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Compressive Strength Characteristics of Compressed Stabilized Earth Block (CSEB) Units and Walls

Er. Toran Prasad Bhatt[1*]
[1]Asst. Professor, Faculty of Engineering, Far Western University, Nepal
[*]Corresponding author: toranpbhatt@fwu.edu.np

Abstract

This paper is mainly focused on compressive strength behavior of Compressed Stabilized Earth Block (CSEB) units and CSEB walls. Compressed Stabilized Earth Block (CSEB) is a rectangular block used in wall construction. The ingredients of CSEB are soil, cement, fine aggregate, crusher dust, and a small amount of water. These blocks have less energy consumption and carbon emission, and they provide improved thermal insulation. In addition they use local resources, and disseminate appealing aesthetics with elegant profile and uniform size. Due to these advantages CSEB can be used as a green construction material. This research aims to study the strength characteristics of CSEB wall in compression and evaluate the suitability of CSEB walls as load bearing walls in structures. This research studies physical and mechanical characteristics of CSEB units made from red residual soil of Lele (Lalitpur) with 8% cement for stabilization. This paper discusses the compressive strength behavior of walls constructed of size 0.660m x 1.100m x 0.220m using CSEB units in cement sand mortar and stabilized mud mortar separately which were tested after 28 days. The experimental values after laboratory testing of CSEB masonry wall with height to thickness ratio 5:1 for cement sand mortar (1:6) and stabilized mud mortar (stabilized with 8% cement and 16% extra sand) separately are compared with relevant values from different codes. Results obtained from compressive strength tests of masonry walls constructed in the laboratory and those values from different codes concerning the strength of masonry unit and mortar are compared, and found to be in agreement. The comparison of laboratory results with codal provisions of design of masonry walls illustrate that CSEB masonry walls can be designed in the similar way as brick masonry walls.

Keywords: *CSEB, compressive strength, stabilized mud mortar, CSEB masonry walls, masonry walls*

Introduction

Masonry is one of the most popular materials for building construction and other different types of wall and fort construction due to its useful properties such as durability, relatively low cost, good sound and thermal insulation, acceptable fire resistance, adequate resistance to weathering, and attractive appearance (Arya, 1992). Masonry construction is generally known for its durability, which relies on several key factors: the materials used, the quality of the mortar, workmanship, and the type of bond used. Common materials for masonry include brick, stone, concrete blocks, compressed earth blocks (CEB), and compressed stabilized earth blocks (CSEB), each having unique advantages (Arya, 1992).

The common building materials used in Nepal are stone, brick, cement, concrete, steel, and timber. These materials along with their technology have been practiced for many decades and there have been negligible improvement and innovations in these materials and their technology. Above mentioned materials are good in structural performance. Despite of this, they are blamed for environmental pollution, more energy consumption, and less thermal resistance. So, need for the development of alternative materials with satisfactory structural performance that consume less energy, become more thermal resistant, and reduce the emission of harmful gases. In the context of Nepal, such material can be compressed stabilized earth block (CSEB). CSEB is a material that can be used in environment-friendly houses fulfilling the strength requirements of masonry walls as well (Riza et al., 2010). The Compressed Stabilized Earth Block (CSEB) is a masonry unit of any shape but it is generally used in cuboidal shape which can be made in solid or interlocking type. The shape and size of a block are defined by the mould and equipment setup used in its manufacture. For the production of CSEB units, soil is mixed with small quantities of cement or other stabilizing material, coarse sand, or stone dust which can be added depending on the quality of the soil (Riza et al., 2010). CSEB has more advantages over the kiln bricks/ the burnt bricks in various ways. CSEB units are produced by dry mixing of soil with proper stabilizing agent uniformly then remixing the dry mixture uniformly with water of optimum moisture content and then compressing the mixture with a suitable amount of compaction pressure.

Soil stabilization is the process of changing the physical properties of soil so that it can improve its strength, durability, or other properties. Stabilized soil behaves in such a way that it can significantly become more resistant to being damaged by water, frost, rain, or inclement conditions(Makusa, 2012). There are several methods of soil stabilization. Some of them are as follows:

Mechanical Stabilization

Mechanical stabilization of soil is the process of compacting the soil by using a heavy load or pressure to reduce the volume of air voids, thus leading to an increase in the density of the soil(Das, 2003). The main effects of compaction of the soil are to increase its strength and reduce its permeability(Das, 2003). The degree of compaction, however, is mainly affected by the type of soil used, the optimum moisture content of the soil, the moisture content during compaction, and the compaction force applied(Oan et al., 2021). The major drawback of mechanically compressed stabilized earth blocks is their lack of durability especially in places of moderate to high rainfall(Das, 2003).

