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Dredged sediments valorisation in compressed earth blocks: Suction and water content effect on their mechanical properties

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HIGHLIGHTS

- Valorisation of natural dredged sediments in compressed earth blocks (CEB).
- Sediments were amended with sand and compacted to MPO + 25 blows.
- Drying-wetting paths were carried out to understand the hydro-mechanical behaviour.
- Relations between mechanical properties and water content or suction were established.

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ABSTRACT

The silting of dams requires periodic dredging campaigns to maintain their functional capabilities. In Algeria, more than 32 million m^3 of sediment are deposited every year. In this paper, we investigate the case of the Bakhadda dam in western Algeria, whose dredged sediments can be valorised as an eco-geo-material for building construction in the form of compressed earth blocks (CEB). Preliminary hydro-mechanical study showed the need to amend the natural sediment with sand fraction up to 30% to reach the recommended characteristics of the standards, as granulometry, plasticity and mechanical properties. To achieve high mechanical strength, compaction energy equivalent to modified optimum proctor + 25 blows was required. The hydro-mechanical properties of the manufactured CEB were then studied. Water content effect on their mechanical properties was highlighted. In fact, the strength increases when water content decreases due to an increase in suction. Using the measured drying-wetting paths, relations were established between small strains modulus and water content and suction. Results of this study have led to the valorisation of natural dredged sediments in CEB which respond to the recommendations. Based on the hydric and mechanical tests carried out, the behaviour of CEB in situ was determined.

1. Introduction

Earth is one of the main construction materials used since thousands of years [1–3]. It is a subject gaining attraction nowadays [4]. In order to reduce energy consumption, researchers and engineers are giving more interest to the use of raw earth as an eco-geo-material for buildings' construction [5,6]. Earth construction is associated with low embodied energy and low carbon dioxide emissions [7–10]. P. Torgal and Jalali. [7] showed that research articles treating earth construction are published 10 times more than in the 1990s.

Earth can be employed using different techniques as rammed earth, adobe, cob, etc. Compressed earth blocks (CEB) are manufactured using a process that can be easily industrialised. This is not the case of other techniques, like rammed earth, which are rather artisanal and requires special labor. Compressed earth blocks are typically more resistant than adobe bricks [7]. They can also be produced in different sizes offering an architectural and aesthetic variety. CEB can be manufactured with local materials using low energy [5].

In this study, the case of compressed earth blocks (CEB) is treated. Their use requires the identification of certain properties of the raw material [11–13]. These properties should meet specific

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requirements about granulometry, plasticity, organic presence, cohesion and dry density. It should be noted that there is a lack of normalized standards for this type of construction material. The standards and recommendations existing [14–18], proposed some limits for the properties allowing an appropriate selection of the materials to be used in CEB.

In west of Algeria, the dredging of a water dam provides natural sediments usually embanked. These dredged sediments can be valorised as CEB. The objective of this work is to investigate the feasibility of using dredged sediments as CEB and to improve their mechanical properties. One of the possibilities is to amend them with natural soil and to use high energy compaction procedure [19,20,6,21].

The problematic is to find the most suitable admixture to let a natural soil become appropriate for the CEB use, without adding any stabilizer. An important criterion for choosing the soil is its grain size distribution [11,14]. The material should not be too clayey (% clay 2 μm <30%) to avoid shrinkage and cracking that make the bricks fragile [14,11,22]. However the presence of clay is essential, it acts as a natural binder [14,23,24]. Particles diameter should not exceed 5–20 mm depending on the brick size [21]. The plasticity index should be between 15 and 30 [11], the dry density value should be between 16 and 22 KN/m^3 [22,11]. According to the standard NF XP P13-901, the UCS of CEB must be greater than 1.6 MPa.

Various studies carried out on compacted soils [3,22,25], have found that their compressive strength ranges between 0.4 and 5 MPa and their Young's modulus ranges between 1 and 5.5 GPa. Moreover, other studies showed that UCS increases with the density [26,24,27,25,18].

