EFFECT OF DIMENSIONAL VARIATION OF CSE BLOCKS

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Abstract: Compressed stabilized earth (CSE) blocks are one of the alternative building materials that are becoming popular due to insufficiency of conventional building materials and its sustainability. CSE blocks are manufactured with different unit dimensions. This research is focused on determination of effect of unit dimensions of CSE blocks on masonry construction. Unit dimensions basically affect on the compressive strength and cost of construction of masonry. Ratio of height to least horizontal dimension (H/W) is a governing factor of compressive strength. In this research, plain CSE blocks having H/W ratio of less than 0.6 have been considered for which there is no provision for characteristics strength (f_k) of masonry in BS 5628: part1:1992 [6]. Four different sizes of blocks with H/W ratio of less than 0.6 were used for the test. Relationships between Characteristic compressive strength of masonry, unit strength, and H/W ratio and load deformation characteristics were developed. Studies were done to determine the cost of construction of each panel. Results show that strengths of all panels are adequate for load bearing construction. Wall strengths increases with the H/W ratio. Panels provide a sufficient warning before ultimate failure. When the H/W ratio is close to 0.6 panel strength is comparable with the values provided in Table 2.0 of BS 5628: part1:1992.

Keywords: Compressed stabilized earth (CSE) blocks, Height to least horizontal dimension ratio (H/W), Compressive strength, Embodied energy, cost of construction

1. Introduction

Masonry has been used for many years as a popular walling material. Masonry wall construction has a number of advantages including relatively low cost, fire protection, thermal and sound insulation, weather protection, wider availability and attractive appearance [2, 3]. Masonry wall construction has undergone a considerable change in last few decades with the introduction of new materials and new type of units [2].

Use of alternative walling material has become increasingly popular due to the scarcity of conventional building materials, such as burnt clay bricks, river sand etc. Compressed stabilized earth (CSE) blocks are one such material that is becoming popular in the recent time. Use of earth as a walling material for houses is gradually regaining the popularity in many parts of the world due to recent development in stabilization techniques [1].

Compressive strength of masonry is an important parameter in designing masonry structures. It is greatly influenced by unit characteristics such as strength, type and geometry [3, 8, 9]. Lack of quality controlling in masonry units manufacturing process in Sri Lanka has resulted various sizes of bricks and blocks coming into the market. Compressed earth blocks are produced in a greater variety than many other masonry blocks [11]. This has resulted a need of a study of effect of unit dimensions of CSE blocks on masonry construction.

It has been shown by Jayasinghe (2007) [1] that the characteristic compressive strength (fk) of CSE masonry with the ratio of height to least horizontal dimension (H/W) of 0.6 can be determined when the unit strengths are known by using the wall strength values specified in Table 2.0 of BS 5628: part1:1992 with some modification factors. But not enough studies were done on the walls constructed with CSE blocks having a ratio of height to least horizontal dimension of less than 0.6. This research paper covers a comprehensive study on effect of dimensional variation of CSE blocks with H/W ratio of less than 0.6 on masonry construction.

2. Objectives

This research was carried out to determine the effect of dimensional variation of CSE blocks with a ratio of height to least horizontal dimension of less than 0.6 on compressive strength of masonry.

3. Methodology

In order to achieve above objectives, following methodology was used:

I. Wall panels were made with plain CSE blocks with four different H/W ratios of less than 0.6 but same horizontal dimensions.
II. Two identical panels were made from each block type.
III. In order to determine the cost of construction, materials required and time taken for construction were measured for each panel.
IV. Wall panels were tested for the compressive strength 28 days after construction.
V. Failure patterns and load deformation characteristics were also observed.
VI. Individual blocks were tested to determine the unit compressive strength.

Results of above tests were used to find the correlations between unit strength, panel strength, load-deformation characteristics and H/W ratio.

