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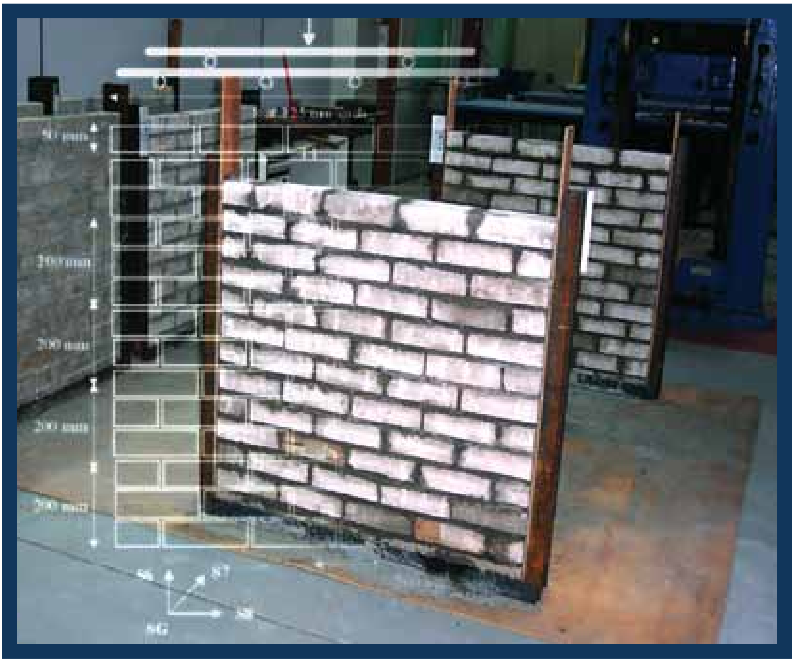

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Optimisation of Calcium Silicate and Sand Cement Bricks in Masonary Bearing Walls

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ABSTRACT

Design and construction of buildings used to be on framed structure incorporating reinforced concrete, steel or timber as structural member to transmit load to the foundation. Bricks are normally used as infill materials in these framed structures. However, research has shown that bricks can also be used as external and internal masonry bearing walls. With the use of structural masonry construction method, cheaper and faster construction can be achieved. Savings are obtained by using less formwork and reinforcing steel, reducing construction time as lesser frames or none are used, and eliminating waiting time for the structural concrete to cure or gain their strength. Calcium silicate and sand cement bricks were tested for their mechanical properties. Investigations were carried out on six masonry bearing walls. Each unit measured 1000 mm × 1000 mm and a half brick thick. The structural behaviour due to compressive axial load was investigated and it shows that both bricks satisfy the requirement as load bearing wall. However, the study concluded that sand cement brick wall showed better performance, with maximum lateral displacement of 3.81mm, vertical deflection of 6.63 mm and ultimate load of 448.13 kN.

***Keywords**: Calcium Silicate Bricks (CSB), Sand Cement Bricks (SCB), Compressive strength, Load Bearing wall (LBW), Displacement*

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Introduction

Malaysia's construction industries have looked into the options of maximising the use of load bearing walls in its buildings. Besides being economical, masonry bearing wall has good aesthetic value where the texture, colour and shape of the finished brick wall structures can be altered as desired. In comparison to reinforced concrete framed buildings, masonry bearing walls can expedite the construction of housing for the low income group in Malaysia. Investigation on masonry bearing walls have been seriously undertaken by many researchers [1-4]. Calcium silicate and sand cement bricks are widely being produced in Malaysia. The mechanical properties showed better results in comparison to the clay bricks and engineering bricks produced locally [5]. Complaints from contractors on the performance of the latter two types of bricks prompted research work to be carried out to look into the possibility of using the other two types of bricks as load bearing wall units. In the earlier investigation on the physical and mechanical properties of various types of bricks [5], the calcium silicate and sand cement bricks showed a higher value of compressive strength taken on bed surface, *i.e.* 10.35 N/mm^2 and 8.59 N/mm^2 respectively, compared to those of engineering bricks which is 6.80 N/mm^2. Table 1 shows the results of physical and mechanical tests conducted on various types of brick units by Kartini and Siti Hawa [5].

