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Effect of mix design on compressed earth block strength

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HIGHLIGHTS

- Effect of a unique CEB geometry on strength testing methods.
- Effect of mix designs on CEB flexural and compressive strength.
- CEBs with optimized mix designs surpass ASTM strength requirements.

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ABSTRACT

Compressed earth blocks (CEBs) are masonry units that combine soil, stabilizer, and water under pressure to form an earth block. Unit block performance is dependent on the characteristics of soil and the mix design. This paper presents CEB unit strength test methods and results for CEBs produced from 14 mix designs at 7 and 28 day curing times in both saturated and unsaturated conditions. Trends in the effect of mix design on block strength reflect that strength increases with both moisture and cement content in the regimes of applicability for the production machinery. The unsaturated, 28-day unit compressive strengths ranged from 4.92 MPa to 15.72 MPa. The optimal mix contained 10.91% cement and 11.40% water which resulted in an average compressive strength of 15.15 MPa; ASTM C90 mandates a minimum compressive strength of 13.79 MPa.

1. Introduction

1.1. Compressed earth blocks

Compressed earth blocks (CEBs) are a relatively new form of earth masonry units that combine local soil, stabilizer and water under pressure to form an earth block. By using soil, a readily abundant resource almost everywhere in the world, as the primary component in block production, CEBs offer a sustainable alternative to traditional masonry units [1–10]. Soil is mixed with a stabilizer, usually Portland cement or hydrated lime, to add cohesion and increase weather resistance. Depending on the type of soil used, sand is sometimes added to act as an aggregate. Water is added to activate the stabilizer, and the mixture is machine-compressed to form and allowed to cure for a 28-day period. Unlike many other masonry elements, CEBs are not baked or fired to achieve final strength [2,4,6,7,11–13].

The proliferation of CEB construction is limited by a lack of standardization in the United States and internationally. While standards that address suitable soil selection and CEB construction do exist in countries such as the United States, France, New Zealand, and various regions in Africa, these standards are wide-ranging in their recommendations and production process guidelines [14,15].

This lack of standardization, and the lack of agreement in the standards that do exist, can at least be partially attributed to the variability inherent in CEB production and construction. The ultimate behavior (e.g. strength properties, energy efficiency, etc.) of a CEB unit is dependent on properties of the character of soil, which varies widely from location to location [2,4,7,11–13,16–19]. The characteristics of the soil type used for block production affects CEB unit performance metrics [2,7,13,17–20]. Soil characteristics can vary widely from location to location and such variations restrict CEB mix designs that defines required portions of soil, sand, stabilizer, and water [14,15,10].

1.2. CEB strength testing

CEB strength testing is subject to variability in testing methods [18,20]. This is primarily due to CEB not being a heavily-

Abbreviations: CEB, compressed earth block; ASTM, American Society of Testing and Materials; CMU, concrete masonry unit.

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standardized building material, such as steel or concrete. As such, block geometries are not consistent across projects, and block geometry affects a CEBs compressive strength. Morel et al. [20] and Walker [17,18] provide an excellent summary of current test methods used to determine the compressive strength of CEBS as well as new test methods that account for the influence of block geometry, specifically the aspect ratio of rectangular prism blocks. They study the effect of block geometry, test procedure, and basic mix design on block strength. Typical block geometries include rectangular prisms of various shapes and sizes both with and without holes.

Grunert [12] followed the standards outlined by the New Mexico Earthen Building Materials code and tested CEBs with different mix designs in direct compression and 3-point bending. Testing was performed on small-scale blocks measuring 63.5 mm × 88.9 mm × 25.4 mm.

Krosnowski [11] continued the work of Grunert [12] and followed the same direct compressive strength and 3-point bending test procedures. Tests were conducted on small-scale blocks as well as full-scale blocks measuring 152.4 mm × 304.8 mm × 88.9 mm. Neither the small-scale nor the full-scale blocks featured holes. Different soil types and mix designs were tested to study the effect of mix design on block strength.

Allen [13] continued the work performed by Krosnowski [11] and studied the structural performance of CEB blocks, subassemblies, and walls using test methods adapted from masonry. General trends in the strength properties of different soil mixes with different water contents and clay-to-sand ratios are highlighted. Full-scale blocks measuring 152.4 mm × 304.8 mm × 88.9 mm were tested. The blocks tested did not have holes.

This paper seeks to relate different mix designs to expected unit strengths for CEB at 7 and 28 day cure periods in both saturated and unsaturated conditions. The CEB used are a unique design that includes holes for vertical reinforcement. Stress concentration factors around the holes are calculated using finite element modeling (FEM) and flexural and compressive strengths for blocks with a variety of mix designs are examined.

2. Block production

For this research effort, several CEBs were produced from a single soil type and tested to determine unit strengths as a function of mix design, cure time, and saturation conditions. Blocks were tested in both direct compression and three-point flexure.

2.1. Block geometry

Blocks were produced using an Earth Blox BP714 machine as shown in Fig. 1. The BP714 employs a two-step compression process: first the soil is compressed into the brick form and then a secondary compression is applied as the 2 cylindrical holes are created. Fig. 2 illustrates the shape and dimensions for a CEB produced using the BP714. The geometry of these particular CEBs, with rails on the bottom surface and a tongue on the top surface, allows the blocks to be easily stacked while leaving a small gap between the middle sections of stacked bricks that can be filled with cement. The block geometry used in this paper is a new geometry that has not been previously investigated. These blocks are unique to CEB construction in that they contain holes, which allow for grouting and the installation of vertical reinforcement in wall construction to make a truly composite structural system. These holes may cause irregular breaks due to stress concentrations in 3-point bending and direct compression tests and testing methods must account for these concentrations.

Many CEBs are produced using manual presses that rely on leverage to achieve proper compaction, however it is difficult to achieve precise compactions from block to block. Machine-produced blocks were used for this paper to increase consistency across all blocks and mixes. The BP714 has a hydraulic pressure gauge, giving the ability to achieve consistent and precise input pressures for each block produced. All blocks tested for this paper were produced using a hydraulic pressure of 15.5 MPa (2250 psi).

2.2. Mix designs

Blocks were made using a total of 14 different mix designs and a single soil type. The mix design variables included soil to sand ratio (SSR), water content, and Portland cement content. The soil type classified as silty-clayey sand according to the Unified Soil Classification System (USCS) and was held constant for all mix designs. Table 1 shows the specifications used for each mix design. Mixes 07, 08, 11, and 12 have "N/A" in the Soil/Sand Ratio column because no sand was added for those mixes. The SSR of each soil does not include the sand contained within the raw soil. The stabilizer content for each mix is based on the dry volume of the mixture. The water content for each mix is based on the total volume of the mixture after water is added and includes the in-situ moisture from the raw soil.

Mixes were created by taking a known quantity of soil (104.1 L) and calculating the appropriate quantities of additives needed to

Fig. 1. Earth Blox BP714.