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Behaviour of Masonry Wall Constructed using Interlocking Soil Cement Bricks

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***Abstract*—**According to the masonry standard the compressive strength is basically dependent on factors such as the mortar strength and the relative values of unit and mortar strength. However interlocking brick has none or less use of mortar. Therefore there is a need to investigate the behavior of masonry walls using interlocking bricks. In this study a series of tests have been conducted; physical properties and compressive strength of brick units and masonry walls were constructed from interlocking bricks and tested under constant vertical load at different eccentricities. The purpose of the experimental investigations is to obtain the force displacement curves, analyze the behavior of masonry walls. The results showed that the brick is categorized as common brick (BS 3921:1985) and severe weathering grade (ASTM C62). The maximum compressive stress of interlocking brick wall is 3.6 N/mm^2 and fulfilled the requirement of standard for residential building.

***Keywords*—**Interlocking brick, soil-cement brick, masonry wall, compressive strength, eccentricities

I. Introduction

In many developing countries especially in the rural, natural compacted soil has good insulation and fire resistant properties [1]. It is, however, vulnerable to weather especially during rainy season and soil material can expand and loose cohesiveness, particularly with cement plaster.There is an initiative to produce bricks by using natural soil bricks because they have been identified as low cost material. The technology uses the available soil on site, which can be stabilized with a small amount of cement or/and lime depending on the characteristics of the soil so as to improve the engineering properties of the produced bricks.

Walls constructed out of well compacted soil, have adequate compressive strength under dry conditions; however they will lose their strength under adverse moisture content. Soil can be improved and used as a building material for various types of structures by adding substances known as stabilizers, and the product is called stabilized soil.

A properly stabilized, consolidated, well-graded soil that is adequately moisturized, mixed, and cured will provide a strong, stable, waterproof and long-lasting building bricks.

Regarding soil, Walker [2] assessed the influence of soil characteristics and cement content on the physical properties of stabilized soil blocks. Both saturated strength and durability of cement stabilized soil blocks were improved by increasing cement and impaired by clay content. He concluded that the most ideal soils for cement soil block production should have plasticity index between 5 and 15. Soils with a plasticity index above 20–25 are not suited to cement stabilization using manual presses, due to problems with excessive drying shrinkage, inadequate durability and low compressive strength. Reddy [3] studied the use of steam curing process and showed that it can lead to quick production of stabilized soil blocks. Venkatarama Reddy and Gupta [4] studied the various characteristics of soil-cement blocks using highly sandy soils. The results indicate that there is 2.5 times increase in strength for doubling of cement content from 6%. Saturated water content of the blocks is not sensitive to cement content, whereas rate of moisture absorption greatly depends on the cement content. Pore size decreases with increase in cement content of block, whereas surface porosity is independent of the cement content.

Stabilised soil cement blocks have been used for load bearing masonry structures in many parts of the world like India [4]. More details on stabilized soil block technology can be found in other studies [5] – [8].

Mortar is used in normal brick construction in order to create continuous structural form and to bind together the individual units in brickwork. In normal bricks, mortar and bricks provides the high strength in brickwork system. Many studies have been done in perfecting the performance of the brickwork [9] – [12]. However conventional brickwork system with the application of mortar still incurs great cost and time of construction.

The higher demand of construction of buildings gives reason to find ways to fulfill and to solve the problems related to the construction. Interlocking bricks is an alternative system which is similar to the “LEGO blocks” that use less or minimum mortar to bind the bricks together. Interlocking bricks was introduced to reduce the use of manpower, hence fulfill the requirement of Industrialised Building Syatem (IBS). Interlocking brick system is a fast and cost effective construction system which offers good solution in construction.

In Malaysia, the use of interlocking bricks is not widely used because there is no specific standard regarding to this system. In addition, limited study conducted in the production and installation of the system for local requirements have all hindered the use of this system in the construction. Hence there is a need to hasten the effort to determine the effectiveness construction system using interlocking brick.

