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CEMENT RATIOS' EFFECT ON MECHANICAL AND WATER ABSORPTION PROPERTIES IN COMPRESSED STABILIZED EARTH BRICKS

***Abstract.** Compressed Stabilized Earth Bricks (CSEBs) are produced from a mixture of soil, sand, water, and a stabilizer typically ordinary Portland cement, lime, fly ash, bitumen, or a combination of these materials and then compacting the mixture in a mold. This research article investigates the effects of varying cement stabilizer ratios (5 %, 7 %, and 10 %) on the mechanical properties and water absorption characteristics of compressed stabilized earth bricks. The experimental program included evaluations of dry and wet state compressive strength, flexural tensile strength, total water absorption, and capillary water absorption. The results indicate that increasing the cement content significantly improves the mechanical properties of compressed stabilized earth bricks while reducing their water absorption capacity. When compared with those of tested fired clay bricks and certain international standards for compressed stabilized earth bricks, demonstrated higher performance in these metrics. The findings of this study underscore the potential of compressed stabilized earth bricks as a feasible and advantageous building material for construction in Afghanistan, where leveraging locally available sourced materials can significantly reduce construction costs and minimize environmental impact, supporting the development of affordable and eco-friendly housing solutions.*

***Keywords:** CSEBs, Stabilizer ratios effect, Mechanical properties, Water absorption, Soil composition, Soil as a construction material in Afghanistan.*

Introduction. In recent years, the growing demand for sustainable building materials that alleviate housing shortages and lessen environmental degradation has caused a paradigm change in the worldwide construction sector. Compressed Stabilized Earth Bricks (CSEBs) are a novel way to address these issues. In contrast to conventional sun-dried mud bricks, these bricks are produced using locally obtained dirt, stabilized with cement, lime, or other binders, and compacted under high pressure to attain improved mechanical qualities. However, the type and amount of stabilizers used have a significant impact on their performance, directly affecting their longevity, mechanical strength, and water absorption resistance.

Earth-based building materials, in comparison to fired clay bricks and concrete, offer several advantages, including thermal comfort, low embodied energy, environmental friendliness, affordability, and local availability [1, 2, 3]. In terms of energy use and associated carbon emissions, there is a significant difference between compressed stabilized earth bricks (CSEBs) and traditional fired clay bricks. CSEBs produced on-site with 5% cement generate approximately 49.37 kg CO_2/m^3 and consume 548.32 MJ/m^3 of energy, whereas country-fired bricks emit as much as 642.87 kg CO_2/m^3 and consume 6,122.54 MJ/m^3 of energy [4]. Cement-stabilized earth bricks typically require less than 10% of the energy inputs needed to produce comparable fired clay and concrete masonry units [5].

Stabilized earth bricks are frequently recyclable or reusable. This makes them especially appropriate for community-driven projects and affordable housing developments [6, 7].

For the good quality of earth bricks production, it is crucial to carefully select the appropriate soil, sand, stabilizing materials, and water. Additionally, ensuring proper compaction in the mold and adequate curing is essential, as these factors significantly influence the quality and durability of the bricks.

The soil used for the produce of compressed stabilized earth bricks shall be of a suitable quality, free of deleterious and organic materials graded in accordance with ISO 14688-1 [8]. It is advised to utilize coarse sand for the production since the blocks will be stronger and have a higher density [9], which affects the strength, shrinkage, and weathering resistance of bricks [10]. Clay particles provide cohesion and bending properties, silt enhances plasticity and workability, and sand particles reduce shrinkage while providing stability to the mixture [11].

Naturally soil have high water absorption, low tensile strength and low resistance against erosion, abrasion [12], by adding proper stabilizers good compression in molding and curing, can enhance soil strength, stability, permeability and durability [13, 14]. To identified soil suitability, some necessary tests (smell test, soil composition, consistency, etc.) are shall be performed [15]. A soil with 15% or less plasticity index, cement is used as a stabilizer agent and for soil with greater than 15% plasticity index, it is recommended to add lime with cement as a stabilizer material [16, 17]. CSEBs produced from different local soils will exert different mechanical properties [18, 19].

