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Experimental investigation on the compressive strength of cored and molded cement-stabilized rammed earth samples

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ABSTRACT

This research aims to improve the insufficient and inadequate quality control techniques currently available on cement-stabilized rammed earth construction sites. To achieve this goal, the comparison between the compressive strength of cored and molded cylindrical samples have been experimentally investigated. In order to gain a deeper understanding of the additional causes influencing the strength of rammed earth samples, investigations on specimen slenderness, size, shape and capping methods have been also conducted. This study shows that in certain cases the mechanical behavior of concrete and cement-stabilized rammed earth are similar. The obtained results also indicate that the strength of cored specimens is always lower than that of molded specimens. A list of recommendations for the assessment of cement-stabilized rammed earth strength is proposed.

1. Introduction

Rammed earth has recently experienced a renewed interest in Australia and in other parts of the world, driven by an increasing awareness in environmental issues and discussions on global warming. Researches around the world have acknowledged the sustainable benefits of earthen structures in general and rammed earth in particular [1–4]. Demand for rammed earth structures has predominantly risen in the last two decades in Western Australia and California (USA). To this regard, a remarkable research project recently funded by the State Government of Western Australia and the Australian Research Council is aiming to promote rammed earth as a sustainable and environmentally friendly solution [5] for the housing program in some Indigenous remote communities of the north of Western Australia.

Although rammed earth has been proven to be a sustainable construction procedure, the lack of rigorous and exhaustive engineering recommendations still represents one of the main obstacles for the use of this material. Especially in Australia, a proper code with specific guidelines does not exist. The two available handbooks, Bulletin 5 [6] and HB195 [7] address various earthen construction techniques and only contain vague recommendations specifically on rammed earth.

To make rammed earth a safer and better understood construction technique, this study aims to provide some recommendations to be used on site as Quality Control (QC) procedures. In particular, this paper investigates the assessment of the material compressive strength. It is a standard QC procedure to ram molded samples on site with the same soil mixture used in the structural members of the edifice. These specimens are then crushed in a laboratory and their strength regarded as the compressive strength of the structure being built. However, it is reasonable to suppose that the degree of confinement and hence the compaction of soil in a relatively small cylindrical mold is different from that of a bigger prismatic formwork of a structural element. This difference might significantly affect the strength of the final product. Is the compressive strength of the molded specimen realistically comparable to the strength of the wall?

This paper attempts to find an answer to this question. In the following section, the materials and methods used in this study are presented. Section 3 shows how the experimental setup is organized in two different phases: a series of preliminary tests on molded samples created in laboratory under rigorous procedures (Section 3.1) and an investigation on cored and molded samples obtained on two different construction sites (Section 3.2) using less rigorous but current standard construction practices. The results of the unconfined compressive strength tests are given in Section 4. Finally, Section 5 contains the main concluding remarks and recommendations of this study.

2. Materials and methods

Materials used in this study are those typically used by rammed earth builders in Perth, Western Australia. The soils used are made of crushed limestone with 13 mm and 19 mm nominal maximum aggregate size respectively and of a red, lateritic gravel mix with 19 mm nominal maximum aggregate size. The particle size

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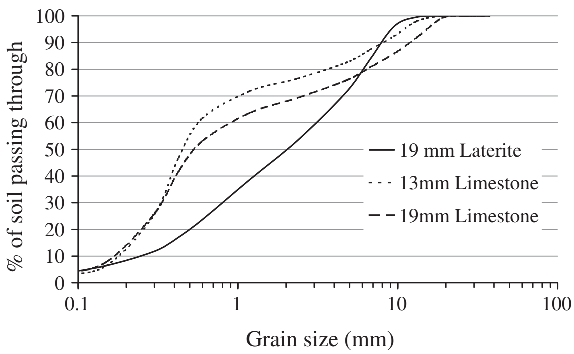

Fig. 1. Particle size distribution of the three soils used in this study.

distribution curves of the soils, found through sieve analysis conforming to AS1141.11.1 [8], are presented in Fig. 1. It is important to highlight that the crushed limestone has negligible or zero clay content. The laterite gravel might have trace of clay that unfortunately has not been calculated in this study.

Two batches have been used for the laboratory samples, made of 19 mm (batch 1) and 13 mm (batch 2) limestone respectively. Exactly 10% of cement by soil mass has been used in each batch. Using the Modified Proctor Compaction test according to the Australian Standards for soil testing [9], the Optimum Moisture Content (OMC), i.e., the amount of water needed to achieve the maximum dry density of the limestone + cement mix has been obtained: 9.15% for the 19 mm limestone and 8.85% for the 13 mm limestone. The samples have been rammed using a jackhammer and applying an equivalent compaction energy per volume used in the Modified Compaction test to achieve consistency in density and compaction effort for all samples.