4. CSE as a sustainable material

Due to limited resources in the world for construction activities sustainability would be a great important concept. A main reason for CSE blocks to gain its popularity is the keenness of developers to attempt the use of alternative building materials to improve the sustainability of building construction industry. In this context compressed stabilized earth bricks and blocks can be considered as viable alternatives [1]. Major advantages of CSE blocks [10, 12] can be listed as follows:

a) Energy efficient; consuming less than half of the energy required for conventional building methods leading to energy conservation
b) Economical; 20–40% savings in cost when compared to brick masonry
c) Plastering can be eliminated
d) Better block finish and aesthetically pleasing appearance
e) Techniques are simple and employ maximum local resources and skills
f) Decentralized production systems and small-scale operations that generate local employment
g) Reduce cost and energy involved in transportation of building products

4.1. Embodied Energy

Embodied energy is the energy needed in preparing and extracting the raw materials, energy for transportation of the same and the external energy applied to raw materials in producing or assembling the final product [10]. When comparing the embodied energy in different materials, what is important is the energy flow of each and every unit including formation, transformation, transportation and installation. Some data available in literature for basic materials have been used in this study. This data can be used to determine and compare the embodied energy in CSE blocks with conventional burnt clay bricks.

CSE blocks contain 5%-6% of cement used for the manufacturing. Block can be either electrically operated machine compacted or manually compacted. Drying is done by solar radiation and no extra energy is consumed. Ordinary bricks have higher energy usage when burning. As CSE blocks do not require burning, it saves about 70% of the energy when compared to burnt clay bricks [12]. In tropical climatic conditions laterite soils are commonly found as laterite hills. Since it is readily available in most of the locations, energy requirement in transportation is comparatively less [10]. As it uses simple techniques, employ maximum local resources and skills, and can finish without a plaster (hence minimum use of cement) embodied energy in final product is much less than in conventional burnt clay bricks. A study done by Reddy (2004) [12] shows that the energy consumed by the load bearing conventional two-storied brickwork building is 2.92 GJ/m2. Two-storied building using alternative building materials like CSE walls is highly energy efficient. The energy consumed by this building is 1.61 GJ/m2, which is about 55% of that consumed by conventional brick wall building respectively.

4.2. Life Cycle energy

Any comprehensive assessment of architectural energy consumption must in fact consider the entire life cycle of the building, which can be divided into three phases: pre-use phase (embodied energy), use phase (operational energy) and post-use phase (demolishing or possible recycling and reuse) [5]. Extensive testing carried out by many researchers has indicated that CSE block masonry is of adequate strength. Since cement based products tend to gain strength with age, the durability of CSE masonry will be comparable with conventional materials. Thus the life cycle energy will primarily depend on the embodied energy and operational energy [10]. Embodied energy of CSE blocks has been already discussed in the previous section.

When considering the life cycle energy, conventional masonry such as cement blocks and other ordinary bricks and blocks have a higher operational and maintenance energy. Replacement of one unit or maintenance in a usage level consumes much high energy. Comparing heat and thermal comfort, CSE blocks perform far better than conventional units.

4.3. Environmental concerns

CSE blocks cause less environmental problem compared to other conventional bricks and blocks. Extensive use of burnt clay bricks and cement sand blocks has given rise to many environmental problems. Extensive clay mining has created deep pits that led to lowering the ground water table. Stagnation of water has become breeding grounds for mosquitoes. Cement sand blocks need high amount of sand for the manufacturing. Both conventional bricks and cement blocks require high amount of sand and cement for the plaster. Excessive sand mining in rivers has caused many problems including lowering water table and salt water intrusion. High usage of cement and burning in the case of burnt clay bricks increases the CO_2 emission to the atmosphere. As CSE block walls can be finished without a plaster, use of sand and cement is less.

At the end of the life cycle, decaying of the materials would cause hazards for the environment in direct and indirect way. Cementing materials cause direct problems in underground water paths and spill ways. And toxic elements which added to the soil and water when at the end also cause problems. As cement blocks contain much higher amount of cement, at the end of the life cycle decaying percentage of the cement is high. Ordinary bricks with plaster are having high percentage of cement. But CSE without a plaster and contains low cement percentage compared to others and less environmental problems are caused.

