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► **To cite this version:**

Taini Chitimbo, Noémie Prime, Feras Abdul Samad, Olivier Plé. Effect of capillary rise on mechanical behaviour of unstabilized rammed earth. NOMAD 2022 - 4e conférence internationale francophone Nouveaux Matériaux et Durabilité, IMT Mines Alès; LMGC; LIFAM, Nov 2022, Montpellier, France. hal-03880924

HAL Id: hal-03880924

<https://hal.science/hal-03880924v1>

Submitted on 1 Dec 2022

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Effect of capillary rise on mechanical behaviour of unstabilized rammed earth

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ABSTRACT

Moisture ingress through capillarity has a great effect on the mechanical properties of unstabilized rammed earth (URE). Limited experimental studies exist to quantify this effect. In this paper, an experimental setup for the capillary test was designed. Rammed earth samples of 15cm x 15cm x 45cm equipped with humidity capacitive sensors were placed on a saturated layer of sand which imposes controlled matric suction at the base of the sample. The kinetics of the capillary rise was determined by continuous measurement of the mass of the sample, height of moisture, and relative humidity. Subsequently, unconfined compressive strength (UCS) tests were performed before and after capillary rise. Samples tested after capillary rise show a decrease in mechanical resistance of 95% (a usual compression strength of 1.4 MPa decreases until 0,07 MPa). Other samples, dried after capillarity, show under uniaxial compression tests a restoration in compressive strength by 80% of the original dried samples. In consequence, a loss of strength capacity is observed under the capillary rise cycle. This contributes to explain many pathologies encountered on rammed earth structures.

Keywords Rammed earth, Capillary rise, Compressive strength

I. INTRODUCTION

URE buildings are constructed by compacting moist earth material without additional binder. Compaction is done layer by layer in a formwork. After compaction, its compressive strength grows as the structure dries (Chitimbo et al., 2022). In design, the characteristic compressive strength is about 2 MPa, which is sufficient enough for construction of a two-storey building (Chauhan et al., 2019). URE is known to be a sustainable option for material construction due to its low embodied energy, and its subsequent low Green House Gases emission (Morel et al., 2001), interesting hygro-thermal properties, low operational cost, and recyclability (Gallipoli et al., 2014).

Despite the numerous environmental advantages, the durability of URE remains poor when exposed to excessive moisture conditions due to capillary rise or rainfall (Gallipoli et al., 2022). Moisture ingress through capillarity is responsible for most of the pathologies of earthen constructions.

Studies of the water movement in such porous material (Hall, 1981) show that the cumulative absorbed mass of water per unit area of the inflow surface increases linearly against

the square root of the elapsed time. In particular, the characterization of capillary absorption properties of rammed earth can be found in Chabriac et al. (2014) and Indekeu et al. (2021). Hall & Djerbib (2004) show that capillary absorption on rammed earth is highly dependent on the particle size distribution but that there was no obvious pattern found between compressive strength and the rate of absorption. Numerical simulation on URE wall without capillary rise shows an increase of the horizontal bearing capacity by 47% in 5 years after construction, while this improvement was only 10% with capillarity rise (Zhang & Nowamooz, 2021).

The effect of capillary rise on mechanical behaviour URE is significant but rarely studied in the literature. In addition, the impact of drying-wetting cycles on the mechanical performance of URE has not been yet accurately quantified and understood.

The study aims to experimentally quantifying, the effect of capillary rise on the mechanical performance of URE at a scale which is representative of a multi-layer structure of rammed earth. To do so, capillary experiments adapted for the large scale were designed, the kinetic of capillary rise and evolution of mechanical strength were followed before and after capillary rise.

II. MATERIAL AND METHOD

Six prismatic samples of size 15 cm x 15 cm x 45 cm, manufactured by compaction in six layers, were used in this study, with an average dry density of 1900 Kg m^{-3} , manufactured at a water content (w) of 10% and an average porosity of 0.29. The earth used contains 10% clay, 12% silt, 33% sand, and 45% gravel, more on the mineralogical composition can be found in Chitimbo et al. (2022). After capillary rise, with hydric instrumentation, samples were subjected to unconfined compressive strength (UCS) test in a moist ($w=10\%$) and dried state ($w<2\%$).

A. Instrumentations

Different methods were used to follow the kinetics of capillary rise.

- Capacitive sensors for relative humidity (RH) and temperature

In total six capacitive sensors were used per sample. Sensors were placed in the middle of each earth layer to provide local evolution of RH with time. Data acquisitions were done by using a microcontroller (Arduino) and a computer. This acquisition needs to be installed during the manufacture, and thus is not suited for the diagnostic of an existing structure.

