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Technical Note

An earth block with a compressive strength higher than 45 MPa!

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HIGHLIGHTS

- The compressive strength measured for an earth block was higher than 45 MPa.
- The direct measurement of the compressive strength on adobe plates is aberrant.
- Compressive strength tests on adobe plates are comparable to oedometric tests.
- A 3 point bending test could be a solution for measuring the UCS of adobe plates.

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ABSTRACT

This paper presents the results of a compressive strength test carried out on an extruded earth block of dimensions $40.7 \times 13.6 \times 4.8$ (cm^3). The failure of the block was not detected by the press used, which reached its highest load (2500 kN). This would correspond to a compressive strength of the block greater than 45 MPa! This value is obviously an aberration and the discussion developed in the paper, based on results from the literature, aims to explain this result and propose solutions for measuring the compressive strength of such products.

1. Introduction

For millennia, human beings have used earth in various forms for construction: compacted in formworks (rammed earth); mixed with straw and put in place by hand, either alone or as filling in timber structures (cob); or as masonry blocks, generally molded (adobes) and dried in the sun. The mechanical strength and durability of this material was recognized long ago, as highlighted by the significant heritage of earth constructions all around the world. In terms of resistance, the example of the city of Shibam in Yemen is often quoted as a reference: in this city, buildings with more than eight stories reaching heights of 30 m were built with earth blocks. Shibam is a UNESCO world heritage site and is known as the most ancient skyscraper city in the world [1].

The main weakness of earth used as a construction material is its sensitivity to water. To protect earth constructions, Man has developed a variety of strategies: orientation of the building and of its earth walls with respect to the dominant rain direction, advanced roof, impermeable foundations or, in some cases, protective lime coating.

The compressive strength of construction materials is a modern notion and is recent in the case of earth construction materials. Until the beginning of the 20th century, empiricism prevailed: earth in its various forms allowed loadbearing walls that did not show too much deformation over time to be built in a sustainable way. In terms of building materials, the 20th century can be considered as the century of concrete. This new material has replaced almost all others in construction for many reasons, including its exceptional compressive strength: 20 MPa for traditional concrete and over 100 MPa since the development of superplasticizers in the 1980s. With concrete, the notion of compressive strength has become the most important characteristic for building materials: this parameter is often considered as a criterion of quality (the higher the compressive strength, the better the concrete) and it is very useful for the sizing of structures because it is one of the main parameters in the majority of computation models.

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Thus, when researchers' interest in the use of earth as a construction material began to revive a little more than 20 years ago, essentially for environmental and heritage reasons, measuring the compressive strength of earthen materials became a priority. The first idea was to apply the same procedures to earth blocks as those used for modern materials like concrete or fired bricks. However, earth blocks are more comparable to compacted soil and the analogy with brittle materials is showing its limits. Shedding light on these limits is one of the aims of this paper, in which a compressive strength higher than 45 MPa will be presented for an earth block.

2. Experimental procedure and results

The soil used for this study came from the quarry of a brickworks in southern France. This brickworks produces both fired bricks and soil blocks but with different compositions, in particular for the proportions of clay and sand in the mixtures. The blocks, whether fired or not, are manufactured in the same way: the clay is crushed and mixed with sand and then mixed with 16–18% water. The fresh mixture is extruded to form a long cable of material that is cut into bricks of the desired length. The bricks are then hardened by drying for nearly four days at a temperature increasing progressively from 25 °C to 100 °C. Several dimensions of bricks exist but the specimens used for this study were $40.7 \times 13.6 \times 4.8$ (cm^3).

The compression test was carried out using a hydraulic press. The test was run at a constant rate of 0.08 MPa s^{-1}. The press had a capacity of 2500 kN and the dimensions of the platen were 42×42 (cm^2). Before the test, the samples were cured in an air-conditioned room at 20 °C and 50% relative humidity until their mass was constant, because the moisture content of soil blocks is considered to have a strong effect on their compressive strength [2,3]. The water content of the sample, measured by its loss of water at 105 °C, was equal to 2.4%.

In this study, blocks were tested in the direction in which they are generally laid (horizontally). The surface area in contact with the platens was thus very large and the aspect ratio was very small (the aspect ratio is defined as the ratio between the thickness of a sample and the smallest characteristic length of its surface). In this case of study, the aspect ratio was equal to 0.35. Block surfaces were usually sufficiently flat and parallel and no specific capping was necessary to correct them. The blocks were tested directly between the platens of the press, which maximized the plate restraint effects.

