

Characteristics of Different Masonry Units Manufactured with Stabilized Earth

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Abstract

Although there are many ancient buildings constructed with earth as a walling material, bricks and cement blocks have overtaken this material in the recent history. With the sustainable concepts being actively promoted in the construction industry, stabilized earth is becoming popular in many parts of the world due to various environmental problems associated with the use of conventional materials such as clay mining, sand mining, etc.

Some recent advances in manually and hydraulically operated machines have allowed the manufacturing of compressed stabilized earth bricks and blocks (CSEB) which could easily compete with burnt clay bricks and cement sand blocks. These blocks have a distinct advantage of use of machines for manufacturing which allow a greater freedom for controlling the quality. Since different sizes and types of stabilized earth blocks are available, it is important to investigate the performance of those as walling materials. Therefore, an experimental study was conducted to assess the performance of stabilized earth bricks manufactured to the standard brick size, interlocking solid blocks, interlocking hollow blocks and plain solid blocks.

In this study, the stabilized earth brick walls, which were constructed with different bond patterns such as Flemish, English and Stretcher, have been investigated for the performance in load carrying capacity and load deformation characteristics. The bricks were bonded with cement sand mortar. Both hollow and plain interlocking blocks were bonded with a soil cement paste. The performance of different CSEB units was compared in the study and also it was compared with that of burnt clay bricks and cement sand blocks. The results revealed that burnt clay brick and stabilized earth brick wall panels behave in a similar manner. However, different bond patterns have shown some variations in failure mechanisms.

Introduction

Compressed Stabilized Earth Bricks and blocks are becoming popular in various parts of the world especially with the introduction of sustainable construction concepts. Stabilization techniques such as mechanical, physical and chemical means are used to improve the strength and durability properties of soil as a construction material (Norton, 1986). Soil types and stabilization techniques suitable for CSEB manufacturing have been specified by various researchers (Norton, 1986, Rigassi, 1985, Perera, 1994, Jayasinghe, 1999). Cement as a chemical stabilizer has shown better performance in terms of strength and durability of CSEB (Rigassi, 1985, Bryan, 1988, Rahman, 1987).

Strength of CSEB masonry is influenced by a number of factors, such as block strength, mortar bed thickness, nature of bonding, mortar strength and slenderness ratio. In a study conducted by Reddy and Jagadish (1989), properties of CSEB with 5% cement were found which included dry strength, wet strength, air dry density and water absorption. The prism testing was done at 28 days to determine the compressive strength. These prisms were also tested in dry and wet conditions with different mortar mixes. In the same study, the modulus of elasticity of CSEB was also determined by measuring stress strain characteristics. These findings were further strengthened by a detailed experimental programmes conducted by Jayasinghe (1999) and Perera (1994) in Sri Lanka

Failure of masonry in compression is related to the interaction of the unit and the mortar joint as a result of their differing deformation characteristics (Hendry, 1990). Many studies were done on CSEB to determine the compressive strength of units (Walker and Stace 1997, Reddy and Jagadish, 1989,

Jayasinghe 1999 and Perera 1994). CSEB wall strengths were found in a detail experimental programme conducted by Jayasinghe (1999) and a relationship of unit and wall strength for CESB was established.

Block manufacturing machines facilitate production of different types of units such as CSE bricks, solid blocks, interlocking solid and hollow blocks. In addition to the basic shapes, there are some other shapes such as lintel blocks, column blocks and units for reinforced masonry mainly for special applications. These different CSE masonry units can give various performances in load carrying capacity, load deformation behaviour, etc. This paper presents the outcome of a study that was focused at determination of such variable properties of different CSE masonry units and to compare those properties with conventional masonry units such as burnt clay bricks and cement sand blocks.

Objectives

The main objectives of the research covered in this paper are to determine the load carrying capacity and load deformation behaviour of different CSE bricks and blocks, different bond patterns and to compare that with the behaviour of burnt clay bricks and cement sand blocks under the applied loads.

Methodology

In order to achieve the above objectives, following methodology was adopted:

- a. Wall panels were constructed with CSE bricks, blocks, burnt clay bricks and cement sand blocks for destructive testing.
- b. All the panels were tested after 28 days of casting and load deformation characteristics were monitored.
- c. Crack patterns and failure mechanisms were observed and compared for different unit types, bond types and masonry types.