Soil is the primary construction material in Afghanistan, where 95 % of buildings are constructed using soil. The main types of soil-based house construction include sun-dried bricks (adobe walls) and cob walls. The soil in most regions of Afghanistan has a clayey nature, and the easy availability of sand makes it suitable for producing stabilized compressed earth bricks. While stabilized compressed earth bricks may be somewhat more expensive due to the composition of the soil and the cost of cement, they are still more cost-effective than fired bricks or cement concrete blocks which are used predominantly in urban areas. Additionally, they are environmentally sustainable and human-friendly, making them a worthwhile option to consider [20].

This research investigates the mechanical properties (compressive strength, flexural strength) and water absorption rate of CSEBs in relation to varying cement stabilizer ratios. It also includes a comparison with fired clay bricks, which are already widely used as a construction material in the region. Since there has been no prior research investigating the mechanical and water absorption properties of CSEBs as a building material in Afghanistan, this study aims to fill this critical knowledge gap and contribute to the development of building construction material in the country.

Material and Methods.

Soil- for this study the used soil was sourced from the Deh-Sabz district of Kabul province, Afghanistan. It is widely utilized in its natural form for the production of sun-dried bricks, fired bricks, and other construction activities within Kabul province. Before using this soil, the clay soil properties (plastic limit, liquid limit, plasticity index, composition, and pH) were determined (Table 1). Additionally, the soil for brick mixture was sieved through a 3.3 mm mesh to eliminate any nodules or impurities. Considering [21], the mix composition for this study consisted of 28 % clay and silt and 72 % sand. These proportions were determined based on the observed shrinkage cracks and composition of the clay and sand used in this study (Table 1, Fig.2).

Table 1

Clay soil properties.

Properties	Values
Natural moisture	7.5 %
Specific gravity	3.33
pH	9.5
Composition	
Clay and silt	90 %
Sand	10 %
Atterberg limits	
Plastic limit (PL)	19 %
Liquid limit (LL)	27.45%
Plasticity Index (PI)	8.45 %

Rolandas et al. [22] analyzed the chemical oxide composition of three types of clay soils (S1, S2, and S3). They found that the SiO_2 content was 70.05%, 62.20%, and 48.15%, respectively, while the Al_2O_3 content was 19.52%, 19.35%, and 12.21%, respectively. Their experimental results showed that the performance of S1 clay was higher than that of S2 and S3, and the performance of S2 was higher than that of S3. The authors suggested that soils with higher concentrations of aluminum oxides (Al_2O_3) and silica (SiO_2) tend to exhibit higher mechanical and physical properties.

According to the studies by researchers [22, 23, 24], the chemical oxide composition of soil significantly influences the performance of Compressed Stabilized Earth Bricks (CSEBs). A thorough understanding of the soil's chemical composition is therefore helpful for achieving consistent and reliable results. In this study, the chemical oxide content of the clay and sand was analyzed using X-ray spectroscopy, and the findings are summarized in (Table 2).

Table 2

Clay soil and sand chemical composition

Raw material	**Chemical oxides, %**										
	SiO_2	Al_2O_2	K_2O	CaO	Fe_2O_3	MgO	Na_2O	P_2O_5	TiO_2	ZnO	SO_3
Clay	39.99	9.801	2.089	13.26	5.014	2.771	0.452	0.147	0.678	0.018	0.235
Sand	57.62	12.96	2.763	2.061	4.890	1.759	0.959	0.157	0.725	0.101	0.031

Sand- In this study used machine-crushed sand sourced from crushed plant, that was sieved through a 4.75 mm sieve. The sand's properties (AASHTO T-84 / ASTM C-128), included a specific gravity of 2.9, bulk specific gravity (SSD) of 2.69, and 0.6%

water absorption, indicating low porosity and suitability for construction applications. It was free of organic matter and impurities and exhibited a suitable grain composition, as shown in (Figure 1). It is worth noting that natural river sand is also available in Kabul province and is commonly used in certain construction activities, such as plastering and mortar preparation. However, its grain size is generally very fine, and it often contains a significant amount of organic matter in its composition. Therefore, for of this study, opted machine-crushed sand.