This paper describes the preparation of the interlocking bricks and brick walls produced from of cement, laterite soil and sand. Interlocking bricks were manufactured at the factory that pressed in a special mould to ensure a solid and rigid shape. The compressive strength of all samples subjected to

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compressive load was determined and crack pattern of interlocking walls were observed with respect to their potential use as a material in construction.

II. Materials And Methods

A. Materials

The soil used in this study is a reddish brown laterite soil. Disturbed sample of laterite (see Fig. 1) was obtained from northern part of Malaysia. The wet soil was dried by heating it over the charcoal kitchen or dried under the sun depending on the weather. Then the soil was grinded into sound particles by using grinder machine and sieved. The size of soil particles was about 2 mm.

Sand used for the test was river sand. Type 1 Ordinary Portland cement (YTL type OPC) which complies with ASTM C 150–89 was used as the stabilizing agent while portable tap water was employed in the laboratory tests conducted. Local natural river sand that passes ASTM sieve number 8 (2.38 mm) was used. The sand did not contain any organic substances which can be harmful to the cement hydration. The size of sand was about 0.7 ± 0.145 mm.

Fig. 1 Laterite soil

B. Manufacturing of interlocking brick

The materials for manufacturing the interlocking brick consists of cement, laterite soil and sand with ratio of 1:1:6 (cement: sand: soil) by volume. The use of volume rather than weight is due to simplicity of the manufacturing. The corresponding mixing mass ratio of the reference sample is 27.6:4.0:4.2 kg. Soil, sand and cement were mixed together in the drum mixer. Water was gradually added into the mixer until having right consistency which ready for moulding. The mixture was then placed into a mould as shown in Fig. 2a and manually pressed under certain amount of pressure (about 1.0 MN/m^2) to become solid and rigid with the interlocking shape. Then the specimen was removed from the mold and leave to air cured for 24 hours. The natural drying is used for drying process where the bricks are stacked on racks and dried by the circulation of unheated air as shown in Fig. 2b. The bricks sizes are 250 mm of length, 125 mm of width and 100 mm of height.

Fig. 2 Interlocking brick; (a) mould for pressing and (b) curing process

C. Determination of Physical Properties of Soil

The physical properties of the laterite soil brick was conducted using sieve analysis and hydrometer test.

D. Determination of Mechanical Properties of Brick Units

In order to understand the mechanical behavior of a given material or structure, it is fundamental to perform experimental tests on it. In this way, it is possible to characterize its behavior from the undamaged state through peak and post-peak state. Therefore physical properties (density, dimension and water absorption) and mechanical properties (compression and bending) of the brick units were determined. The mechanical properties of the brick units were conducted in accordance to BS EN 772-1 and BS EN 772-2. As the interlocking bricks contain frogs and the net loaded area are more than 35% of the bed face, the frogs were removed without filling them with mortar. Fig. 3 shows the test set-up for compression test for the brick.

Fig. 3 Test set-up for compression test

The moisture absorption characteristics of the brick unit were conducted in accordance with BS EN 772-7. Ten bricks were immersed in hot water for 24 hours before subjecting them to compressive test using an ELE compression machine. The water absorption was determined using Equation (1).

$$\text{Water absorption (\%)} = \frac{m_1 - m_2}{m_2} \; x\; 100\% \qquad (1)$$

Where, m_1 is the final mass and m_2 is the initial mass of the brick.For comparison of the obtained values for compressive strength another set of tests on cube samples with dimensions 50x50x50 mm extracted from the actual bricks was performed.

