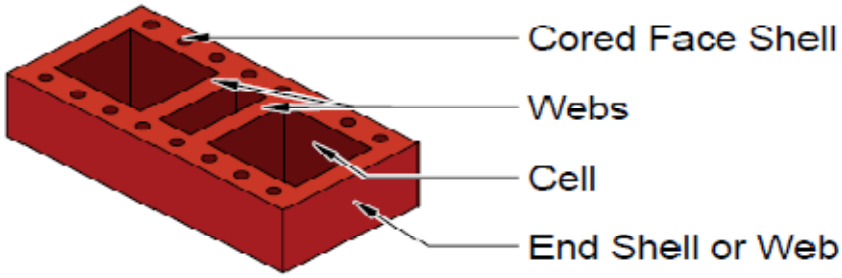
Figure 1.1 presents the three typical configurations of hollow brick units. Actual coring patterns vary by manufacturer and may depend on raw materials, extrusion equipment, firing methods or other factors. Note that as used in Figure 1.1 and throughout this definition, a “core” is a void having a cross sectional area of 1.5 $in.^2$ (968 mm^2) or smaller, and a “cell” is a void larger than a core.



(a) Solid Shell Hollow Brick



(b) Double Shell Hollow Brick



(c) Cored Shell Hollow Brick

Figure.1.1 Hollow brick configuration

1.2 Properties of hollow brick masonry

1.2.1 Strength

The structural design of hollow brick masonry is governed by model building codes and ACI 530/ ASCE 5/TMS 402 Building Code Requirements for Masonry Structures, also known as the Masonry Standards Joint Committee (MSJC) Code [1]. Hollow brick masonry can be designed by empirical requirements or by rational design procedures. Depending on materials and mortar bedding, prescriptive

stresses can be different for hollow brick masonry than for solid brick masonry. The following sections highlight some of the specific requirements for hollow brick units.

1.2.2 Compressive strength of unites

Compressive strength of hollow brick can be reported on either a gross or net cross-sectional area basis, depending on how the value is to be used. The gross area compressive strength is used to determine compliance with ASTM C652, Standard Specification for Hollow Brick (Hollow Masonry Units Made from Clay or Shale) [2] for purposes of durability and empirical design requirements. The net area compressive strength is needed for structural computations in structural applications using rational design of masonry.

An internal BIA survey conducted in 1994 showed that the range of compressive strength of 6 to 8 in. (152 to203 mm) thick hollow brick based on gross cross-sectional area is between 10 MPa to 15 MPa, with an average compressive strength equal to 12 MPa. More recent testing indicates hollow brick of 3- to 4-in. (76- to 102-mm) nominal thickness have similar compressive strengths as solid units of the same size [3]. Brick units generally have higher compressive strengths than other load bearing masonry materials. This makes hollow brick particularly well-suited for reinforced masonry applications where the increased strength of the unit can allow thinner wall sections to handle the same loading.

