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Case study

Use of construction waste to modify soil grading for compressed stabilized earth blocks (CSEB) production

S.N. Malkanthi [a,*], W.G.S. Wickramasinghe [a], A.A.D.A.J. Perera [b]

[a] Department of Civil and Environmental Engineering, University of Ruhuna, Sri Lanka
[b] Department of Civil Engineering, University of Moratuwa, Sri Lanka

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ABSTRACT

Earthen materials have been used in civil engineering construction worldwide with different forms, such as mud, adobe, rammed earth and bricks. Compressed stabilized earth blocks (CSEB) can be considered as a new member of the earthen building material family. Also, it can overcome the problems associated with fired bricks and cement blocks. Cement is the most commonly used as stabilizers to enhance the properties of CSEB. The governing factor which controls the properties of CSEB is the amount of clay content in the soil. Researches have concluded that about 25% of clay and silt (finer) content contributes to high compressive strength. However, controlling of larger particles is not addressed much. This study focused on controlling the finer content as well as larger particles with the use of construction waste (mostly with crushed concrete) and river sand. Selected soil was modified to get the finer content as 5%, 10%, 15% and 20%. This modification was done by adding river sand and construction waste to the soil to optimize the particle packing based on particle packing theories. Cement was used as the stabilizer with 6%, 8%, and 10%. (150 × 150 × 150) mm^3 cubes were cast and tested for dry density, water absorption, 28 days wet and dry compressive strength, accelerated erosion and compared with SLS 1382; part 2 requirements. Block properties were conformed with SLS 1382 requirement when finer contents are 10% and 5% with 10% and 8% cement. Further, Industrial-scale blocks of (350 × 100 × 175) mm^3 made with 10% finer and 8% cement satisfied the Grade 1 block properties. CSEB made mixing with construction waste contributes to manage the environmental pollution due to construction waste while giving a fair solution to the problem with the shortage of building materials.

1. Introduction

For centuries, use of earth as a building material began with plain mud and straw with low strength and durability until it grew into fired clay bricks with mass rapid production in the kiln. Compressed Stabilized Earth Blocks (CSEB) can be considered as the youngest member of the earth building material family. CSEB gives a view of environmentally friendly building material resulting overall contribution to sustainable development. CSEB represents a cost-effective, good energy-efficient, good sustainable building material [1]. It turned out that CSEB properties can help to resolve the problems associated with other materials such as concrete blocks or common fired bricks. CSEBs are made with soil as the main raw material. Cement, fly ash, lime, etc. are used as stabilizers for CSEB

* Corresponding author.
E-mail address: snmalkanthi@cee.ruh.ac.lk (S.N. Malkanthi).

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production. Some researchers have used recycle materials like, rubber, fly ash [2], bottom ash, construction waste, and fibers [3], to enhance the properties of CSEB. CSEB can be considered as a sustainable construction material. However, its usage as a common building material is still not the same as other materials. Still, CSEBs are associated with strength and durability issues. Moisture causes for reducing the strength of CSEB [4]. Higher clay & silt content coupled with the lower cement content found in the CSEB when compared to ordinary concrete masonry units, as much as half the dry strength of CSEB can be lost when CSEB becomes saturated [5].

Since the main raw material for CSEB production is soil, the clay content in the soil greatly affects the strength and durability. The past research work has established the optimum clay in the region of 5–20% leads to required compressive strength [5,6]. Also, most of the researchers have added different materials like sand to reduce the clay content in the soil. Malkanthi and Perera [7] have suggested a soil washing method to reduce clay and silt content. Further, most of the researchers have not considered the amount of larger particles in the soil. Malkanthi & Perera [8] have proven that the modification of soil grading leads to more than 50% compressive strength improvement and significant improvement with other properties also. But they have used the larger particles extracted from the same soil for the soil grading modification considering the particle packing concept as suggested by Santhanam [9] and Wong et al. [10]. Abdullah et al. [11] also suggested adjusting the particle distribution of the soil mixture until it reaches an ideal curve. Bogas et al. [12] has investigated properties of CSEB by adding partially recycled aggregates but they have not considered that aggregates addition as a larger particle replacement. Nagaraja et al. [13] has proposed use of chemicals to enhance the properties of CSEB. As per Jayasinghe, the availability of raw materials for the production of bricks and cement blocks are short; hence, many alternatives have been developed as walling materials [14]. Alam et al. [15] has explained by referring to many past researchers, raw earth is one of the oldest construction materials and it is still widely used all over the world even though many advanced building materials are available at present.