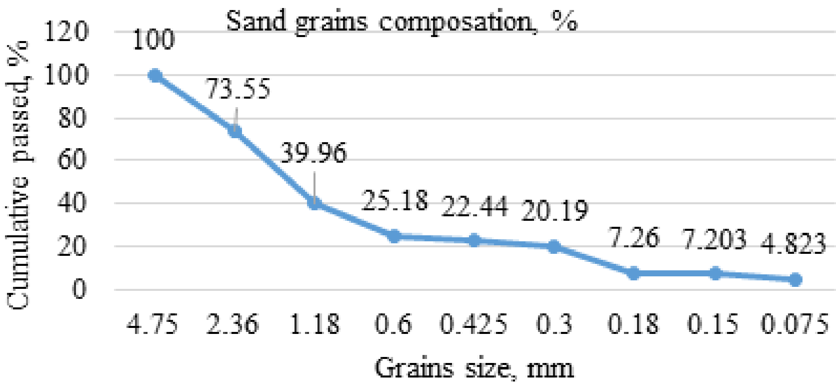

Fig. 1. Show sand grain size composition in %.

Cement – As a stabilizer agent, used ordinary Portland cement (Grade 53) in amounts of 5 %, 7 %, and 10 %, relative to the dry soil weight which is available in Afghanistan. However, [5] propose that bricks with less than 5 % cement are often too friable to handle, while [25] suggested, that cement content more than 10 %, becomes uneconomical for CSEB production. Moreover [15] recommended 5 % up to maximum 10 % cement as a stabilizer agent.

Water – For the preparation of the brick mixture, groundwater sourced from Kabul Polytechnic University was used, as it is commonly utilized for all construction activities in the area. The dry ingredients were first mixed by hand, after which water was gradually added until the optimum moisture content was reached. The resulting mixture was then molded and compacted using a CINVA-Ram machine which is a manually operated for brick making (Fig.2). The size of the produced bricks was (302 × 152 × 102) mm. The bricks were cured for 7 days at about 23–30 °C in laboratory room. According to [26], the optimum moisture content (OMC) of mix, considered the drop test method and all tests were conducted after 28 days.

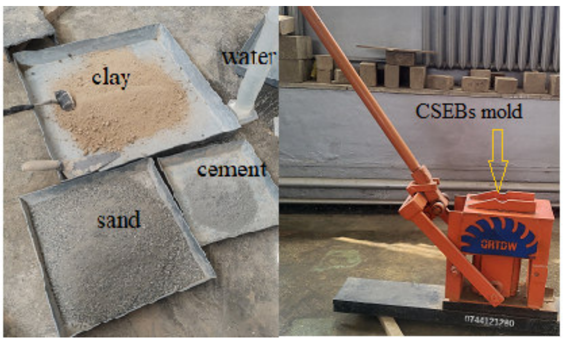

Fig. 2. CSEBs raw materials and molding machine for CSEBs production.

Compressive strength. In this study, the compressive strength test was conducted on non-stabilized compressed earth bricks (CEBs), clay fired bricks and compressed stabilized earth bricks (CSEBs), in dry condition to be compared stabilizer effect and also CSEBs were tested in wet condition to be compared their strength with dry state (Fig. 3). For determining the compressive strength values, we randomly selected 3 to 5 bricks from each brick category, tested them, and calculated the average value for each type. The compressive strength of the bricks was calculated by using "Equation (1)."

$$P_d = \frac{F}{A}, P_w = \frac{F}{A} = N / mm^2 \qquad (1)$$

where P_d – Dry compressive strength (N/mm^2); P_w – Wet compressive strength (N/mm^2); F – Total applied load (N); A – Bed area of the brick (mm^2).