1.3 Design and detailing

1.3.1 Mortar bedding

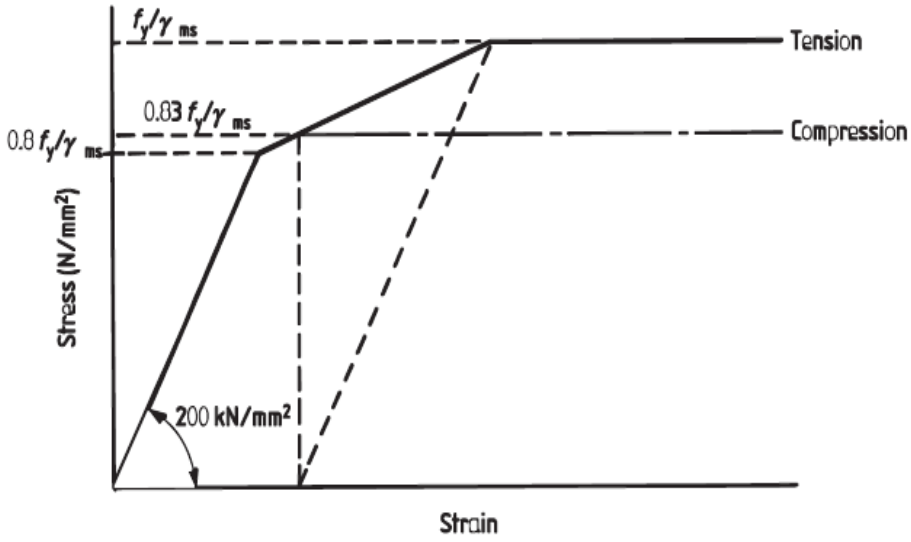
Requirements for brickwork constructed of hollow brick depending on the intended use of the brickwork. For larger hollow brick units used in structural (non-veneer) walls, mortar should be applied to the full thickness of the face shell (face-shell bedding). For smaller hollow brick units that are used in veneer applications, mortar should be applied to the full width of the brick veneer (full bedding) to maintain proper anchor embedment and cover.

1.3.2 Reinforcement

Although reinforcement is not always used in hollow brick masonry, the large cells allow the units to be easily reinforced and grouted. The reinforcing must be embedded in grout, not mortar. Reinforcing often positioned in the center of the wall but may be placed to one side to maximize the distance from the compression face. Reinforcement is grouted into hollow brick walls to increase the flexural strength, to provide ductility and to carry tensile forces. The flexural strength of a reinforced hollow brick wall depends primarily on the amount of vertical reinforcement because the compressive strength is rarely the limiting factor [2]. The reinforcement resists the flexural tension and the brickwork resists the flexural compression. Building codes may dictate a minimum amount of reinforcement for improved ductility in seismic regions. In reinforced masonry design, any tension resistance provided by the masonry is neglected. The characteristic tensile yield strength of reinforcement, fy, is given in Table 1.1.

Table 1.1 Characteristic tensile yield strength of reinforcing steel, f_y

Designation	Grade	Nominal size	Tensile yield strength fy (Mpa)
Steel reinforcement , conforming to BS 4449	500	All	500
Steel wire reinforcement , conforming to BS 4482	250	≤ 12mm	250
Steel wire reinforcement , conforming to BS 4482	500	≤ 12mm	500
Steel wire reinforcement , conforming to BS 4483	500	All	500
Plain dowel bars, conforming to BS EN 10025-2	250	> 12mm	235
Plain stainless steel bars, conforming to BS 6744	200	All	200
Ribbed stainless steel bars, conforming to BS 6744	500	All	500



1.3.3 Elastic module

Where elastic methods of analysis are adopted, the following elastic module may be used in the absence of relevant test data:

a) Elastic modulus for reinforced clay masonry including calcium silicate with infill material is following, $E_m = 0.9\, f_k$ kN/mm^2;

b) For all steel reinforcement and all types of loading, the elastic modulus, Es = 200 kN/mm^2;

1.4 Hollow brick specification and sizes

1.4.1 Type

Four types of hollow brick are defined by ASTM C652: Types HBS, HBX, HBA and HBB. Each of these types relates to the appearance requirements for the brick. Dimensional variation, chip page, war page and other imperfections are qualifying conditions of type. The most common, type HBS, is considered to be standard and is specified for most applications. When the type is not specified, ASTM C652 stipulates that the requirements of type HBS. Type HBX brick are specified where a higher degree of precision is required. Type HBA brick are unique units that are specified for no uniformity in size or texture. Where a particular color, texture or uniformity is not required, type HBB brick can be specified (these applications are typically unexposed locations).

1.4.2 Class

The extent of void area of hollow brick is separated into two classes: H40V and H60V. Brick with void areas greater than 25 percent but not greater than 40 percent of the units' gross cross-sectional area in any plane parallel to the surface containing the voids are classified as class H40V. Brick with void areas greater than 40 percent but not greater than 60 percent of the gross cross-sectional area are classified as class H60V. When the class is not specified, ASTM C652 stipulates that the requirements for class H40V govern.