Cement Stabilization

Cement is an easily understood, thoroughly researched and well defined stabilizing material with clearly defined properties among the chemical stabilizers. Earlier researches have suggested that cement is a most suitable stabilizer among chemical stabilizers for the production of compressed stabilized earth (soil) blocks (CSEB)(Shariful et al., 2020). Lime (CaO) and Silica (SiO2) are the main ingredients of Cement, which react with each other and with other components in the mix during hydraulic reaction(Das, 2003)(Hanafi, 2021)(Makusa, 2012). This reaction forms Bogues Compounds named Tri- calcium silicate referred as C3S and Di-calcium silicate referred as C2S in the cement as main compounds. The chemical reaction eventually generates a matrix of interlocking crystals that cover any inert filler and provide a high compressive strength and stability to the matrix (Makusa, 2012).

Lime Stabilization

Before cement lime was used as a binding material and nowadays also lime is main alternative binder of cement. After adding lime to the soil for stabilization, four basic reactions are believed to occur: Cation exchange, flocculation and agglomeration, carbonation, and pozzolanic reactions. The pozzolanic reaction is believed to be the most important and it occurs between lime and certain clay minerals to form a variety of cementing compounds, which bind the soil particles together(Saleh, 2024), (Christopher, 1996). Lime can also reduce the tendency of clay to absorb the water which can make the soil less sensitive to changes in moisture content and improve its workability(Das, 2003). Lime is known as a suitable stabilizer for clay soils.

Researches conducted on Compressed stabilized earth blocks and earth stabilizing techniques suggested technical specifications for CSEB blocks as stabilizing performs better with 5% cement or more than it (Davis & Maïni, 2017)(Walker, 1995)(D. R. Bhatt, 2011). Mechanical characteristics are influenced by the soil quality, the compressive force applied by the press, the quality of manufacturing, curing, quality and percentage of stabilizer(Maini, 2010), (Bhatt, 2011). These results has proven CSEB as an environment friendly, low carbon emitting, energy efficient, sufficiently strong alternative building material (Maini, 2010). Other stabilizers those can used to produce CSEB blocks could be bitumen, gypsum, pozzolanas, and traditional stabilizers. Cementitious stabilization in combination with compaction gives a product of sufficient dry and wet strength, erosion resistance, and sufficient durability which suggests among above above-discussed soil stabilizers, in CSEB, Cement is superior as a stabilizer due to its availability at acceptable quality everywhere among cementitious stabilizers (Maini, 2010).

Compression failure and Compressive Strength of masonry wall

The compression failure in masonry wall occurs rarely which occurs when the applied compressive stress exceeds the compressive strength of the masonry wall. The compression failure mode is characterized by the formation of longitudinal (vertical) cracks which are parallel to the compression strut (Oan , et. al, 2013). Compressive strength test method of masonry prisms covers procedures for masonry prism construction and testing, and procedures for determining the compressive strength of masonry, f_{mt}, used to determine compliance with the specified compressive strength of masonry, $f_{m'}$. When this test method is used for research purposes, the construction and test procedures within serve as a guideline and provide control parameters(ASTMC-1314). Eurocode 6 - Design of masonry structures - Part 1-1 suggested characteristic compressive strength of masonry other than shell bedded masonry as follows (Eurocode 6). The characteristic compressive strength of masonry can be determined from the results of tests in accordance with EN 1052-1 which tests may be carried out for the project or be available from tests previously carried out e.g. a database; the results of the tests should be expressed as a table, or in terms of following equation(Eurocode 6).

$$f_k = K f_b^{\alpha} f_m^{\beta}$$

where:

f_k Characteristic Compressive Strength of the Masonry, in MPa

K is a constant

α, β are constants

f_b compressive strength of the units, in the direction of the applied action effect, in MPa

f_m is the compressive strength of the mortar, in N/mm

Experimental research carried out on blocks produced by varying cement contents from 4% in to 13% at constant compressive pressure shown that wet compressive strength of blocks are good enough for use in structural work if we are using cement content more than 5%(Bhatt, 2011)(Darshan Shrestha, 2012)(Walker, 1995). With the increase in cement content causes an increase in the compressive strength of the block and a decrease in the absorption capacity of the soil block. Increase in the compaction pressure also improves the compressive strength of soil cement block (Bhatt, 2011). It is seen that Compressed Stabilized earth blocks produced by applying 200 kg/cm^2 and 8% cement content are found optimum for use considering their dry compressive strength, wet compressive strength and water absorption capacity(Bhatt, 2011). Results of the previous research works have shown that cement can be selected as the best soil stabilizing material for producing CSEB units.