E. Experimental tests on interlocking brick wall

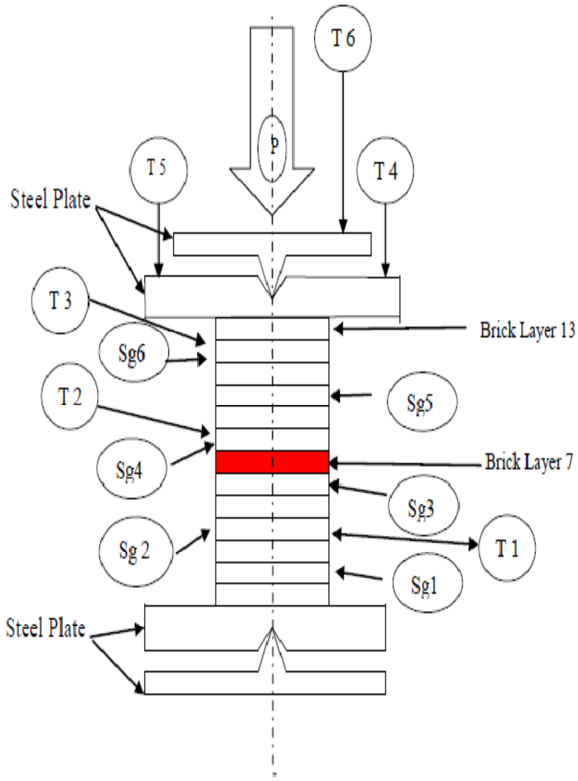
A series of unreinforced masonry walls from interlocking bricks were constructed. In this masonry unit, no mortar was used. The connection between the units was provided by the frogs and the hole at the opposite units. Therefore to determine the compressive strength properties of the masonry, the specimens were prepared in accordance with EN 1052 by testing the wall units with dimensions 1000 mm x1300 mm x 125 mm denoted as ILBW1 (slenderness ratio < 20). Three replicates were constructed. Another series of walls with different eccentricities (6.25, 12.5, 25 and 50) were also constructed and tested to depict the real walling system where the walls were loaded at different eccentricities (see Table I).

TABLE I
SPECIFICATIONS AND DIMENSIONS OF INTERLOCKING BRICK WALLS

Sample Labels	Dimension: Length x Height x Width(mm)	Eccentricity, e (mm)
ILBW1	1000 x 1300 x 125	0
ILBW2	1000 x 1300 x 125	6.25
ILBW3	1000 x 1300 x 125	12.5
ILBW4	1000 x 1300 x 125	25
ILBW5	1000 x 1300 x 125	50

The main objective of the experiment is to measure the structural behavior of the interlocking brick walls due to compressive load. In this experimental work, all samples were subjected to axial compressive loads. The loading system was designed to produce uniform line load along the width of the specimen. Load cell and hydraulic pump were used for loading purposes and the transducers, strain gauges and data logger were used in determining and recording the necessary data for walls. The parameters measured are ultimate load capacity, lateral displacement, compressive strength, stress-strain relationship and crack patterns.

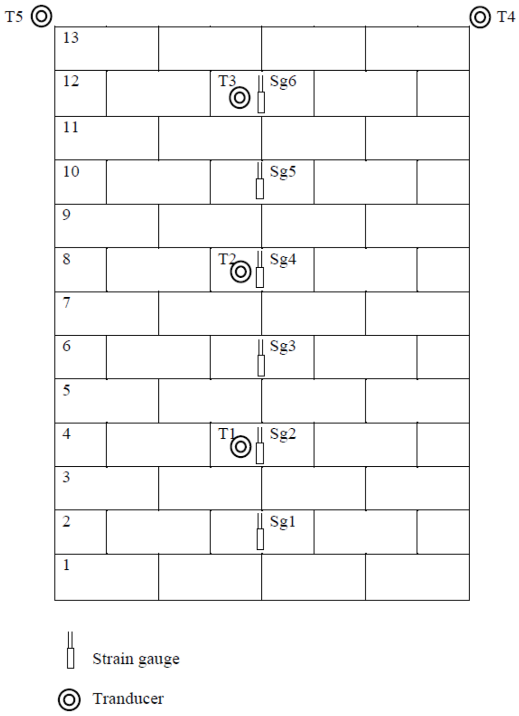
The lateral displacement and the stresses due to load applied were measured at the brick layer at brick layers 2, 4, 6, 8, 10 and 12 for ILBWs. Figs. 4 and 5 show the schematic layout of experimental set ups.