In 2020, it is projected that the proportion of urban population to total population in Malaysia will exceed 70 %, [6]. The future housing need for this population is indeed imminent. As the masonry bearing wall can be incorporated easily into building construction, the suitability of these bricks in the form of structural carrying capacity and performance requires experimental investigations.

Schubert [7] identified factors such as mortar mix, units' properties especially the suction behaviour during erection the brick wall, site conditions of workmanship and hardening affect of the compressive strength of mortar. Depending on the stress state acting on the joints, failure can occur in the joints alone, or in some form of combined mechanism involving the mortar and the brick unit itself. From Andreaus [8], ten types of failure mechanism pattern was identified in masonry bearing walls (Table 2).

Table 1: Physical and Mechanical Test Results on Brick Units [5]

Sample	Clay Bricks	Engineering Bricks	Calcium Silicate Bricks	Sand Cement Bricks
Water Absorption (%)	22.33	18.23	13.37	14.53
Rate of suction kg/(mm^{2}min)	2.00	0.77	2.54	6.47
Correction Rebound Perpendicular to bed face of bricks	12	13	16	9
Compression Strength Perpendicular to bed face of bricks (N/mm^2)	2.81	6.80	10.30	8.59

Table 2: Failure Mechanism Patterns [8]

Failure Mode	Mechanism	Failure pattern
Slipping Mode	I	Slipping of mortar joints
	II	Slipping of bed joints
	III	Splitting and slipping of bed joints
Splitting Mode	IV	Splitting of bricks and slipping of mortar joints
	V	Splitting of bricks and head joints
	VI	Slipping of bed joints and splitting of head joints
	VII	Splitting of bed joints
	VIII	Slipping and splitting of mortar joints
	IX	Biaxial deformation
Spalling Mode	X	Middle plane spalling

Experimental Work

The experimental work is to identify the structural behaviour of the brick wall due to compressive axial load, which involved erection of six (6) rectangular brick wall of size 1000 mm high by 1000 mm wide with 102.5 thicknesses on stretcher bond. The mortar grade of 1:3 binds to the bricks, and was left for a minimum of 28 days before testing. The bricks were obtained from the local producer. Findings from earlier works [5] resulted in the focus of this study concentrated on calcium silicate and sand cement bricks.

The loading system was designed to produce uniform line load along the mid width of the wall panel to simulate axial compressive loads. Load cell and hydraulic pump were used for loading purposes and the transducers, strain gauges and data logger were used in obtaining and recording the necessary data. U shaped steel frames were constructed and served two purposes, firstly, to ensure wall samples are laid according to the specified dimension and secondly, as an aid to place the samples on the testing rig as shown in photo 1 and photo 2. The parameters determined include the lateral displacement, ultimate load capacity, and crack pattern. Figure 1 shows the schematic layout of the experimental setup.

Photo 1: U shaped steel frame

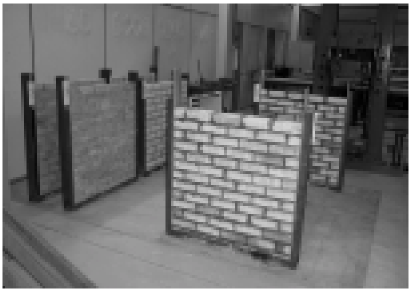

Photo 2: Wall samples

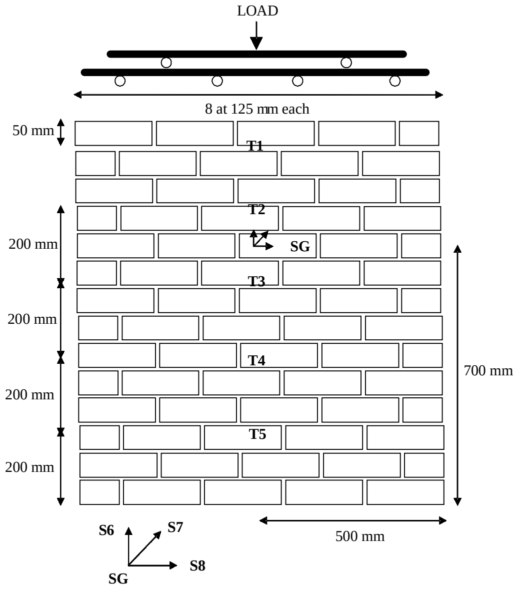

Figure 1: Schematic Layout of Experimental Set-up

Results and Discussions

All experimental data which are digitally recorded are discussed herein in the form of their lateral displacement, ultimate load and crack patterns.