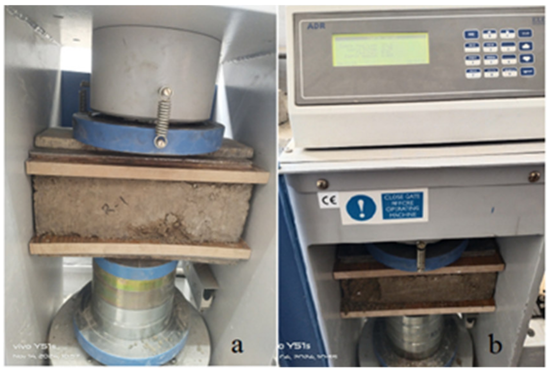

Fig. 3. Illustrates the, a) dry state and b) wet-state compression tests on CSEBs

Flexural tensile strength (Modulus of rupture). The flexural tensile strength of the bricks was carried out by the three-point bending method as stated by ASTM - C67/C67M-19 and [26, 8], used hand operating hydraulic machine (Fig. 5a). The external load was gradually applied on the midpoint of the specimens until fracture occurred. The bricks were positioned within the testing apparatus in a manner similar to that used in a wall (Fig. 5).

Fig. 4. Shows the flexural tensile testing apparatus.

The flexural tensile strength (f_t) of the bricks is calculated using Equation (2) and their results also shown in (Fig. 7).

$$f_t = \frac{3 \times F \times l}{2 \times b \times d^2} = N / mm^2 \quad (2)$$

where f_t – Flexural tensile strength (N/mm^2); F – Total applied load (N); L – Effective span of the brick (mm); b – Width of the brick (mm); d – Thickness o f the brick (mm).

Water absorption. The absorption of water in earthen bricks is a result of clay and cement content, which is frequently associated with the strength and durability of earthen bricks.

In this study, two types of water absorption tests are conducted: one for capillary absorption and the other for total water absorption (Fig. 5a, b). The tested bricks were dried in an oven at 105°C for 24 hours. According to [26], for the capillary action test, the bricks were immersed to a depth of approximately 1 cm for 24 hours. For total water absorption, the bricks were fully immersed in water for 24 hours.

The capillary action and total water absorption values, expressed as percentages, were calculated using Equation (3), and the results are presented in (Figure 8).

$$W = \frac{w_w - w_d}{w_d} \times 100 \quad (3)$$

where W- Absorbed water (%); W_d- Dry weight of the brick (Kg); W_w- Wet weight of the brick (Kg).

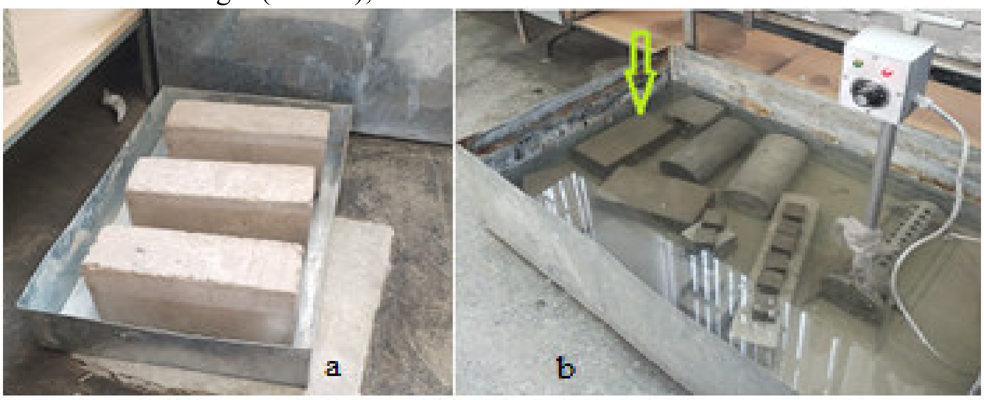

Fig. 5. Shows: a) CSEBs for capillary water absorption, b) CSEBs full immersed in water for total water absorption.