Note :

P	=	Force (kN)
T1	=	Displacment Tranducer layer 4 (mm)
T2	=	Displacment Tranducer layer 8(mm)
T3	=	Displacment Tranducer layer 12 (mm)
T4	=	Displacment Tranducer Left (mm)
T5	=	Displacment Tranducer Right (mm)
T6	=	Displacment Tranducer Center (mm)
Sg1	=	Strain gauge(1)
Sg2	=	Strain gauge(2)
Sg3	=	Strain gauge(3)
Sg4	=	Strain gauge(4)
Sg5	=	Strain gauge(5)
Sg6	=	Strain gauge(6)

Fig. 4 Set up arrangement for brick wall



(a) (b)

Fig. 5 Test set-up for ILBW; (a) schematic diagram and (b) actual test set-up

III. Results And Discussions

A. Properties of Soil

From sieve analysis, it was found that the size passing the sieve pan size of 2 mm is high. When the size of passing pan become smaller, then the mass of soil retained become less. This can be said that the size of soil particles is very fine.

From the hydrometer test, it was found that the laterite soil contained silt (32.9%), sand (69.6%), gravel (1.2%) and clay (3.77%) which indicates the soil is very clayey sand (clay of low plasticity). Graham and Burt [13] proposed that the ideal soil should composed of soil with a combined clay (15-20 percent) and silt (powder) content of approximately 25-40 percent (by volume), and a sharp sand content of approximately 40-70 percent (by volume). Since the clay content for the soil used in this study is lack of clay particles therefore cement was added to strengthen the bonding between particles.

B. Properties of Bricks

The properties of bricks were obtained by experimental testing according to standard. Table II summarizes the results. The tests were conducted with 10 replicates.

TABLE II
Physical And Mechanical Properties Of The Interlocking Brick

Physical and mechanical properties							
Length [mm]	Width [mm]	Height [mm]	Unit Weight [kg/m^3]	Compressive Strength[a] [N/mm^2]		Moisture absorption [%]	Compressive Strength[b] [N/mm^2]
				Mean	COV (%)		
249.2	125	98.8	1603.2	7.5	13	18.8	3.5
50.0	50.0	50.2	-	13.6	8		

[a] compressive strength before soaking
[b] compressive strength after soaking

From Table II, it can be seen that the compressive strength of the brick is 7.5 N/mm^2 with low variations. According to British Standard (BS 3921:1985), the minimum requirement for compressive strength of non-load-bearing masonry units is 5N/mm^2 and based on ASTM C129 standard, the minimum requirement for compressive strength is 2.5 N/mm^2. Therefore, the compressive strength determined from the testing is above the minimum requirement for bricks. Based on BS 3921:1985, the results is less than 50 N/mm^2, so this brick is categorized as common brick.

For comparison of the obtained values for compressive strength, another set of tests on cube samples with dimensions 50x50x50 mm extracted from the actual bricks was performed. The results from these tests are presented in Table 2. It can be seen that cube samples has strength 1.8 times higher than the interlocking brick. The lower strength in interlocking brick is mainly due to the presence of frogs on the surface and hole through the bricks.

To determine the moisture absorption characteristic of the bricks, the water absorption tests were conducted and the results were compared with the specification in accordance with ASTM C62 as shown in Table 3.

From the water absorption tests, the water absorption in cold water for 24 hours is 8.5% and 17% when immersed in 24 hours boiling water. Therefore the saturation coefficient is 0.5 which is less than 0.80 and hence this bricks met the ASTM C62 specification for the severe weathering (SW) grade.