Lateral Displacement

The lateral displacement plots showed the deformation profile of the wall samples (Figure 2). All samples showed single curvature profile indicating that the buckling behaviour dominated. From Figure 2, the corresponding maximum displacements for calcium silicate brick walls are 2.08 mm, 3.65 mm and 14.22 mm occurred at T2 placed at the height of 800 mm from support with maximum load recorded at 228.87 kN, 393.09 kN and 412.90 kN respectively. Similarly, for sand cement brick walls, maximum displacements are 5.79 mm, 2.71 mm and 2.93 mm with the maximum load recorded at 527.39 kN, 346.49 kN and 470.5 kN respectively. All samples bent at four fifths height of the sample and showed a typical pattern with the largest lateral displacement recorded near the loaded end. The lateral displacement reduces in magnitude in a linear pattern towards the support. Generally, LBCS 3 shows the largest profile with maximum lateral displacement of 14.22 mm whilst LBCS 1 shows the

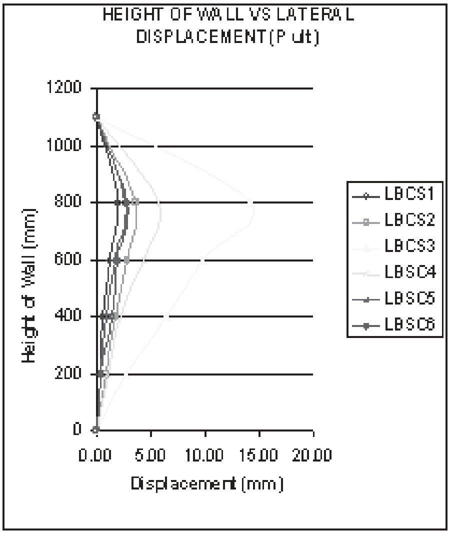

Figure 2: Lateral Displacement Profile at Ultimate Load

smallest profile with maximum lateral displacement of 2.08 mm, of which both are from calcium silicate bricks. The overall stability in terms of lateral displacement for sand cement masonry wall is better than the calcium silicate masonry wall, where the largest lateral displacement ratio between the two types is 1:2.46.

Ultimate Load

Ultimate load capacity is easier presented according to the type of bricks. The relationship of load against lateral displacement, load against vertical deflection and trend of the experimental result are highlighted herein.

Figure 3, 4 and 5 show relationships between load and lateral displacement for calcium silicate masonry bearing walls. In LBCS 1, all transducers recorded almost constant displacement as the load increases before reaching its ultimate. Ultimate load was recorded at 228.87 kN, after which the sample begins to fail. Once the sample failed, the load decreased at rapid rate and at the same time the displacement increased. At ultimate load T2, T3, T4 and T5 recorded lateral displacement of 2.08 mm, 1.18 mm, 0.63 mm and 0.33 mm respectively. Transducer T2 which is located at 800 mm from the support recorded the maximum displacement. Transducer T1 records vertical deflection, and at ultimate