Therefore, this research study is using the particle packing concept to modify soil grading. Crushed construction waste with different sizes and sand were used for the soil grading modification.

1.1. Properties of CSEBs

Compressive strength has become a fundamental and universally accepted unit of measurement to specify the quality of masonry units [9]. Most of the past researchers have shown that clay and silt (finer) content is the governing factor for the properties of CSEB, hence they have proposed minimum clay content limited to 15% [9,16–18]. Based on their experiments, the compressive strength has an increasing tendency with decreasing finer content for different amounts of cement. Moreover, researchers have concluded that the soil with a low plasticity limit can contribute to increase the compressive strength [9,19–21]. However, these researchers did not consider any durability issues with CSEBs.

According to the past research papers, the content of stabilizer and clay, compacting stress are associated with the durability of the CSEB. Mainly, durable stabilized clay material buildings can be achieved as long as they are not saturated. Compared to burnt bricks and concrete blocks, energy emission of CSEB is significantly less [21]. Priji et al. also have shown that the manufacturing of CSEB is energy-efficient and cost-effective [22].

The aforementioned literature says that CSEBs with a minimum clay content of 15% have been tested by many researchers, and they have not considered the amount of larger particles. The main focus of this paper is also lowering the clay and silt content while modifying the soil grading by adding construction waste to fit into the optimization curve.

1.2. Application of particle packing technology for CSEBs

The particle size distribution of the soil is the main part of the soil preparation for CSEB production and the strength of the CSEB depends on the compaction of the soil particles. Particle packing theory says, how to optimize the particle size to minimize the void ratio. According to the optimization curves, as explained in particle packing theories, different size soil particles are added to the mixture to improve the packing density by reducing the voids as in Fig. 1. Fig. 1(a) shows that the large particles have filled the container with large voids and smaller particles are added to reduce the voids (Fig. 1(b)). Then, tiny particles are filled to further

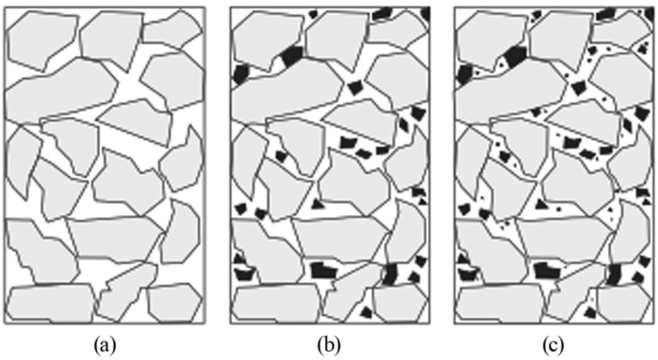

Fig. 1. Illustration of the particle packing concept [9].

reduce voids and increase the density (Fig. 1(c)).

The concept of particle packing optimization has been used by researchers in the field of concrete technology like high-performance concrete [10] and interlocking paving blocks [23]. These researchers have focused on an ideal grading curve, which represents the grading with the greatest density. Malkanthi and Perera [8] focused on rearranging the particle distribution of the soil to match the optimization curves while reducing the clay and silt content. CSEBs produced with this rearranged soil showed improvements in block properties. They have rearranged the soil grading for three different clay and silt contents: 5%, 7.5%, and 10%. The results showed that high compressive strength can be achieved with a 7.5% clay and silt content and 8% and 10% cement contents with modified soil.

Different past studies are available on particle packing density with this optimization concept. The particles are considered as a continuous distribution in Fuller's curve theory [24]. It is based on a correlation between the small and large particles in the distribution [25]. The equation of Fuller's curve theory is shown in Eq. (1). Fennis and Walraven has explained that the Eq. (1) was modified by Funk and Dinger [24], as in Eq. (2) with the exponent $q = 0.37$ for optimum packing.