5. Experimental programme and results

In order to determine the effect of H/W ratio of CSE blocks on masonry construction four sizes of blocks were selected for testing. All the blocks are having the same horizontal dimensions but different heights so that the H/W ratios are different. H/W ratio was kept less than 0.6 as the scope of this research is limited to that. Selected block sizes are shown in the Table 1. Figure 1 shows the blocks used for the experiment.

Table 1- *Selected block sizes*

Block dimensions (mm)	H/W ratio
225x220x100	0.45
225x220x110	0.50
225x220x120	0.55
225x220x128	0.58

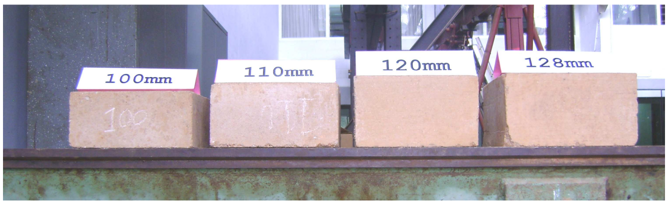


Figure 1- *Blocks used for the experiment*

5.1. Construction of wall panels

Appendix A of BS 5628: part1:1992, specifies the sizes of wall panels that should be used to test the compressive strength of masonry [6]. Size of a test panel was limited to a length of 3 blocks and height of 6 courses to avoid slenderness effect and for easy handling. Heights of wall panels were not the same due to the variation of block height. But the number of courses was kept equal. Bond pattern used was stretcher bond.

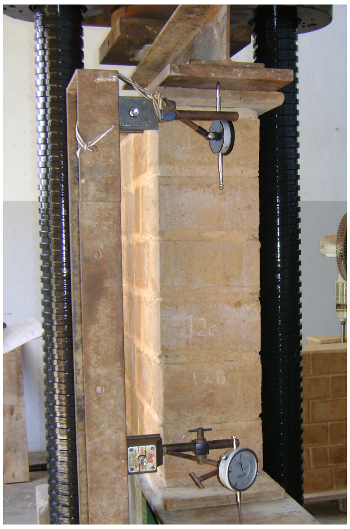
Panels were made using 1:2:6 cement: soil: sand mortar. Soil used for the mortar was laterite soil sieved with 2.36mm sieve. Soil was kept 24 hrs in water and saturated soil was used. Top of the panel was capped with the same mortar to have a level surface. Figure 2 shows the test panels constructed for testing.


Figure 2 - *Test panels constructed for testing*

Materials used to prepare the mortar were measured using a gauge box. Amount of mortar used for each panel and time taken to construct was recorded to determine the effect on cost of construction of masonry.

5.2. Unit strength and compressive strength of masonry

Compressive strength has become a basic and universally accepted unit of measurement to specify the quality of masonry units. The relative easiness of undertaking laboratory compressive strength testing has also contributed to its universality as an expression of material quality [11]. Dry strength of CSE block units were tested according to the standard test method. Three blocks from each size were tested and the average value was taken as the compressive strength unit.
Compressive strength of masonry can be determined from the ultimate strength of block panels tested in accordance with the test procedure given in BS 5628: part1:1992 [6]. Test was carried out on two nominally identical wall panels. Deformation of the wall with the load was observed using two dial gauges fixed to the top and bottom of the test panel. Figure 3 shows a test panel prepared for testing.



5.3. Results

Unit strength of CSE block

Average unit strengths of CSE blocks obtained from test are shown in Table2.