During the test, the force continued to grow linearly until the maximum capacity of the press (250 tons) was reached. Theoretically, this should mean that the earth block tested had a compressive strength greater than 45 MPa, which was extremely improbable. Tests were performed on samples cut from these blocks and cured in the same way. Six samples of $5 \times 5 \times 10$ (cm^3), tested vertically (aspect ratio of 2) gave the usual compressive strength for earth blocks, ranging from 4.4 to 6.3 MPa (with an average value of 5.5 MPa).

During the test, cracks appeared around the edges of the sample (approximately 1 cm from the edge) as shown in Fig. 1. Despite the appearance of these cracks, the press did not detect a fall in force and continued to load the sample. At the end of the test, the height of the sample had decreased from 48 mm to 38 mm as shown in Fig. 1. In addition, initially rough brick surfaces had become smooth and it could be seen that the density of the central part of the block had increased considerably. The block, which can be considered as a sample of clayey soil, had thus undergone settling without actual failure in extension.

3. Discussion

Before developing the discussion, it is necessary to define the differences between UCS, "Unconfined Compressive Strength", which is calculated using the maximum force (divided by the surface area of the sample) that a material can withstand in an unconfined compression test, and the stress called "Apparent Compressive Stress", ACS. UCS is a characteristic of the material and must therefore be independent of the means and methods used to measure it. In contrast, the influence of the geometry of samples of earth blocks on the result of compressive strength tests has already been observed by many authors (e.g. [2,4,18]). All these results tend to show an increase of the ACS as the aspect ratio decreases. The reason typically given to explain this is the phenomenon of friction between the sample and the press.

For example, Piattoni et al. [4] carried out compressive strength tests on two geometries of samples ($46 \times 31 \times 13$ (cm^3), aspect ratio = 0.42; and $23 \times 15 \times 13$ (cm^3), aspect ratio = 0.87) and compared the results with those obtained on a wall of similar composition (aspect ratio = 2.55). They observed a significant increase in the compressive strength with decreasing aspect ratio: from 6.56 MPa for the sample of aspect ratio = 0.42 to 1 MPa for the walls. In fact, different experimental studies seem to indicate that, depending on the type of material, the ACS tends to the UCS for aspect ratios ranging from 2 (e.g. standard ASTM 1314 [5]) to 5 [6,7].

3.1. Limits of the use of correction factor in the case of adobe plates

The conventional way to account for the effect of the aspect ratio on the value of the compressive strength is to modify the ACS of bricks by a correction factor depending on the aspect ratio [6,8]. However, this approach has reached its limits in the study of the adobes of heritage buildings or in the cases of some modern extruded bricks (themselves inspired by the heritage bricks). In such cases, the material is often in the form of plates with a very low aspect ratio (close to 0.3) to facilitate the drying of the brick. With such dimensions, the problem becomes more delicate and the application of a single correction factor does not appear to be sufficient for several reasons.

First, the geometry strongly influences the characteristics of the material during its manufacture and curing (kinetics of drying, modifications of the homogeneity and the arrangement of earth) [9]. Thus, applying a correction factor to the ACS of plates in order to obtain a compressive strength comparable to those measured on blocks does not really have any sense since it would compare two different materials and would therefore lose the intrinsic character of the UCS.

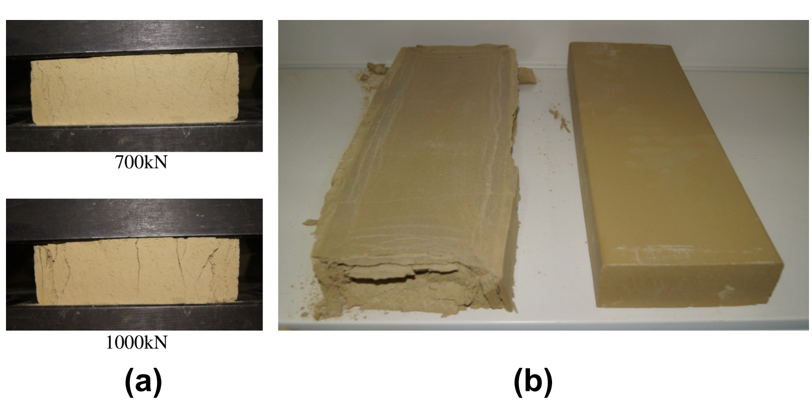

Fig. 1. (a) Cracking on the block (b) block before and after the test.