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Rammed earth construction with granitic residual soils: The case study of northern Portugal

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HIGHLIGHTS

- The strength of unstabilised rammed earth built with granite residual soils is low.
- Stabilization is required to build rammed earth with granite residual soils.
- The alkaline activation of fly ash was tested as stabilisation technique.
- The alkaline activation improves the strength and durability of rammed earth.

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ABSTRACT

Building in unstabilised rammed earth results in low environmental impact. However, northern Portugal has not historical tradition with this technique, and thus the suitability of the local granitic residual soils is unknown. This paper presents an experimental investigation, where this possibility is assessed. The results showed that these soils are unsuitable, and that rammed earth construction is only feasible if these soils go through a stabilising process. The alkaline activation of fly ash was investigated as an environmentally friendly stabilisation technique, and it proved to be capable of improving the performance of rammed earth.

1. Introduction

In 1982 the World's population living in a house built with raw earth was of about one third [1], whereas nowadays is estimated to be of about one fourth [2]. Despite that, building with earth continues to be a popular solution for sheltering and housing in many countries around the world, especially in developing countries. In developed countries this practice has fallen into disuse over the past century, as consequence of the technological development and extensive use of modern building materials (concrete and steel). Earthen materials are in general considered to be non-standard, since they are not produced according to industrialized processes [3]; in many cases these materials are produced on-site and their properties are extremely dependent on the characteristics of the available soil, which itself is a rather heterogeneous material. In addition, there are only few countries that have codes or standards for earth construction (e.g. New Zealand [4–6], Peru [7] and the USA [8]), which further discourages the option for this building solution where those are absent. However, the building industry has been recalling earth construction as a modern building solution due mostly to its recognized sustainability, low environmental impact, and good thermal and acoustic performance [9].

The earth construction concept includes several building techniques that have different constructive features, which depend mostly on cultural and social factors and on local limitations related with the characteristics of the available soils. In Portugal, there are present and widespread earth constructions erected according to three main building techniques: rammed earth ("*taipa*"), adobe and wattle-and-daub ("*tabique*"). Rammed earth, which consists in compacting moist soil by layers between a removable formwork to build monolithic walls, is found almost exclusively in southern Portugal. On the other hand, the traditional building stock of northern Portugal is mainly constituted by stone masonry dwellings, whose construction was supported by the great availability of this resource in the region. This type of

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construction has gradually been replaced, and nowadays the building industry is dominated by a solution consisting of a reinforced concrete framed structure with fired brick masonry infill and concrete slabs. According to Lourenço [10], the embodied energy of a 92 m^2 house built resorting to this solution is more than the double of that of a solution constituted by exterior rammed earth walls, interior adobe walls and timber roof. Therefore, adopting rammed earth as a building solution in northern Portugal would probably contribute to a more sustainable building industry. However, this technique is historically almost absent from the region, which raises the question about the suitability of the typical and abundant granitic residual soils (GRS) from northern Portugal for unstabilised rammed earth (URE) construction.

Stabilising the soil chemically (e.g. by addition of cement) is an option that may allow the GRS to be used in rammed earth construction if they are not adequate for URE. However, the embodied energy and cost of rammed earth construction would increase substantially [1,10], making this solution less competitive.

Having the aforementioned in mind, an experimental program that included the assessment of four representative soils from northern Portugal was carried out, regarding their suitability for URE. In addition and as a consequence of the results observed for each soil, an alternative stabilisation technique based on alkaline activation of fly ash is proposed. This technique aims, in first instance, at reducing the environmental impact of stabilised rammed earth (SRE), by incorporating an industrial waste material (fly ash).

2. Rammed earth construction in portugal

Rammed earth construction was extensively used in Portugal during the Islamic domination period (between 7th and 13th centuries), both to build military and civil constructions. The military constructions are mainly constituted by fortresses, which were firstly built between the 7th and 9th centuries. Currently, the castles of Silves and of Paderne, more than 800 years old, are live examples of such fortresses. The military rammed earth is in general stronger and more durable than civil rammed earth, since in general soil stabilised by addition of lime and natural pozzolans was frequently used in the first case [11]. On the other hand, the civil constructions were mainly built with URE, as lime is a resource that used to be too expensive and inaccessible for the majority of the population.