Fig. 2. Block casting and compressive test procedure.

$$p(d) = \left(\frac{d}{d_{maz}}\right)^q \tag{1}$$

$$P(d) = \frac{d^q - d^q_{\min}}{d^q_{\max} - d^q_{\min}} \tag{2}$$

Where;

P(d) = size cumulative distribution function, d = particle diameter being considered (m).

d_{max} *= maximum particle diameter in the mixture (m).*

q = exponent (0.33–0.5), which adjusts the curve for fineness or coarseness.

d_{min} *= minimum particle diameter in the mixture (m).*

Other than the above two equations, Power [26] proposed a maximum density line that provides a guide to blend aggregates and obtain the maximum density.

2. The research methodology

Construction waste, two types of soil (Soil Type 1 & Soil Type 2), sand, and cement were used to cast CSEB. The soil was obtained from a nearby borrow pit in Hapugala, Galle, Sri Lanka. Dry and wet sieve analysis tests, Atterberg test were performed to determine the clay and silt percentage, total particle size distribution, and the plasticity index of soil. The maximum particle size of all the materials is 12 mm. The main focus of this study was modifying the soil grading based on particle packing theories. Fuller's curve theory (Eq. (1)) and Funk & Dinger Equation (Eq. (2)) were used as theoretical curves. Considering that, groups of particles in different sizes of construction waste, soil, and sand were combined in a way that the total particle size distribution of the modified soil mixture was closest to an optimum curve.

12 types of mix proportions were designed with clay and silt contents of 5%, 10%, 15% and 20% with a cement content of 6%, 8% and 10%. $(150 \times 150 \times 150)\ mm^3$ blocks were cast. Water was added to the mixture in less than 10% of the total weight of the mixture. Initial curing was done within 7 days by using black polythene and final curing was done within 28 days by exposing to the environment. All the blocks were tested according to the SLS 1382 part 2 [27]. 28 days of dry and wet compressive strength, dry density, water absorption and accelerated erosion were determined to identify the properties of the CSEBs. Based on the results of CSEBs, the best mix proportion for industrial blocks was determined. The size of the industrial scale block was $(350 \times 100 \times 175)\ mm^3$. Fig. 2 shows the block casting, curing and testing procedure. The accelerated erosion test procedure is shown in Fig. 3.

3. Modification of soil grading based on particle packing concept

The selected two soil types (Soil Type 1 and Soil Type 2) consist of clay and silt (finer) content of 38% and 14% respectively. Soil Type 1 was modified to get finer content of 20%, 15% and 10%. Soil Type 2 was modified to 5% finer content. Soil grading distribution of two soil types and construction waste, compared to theoretical optimization curves are shown in Fig. 4. The maximum particle size for construction waste was selected to be 12 mm. Construction waste mainly consists of crushed construction waste and its appearance is as shown in Fig. 5.

Fig. 6 represents the modified soil with Soil Type 1 and construction waste to get the finer content 20% and how it is positioned with theoretical packing curves. With this modified soil 10%, 8% and 6% cement contents were used as the stabilizer. Similarly, the modification was done to get the finer content to 15%, 10% and 5%.

This modified soil was used to cast blocks with the size of $(150 \times 150 \times 150)\ mm^3$. Fig. 7 shows the 28-day dry compressive strength for blocks made with modified soil for varying cement contents and finer contents.

According to the strength results shown in Fig. 6, high compressive strength for all finer contents can be achieved with 10% cement

Fig. 3. Accelerated erosion test procedure.

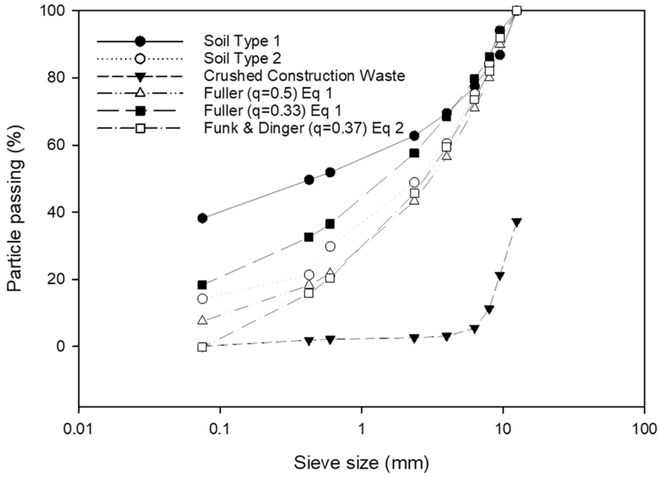

Fig. 4. Comparison of particle distribution of the used soil, construction waste with the theoretical distribution.