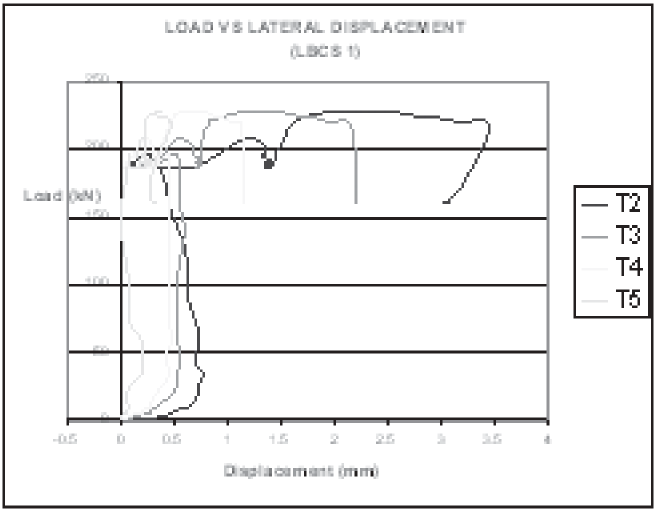

Figure 3: Load Against Lateral Displacement for LBCS 1

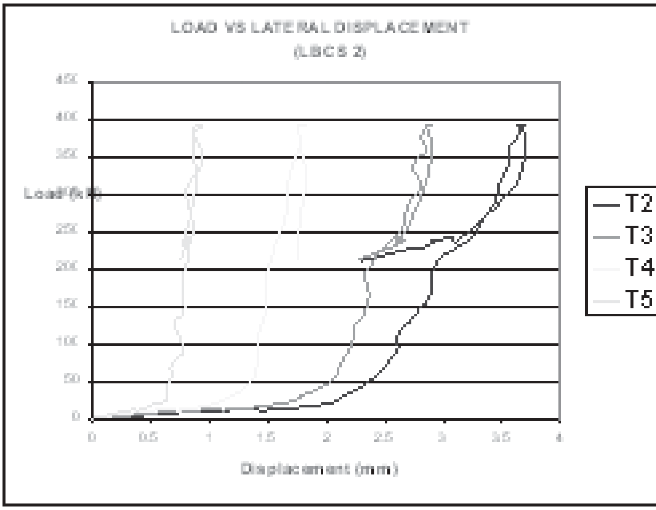

Figure 4: Load Against Lateral Displacement for LBCS 2

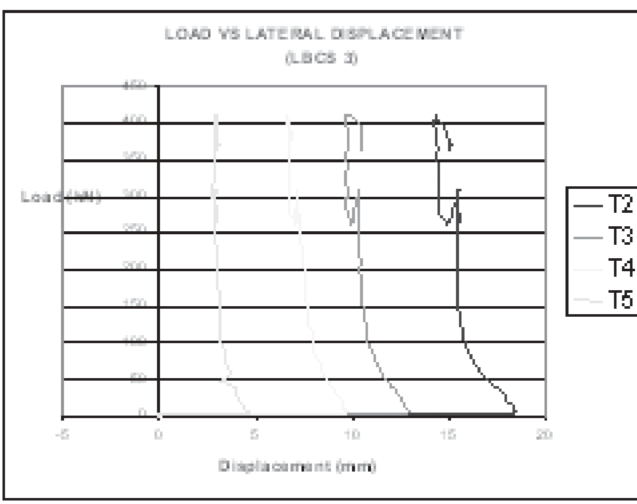

Figure 5: Load Against Lateral Displacement for LBCS 3

load, T1 recorded a magnitude of 13.9 mm. Similarly for LBCS 2, similar pattern in the load against lateral displacement obtained when compared to LBCS 3. It can be seen that the transducer reading goes from the minimum to maximum in a sequence of T5, T4, T3 and T2 in both figures 4 and 5. Figure 4 shows load increased to about 16 kN whilst the lateral displacement remain low ranging between 0.48 mm to 1.83 mm before a linear relationship is seen. It was recorded that LBCS 2 reached an ultimate load of 393.09 kN and correspondingly the lateral displacement were 3.65 mm, 2.88 mm, 1.78 mm and 0.93 mm for T2, T3, T4 and T5 respectively. Vertical deflection T1 at ultimate load is 29.83 mm which is 114 % more than that recorded in LBCS 1. The last brick wall tested in this set is LBCS 3. Figure 5 shows the load versus lateral displacement relationship. Similar trend can also be seen in this graph where the sequence of transducers' readings follows those in sample LBCS 1 and LBCS 2, *i.e.* in the order of T5, T4, T3 and T2. However, the load started to increase only after a lateral displacements ranging from 4.53 mm to 18.38 mm were recorded. The load recorded at those displacements was as low as 3.83 kN. Early stage of loading showed a reverse profile of the load versus lateral displacement until it reached a load of about 72 kN before showing a linear relationship. However when reached to about 310 kN, the load decreased to about 262 kN before increased back to ultimate load of 412.9 kN. Lateral displacements for T2, T3, T4 and T5 at ultimate load were 14.22 mm, 9.78 mm, 6.5 mm and 2.82 mm whilst vertical deflection T1 was 11.67 mm which is 16 % lower than LBCS 1.