Until the 1950s, URE was the main building technique used in southern Portugal for sheltering, namely in Ribatejo, Alentejo and Algarve regions, which resulted in the geographical distribution of Fig. 1a [12]. Nowadays, this technique represents a very low percentage of new construction. Moreover, the few new rammed earth constructions are frequently built with SRE (by addition of cement or lime) and/or by embedding a reinforced concrete framed structure (Fig. 1b), which are procedures that aim at improving the structural behaviour, namely the seismic performance.

The traditional construction in northern Portugal is dominated by granite stone masonry. Regarding the earth construction techniques, the wattle-and-daub ("*tabique*") is the most common and was usually used to build partition walls of traditional stone masonry buildings [13]. Rammed earth constructions are almost absent from northern Portugal as there are only a few known cases reported in Viana do Castelo [12]. This absence can be explained by several factors, including: history and culture of the population, availability of stone, suitability of the soils for rammed earth construction, and climate and hazards of the region.

The fact that northern Portugal has not been under a real Islamic domination (unlike southern Portugal) may be pointed out as a reason to explain the absence of rammed earth from the region. Nevertheless, this technique is not strange to the northern neighbouring region of Galicia in Spain [14], which also has not been under Islamic domination.

The absence of rammed earth can also be explained by the great availability of granite and schist as building materials and by the unsuitability of the region's soils. The soils from northern Portugal are mainly saprolitic residual soils from granite rocks, which are weathered by high rainfall rates. In general, these soils are well graded in particle size distribution and have low plasticity indexes, and thus are usually classified as silty sands (SM) and clayey sands (SC). Mineralogically speaking, GRS are constituted mainly by silicates (in more than 65%). The main silicate minerals are quartz, which is very slowly affected by weathering processes, and feldspars, which are continuously transformed into kaolinite, and mica minerals [15]. However, and according to Correia and Merten [12], the rammed earth walls of dwellings from Alentejo built with soils resulting from the weathering of schist are those presenting better mechanical properties. These soils are commonly found in the region and present relatively high clay content and elongated-shaped coarse particles, which result in URE walls with good cohesion and improved interlocking. Moreover, the same authors [12] highlighted that rammed earth walls built using soils with high content of round shaped quartz particles show high tendency to disaggregate. Unfortunately, the GRS characteristics seem to fit within this last case, which means that rammed earth walls built with this type soil may show low strength and disaggregation problems. Furthermore, an URE wall built with a soil with such characteristics may have durability problems when facing the climate of northern Portugal, which is characterized by high annual rainfall rates [16].

The seismic hazard of northern Portugal combined with the generally accepted poor seismic performance of earth construc-

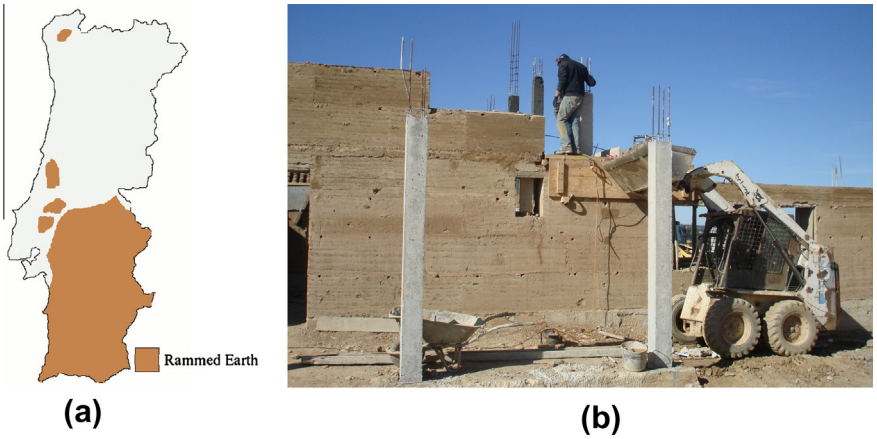

Fig. 1. Rammed earth construction in Portugal: (a) geographical distribution; (b) new rammed earth house with embedded concrete structure (Odemira, Portugal).