Objective of Study

This research aims to study the strength behavior and response of CSEB material for its suitability as a masonry building material. The specific objectives of the present study are as follows:

i) To conduct an experimental study of Compressed Stabilized Earth Block (CSEB) units using 8% cement as stabilizing material.
ii) To conduct an experimental study of CSEB masonry walls (constructed from CSEB units manufactured with 8% cement as stabilizing material) under compressive loading.
iii) Comparison of Experimental results of CSEB units and their masonry walls with those of Bricks and Concrete Masonry Units (CMU).

Methodology

The study is quantitative and based on laboratory tests of CSEB units, their masonry walls and their comparison with codal provisions and similar research works conducted by other researchers. In order to understand the characteristics of compressed stabilized earth block (CSEB) and its masonry wall structure, series of laboratory tests were carried out by researcher during his previous work. Test results of those laboratory tests will be analyzed and interpreted for the suitability of CSEB as alternative masonry blocks. To accomplish the objective of the research work, following procedure is adopted:

i. Preliminary study

- Comprehensive study of previous works and literature review.
- Collection of required data including material properties and other different parameters.

ii. Collection of Laboratory Test Results

- Laboratory Test results for density, water absorption capacity, compressive strength of CSEB units (in dry and wet conditions) conducted by researcher during his previous work will be collected for analysis.
- Laboratory Test results for compressive strength of CSEB masonry walls (constructed with cement sand mortar and stabilized mud mortar separately) conducted by researcher during his previous work will be collected for analysis.

iii. Analysis and Interpretation of Test Results

- Laboratory Test results will be analyzed and compared with those of burnt bricks and concrete masonry units.

Results

Calculation of Density and unit weight of CSEB Units

Density and unit weight of CSEB Units are calculated with the help of mass of CSEB unit samples, weight of the samples and their net volume (excluding volume of frog) measured during previous work. Calculation of Density and unit weight of the CSEB units and their average is illustrated in following table. Average density and unit weight results of above data are 1949.86 and 19.13 respectively. Standard deviation calculation for density and unit weight results of above data are 32.77 and 0.3202 respectively which indicates that the test results are relatively close to the mean.

Table 1: Calculation of density and unit weight of CSEB units (Bhatt, 2015)

Sample No.	dimension(m)			Net Volume ($x10^{-6}m^3$)	Mass (Kg)	Density (Kg/m^3)	Unit weight (KN/m^3)
	Length	Breadth	Height				
1	0.222	0.100	0.051	1072.692	2.116	1972.61	19.35
2	0.223	0.100	0.052	1096.24	2.168	1977.67	19.40
3	0.220	0.100	0.052	1080.682	2.143	1983.01	19.45
4	0.223	0.100	0.051	1075.38	2.103	1955.59	19.18
5	0.222	0.100	0.050	1051.536	2.000	1901.98	18.66
6	0.222	0.100	0.051	1072.692	2.047	1908.28	18.72
Average	**0.222**	**0.100**	**0.051**	**1074.87**	**2.10**	**1949.86**	**19.13**

Water Absorption Capacity

Water absorption capacity of CSEB units is calculated with the help of saturated weight of sample, dry eight of samples as illustrated in following table.

Calculation of Dry Compressive Strength of CSEB Units

Dry compressive strength of CSEB units is calculated with the help of Compressive load at Failure during compressive strength test of CSEB units in their dry state and cross sectional area of samples as illustrated in following table. Average compressive strength of above data is 8.1. Standard deviation calculation for the above data is 1.79 which indicates that the test results are nearly close to the mean.

