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Influence of compaction pressure on the mechanical and acoustic properties of compacted earth blocks: An inverse multi-parameter acoustic problem

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ABSTRACT

In this work we focus on the study of the acoustic and mechanical behavior of compressed earth blocks (CEBs). The aim was to study the influence of compaction pressure on the compressive strength and intrinsic acoustic parameters influencing sound absorption of these materials (porosity, tortuosity, airflow resistivity, viscous characteristic length). Specimens made by varying the applied compaction pressure and therefore having various bulk densities were studied. Low bulk density CEBs where stabilized by adding 15% cement. The acoustic absorption coefficients of the different specimens were determined experimentally employing data obtained using the Kundt tube. The intrinsic acoustic parameters were identified by minimizing the discrepancies between the experimentally measured absorption coefficient (α) and the theoretical one modeling the CEBs using the equivalent fluid model. The results showed that the acoustic and mechanical behavior of CEBs were strongly influenced by the applied compaction pressure including, inter alia, the bulk density of the specimen and the added cement used as stabilizer.

1. Introduction

Today, it is expected of construction materials to perform multiple functions and be sustainable. They are supposed to satisfy the structural, thermal and acoustic requirements. This multifunctionality allows an attractive gain of space in buildings when compared to the use of different materials placed side by side and in parallel consequently saving time and money in the construction. The second requirement which aims to reduce greenhouse gas emissions is increasingly becoming important with the growing interest in sustainable construction [1].

Earth is a natural raw material. It is one of the oldest building material in history [2] and is cheap, ecological and abundant. It has been widely used for the construction of walls, especially in developing countries [3]. Compressed earth blocks (CEBs) have taken up as the principal building material in ancient cities such as Jericho (Palestine), Atal- Huyuk (Turkey), Harappa (Pakistan), Akhlet-Aton (Egypt), Chan- Chan (Peru), Babylon (Iraq), Duheros (Spain). Unfortunately, this building material has been ignored for many years; this is due to the fascination for modern materials such as concrete, brick or steel. Second, it is due to the lack of international standards to evaluate the different products. During the last few years, there has been a growing interest for earth as a sustainable building material. This has spurred studies in the engineering laboratories around the world aiming at the certification of earth building products. The reason for this interest is that it presents several advantages that allow it to be a current response to energy and climate issues. Indeed, earth is an abundant natural and recyclable resource. It is low embodied energy building material, compared to fired clay bricks and concrete. It reduces the amount of energy required for construction as well as transportation needs [4].

Compacted earth blocks are porous materials with open porosity, they allow water transfers in liquid and vapor forms. In the case of liquid water, one speaks of absorption and in the case of water vapor one speaks of adsorption. In general, the problem of sensitivity to water can be solved either by the superposition of an additional layer or by stabilization of the compressed earth blocks using hydraulic binders. Numerous studies have shown that

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stabilization by cement reduces the sensitivity of these materials to water and to humidity. Experimental studies realized by Meukam et al. [5,6] showed that the addition of cement improves the hygric behavior of compressed earth blocks. Indeed, the amount of absorbed water decreases with the increase in the cement content. In the same context, the study by Bahar et al. [7] showed that the stabilization of CEB by a cement content greater than 4% greatly improves the moisture resistance of CEBs.

Numerous previous works [5,6,8] have studied the possibility of improving the thermal performance of compacted earth blocks by making them lightweight. Meukam et al. [5,6] have shown that the addition of lightweight materials such as sawdust and pozzolan decreases the thermal conductivity of CEBs. Ben Mansour et al. [8] have studied the effect of the compaction pressure on the thermal performance of CEBs. It has been demonstrated that the compaction pressure employed to manufacture the CEBs has an important influence on the bulk density which in turn has a direct impact on its thermal performance. In fact, the reduction of compaction pressure leads to improved thermal performance of the CEB. A non acoustical study using X-ray microtomography to analyze CEB microstructure reported that soil compaction significantly reduces the total pore volume, the proportion of interpores volume and surface area [9].

This article presents a study of the influence of lightweighting of the CEB on their acoustic and mechanical behaviors. We first focus on the identification of the intrinsic acoustic parameters that affect the acoustic performance of this material (sound absorption and attenuation coefficient). In a second step we study the effect of the reduction of compaction pressure on the sound absorption coefficient and the compressive strength of the CEB.