Fig. 5. Crushed construction waste.

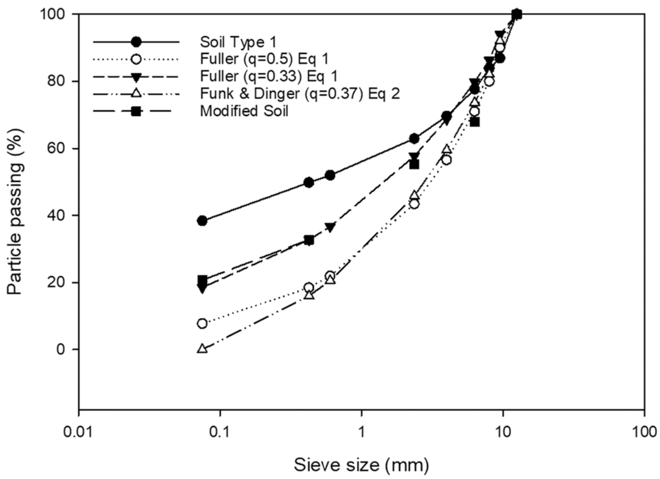

Fig. 6. Modification of the particle distribution of the used soil compared to the theoretical distribution.

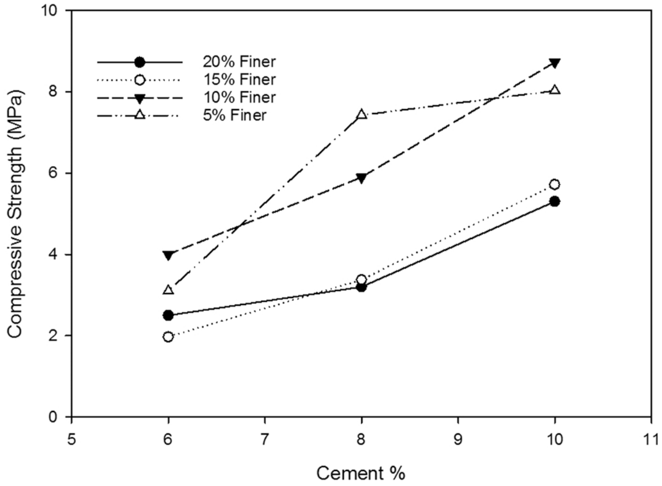

Fig. 7. 28 Days dry compressive strength results of soil blocks with modified soil.

content. All the values for CSEB properties are shown in Table 1. To obtain the value for one property, three specimens were tested and the average value was taken. Standard deviations for all the set of measurements were also shown in Table 1. The water absorption ratio clearly shows a notable improvement when optimizing particle packing. The dry density values also show that all the blocks made with upgraded soil arrangements achieve values of more than 1750 kg/m^3 except for one soil mixture. The SLS 1382: Part 1 defines minimum value as 1750 kg/m^3 for dry density and maximum value as 15% for water absorption. 6.0 MPa, 4.0 MPa and 2.8 MPa are the dry compressive strength limits for Grade 1, Grade 2 and Grade 3 respectively. 2.4 MPa, 1.6 MPa and 1.2 MPa are wet compressive strengths limits for Grade 1, Grade 2 and Grade 3 respectively [28]. All the blocks made with different combinations are categorized to Grades and those are also shown in Table 1. According to that, the use of 6% cement with 20% or 15% finer cannot satisfy the SLS 1382 requirements.

Based on the above results, the use of 10% finer is more appropriate. Changing the finer content to 5% needs more sand and construction waste hence compared to 10% finer, it is not economical. 8% cement usage is the most used cement content in the industry to cement block preparation. Therefore, industrial blocks with the size of (350 × 100 × 175) mm^3 were made with 10% finer and 8% cement. Industrial available block-making machine with skilled labor was used for casting. Fig. 8 represents the block-making process and prepared blocks.