- Electrical investigation

This geophysics method uses an electrical resistivity survey to measure the presence of moisture in the structure. Four electrodes were stuck with a gel around each layer to measure the local electrical resistivity as the water rise through capillarity. This method is non-destructive since electrodes are only glued to the surface of the structure. It could be thus suited for the expertise of an existing structure.

- Balance and camera

Balance was used to measure the mass of water absorbed. A camera was used to take picture of the sample at a regular interval during the capillary rise. These pictures were then analysed to determine the evolution of moisture rise at the surface of the sample observed.

B. Capillary experimental setup

The capillary bench shown in Fig. 1 was designed to study the capillary rise on a large RE sample. It consists of two plastic containers connected by a siphon pipe to ensure an equal level of water. As RE disintegrates and liquefies when immersed in water (Indekeu et al., 2021), using fine sand as a medium of contact between sample and water level was adopted to have a less intensive hydric boundary condition. The container on the left consist of the sample and fine sand all placed on high precision balance for continuous mass measurement. On the other hand, the water level was maintained constant thanks to the water reservoir system visible on the right container (Fig. 1). The water level can be varied to change the height of capillary in sand hence imposing a certain suction at the base of the sample. In this study, the height of capillary into sand was maintained constant at 2 cm (equivalent to a suction value of 200 Pa). Indeed, this condition can be encountered in the case of flooding.

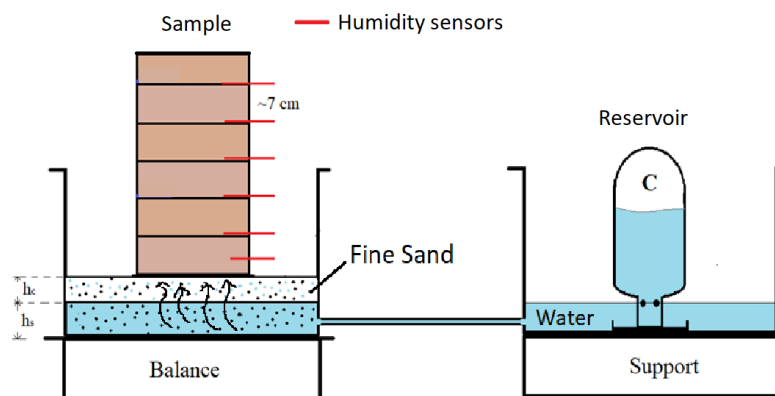


FIGURE 1. Experimental setup for capillary rise on RE column

III. RESULTS & DISCUSSION

A. Kinetics of capillary rise

The capillary rise test lasted for 20 days when the moisture stopped and the mass of the sample was stabilized. The moisture rose by about 30 cm to 40 cm and the total mass of water absorbed ranged from 1.5 kg to 1.8 kg in different samples. The test was done in a closed room with a RH of around 45/55% and a slightly varying temperature of 20/23°C (ambient conditions are visible in figure 2)

Fig.2 shows the evolution of RH and electrical resistivity during the capillary rise. An increase in RH from the ambient value of 50 % to saturation (100 %) after moisture rise is observed for all layers. In addition, an instantaneous rise in RH for the first two layers (at the bottom), then followed by a gradual increase in RH from fourth to sixth layer can be observed. A similar trend was observed in the evolution of electrical resistivity, a sharp decrease in resistivity of the sample from 2000 $\Omega.m$ to 100 $\Omega.m$ on the first layers followed by a gradual drop in resistivity as seen on the sixth layer.