However, in the sand cement masonry bearing wall samples, some erratic relationships were obtained. In Figure 6, LBSC 4 shows ultimate load was recorded at 527.39 kN with lateral displacement at T2, T3, T4 and T5 recorded as 5.79 mm, 4.41 mm, 2.23 mm and 1.09 mm respectively. All transducers showed linear increment in displacement with respect to loads, however, there was only a small initiation load that caused maximum initial lateral displacement of T2 to be as much as 2.93 mm. T1 recorded a magnitude of 7.77 mm as its vertical deflection. Similarly, for LBSC 5, the graph (Figure 7) shows negative records in lateral displacements to a maximum of -1.08 mm which is recorded in T2. However as the load increased to 223 kN, all transducers showed lateral displacement readings in the positive ranges. It can also be seen from this load that the relationship between load and displacement is linear until an ultimate value of 346.49 kN. It was recorded that LBCS 5 corresponding lateral displacement were 2.71 mm, 1.79 mm, 0.97 mm and 0.33 mm for T2, T3, T4 and T5 respectively. Vertical deflection T1 at ultimate load is 2.3 mm which amounted to only 30 % of the magnitude recorded in LBSC 4. The last sample in this set (LBSC 6) also showed similar trend in terms of the load versus lateral displacement when compared to LBSC 4. Figure 8

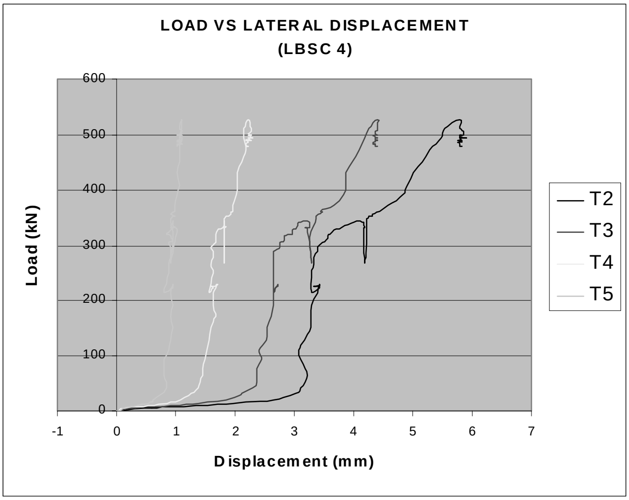

Figure 6: Load Against Lateral Displacement for LBSC 4

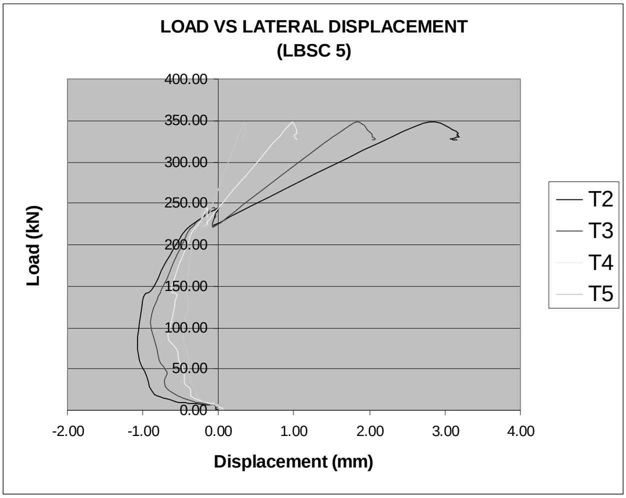

Figure 7: Load Against Lateral Displacement for LBSC 5

shows the relationship with an ultimate load of 470.5 kN achieved. Lateral displacements for T2, T3, T4 and T5 at ultimate were 2.93 mm, 1.94 mm, 1.45 mm and 0.48 mm whilst vertical deflection T1 was 9.81 mm, higher by 26 % than in LBSC 4.