Manufacturing of Compressed Stabilized Earth Blocks

Soil is the main raw material used in CSEB manufacturing. Soils are made up of inert materials (gravel, sand, silt) and active materials (clay). The former acts as a skeleton and the latter acts as a binding agent. The proportion in which each type of material present will determine the behaviour and the properties of different soils. There is a requirement for a small amount of fines (clay and silt), but an upper limit is also necessary to limit shrinkage to ensure effective stabilization. Therefore, special attention is needed for the clay and silt (fines) content in the soil. A fines content of less than 35% has been recommended by Perera and Jayasinghe, (2003) as one of the criteria for soil selection. Rigassi (1995) has proposed the boundaries for the grading curve of soils to ensure satisfactory compaction and durability. Physical testing proposed by Norton (1986) and Perera (1994) can be used to select preferred soil types for the CSEB manufacturing. The suitable soils for CSEB manufacturing are also specified in the Earth Building Standards (Australian Earth Hand Book, 2002, NZS 4297: 1998). The selected soil is first mixed with the required amount of stabilizer and water is added to maintain the correct moisture content. Moisture content is maintained by conducting "drop test" (Spence & Cook, 1983). This mixture is compacted in a machine and then the blocks are stacked in a moist environment for about 14 days.

There are different types and sizes of CSEB available since the different machines are capable of manufacturing solid, hollow, solid, interlocking and plain blocks for various applications. Morel et. al (2001) stated that since compressed earth blocks are produced in a greater variety of unit sizes than many other masonry blocks, the influence of unit geometry on performance needs to be accommodated in a reliable and consistent manner.

Use of different machines can give variable compaction ratio (Compaction ratio is the height of the loose soil/ height of the finished block) in block manufacturing. A minimum compaction ratio of 1.65 has been recommended by Jayasinghe (1999) for the blocks used in load bearing walls.

Mortars Used

There can be a number of cement soil and sand mortars that can be used for CSEB construction. It was reported by Reddy and Jagadish (1989), soil cement mortar with 5% cement by weight appears to be

more ductile than the cement sand mortars. Alternatively, Cement, lime and sand in 1:1:6 or 1:1:8 also can be used for CSEB wall construction. When it is necessary to reduce the cost of mortar further, stabilised mud mortars such as 1:2:6 and 1:2:8 cement, soil and sand are recommended (Reddy, 1995). A study done by Jayasinghe (1999) has shown that CSEB bonded with 1:6:6 mortar performs well, and wall compressive strengths comparable with that constructed with 1:6 cement sand mortar could be obtained (Jayasinghe, 1999).

Strength Characteristics of CSEB Masonry

For masonry, it is recommended to consider the ultimate stresses and then to couple it with a sufficient factor of safety to ensure satisfactory behaviour under the service conditions (Hendry, 1990). The adequacy of wall strengths can be checked with partial factors of safety of 1.4 for dead load and 1.6 for the imposed load (an average of 1.5). A partial factor of safety for the material strength of 3.5 can be recommended for CSE bricks and blocks. Therefore, the factor of safety of $1.5 \times 3.5 = 5.25$ can be recommended in the structural design of CSEB walls. This will be useful to compensate for any strength reduction anticipated under saturated conditions. However, such adverse conditions are not generally expected with the adoption of good construction practices recommended for CSE blocks.

According to the previous studies conducted by Perera (1994), Jayasinghe (1999), Perera and Jayasinghe (2003), CSEB wall panel strength is based on various factors such as unit strength, mortar strength and dimensions of the blocks. Another important aspect is to ensure that the walls do not form cracks under working loads.

The interlocking blocks are also used in CSEB wall construction which is generally bonded with a cement soil paste. The failure mechanism of interlocking block walls can be somewhat different to that of the plain blocks and needs investigations.

The prisms made out of interlocking cement blocks tested by Jaafar et al. (2006) have shown that the failure mode was a splitting failure between the webs and the shells of the block. The interlocking mechanism had restrained the movements in horizontal and vertical directions. Moreover, due to poison's ratio effect, tensile stresses were developed in the restrained block shells and also shear stresses at the interlocking key. The shear stresses developed at the web shell intersection were higher than the tensile stresses in the shell; hence the web splitting failure occurred. These cracks have widened with the increase of applied load until failure. The study presented in this paper covered the behaviour of interlocking CSE blocks as well.