Table 2: Water absorption capacity of CSEB units (Bhatt, 2015)

Sample	Saturated Weight (Kg)	Dry Weight(Kg)	Water Absorption %	Average Absorption %
1	2.4	2.085	15.11	15.73
2	2.31	1.995	15.79	
3	2.285	1.965	16.28	

Figure 1: Test of dry compressive strength of CSEB unit ((Bhatt, 2015))

Table 3: Dry compressive strength of CSEB units (Bhatt, 2015)

Sample	Dimension(mm)			Cross sectional Area(mm^2)	Mass (Kg)	Compressive load at Failure (KN)	Compressive Strength (MPa)
	Length	Breadth	Height				
1	222	100	53	22200	2.3	240	10.8
2	221	96	52	21216	2.31	250	11.8
3	220	99	54	21780	2.27	150	6.9
4	222	100	54	22200	2.3	140	6.3
5	222	100	54	22200	2.3	160	7.2
6	222	100	54	22200	2.38	210	9.5
7	222	100	53	22200	2.37	150	6.8
8	221	100	52	22100	2.26	150	6.8
9	222	100	53	22200	2.35	190	8.6
10	221	100	52	22100	2.34	140	6.3
11	221	100	53	22100	2.37	180	8.1
Average						178	8.1

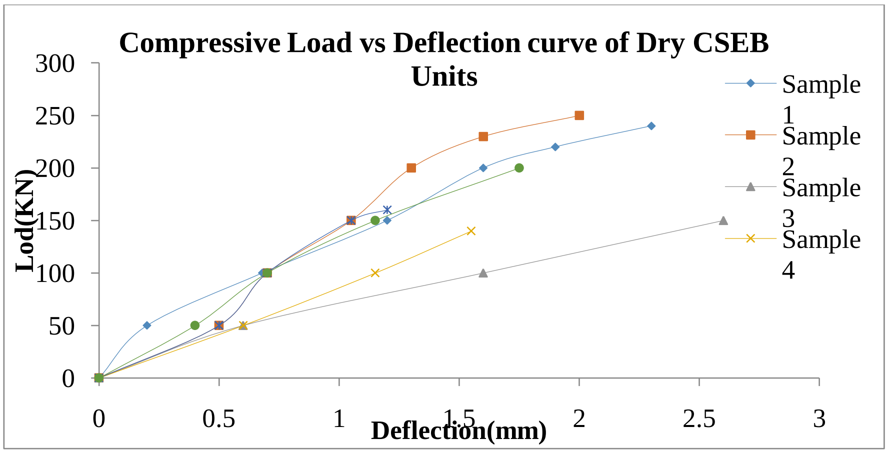

Figure 2: Compressive load versus deflection curve of dry CSEB units (*Bhatt., 2015)*

Wet Compressive Strength of CSEB Units

Wet compressive strength of CSEB units is calculated with the help of Compressive load at Failure during compressive strength test of CSEB units in their fully saturated wet state and cross sectional area of samples as illustrated in following table. Average compressive strength of above data is 5.5. Standard deviation calculation for the above data is 0.64 which indicates that the test results are nearly close to the mean.

Table 4: Wet compressive strength of CSEB units (Bhatt., 2015)

S. No.	dimension(mm)			Mass (Kg)	Failure Compressive load (KN)	Compressive Strength (Mpa)
	Length	Breadth	Height			
1	222	100	52	2.67	100	4.5
2	218	99	53	2.69	130	6.0
3	222	100	52	2.505	140	6.3
4	223	99	52	2.63	100	4.5
5	221	99	55	2.71	120	5.5
6	222	100	52	2.71	120	5.4
7	223	100	56	2.641	120	5.4
8	222	100	55	2.625	110	5.0
9	222	100	54	2.585	140	6.3
10	222	100	54	2.6	120	5.4
11	222	100	55	2.595	140	6.3
Average					122	5.5

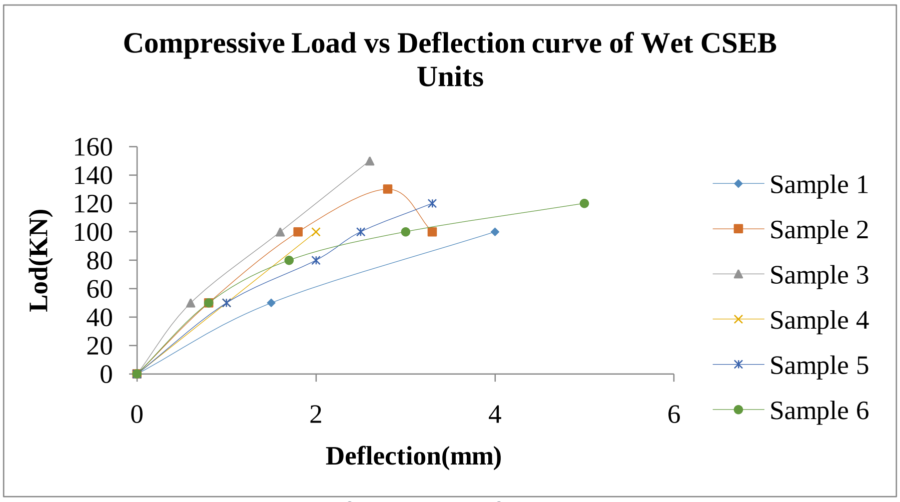

Figure 3: Compressive load versus deflection curve of wet CSEB units (Bhatt., 2015)