1.4.3 Hollow spaces (voids)

Hollow spaces may be cores, cells, deep frogs or combinations of these. In ASTM C652, a core is defined as a void having an area equal to or less than 1½ in.² (968 mm²), while cells are voids larger than a core. A deep frog is an indentation in the bed surface of the brick that is deeper than ⅜ in. (9.5 mm). The thickness of face shells and webs are limited by ASTM C652. Figure 1.1 and Table 1.2 define the nomenclature associated with hollow brick units and the minimum required thickness of face shells and cross webs.

Table 1.2 ASTM C652 Hollow Brick Cross-Sectional Requirements

Type of void	Minimum Distance from void to Exposed Edge 1.2 in (mm)	Minimum Web Thickness (Between Void and Core), in. (mm)	Minimum Web Thickness (Between Void and Cell), in. (mm)
Core	5/8 (15.9)	1/2 (12.7)	3/8 (9.5)
Cell	3/4 (19.1)	1/2 (12.7)	1/2 (12.7)

The dimensions of the unit and the configuration of its voids are critical for reinforced brick masonry. The cells intended to receive reinforcement must align so that reinforcing bars can be properly placed. Most Class H60V hollow brick contain two cells that are aligned when laid in running and stack bonds. Other bond patterns, such as one-third bond and bonds at corners, may require different unit configurations to permit placement of reinforcement. Size of cores will also influence grout type and grout placement methods. It is advisable to check with the brick manufacturer to determine the coring patterns available.

1.4.4 Sizes and shapes

Hollow brick are commonly available in a variety of sizes. Hollow brick are also made in a variety of special shapes. Special shapes include radial, bull nose, interior and exterior angled corner units and others. Bond beam units are often used where horizontal reinforcing is required. They may be specially made at the plant or cut on site. The brick manufacturer should be consulted for the availability of special shapes.

1.5 Problem statement

Currently there is limited standard available for the design of interlocking hollow brick system. Most of the published researches focus on testing the IHBS experimentally; Published data are available on the theoretical analysis on normal masonry but no published data are available.

The structural behavior and design parameters for this system are expected to be different than the conventional load bearing beam and wall system. This research is mainly focused on the structural behavior of interlocking hollow brick beams with infill Normal Compacting Concrete (NC) and Self Compacting Concrete (SCC) under effect of mid-span vertical load on beams with simply support.

Building codes state that situation should be avoided where damage to small area or failure of single element could lead to collapse of major parts of the structure. The provision of effective ties is necessary precaution to prevent progressive collapse. The layout also must be such as to give a stable and robust structure. However there are several types of ties as peripheral ties, internal ties, horizontal ties to column and walls, and vertical ties.

1.6 Objectives of study

The main objectives of this study are:

1. To investigate the structural response of the interlocking hollow brick designed as composite beam subjected to mid-span loading conditions.

2. To investigate the structural behavior of IHBS to based on ductility or deflection between the bricks through the interlocking keys.

3. To study the structural behavior of tested with two different NC and SCC infill grout.

1.7 Scope of study

The main scopes of this study include:

1. Study on interlocking hollow brick system with different infill grout based on two main different reinforced and unreinforced composite beams.

2. Study on different interlocking composite beams of different row bed arrangement of brick.

3. To investigate behavior hollow bricks and reinforced interlock hollow brick (RIHB) beams under vertical mid-span loading

4. Analysis on the effect of vertical load rating on the overall flexural response of the beams.

5. To investigate the cracking mode of interlocking hollow brick beams.

1.8 Significance of the study

In the absence of any theoretical analysis to provide sufficient technical information about the IHBS, this study provides the properties which affect the structural behavior of different IHBS. The interlocking mechanism plays a significant role in the distribution of the stresses developed in the brick due to the applied load.

This study provides useful information regarding the properties and interlocking mechanisms of the bricks. In addition, the non-linear analysis identified the cracking load and hence, enhances the design of load bearing wall.

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