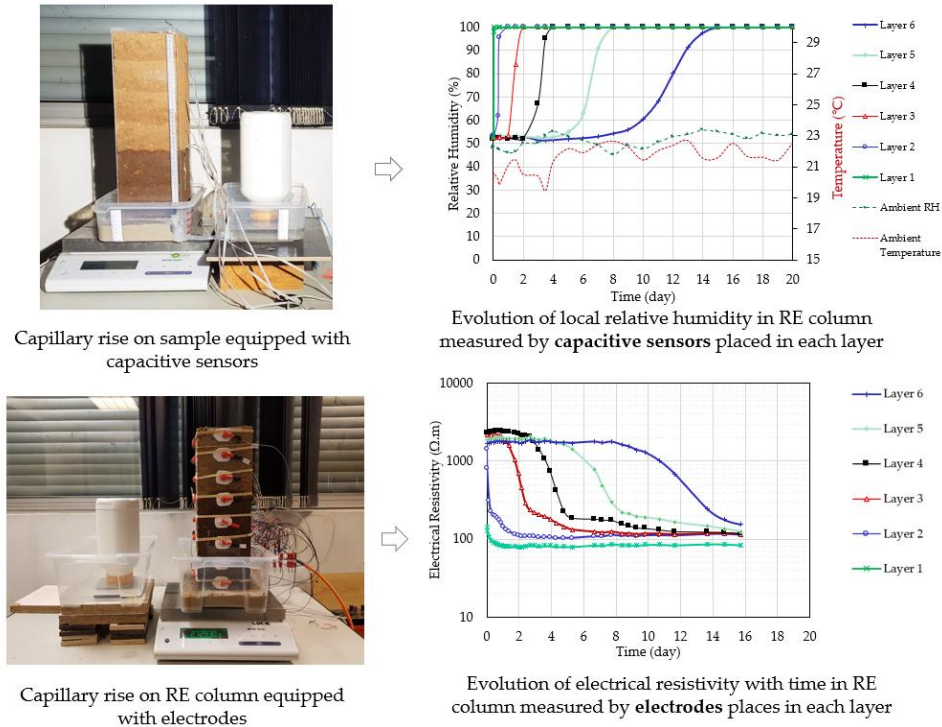


FIGURE 2. Kinetic of capillary rise on RE column followed by capacitive sensors and electrical resistivity measurements

B. Mechanical test

A series of UCS tests were done before and after the capillary rise experiment. Fig. 3 presents the results of the UCS test on total of 6 samples. Two samples at dried state ($w= 1.5\%$) tested before capillary rise have an average compressive strength of 1.4 MPa. Three samples tested after capillary rise show a decrease in average compressive strength to 0.07 MPa. (a reduction in strength by 95% from the initial dry state). Another sample, after capillary dried in an enclosed environment of temperature ranging between 15°C/20°C and relative humidity of 40°C/60%, shows a compressive strength of 1.11 MPa. This account for restoration in compressive strength by 80% of the dry original samples. The reduction in strength after a cycle of drying-wetting could be explained by possible shrinkage-swelling of earth materials that can promote micro-cracking (Nowamooz & Masrouri, 2008).

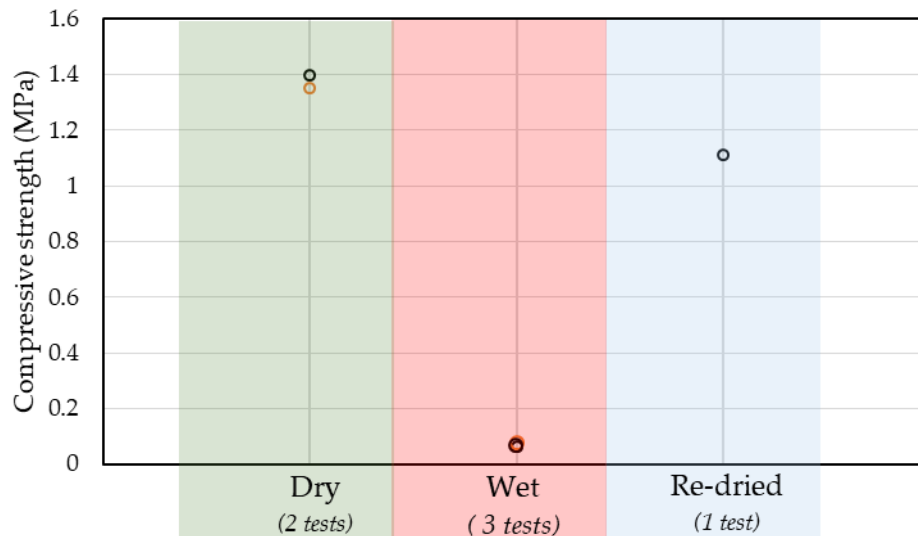


FIGURE 3. Compressive strength of 6 RE columns before and after capillary rise

IV. CONCLUSION AND PERSPECTIVES

In this paper, the effect of capillary rise on the mechanical behaviour of URE has been studied experimentally. RE columns equipped with different instruments for hydric measurement were placed for a capillary test. A good correlation between different methods: the evolution of RH and the electrical resistivity of the sample is observed. A high rate of capillary rise was observed in the first days then slowly reduces until equilibrium is reached after 20 days.

After the capillary rise, the samples were subjected to the UCS test. Results of the UCS test after capillarity show a drop in mechanical resistance by 95% (a usual compressive strength of 1.4 MPa decreased to 0.07 MPa). Other samples dried after the capillarity test, shows restoration of strength by 80% of the original sample. This suggests that a cycle of wetting and drying might have effect on the mechanical performance of URE structure, and thus reduces the durability of URE building. In the future, experiments at wall scale of 0.20 m × 0.75 m × 1.5 m will be done as a continuation of this work. Thus, size effects on kinetic of capillary rise and evolution of moisture content could be highlighted. In future, further researches are welcomed to study the effect of several drying-wetting cycles on mechanical behaviour of URE.

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