Table 2 - *Average unit strengths of CSE blocks*

Block dimensions (mm)	H/W ratio	Average strength (N/mm^2)
225x220x100	0.45	5.879
225x220x110	0.50	4.336
225x220x120	0.55	4.851
225x220x128	0.58	6.387

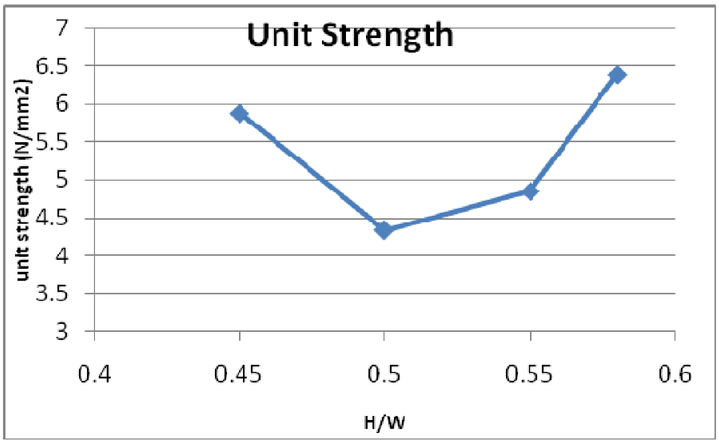


Figure 4- *Unit strength variation*

Compressive strength of masonry

Load at the first crack is one of the most important indications of suitability of brickwork for construction. It is of paramount importance to ensure that the wall is free from cracks under working load stresses [15]. Ultimate strength is important to determine the characteristic compressive strength. Compressive strengths of wall panels were tested according to standard method to determine the load at the first crack and failure load. Figure 5 shows two test panels after ultimate failure. Results are shown in the Table 3.

Figure 5 - *Test panels after ultimate failure*

Table 3 – *Average panel strengths*

Block dimensions (mm)	H/W ratio	Stress at first crack (N/mm^2)	Average panel strength (N/mm^2)
225x220x**100**	0.45	1.038	1.965
225x220x**110**	0.50	1.301	2.032
225x220x**120**	0.55	1.752	2.275
225x220x**128**	0.58	1.956	2.384

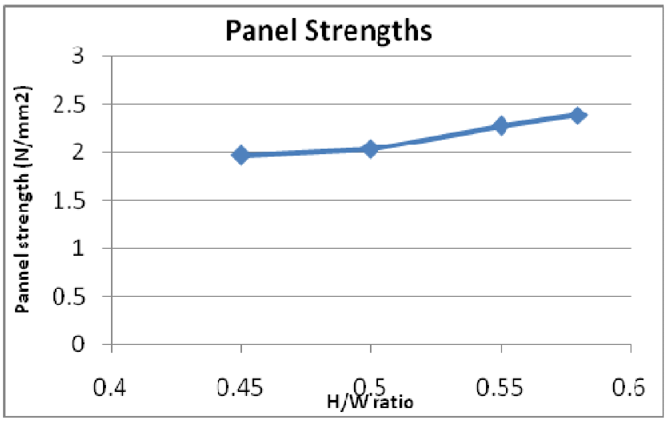


Figure 6 – *Panel strength variation*

Load deformation characteristics

Determination of load deformation characteristics for CSE block masonry is important because CSE blocks use for load bearing wall construction, it should give sufficient warnings prior to failure [1, 14].
Load deformation relationships for different blocks were developed by using two dial gauge readings. Those curves are shown below.