2. Materials and methods

2.1. Preparation of compressed earth blocks

Earth is first sifted to retain particle sizes whose diameters are less than 8 mm. The sieved soil is then placed in an oven heated at 105 °C for 24 h. After drying, the earth is mechanically mixed with cement. Then, water is added and the mixing is continued until the obtention of a homogeneous mixture. Thereafter the mixture is compacted in a mold using a hydraulic press. Two types of molds were used

- A 100 mm diameter cylindrical mold for making CEBs that can fit into the Kundt tube used to determine the sound absorption coefficient. This bigger diameter has an advantage over the smaller Kundt tubes because it permits a more uniform application of the compaction pressure. The specimens were 2 cm thick.
- A parallelepiped shaped mold whose dimensions are $7 \times 7 \times 28$ cm. The specimens of this geometry were the ones employed to determine the compressive strength of material.

The compaction pressure applied to each mixture was determined at each test. The mass water content used in the preparation of the unstabilized (i.e., 0% cement) compressed earth block specimens was 13%. It was 17% in the case of stabilized blocks (using 15% cement). The earth block stabilization procedure employing cement was only used for low density CEBs in order to make them sufficiently strong mechanically and reduce crumbling. Table 1 gives the percentages of cement, the water content, as well as the compaction pressure applied (ϑ) for the preparation of each specimen.

After compaction, the specimens were placed in a humid chamber having a relative humidity of about 80% and at a temperature close to 20 °C.

2.2. Density and porosity of the compressed earth blocks

The bulk density (ρ) was determined from the ratio between the mass of the specimen and its apparent volume, for a given water content(w). Knowing the bulk density ρ and the water content of the specimens, the dry bulk density ρ_0 was calculated from the following relationship:

$$\rho_0 = \rho/(1 + w) \tag{1}$$

The porosity (ϕ) of the CEBs was determined based on the following relationship:

$$\phi = 1 - \rho_0/\rho_{ab} \tag{2}$$

where ρ_{ab} is the absolute density measured using a pycnometer. It represents the mass per unit volume of the material constituting the granulate. It is equal to 2597 kg/m^3 for the soil and 3080 kg/m^3 for cement (see Fig. 1).

2.3. The sound absorption coefficient measurement method

The sound absorption coefficient was measured using a Kundt tube by the method of two microphones [10]. The tube used had a circular cross section with a diameter of 100 mm and is 1 m long (standing wave Apparatus type B&K 4002, Naerum Denmark). The upper and lower cutoff frequencies of this tube geometry are 2 kHz and 170 Hz respectively. At one end of the tube, the test specimen was slid into the tube then blocked with a rigid movable piston (Fig. 2). Plane acoustic waves were generated from a sound source placed at the opposite end of tube. The microphone measurements at two positions were performed using a single microphone. Instead of doing a single measurement at two points simultaneously, a single microphone was moved at the two measurement positions alternately. This avoids the calibration problems requiring that the two sensors be identical. The two different positions for the acoustic pressure measurements were 8 cm and 11 cm from the specimen (a separation of 3 cm).

The experimental sound absorption coefficients were obtained from the transfer functions acquired at the two pressures field measurement points. The advantage of using this tube over the new ones with smaller diameters, is its larger diameter that allows the characterization of bigger specimens.

The derivation of the analytical expression of the reflection coefficient for the Kundt tube in the frequency domain is straight forward and its expression is given by

$$R = \frac{Z_{CEB} - z_0}{Z_{CEB} + z_0}, \quad Z_{CEB} = -\mathrm{i}\frac{z_c}{\phi}\cot(k_{CEB}d) \tag{3}$$

where $z_0 = \rho_f c_f, z_c = \rho_{CEB} c_{CEB}$ and $k_f = \omega/c_f$ is the wavenumber in the fluid (ρ_f is the density of the fluid, c_f and c_{CEB} are the velocities of sound in the fluid and the CEB respectively), k_{CEB} is the wavenumber in the CEB and d is its thickness. The absorption coefficient is given by $\alpha = 1 - |R|^2$. The correction factors for the frequency dependency of the CEB material parameters (the complex density and compressibility) are given in the Appendix A. The modified sound velocity in the CEB is given by

$$c_{CEB} = \sqrt{\frac{K_f}{\rho_{CEB}}}, \tag{4}$$

where K_f is the modified bulk modulus.