Compressive Strength Test of CSEB Masonry Wall

Following Figure shows (Picture was taken during testing of masonry walls by the researcher at Central Material Testing Laboratory, Pulchowk Campus) the crack pattern that was seen while applying static (monotonic) compressive loading (Bhatt, 2015). In cement sand mortar, the cracks observed were seen uni-directional, where the cracks start at the middle of the wall on front and back face of wall and with increasing load, more vertical cracks were observed along the sides on the plane of wall. In stabilized mud mortar the cracks were seen uni-directional, where the cracks start at the middle of the wall on front face, back face and on side faces as well and with increasing load, more vertical cracks were observed along the sides on the plane of wall(Bhatt, 2015). For Each masonry wall, compressive strength was calculated by dividing each wall's maximum compressive load sustained by the cross-sectional area of that wall.

Figure 4: Cracking of CSEB masonry wall for a monotonic compression load (Bhatt., 2015)

Compressive Strength of CSEB Masonry Wall (in 1:6 Cement Sand Mortar)

Compressive strength of CSEB Masonry Wall (in 1:6 Cement Sand Mortar, mortar having average compressive strength of 3.33 MPa) is calculated with the help of Compressive load at Failure during compressive strength test of the masonry walls and cross sectional area of the masonry walls under compression as illustrated in following table.

Table 5: Compressive strength of CSEB masonry wall in 1:6 cement sand mortar (Bhatt, 2015)

Sample	Dimension(mm)			Sectional Area (mm^2)	Failure Load (kN)	Compressive Strength (Mpa)	Average Compressive Strength (Mpa)
	Length	Height	Thickness				
1	660	1100	220	145200	378.4	2.606	2.705
2	660	1100	220	145200	368.7	2.539	
3	665	1100	220	146300	434.4	2.969	

Compressive Strength of CSEB Masonry Wall (in 8% cement stabilized mud mortar mortar)

Compressive strength of CSEB Masonry Wall ((in 8% cement stabilized mud mortar, mortar having average compressive strength of 1.33 MPa) is calculated with the help of Compressive load at Failure during compressive strength test of the masonry walls and cross sectional area of the masonry walls under compression as illustrated in following table.

Table 6: Compressive strength of CSEB masonry wall in 8% cement stabilized mud mortar (Bhatt, 2015)

Sample	Dimension(mm)			Sectional Area (mm^2)	Failure Load (KN)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
	Length	Height	Thickness				
1	655	1150	220	144100	141.6	0.98	1.215
2	655	1150	220	144100	161.8	1.12	
3	655	1165	220	144100	221.8	1.54	

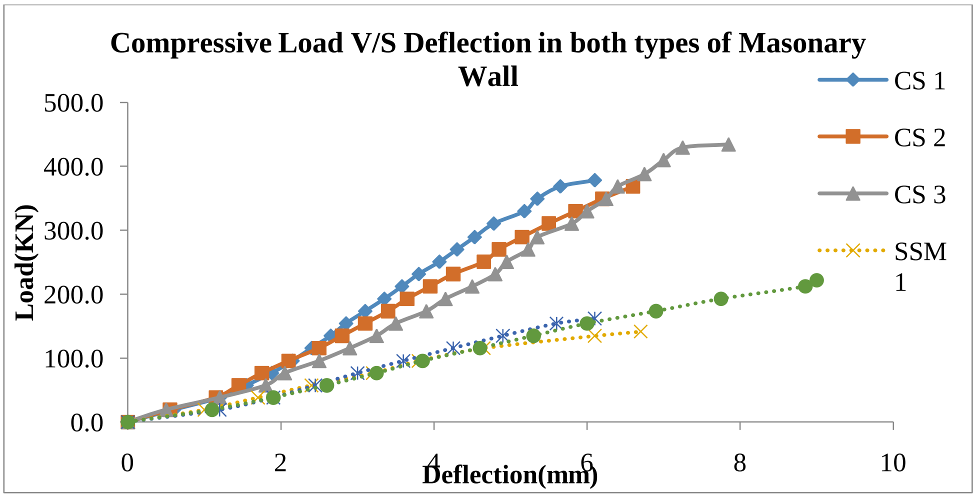

Figure 5: Compressive load versus deflection (Bhatt, 2015)

Comparison of Test Result of CSEB Units with other materials

Comparison of test results for bulk density, water absorption capacity and compressive strength of CSEB units with those of Concrete Masonry unit (CMU IOE 2014) and Indian Standard Brick is illustrated in the following table(Pokhrel, 2014)(Code of Practice for Structural Use of Unreinforced Masonry, 1987).