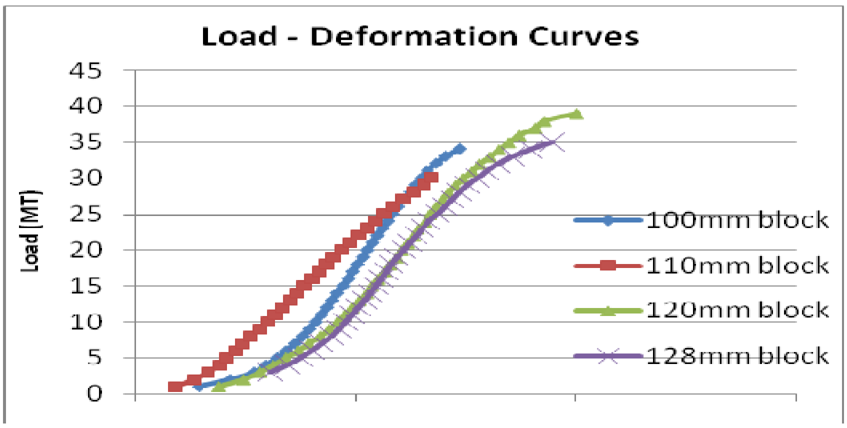


Figure 7 – *Load-Deformation curves*

6. Analysis of results

Generally the compressive strength of blocks decreases with the increasing height [8, 9]. But the test results of blocks used for this research did not show such a variation. That may be due to some defects of blocks. Further studies should be done to verify the variation.
A number of investigations done on effect of unit height of masonry units on compressive strength of masonry, show that the compressive strength of walls increases with the unit height [8, 9]. Test results of this research are also complying with that. Compressive strength of masonry increases from 1.965N/mm^2 to 2.384 N/mm^2 when H/W ratio increases from 0.45 to 0.58. Stress at the first crack also increases. It is shown that for two storey houses with normal room sizes wall strength of 1.5 kN/mm^2 is sufficient [4]. Hence compressive strengths of all panels are adequate for load bearing wall construction.
Load deformation characteristics obtained by plotting test results shows that wall panels undergo sufficient deformation before they fail. Hence it provides sufficient warning before ultimate failure. Panels made with blocks having H/W ratio of 0.55 and 0.58 show more ductile behavior than those made with blocks having H/W ratio of 0.45 and 0.5.
Australian earth building handbook recommends a design E value of about 0.2 kN/mm^2 [13]. Panels tested for this research are having E values in the range of 0.27-0.37 kN/mm^2.
Cost of construction is an important parameter when considering the viability of using alternative building materials. Determination of effect of unit dimensions on cost of construction is one objective of this research. Cost of construction for different panels is shown in Table 4.

Table 4 – *Cost of construction*

	Sizes of block thickness			
	128mm	120mm	110mm	100mm
Cost of panel (Rs/-)	2079.31	2045.20	2214.83	2437.37
Cost for unit area(Rs/m2)	3572.60	3725.31	4359.90	5208.05

7. Comparison of results with burnt clay bricks

The mortar used for the construction of wall panels is 1:2:6 Cement: Soil: Sand mortar. This can be considered as equivalent to mortar designation iv. When tested for the compressive strength of panels, the panel made of 128 mm high (H/W ratio of 0.58) blocks gave strength of 2.384N/mm^2. This can be compared with the wall strength values given for the masonry, constructed with blocks having H/W ratio of 0.6, in table 2 (b) of BS 5628: part1:1992 [6] as 0.58 is close enough to 0.6.
A study done by Jayasinghe and Mallawarachchi (2009) [3] has shown that cement stabilized earth bricks and blocks walls would be capable of performing in a manner comparable to good quality burnt clay bricks of 5 N/mm^2 compressive strength. Thus the CSE stabilized with 5% cement has the potential to provide an alternative that can be manufactured to perform very similar to burnt clay bricks of 5N/mm^2 compressive strength [3]. Thus for a unit strength of 5N/mm^2, Table 2 (b) of BS 5628: part1:1992 [6] gives a characteristics compressive strength of 2.2 N/mm^2 which is very close to the value we got for blocks of H/W ratio of 0.58.

8. Conclusion and Recommendations

CSE blocks used in masonry construction are becoming popular in order to meet sustainable construction concepts. These blocks are manufactured in different scale using manual, semi automated and fully automated machines. Different quality controlling procedures can give rise to dimensional variations for the CSE blocks. It was found in the experimental program covered in this paper, maintaining H/W ratio around 0.6 would be beneficial in terms of characteristics wall strength. This can also lead to use BS 5628: part1:1992 for design of masonry constructed with CSE blocks. It is also recommended to maintain good quality controlling at the manufacturing stage.

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