Table 2 shows the properties of industrial-scale compressed stabilized earth blocks. For one property, three specimens were tested and the average value was reported. According to the results of the Industrial scale compressed stabilized earth blocks, those were satisfied with SLS conditions and those belong to Grade 1. SLS 1382 requires 10 mm of maximum erosion with the accelerated erosion test. The prepared blocks showed 3.04 mm average value.

4. Conclusions

Compressed Stabilized Earth Blocks (CSEBs) have been considered a key researched masonry unit over the past few decades. Many studies have shown that the compressive strength decrease with increasing clay and silt content and the majority of the researchers are interested in clay and silt content of up to 15%. As a method of reducing clay and silt content, researchers have considered lowering of clay and silt content by adding different materials without focusing on the amount of larger particles. This research considered lowering of clay and silt content while controlling the larger particle amount based on the particle packing optimization method. Construction waste and sand were used to control the larger particle content.

In this study, 12 different soil mixtures were used to make compressed stabilized earth blocks. Clay and silt percentage was changed as 5%, 10%,15% and 20% for 6%,8% and 10% cement percentages. Prepared CSEB properties were compared with SLS 1382: Specification for Compressed Stabilized Earth Blocks. According to the results of compressive strength, blocks made with 10% and 5% clay and silt content with any cement percentage used belong to either Grade 1, Grade 2 or Grade 3 as defined in SLS 1382. When using high clay and silt content, only high cement percentages support to achieve the minimum strength requirements. When considering the dry density all the compressed stabilized earth blocks were achieved the specification value given in the SLS 1382; part 1 (> 1750 kg/m^3). In addition, all compressed stabilized earth blocks met the SLS 1382; part 1 specification value for water absorption (< 15%). Considering the results, it is decided to select 10% clay and silt content with 8% cement to prepare industrial-scale CSEB. According to the measured properties of industrial-scale blocks, those satisfied with SLS 1382 and belong to Grade 1.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to

Table 1
Properties of CSEB with modified soil and its standing in SLS 1382.

Finer percentage (%)	Cement percentage (%)	Compressive strength (MPa)				Dry density (kg/m^3)		Water absorption (%)		Standing of CSEB in SLS 1382
		28 day – Dry (Avg)	S.D.	28 day – Wet (Avg)	S.D.	Avg.	S.D.	Avg.	S.D.	
20	10	5.3	0.100	2.4	0.058	1759	0.044	13.7	0.023	Grade 2
	8	3.2	0.153	1.6	0.153	1808	0.024	12.9	0.063	Grade 3
	6	2.5	0.173	0.9	0.000	1593	0.022	12.8	0.065	Not satisfy
15	10	5.7	0.421	2.6	0.210	1773	0.103	12.5	0.050	Grade 2
	8	3.4	0.245	1.7	0.000	1756	0.111	12.9	0.076	Grade 3
	6	2.0	0.208	1.1	0.058	1750	0.058	13.3	0.076	Not satisfy
10	10	8.7	0.208	4.8	0.058	1840	0.070	11.1	0.031	Grade 1
	8	5.9	0.100	3.3	0.058	1773	0.088	13.9	0.029	Grade 2
	6	4.0	0.000	1.9	0.058	1761	0.045	13.4	0.028	Grade 3
5	10	8.0	0.208	6.9	0.115	2021	0.027	7.5	0.042	Grade 1
	8	7.4	0.153	5.3	0.153	1992	0.112	8.9	0.115	Grade 1
	6	3.1	0.173	1.6	0.000	1903	0.038	11.7	0.050	Grade 3

Avg: Average S.D.: Standard Deviation.

Fig. 8. Industrial scale block making process.

Table 2
Properties of Industrial scale [(350 × 100 × 175) mm^3] compressed stabilized earth blocks.

Clay percentage (%)	Cement percentage (%)	28 days Compressive strength (MPa)		Dry density (kg/m^3)	Water absorption (%)	Depth of erosion (mm)	Grade As per SLS 1382
		Dry	Wet				
10	8	Avg = 6.8 S. D. = 0.142	Avg = 4.3 S. D. = 0.049	1914.7	10.37	3.04	1

influence the work reported in this paper.

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