The materials of the samples cored and molded in situ are rammed earth mixes of two real construction sites in Perth, named Bullcreek and Parkerville. The batches are made of 19 mm limestone (Bullcreek) and 19 mm laterite (Parkerville) soil respectively. The in situ samples have been obtained with a procedure less accurate than that used in the laboratory. Both batches have been stabilized with approximatively 10% (by soil mass) of cement. The term "approximatively" depends on the fact that on site the soil mass is roughly estimated by volume rather than by weight, due to the inconvenience of weighing on site. Furthermore, a water content similar but not exactly equal to the OMC has been added. This other approximation is due to the fact that, given the difficulties of measuring large mass proportions on site, water is generally added gradually by hosing, until the builder believes that the moisture is optimum. This is typically confirmed through arbitrary tests such as the "Drop Test" [7,10]. The panels from which the samples have been cored and the bigger in situ molded specimens have been rammed with a professional pneumatic hammer with a circular head of 150 mm diameter (in other parts of the world, size and shape of the ramming plate might be different). The smaller in situ molded samples have been rammed using a jackhammer with a smaller head.

All samples have been extracted from the molds after a couple of days. They have been wrapped in plastic sheets for a couple of days and then left to cure inside the laboratory in ambient conditions (dry conditions but not temperature controlled; the temperature ranged between 13 °C and 25 °C). All specimens and panels have been tested after at least 28 days of curing time. The samples were not oven dried.

3. Experimental program

As already mentioned in Section 1, the experimental program is divided into two parts. The first part consists of testing the unconfined compressive strength of molded samples obtained in laboratory under rigorous procedures. For the second part, the experiments are carried out on cored samples extracted from panels made on a construction site and molded samples produced on the same construction site.

Table 1
Summary of laboratory molded specimens. Type "C" stands for cylinder, "P" for prism. Batch 1 refers to 19 mm limestone + 10%cement, batch 2 to 13 mm limestone + 10%cement.

Effect investigated	Type	Size (mm)	Slender ratio	# Samples	Boundary conditions	Batch
Boundary conditions	C	100	2	4	Ground flat ends	1
	C	100	2	4	Plywood block	1
	C	100	2	4	Plaster capping	1
	C	100	0.75	3	Ground flat ends	1
Slenderness and shape effect	C	100	1	3	Ground flat ends	1
	C	100	1.25	3	Ground flat ends	1
	C	100	1.5	3	Ground flat ends	1
	C	100	1.75	3	Ground flat ends	1
	C	100	2	3	Ground flat ends	1
	C	100	0.75	3	Ground ends and Teflon sheet	1
	C	100	1	3	Ground ends and Teflon sheet	1
	C	100	1.25	3	Ground ends and Teflon sheet	1
	C	100	1.5	3	Ground ends and Teflon sheet	1
	C	100	1.75	3	Ground ends and Teflon sheet	1
	C	100	2	3	Ground ends and Teflon sheet	1
	P	100	0.75	3	Plaster cap	1
	P	100	1	3	Plaster cap	1
	P	100	1.25	3	Plaster cap	1
	P	100	1.5	3	Plaster cap	1
	P	100	1.75	3	Plaster cap	1
	P	100	2	3	Plaster cap	1
	P	100	0.75	3	Plaster cap and Teflon sheet	1
	P	100	1	3	Plaster cap and Teflon sheet	1
	P	100	1.25	3	Plaster cap and Teflon sheet	1
	P	100	1.5	3	Plaster cap and Teflon sheet	1
	P	100	1.75	3	Plaster cap and Teflon sheet	1
	P	100	2	3	Plaster cap and Teflon sheet	1
Size effect	C	50	2	3	Ground flat ends	1
	C	80	2	3	Ground flat ends	1
	C	100	2	3	Ground flat ends	1
	C	129	2	3	Ground flat ends	1
	C	150	2	3	Ground flat ends	1
	C	100	2	3	Ground flat ends	1
	C	50	2	3	Ground flat ends	2
	C	80	2	3	Ground flat ends	2
	C	100	2	3	Ground flat ends	2
	C	129	2	3	Ground flat ends	2
	C	150	2	3	Ground flat ends	2
	C	100	2	3	Ground flat ends	2