The compressed earth blocks acquire more strength while drying after fabrication. Water evaporates and the material reaches a thermodynamic equilibrium. When water content decreases and suction increases, the clay particles get closer because of the increasing in capillary forces. This also leads to a contraction causing soil shrinkage. This suction and its consequence on the mechanical and shrinkage properties are mainly studied in the framework of unsaturated soil mechanics [28,2]. Previous studies have reported the water content effect on the mechanical properties of CEB [24,29,30,31,25,32]. They have mostly observed lower resistance for higher water content. This is attributed to the decrease in suction when the water content increases. In fact, when water content increases, the water lubricates the points of contact between the grains and the friction between them decreases. The soil's retention curve makes it possible to estimate the suction within the material knowing its water content. Generally hysteresis exists, so it is important to know the hydric path followed. Strength's decrease with water content's increase is very familiar in the literature. This reduction may cause, unlikely, problems under normal operating conditions [33]. Moreover, the modulus of elasticity increases when the water content decreases [34]. This is due to the clay binders' reinforcement by the evaporation of the water and the development of suction [29–31,22]. That is why, a good identification of the water effect on mechanical properties of CEB is necessary.

This paper presents an experimental study to assess the properties and compatibility of dredged sediments for manufacturing compressed earth block. It outlines the hydro-mechanical response of bricks fabricated from natural sediments. The water content and suction effect on the mechanical properties (compressive strength and elastic modulus) is identified. Drying-wetting cycles are carried out to explain this effect. Relationships between matrix suction and the mechanical behaviour of the dredged sediment are analysed on the basis of drying–wetting cycles. First, results of the sediments classification are presented according to the norms. Second, an improving of their physical properties when adding natural sand and an identification of their drying-wetting paths is done. Finally, mechanical properties of the CEB are discussed with water content change.

2. Methods and materials

The dredging of Bakhadda dam, in west of Algeria, provides natural sediments (NS). Once dredged, using hydraulic plain suction dredger, the sediments are stored and drained in decantation basins. Four bags of materials of 200 kg each were taken at 4 locations in the decantation basins. The 4 bags were then methodically mixed to have a homogenized material, with average characteristics representative of the natural sediments. These sediments need to be identified and compared to the recommendations proposed by the several norms found in the literature. This will show if they are eligible to be used as CEB, and if not, to be amended in order to be it. For this purpose, different tests were conducted, firstly for material's identification, and secondly to understand the CEB's behaviour while in contact with their environment.

2.1. Material identification and characterisation

To characterize the material several tests are necessary when fine particles' percentage is not negligible, this is the case of Bakhadda dam sediment. The tests are particle-size distribution PSD, Atterberg limits, methylene blue, organic matter content, and Proctor compaction.

Particle-size distribution was carried out in two steps. The fraction greater than 80 μm was analysed using the wet sieve analysis test according to the French standard NF P 94-41 [35]. The fraction less than 80 μm was analysed by sedimentation rate test according to the standard NF P 94-57 [36].

Atterberg limits tests were carried out according to the standard NF P 94-051 [37]. Methylene blue test was carried out according to the standard NF P94-068 [38]. The Specific Surface Area (SSA) (m^2/g) was then deduced from the Methylene blue test (SSA = 21* Methylene blue test). Organic matter content OM (%) was measured according to the standard NF P94-047 [39].

Proctor compaction tests were realised for the standard optimum Proctor and for the modified optimum Proctor according to the standard NF P 94-093 [40] to found the optimum values of water content and maximum dry density of the material.

2.2. Drying-wetting paths

Drying-wetting paths were realised using different techniques:

- Imposing suction techniques: osmotic method and the technique of saturated salt solutions [41–47].
- Filter paper method for soil suction measurement using Whatman 42 filter paper, according to ASTM standard D529810 [48].

2.2.1. Imposing suction techniques

Concerning the imposing suction techniques, the method was chosen according to the suction range. For suction ranging from 0.1 to 1.5 MPa, the osmotic method was used. It consists of using dialysis membranes with very small pores (5 nm) and a polyethylene glycol solution (PEG 6000 or PEG 20000). Samples of 2–3 cm^3 were prepared. Soil samples were placed on the membrane that separates them from the solution. As the macromolecules tend to hydrate and attract water from the samples, this latter is submitted to a matric suction that depends on the PEG concentration in the solution. For higher suctions (2–1000 MPa), water transfer's occurs in the vapour phase. Several salt solutions (NaCl, K_2SO_4, $NaNO_2$, KCl, NH_4CL, $CuSO_4$, $ZnSO_4$, LiCl) were used to control the relative