Experimental Programme

According to BS 5628: Part 1: 1992, masonry wall strength can be determined by testing wall panels. Different units considered in this study are CSE bricks manufactured to the standard brick size, solid interlocking blocks, hollow interlocking blocks and solid plain blocks of the dimensions given in Table 1. They are shown in Figure 1. The conventional masonry units considered are the burnt clay bricks and cement sand blocks. The wall panels were cast with English, Flemish and stretcher bond patterns (www.archifacts.co.uk). Plain blocks and bricks were bonded by cement sand mortar (1:5) and the interlocking blocks were bonded with a soil cement paste. The dimensions of wall panels were selected in accordance with BS 5628: Part 1: 1992 and also considering the slenderness effects and practical constraints (Jayasinghe, 1998). Panel dimensions, load at failure and moisture content of the wall at the time of testing are given in Table 2.

The bricks and blocks complying with following conditions were selected for the research study:

1. Burnt clay bricks and CSE bricks/blocks having a unit strength of 5 N/mm^2
2. Cement sand blocks having unit strength of 5 N/mm^2

All the CSE bricks and blocks were tested under dry and wet conditions and found that the wet strength is more than $0.4 \times$ dry strength of the unit as recommended in the relevant standards (Australian Earth Building Hand book, 2002, Heathcote, 1995).

Table 1 Different masonry units used in the study

Masonry unit	Size	Type	Bond pattern
CSE brick	225 x 105 x 80	Plain brick	English, Flemish
CSE block	235 x 235 x 140	Solid plain	Stretcher
CSE block	235 x 235 x 140	Solid interlocking	Stretcher
CSE block	295 x 145 x 100	Hollow interlocking	Stretcher
Burnt clay brick	215 x 105 x 65	Plain brick	English, Flemish
Cement sand block	400 x 200 x 200	Hollow plain	Stretcher

Some of the wall panels constructed with different bond patterns and units are shown in Figures 2 to 6.

Results and Analysis

In this experimental programme, wall panels constructed with different masonry units were tested to failure and the ultimate load carrying capacity was recorded for each panel together with the load at first crack. In order to investigate whether a ductile behaviour can be obtained with CSE bricks and blocks, similar to other two conventional materials, load deformation behaviour was monitored while testing each panel.

The ultimate failure stress and the characteristic strength obtained for different wall panels tested are given in Table 2. This table compares the compressive strength of masonry walls constructed with three different materials.

Table 2 Results of the strength testing

Unit	Bond pattern	Panel size (mm) (length x height x thickness)	Ultimate Strength (N/mm ²)	Characteristic Compressive Strength (N/mm ²)	Moisture content of the wall panel
CSE bricks	English bond	736 x 690 x 225	2.56	2.13	3.5%
CSE bricks	Flemish bond	852 x 685 x 225	2.92	2.43	3.0%
Burnt clay bricks	English bond	698 x 576 x 225	3.10	2.58	3.11%
Burnt clay bricks	Flemish bond	755 x 638 x 225	3.18	2.65	3.20%
CSE blocks – Hollow interlocking	Stretcher	750 x 625 x 145	2.22	1.85	3.70%
CSE blocks – solid interlocking with horizontal groove	Stretcher	690 x 600 x 235	1.50	1.25	3.5%
CSE blocks – solid plain	Stretcher	750 x 620 x 235	3.19	2.66	3.65%
Cement blocks (hollow)	Stretcher	1216 x 812 x 100	3.19	2.66	2.65%

The following results were obtained from this comprehensive experimental study:

1. English and Flemish bond patterns of CSE bricks (Figures 2 and 3) and burnt clay bricks have shown compressive strength in the same range. However, marginal increase in strength was recorded for burnt clay brick panels. Therefore, the Table 2 given in BS 5628: Part 1: 1992 which presents the relationship between the unit strength and the wall strength needs to be modified for CSEB.
2. Cracks were initiated at the vertical mortar joint and propagated as a result of tensile failure due to Poisson's effect of both burnt clay and CSE bricks, for all English, Flemish and Stretcher bond.
3. Hollow interlocking CSE blocks (Figure 4) and cement sand hollow blocks have failed in a similar manner with splitting failure across the thickness of the wall; indicating some weaker planes aligned with the hollow area.