Result and Discussion

Compressive strength. Compressive strength is the most widely recognized metric for assessing brick quality. However, the soil types, stabilizer types and content, and applied compression in the mold had a significant impact.

These results are presented in (Table 3, Figure 6). Moreover, CSEBs were tested for wet compressive strength (Fig.3b), to identify the reduction in strength of bricks under wet conditions, which occurs due to pore water pressure and the liquefaction of unstabilized clay minerals within the brick matrix. To assess their minimum performance capabilities under the worst conditions, it is beneficial to test them in a moist state. The obtained data (Table 3), shows that the bricks have reduced their compressive strength by approximately 28-31% in the wet state, respectively. This reduction indicates that moisture has an effect on the structural integrity of the bricks. According to [8], the specimens were fully immersed in water for 24 hours before testing.

The obtained results from this study compare with those reported in (Table 4), indicating that the type of soil and the material composition used in the production of CSEBs are appropriate and well-optimized.

The obtained results (Table 3), in comparison with those presented in (Table 4), demonstrate that the type, quality and quantity of materials used in the study were appropriate and well optimized. The bricks were also tested for compressive strength at 56 days, revealing a 30–33% increase in strength. This suggests that the compressive strength of CSEBs increases over time under favorable conditions.

Table 3

Mechanical properties and water absorption values considering cement stabilizer ratios of CSEBs and fired clay brick.

Tests for the properties	CSEBs cement contents, %				Fired clay brick
	0%	5%	7%	10%	
Dry state compressive strength (MPa)	5.2	7.6	11.6	14.5	13.7
Wet state compressive strength (MPa)	-	5.4	8.01	10.38	-
Flexural tensile strength (MPa)	0.45	1.13	1.46	2.14	2.13
Capillary water absorption (%)	-	9.85	8.76	8.94	22.07
Total water absorption (%)	-	10.36	10.31	9.67	22.72

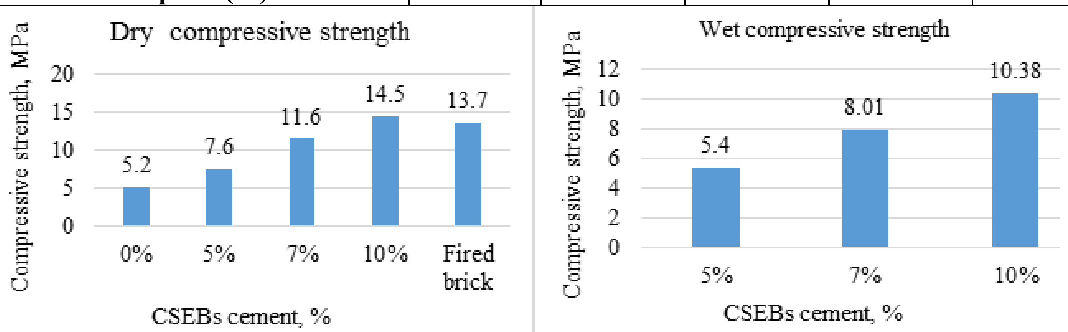

Fig. 6. Indicates dry compression strength and wet compression strength, MPa.

Table 4

Show the minimum dry and wet stats compressive strength of same countries standards for CSEBs.