TABLE III
WATER ABSORPTION CAPACITY OF THE BRICKS WITH RESPECT TO THE REQUIREMENT FOR WATER ABSORPTION FOR BUILDING BRICKS (ASTM C62)

ASTM C62 Class specification	Maximum 24-h cold water absorption, 8%*			
	Maximum 5-h boiling water absorption % Individual Brick		Maximum Saturation Coefficient**	
	5 bricks average	Individual brick	5 bricks average	Individual brick
Class SM	17	20	0.78	0.8
Class MW	22	25	0.88	0.90
Class NW	No limit	No limit	No limit	No limit

SW, MW and NW denote sever weathering, moderate weathering and normal weathering respectively. *If the cold water absorption does not exceed 8 wt%, then the boiling water absorption and saturation coefficient specifications are waived; **The saturation coefficient is the ratio of absorption by 24 hour submersion in cold water to absorption after 5 hr submersion in boiling water.

C. Compressive Strength of Masonry Walls Constructed Using Interlocking Brick

The compression tests were conducted on a series of interlocking brick wall (ILBW) for different eccentricities according to the procedures in EN 1052. Since the masonry walls are constructed using interlocking bricks, therefore no mortars are used as the joint. In order to determine the compressive strength of the wall, the calculation of the compressive strength of wall with e=0 is used as an example.

TABLE IV
COMPRESSIVE STRENGTH OF ILBW1

Sample	Maximum load (kN)	Compressive strength f (N/mm^2)
1	443.1	3.54
2	458.6	3.67
3	433.3	3.47
Average		**3.56**

Using the clauses in EN 1052-1, since the mean f is 3.56N/mm^2 and differ more than 25% of the compressive strength of brick units (7.5N/mm^2) then the value need to be modified. Therefore the characteristic compressive strength f_k of the wall is taken as follows;

$f_k = f/1.2 = 3.0$ N/mm^2 or
$f_k = f_{min} = 3.47$ N/mm^2 whichever is the smaller.

Therefore in this case, the characteristics compressive strength, f_k is taken as 3.0 N/mm^2.

The compressive strength properties of the masonry walls with slenderness ratio < 20 with different eccentricities are tabulated in Table 5. In most cases, the load is basically applied at certain eccentricity to the center of the bed member. From Table V, it can be seen that the value of the stresses were reduced accordingly to the eccentricity of the load applied on the walls.

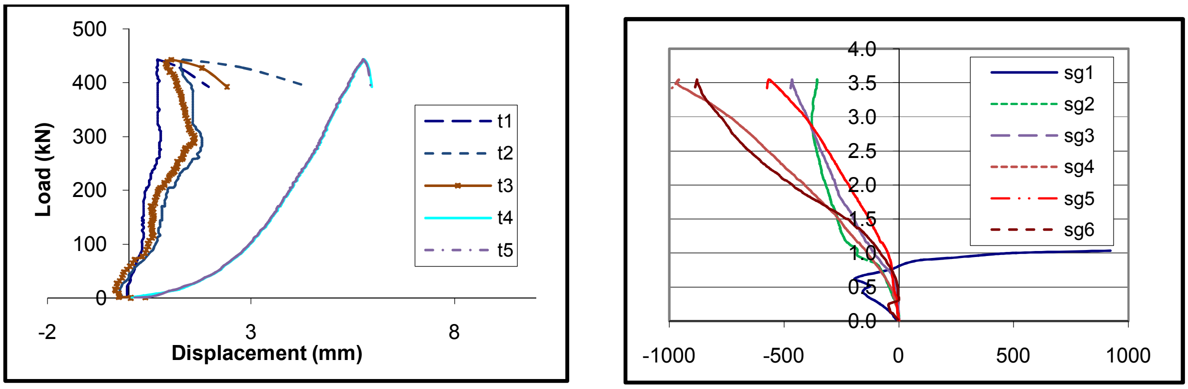
The maximum value of stresses was found when e = 0 with the value of 3.56 N/mm^2 . It is also can be seen that the ultimate applied compression load is higher than ultimate design load based on BS 5628: Part 1: 1992 (Section 8.4.6 and 8.4.7) except for ILBW5. According to the practice standard, it is not necessary to consider the effects of eccentricities up to 0.05t where t is thickness. Normally, wall will collapse when the eccentricity is more than 0.3t.