- When thicker blocks were tested, the CSE solid blocks (Figure 6) and CSE interlocking blocks with the horizontal groove of the same size (Figure 5), gave two different results. Solid CSE block gave much higher strength than the CSE interlocking block with the horizontal groove. Therefore when selecting CSE blocks for thicker walls, the units with horizontal groove can be chosen only where services have to be inserted. For the other locations solid block is preferred.

This lower strength of the blocks with groove (Figure 5) can be attributed to the formation of a weak plane of lower cross sectional area in the middle of the wall. When the vertical compressive stresses are acting, the resultant lateral tensile strain can cause the splitting of the block at this plane where higher stresses occur. Thus, the block tends to fail at much lower stresses than expected.

These interlocking blocks were laid with 1:5 cement sand mortar and another series was carried out with cement soil paste. Both types gave similar results. The CSE solid blocks of this size (235 mm thick) can be recommended for the ground floor of a load bearing two storey houses or for the walls which will carry heavier loads.

- Load deformation curves for the walls constructed with all the masonry units have shown adequate warning before failure. Therefore, CSE bricks can be considered as a walling material with sufficient ductility.
- Interlocking blocks as shown in Figure 5 can give many advantages like lower labour requirement, speedy construction, less mortar consumption etc. However, interlocking blocks should be manufactured in such away that the wall will not form any weak planes when transferring the load. Such weakness was shown when the block of 235 mm thick with the horizontal groove was compared with the solid blocks of the same dimensions (without the groove) which were manufactured with the same machine. The solid block gave a substantially high compressive strength. Therefore the plain solid CSE block is recommended for load bearing two storey constructions and for the heavily loaded walls. Interlocking blocks can be recommended for single storey construction and as infill walls in reinforced concrete frame construction.

Stress Strain Relationships

The modulus of elasticity (E value) of CSEB walls can be determined by monitoring the stress strain characteristics of wall panels. Load deformation behaviour of all the wall panels tested was monitored and the E values were evaluated. The average modulus of elasticity obtained at a stress of 0.3 N/mm^2 tangent modulus is in the range of 0.25 kN/mm^2 for the CSEB walls. Chart 1 shows a specimen load deformation curve for a CSEB wall panel. Similar curves were obtained for all the panels and the average E value was evaluated for CSEB walls.

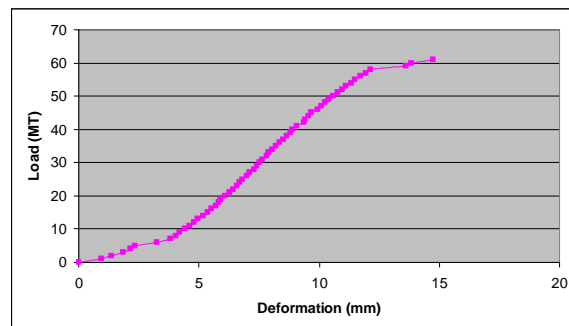


Chart 1 Load deformation curve for a CSEB wall panel

Conclusions and Recommendations

CSE bricks and blocks can be good alternatives to the conventional materials such as burnt clay bricks and cement sand blocks. There are various types of machines available, which can produce different block types and sizes. The study presented in this paper identified some differences in failure mechanisms and load carrying capacities of several block types.

CSE bricks manufactured to the standard brick size can be recommended for load bearing construction with English and Flemish bond types. Although the design can be carried out in accordance with BS 5628: Part 1: 1992, modification factors should be introduced for the wall and unit strength values for CSEB, depending on the bond pattern and the unit type. The interlocking CSE blocks have shown a different failure mechanism compared to the plain blocks. Therefore, further investigations are needed to establish the failure mechanism.

When thicker walls are required to carry heavier loads, solid, plain CSE blocks of 235 mm thickness can be used as an alternative to the English and Flemish bonded CSE bricks.



Figure 1 Block types used in the study



Figure 2 CSE bricks-English bond



Figure 3 CSE bricks - Flemish bond



Figure 4 CSE Interlocking block panel 1- Failure pattern (145 mm thick wall)



Figure 5 CSE Interlocking block panel 2 (235 mm thick wall)



Figure 6 CSE solid plain block (235 mm thick wall)

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