Table 7: Comparison of test result of CSEB units with other materials

Test Parameter	CSEB Unit (IOE 2015)	CMU IOE 2014		Indian Standard Brick	
		A (1:6)	B(1:9)	1st Class	2nd Class
Bulk density (kg/m^3)	1949.86	1471.82	1432.28	NA	NA
Water Absorption Capacity (%)	15.73	6.41	7.48	upto 20	20-22
Dry Compressive Strength (MPa)	8.1	5.46	4.22	>13.73	6.87-13.73

Comparison of Test Results of Wall

Comparison of test results for Compressive strength of CSEB masonry wall in 1:6 cement sand mortar and 8% cement stabilized mud mortar is made with the Compressive Strength test results of Concrete Masonry unit wall (CMU Wall, IOE 2014)(Pokhrel, 2014) and those values suggested by Indian Standard IS 1905:1987 and Euro code 6 are illustrated in the following table.

Table 8 Comparison of test result of CSEB masonry wall

Test Parameter	CSEB Wall (IOE 2015), by researcher		CMU Wall (IOE 2014)		IS 1905: 1987	EN 1996-1-1 (2005) Euro code 6
	1:6 Cement	8% Cement Stabilized	A	B		
Compressive Strength (MPa)	2.705	1.215	3.31	2.51	2.56	2.73

Discussion

From the analysis of experimental results of CSEB units, different properties of CSEB units are as follows: Average Density and unit weight of CSEB unit are found to be 1949.86 kg/ m3 and 19.13 kN/m^3 respectively with standard deviations showing test results are relatively close to average value for both parameters. Water absorption capacity of these CSEB units is found to be 15.73% which is permissible for 1st class brick as per Indian Standard. Dry compressive strength of CSEB units with 8% cement stabilization vary from 6.3 to 11.8 MPa averaging 8.1 MPa with standard deviation of test results showing data are nearly close to average value and wet compressive strength of CSEB units vary from 4.5 to 6.3 MPa averaging 5.5 MPa with standard deviation of test results showing data are nearly close to average Test results of CSEB units in dry and wet condition have shown nonlinear behavior and have similar strength results as those of second class brick. The average saturated compressive strength of CSEB block was found to be 32 % less than the dry compressive strength of CSEB block. Similar results were obtained in (Riza et al., 2010).

Average Compressive strength of CSEB masonry wall is found to be 2.705 MPa in cement sand mortar (1:6) which is slightly higher than test result of Indian standard (Failure Stress) and approximately similar with proposed result from Euro Code 6. These test results are comparable with those of concrete masonry unit wall results carried in 2014 at TU,IOE(Pokhrel, 2014). Average Compressive strength of CSEB masonry wall is found to be 1.215 MPa in Stabilized Mud mortar which is very less as compared to those in Cement sand mortar.

Conclusion and recommendation

Experimental analysis of Compressed Stabilized Earth Blocks (CSEB) made from red residual soil of Lele with 8% cement content at 200 kg/cm2 compaction pressure shows satisfactory results. CSEB units show dimensional stability. Bulk density, water absorption capacity, Dry Compressive Strength, Wet Compressive Strength of CSEB units are found good enough to use CSEB as wall making material. Bulk density of CSEB units is 1950 kg/m3 and Unit weight of CSEB units is 19.13 KN/m3. Average Water absorption Capacity of CSEB units is 15.73%. Average dry compressive strength of CSEB units is found to be 8.1 MPa and average wet compressive strength of CSEB units is found to be 5.5 MPa. Tests on walls constructed from CSEB units with cement sand mortar and stabilized mud mortar shows satisfactory results. Average compressive strength of CSEB masonry wall of height to thickness ratio 5:1 for cement sand mortar (1:6) is found to be 2.705 MPa and for stabilized mud mortar (8% cement and 16% extra sand) is found to be 1.215 Mpa. Considering above test results CSEB Load bearing masonry walls of 220 mm thickness in cement sand mortar can be designed as unreinforced or designed with proper reinforcement but for stabilized mud mortar walls, thickness of wall needs to be increased from 220 mm to 330 mm or above as per requirement.

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