The lateral displacements, stresses and crack patterns of the walls have been investigated and compared. Figure 6 shows the typical load displacement curve for the wall. Transducer T2 which is located at the middle of wall recorded the maximum displacement at ultimate load of 443.05 kN for sample ILBW1. Sample ILBW2, ILBW3 and ILBW4 shows the maximum displacement at transducer T5 which is located at 135 mm from the left.

The last brick wall tested in this section is ILBW5 that shows ultimate testing load of 6.03 kN and maximum displacement at transducer T2 which located at brick layer number 8 measured from the wall base.

TABLE V
SUMMARY OF COMPRESSIVE STRENGTH PROPERTIES OF MASONRY WALLS (SLENDERNESS RATIO < 20) WITH DIFFERENT ECCENTRICITIES

Sample	Ultimate Testing load (kN)	Ultimate design load (kN)	Compressive strength, f (N/mm^2)	Characteristics compressive strength, f_k (N/mm^2)	Maximum Displacement (mm)	Location of the displacement
ILBW1	443.05	131.35	3.56	3.0	5.79	T2
ILBW2	348.42	131.35	2.79	2.3	7.95	T5
ILBW3	271.63	108.36	2.17	1.8	7.18	T5
ILBW4	239.94	105.08	1.92	1.6	6.58	T5
ILBW5	6.03	32.84	0.048	0.04	11.63	T2



(a) (b)

Fig. 6 Typical graph for ILBW1: (a) load versus displacement and (b) stress versus strain

The failed wall specimens were investigated in terms of cracks formation. For eccentricity loading, global buckling occurred where the wall bent, cracked and broke. For ILBW5, when the sample reached the ultimate load, the wall began to bend and cracked until it reached the ultimate load and after that the wall collapsed. For other samples, the mode of failure more to the bearing mode in which the skin wall crushes under the top plate where the load was applied to the wall. The cracks can be seen on the brick walls from the loaded point to downwards. The cracks are tensile crack which propagates through the units in the direction of the applied load as shown in Figure 6a. Since there was no mortar, this crack was caused by secondary tensile stresses resulting from the restrained deformation of the frogs in the bed joints of the brickwork. Once the wall buckled this induced flexural tension and the contact between the bricks loosen as can be seen in Figure 6c.

In general, all samples have similar patterns of crack which is combination of shear and compression failure with bed and head joint failure, brick failure or movement in the bed and head joint. The difference is the intensity of the cracks. The details of cracking of each sample are shown in Figure 7.

(a) (b) (c) (d)

Fig. 7 Observed failure mechanisms and crack propagation for walls; (a)ILBW1, (b)ILBW2, (c)LBW3 (showing bending at the bed joint and (d)ILBW4

IV. Conclusion

The behavior of wall constructed using interlocking soils bricks was investigated and encouraging results were reported.

- The physical properties of the laterite soil are categorized as very clayey sand (clay of low plasticity). Lack of clay particles in this type soil is overcome by the addition of the cement particles which can play their roles to strengthen the bonding between particles.
- The average of compressive strength of single unit bricks is 7.5 N/mm^2. The brick is categorized as common brick (BS 3921:1985) and severe weathering grade (ASTM C62).
- The compressive strength of interlocking soil bricks is reduced from a single unit bricks (f = 7.5 N/mm^2) to a member such as wall, which is much higher than compressive strength of the wall (f = 3.56 N/mm^2).
- In the masonry interlocking brick walls, the eccentricity of the loading influenced the value of strength of the wall. The strength is reduced when the eccentricity is away from the center.
- In general, all samples have similar patterns of crack which is combination of shear and compression failure with bed and head joint failure, brick failure or sliding in the bed and head joint. The difference is the intensity of the cracks.

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