Country standard	Minimum dray compressive strength (MPa)	Minimum wet compressive strength (MPa)
Nepal [15]	class (A), 5-7 class (B), 2-5	class (A), 2-3 class (B), 1-2
India [27]	class (20), 1.96 class (30), 2.94	-
Sri Lanka [28]	2.8	1.2
Kenya [8]	class (A), 5-12 class (B), 4-5 class (C), 3-4	class (A), 3-4 class (B), 2-3 class (C), 1.5-2
New Zealand [26]	3.6	-

Flexural tensile strength (Modulus of rupture). From the result (Fig.7), it is well-established that the flexural strength of bricks develops with increasing cement content. However, the observed strength of 0.5 MPa for CEBs (0% cement) suggests that some flexural strength is still present. This can be attributed to the adhesion of clay particles, friction between sand grains in the consequence of effective compaction pressure applied in the mold.

The minimum flexural strength requirements are: for Class A, grater then 2 MPa; for Class B, from 1-2 MPa; and for Class C, 0.5–1 MPa [8]. In contrast, according to [15], the flexural strength for Class A is 1–2 MPa, while for Class B, 0.5–1 MPa.

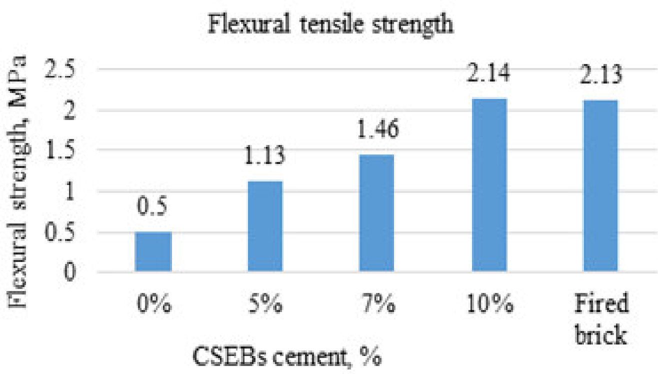

Fig. 7. Shows the flexural tensile strength of bricks, MPa

Water absorption. Earth bricks must be strong and waterproof to avoid adverse environmental effects such as rain, winds, dampness, and other extreme weather conditions. When materials are subjected to varying climate conditions and continuous saturation, problems may arise.

The result of the water absorption (Fig. 8), demonstrate that the absorption rates of CSEBs, are lower than the maximum average total water absorption as stated by [15], 20 %, and [8, 27, 28] mentioned 15 %, also from the conventional fired clay bricks.

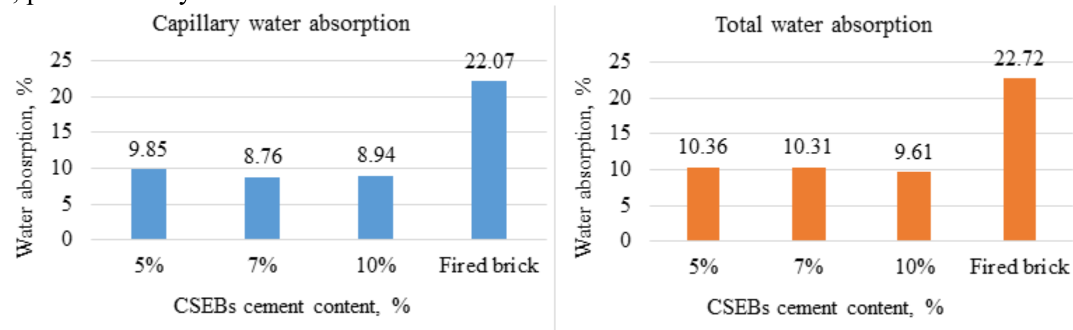

Fig. 8. Shows total and capillary water absorption in CSEBs and clay fired bricks in %

During the capillary test, the moisture rising speed in the 5 % cement content bricks was higher than in those with 7 % and 10 % cement content bricks; however, in 24 hours, the brick was fully wetted, while the bricks with 10 % and 7 % cement were seen as only half-moistened and slightly more than half-moistened, respectively. This difference can be attributed to the amount of cement content.