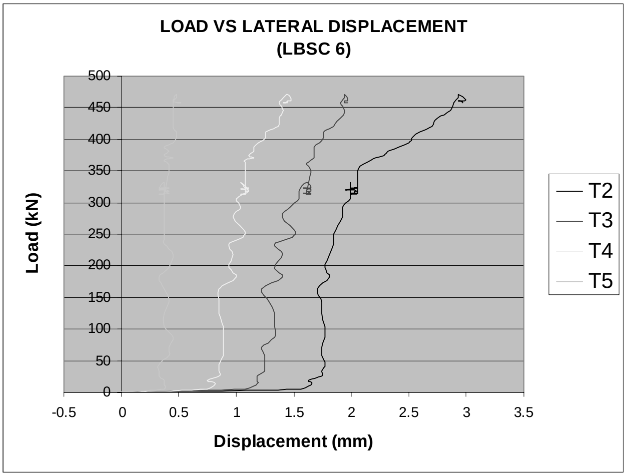

Figure 8: Load Against Lateral Displacement for LBSC 6

In general, all brick walls showed similar trend in their load versus lateral displacement relationship, load versus vertical deflection relationship (Figure 9 and Figure 10), and sequence of transducers readings in lateral displacement with respect to height of wall. It is seen after ultimate load, lateral displacement increased whilst the load decreased. The ultimate load is taken to be the failure load. All samples showed maximum lateral

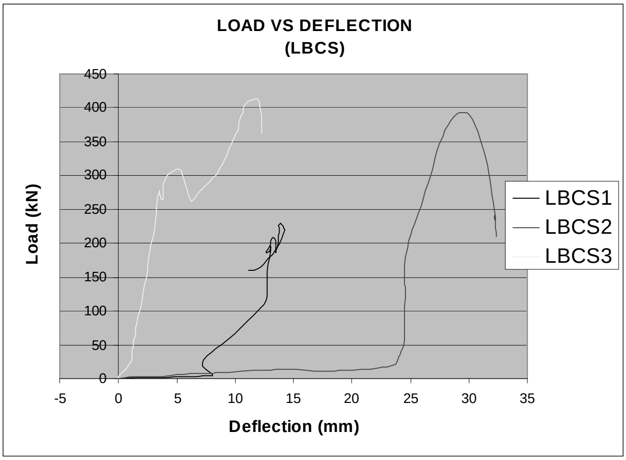

Figure 9: Load Against Vertical Deflection for Calcium Silicate Brick Walls

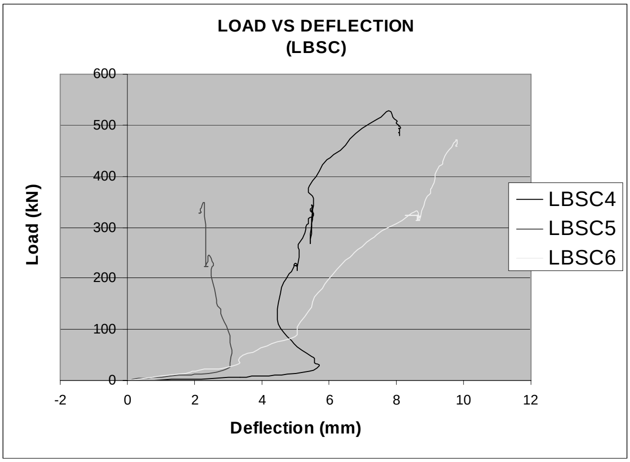

Figure 10: Load Against Vertical Deflection for Sand Cement Brick Walls

displacement at ultimate load happened at T2, 800 mm high from the support end and the least at T5, positioned at 200 mm wall height. Difficulty in controlling the workmanship skill causes variations in mortar binding force in which the thickness may differs between samples.

Crack Pattern

Failure pattern in terms of crack patterns are discussed in this section, and as previously mentioned failure criteria of the masonry bearing wall may be grouped into three failure modes, *i.e.* slipping of mortar joints, cracking of bricks and splitting of mortar joint and middle plane spalling. The crack patterns for both types of brick walls under study would be grouped according to the first two modes. The other modes are applicable to masonry walls of full brick thick.

For calcium silicate brick walls (LBCS 1, LBCS 2 and LBCS 3) and sand cement brick walls (LBSC 4, LBSC 5 and LBSC 6), crack initiation load for the samples shows crack initiation load of 196.20 kN, 336.88 kN, 276.84 kN and 150.88 kN, 145.78 kN and 331.70 kN respectively. The crack patterns of samples are shown in Figures 11. It shows that all samples have similar patterns of crack initiation development, *i.e.* from the mortar bondage positions. Cracks first initiated under shear and can be seen on the brick walls and propagated from the loaded end downwards. However, the amount of cracks recorded in sand cement

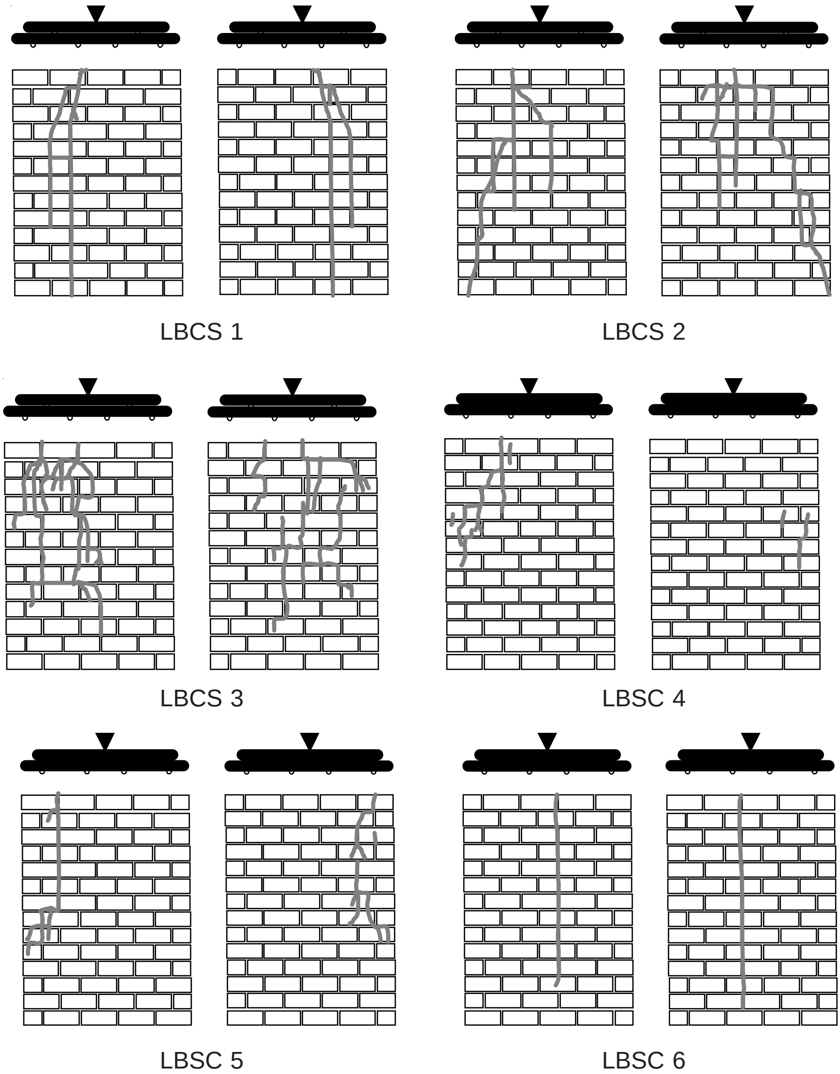

Figure 11: Crack Pattern for LBCS and LBSC, Front and Back Respectively

brick wall samples are much less than those seen on the calcium silicate brick wall samples.