In the presence of water, cement reacts with clay minerals, forming bonds that help bind the particles together. Clay particles, which carry a negative charge, possess inherent water-absorbing and water-retaining properties. In the low cement content cases, the proportion of clay particles whose chemical properties remain largely unaffected by the cement is higher. Consequently, this leads to increased water absorption due to the dominance of clay's hygroscopic behavior.

In the total water absorption test, the dry density of bricks containing 10 % cement was lower than that of bricks with 5 % and 7 % cement. However, their total water absorption was lower than both. Brick content 10 % cement capillary rate is slightly higher than 7 % cement content, this can be attributed to the lower dry bulk density likely caused by the presence of voids within brick.

Conclusion. Compressed stabilized earth bricks (CSEBs) containing 10 % cement exhibit higher compressive and flexural strength and lower water absorption compared to the 5 % and 7 % cement content CSEBs and clay fired bricks. However, using more than 10% cement in CSEBs is uneconomical. Therefore, the optimal cement content for CSEBs should be determined based on environmental conditions and the structural loads expected in buildings. To further enhance their performance and sustainability, it is recommended to optimize the cement content and refine production techniques. In structures where CSEBs are exposed to the risk of water absorption, it is advisable to consider the wet compressive strength of the bricks during the design phase or implement measures to mitigate water absorption.

These findings indicate that the materials and their proportions used in this study are suitable, and the bricks were effectively compacted.

The results indicate that the mechanical properties, and water absorption of CSEBs are influenced by:

- Soil types and their properties, mixture proportion and mixing;
- Amount of clay soil, significantly impact the mechanical properties, and water absorption of the bricks;
- Amount of stabilizer ratios, applied pressure in the mold and proper curing condition;
- The size, angularity and good proportion of sand particles in mixture;
- The compressive strength of CSEBs increases over the time in favorable condition.

The research findings demonstrate that CSEBs can have significant potential as a sustainable, beneficial, and applicable building material in Afghanistan, where the use of locally sourced materials can consequentially reduce construction costs and minimize environmental impact compared to conventional fired clay bricks.

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ВЛИЯНИЕ СОДЕРЖАНИЯ ЦЕМЕНТА НА ПРОЧНОСТЬ И ВОДОПОГЛОЩЕНИЕ ПРЕССОВАННЫХ СТАБИЛИЗИРОВАННЫХ ЗЕМЛЯНЫХ КИРПИЧЕЙ

Аннотация. *Прессованные стабилизированные земляные кирпичи (CSEB) изготавливаются из смеси почвы, песка, воды и стабилизатора — как правило, обычного портландцемента, извести, летучей золы, битума или их комбинации, с последующим прессованием смеси в формах. В данной исследовательской работе изучается влияние различных содержаний цементного стабилизатора (5 %, 7 % и 10 %) на механические свойства и характеристики водопоглощения CSEB. Экспериментальная программа включала определение прочности на сжатие в сухом и влажном состоянии, прочности на изгиб, общего водопоглощения и капиллярного водопоглощения.*

Результаты показали, что увеличение доли цемента значительно улучшает механические характеристики кирпичей и снижает их способность к поглощению воды. При сравнении с обожженными глиняными кирпичами и установленными международными стандартами для сжатых стабилизированных земляных кирпичей испытанные образцы показали более высокую эффективность по этим параметрам.

Данное исследование подчеркивает потенциал использования сжатых стабилизированных земляных кирпичей как экономически целесообразного и экологически устойчивого строительного материала в Афганистане. Использование местных природных ресурсов может существенно снизить затраты на строительство и минимизировать негативное воздействие на окружающую среду, способствуя развитию доступного и устойчивого жилищного строительства.

Ключевые слова: *CSEB, коэффициенты стабилизатора, механические свойства, водопоглощение, состав почвы, почва как строительный материал в Афганистане.*

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