The summary of the values obtained from the maximum lateral displacement, vertical deflection, ultimate stress, crack pattern and failure mechanism of brick wall samples for both the sand cement and the calcium silicate brick walls are tabulated in Table 3.

Table 3: Summary of the Maximum Lateral Displacement, vertical Deflection, Ultimate Stress and Crack Pattern for Calcium Silicate and Sand Cement Brick Walls

Sample No	Maximum Load, P_{ult} (kN)	Lateral Displacement (mm)	Vertical Deflection (mm)	Layers of Bricks Cracked (Front)	Layers of Bricks Cracked (Back)	Ultimate Stress (N/mm^2)	Failure Mech. Pattern
LBCS 1	228.87	2.08	13.90	1^{st} – 13^{th}	1^{st} –13^{th}	2.233	V
LBCS 2	393.09	3.65	29.83	1^{st} – 13^{th}	1^{st} –13^{th}	3.835	IV
LBCS 3	412.90	14.22	11.67	1^{st} – 11^{th}	1^{st} – 11^{th}	4.028	IV
LBSC 4	527.39	5.79	7.77	1^{st} – 8^{th}	5^{th} – 8^{th}	5.145	IV
LBSC 5	346.49	2.71	2.3	1^{st} – 10^{th}	1^{st} – 9^{th}	3.380	V
LBSC 6	470.50	2.93	9.81	1^{st} – 12^{th}	1^{st} – 13^{th}	4.590	V

Discussion

To predict the strength of the brick wall, it is imperative to obtain knowledge of how bricks and mortar act together, *i.e*. the strength of the brickwork must be determined on the basis of the known strength of the brick unit specimens. Experiments by Henry [9] have revealed that brickwork built of bricks with identical carrying capacity but with different performance characteristics, result in different carrying capacities. Traditionally, it is known that the carrying capacity of the brick wall has been determined by the knowledge of the strength of the bricks and the mortar, however, the strength of the bricks and of the mortar alone was insufficient to predict the strength of the brick wall. From the earlier study [5], it was found out that the brick strength, f_c brick for calcium silicate brick was 10.30 N/mm^2 where else for sand cement brick was 8.59 N/mm^2, however, from this investigation carried out, the average maximum lateral displacement values obtained for the calcium silicate brick walls are much higher than the sand cement brick walls in which the values are 6.65 mm and 3.81 mm respectively. The vertical deflection of calcium silicate brick walls on average gives a magnitude of 18.47 mm whilst sand cement brick walls gives an average of only 6.63 mm. In terms of ultimate load capacity, calcium silicate brick walls gives an average of 345 kN whilst sand cement brick walls gives an average of 448.13 kN. These results show that sand cement brick walls gives higher ultimate stress and thus capable of sustaining compressive load and suitable as load bearing structure.

Looking at the cracking pattern, both the calcium silicate and sand cement brick walls fall within the splitting mode failure where bricks cracked and sliding in the bed and/or head mortar joint. This type of failure requires strengthening in terms of proper meshing. Meshing will provide better bonding between the bricks and in turn enhances the bearing capacity of the masonry walls.

Conclusion

The strengths of the brick wall are thus not just dependent on the strengths of the bricks or the strength of mortar, but are also dependent on other qualities and especially on how the bricks and the mortar operate together. From this study, sand cement brick wall showed a better performance than calcium silicate bricks in terms of lateral displacement, vertical deflection and ultimate load even though it has a lower unit compressive strength. Therefore it can be concluded that the sand cement bricks which are locally produced can be used not only as an infill material but also as load bearing structural element. Apart from the strength, a unit cost of sand cement brick is much cheaper than the calcium silicate brick by 52 % and the production of sand cement are much simpler than the calcium silicate in which the calcium silicate bricks have to undergo the high pressure steam hardening processes.

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