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Hydro-mechanical characterization of lime-treated and untreated marls used in a motorway embankment

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ABSTRACT

Some embankments on the A10 motorway, in Portugal, were built with marls. A lime treatment was prescribed for the material placed on the shoulders to protect it from the actions of the weather. This zoned profile design solution was a cheaper alternative to giving the embankment a full treatment.

Two major concerns emerged during the construction, which motivated the research presented in this paper. The first was the possibility of cracking induced by the different stiffness of the core and treated shoulders, thus providing access of rain water to the core material, which was exactly what the treatment intended to avoid. The second was the difficulty in estimating the amplitude of long-term deformations, which can be expected due to the evolving nature of the marls used.

The research program included the instrumentation of a selected embankment and laboratory tests on samples of treated and untreated compacted marls. The instrumentation allowed the measurement of vertical displacements and water content distribution to investigate if long-term displacements would be a concern during operation. The laboratory tests characterized the hydro-mechanical behavior of the material and its changes with the lime treatment. This research also stimulated discussion of some ideas about the expected performance of the embankment during its life cycle.

1. Introduction

Some embankments on the A10 motorway in Portugal were built with the marls from the region crossed by this motorway. Marls are evolving materials, i.e., their mechanical properties (stiffness and strength) degrade rapidly when they are exposed to the actions of the climate (wetting–drying cycles). Even when compacted, if wetted and under stress, the marl fragments can break or lose their stiffness (Cardoso, 2009). This physical degradation mechanism may be responsible for long-term deformations of the structure.

The characteristics described justify why marls cannot be considered as traditional materials when used to build embankments. A lime treatment has been prescribed to minimize the effect of this problematic behavior to make possible the marls to be used, which was intended due to economical and environmental reasons. As a matter of fact, it is a common design provision adopted in embankments where materials sensitive to water are employed (Oakland and Lovell, 1983; Miscevic et al., 1998; Guerpillon and Virolet, 2006, among others). However, for this particular case, the treatment would triple the construction costs and, for this reason, it was applied only to the material placed at the shoulders as they are more exposed to the actions of the climate.

Two major concerns emerged during the construction of the embankments. The first was the possibility of cracking induced by the different stiffness of the core and shoulders. These cracks provide access of rain water to the core material, which was exactly what the treatment intended to avoid. The second was the difficulty in quantifying the long-term deformations, where the evolving nature of the marl fragments could play a significant role. Large settlements during the operational period are not unusual in embankments made of evolving materials (as is the case of hard cemented soils, shales, mudstones, claystones, marls, calcarenites and weak limestones) (USTR, 1980, for example).

It is worth mentioning that, when long-term performance is being investigated, the effect of the lime curing period on the properties of the treated material must be evaluated. Over time, at least in the first years, the differential stiffness of the zoned profile can change and may affect the long-term behavior of the embankment.

The concerns mentioned above motivated the research presented in this paper. The investigation started by monitoring a selected embankment in order to measure vertical displacements and the evolution of the water content distribution in depth. It was possible to install the instruments during the construction of one of the A10 embankments built with marls. Data on the evolution of vertical displacements provide information on the long-term displacements and their rate. The evolution of water content provides information on

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suction changes. The combined interpretation of the displacements and suction changes improves the interpretation of the observed deformations.

In parallel with the construction, an extensive set of laboratory tests was performed on marl samples with and without treatment to characterize their unsaturated hydro-mechanical behavior. It should be noted that this information was missing at the design stage. In fact, concepts of unsaturated soil mechanics are necessary to define the experimental plan because wetting and drying cycles (suction changes) are the main causes of changes of the hydro-mechanical properties of the marls. The main results of the research are presented in this paper. Their interpretation may clarify the concerns pointed out above, as well as to learn some lessons regarding the use of lime treatment for this type of geomaterial when employed in road embankments.

Finally, only a few cases of embankments built with evolving materials are described in the literature and reference has to be made to embankments where shales have been used (Oakland and Lovell, 1983; Wu et al., 1993). The study presented in this paper intends to contribute to a better knowledge of the behavior of these problematic materials in road embankments.

2. The embankment

The construction of the selected embankment on the A10 Motorway started at the end of April 2005 and finished at the end of July of the same year. Existing in situ measurements cover the period until October 2008. A simplified cross-section is presented in Fig. 1. The embankment has been built on a slope and is relatively high (close to 10 m at the pavement axis). As mentioned above, the treatment was applied to the shoulders (thickness 3 m and 5 m). Drainage systems were included in the surface and in the contact between the embankment and the foundation rock to minimize water access to the untreated core.

Design specifications were focused on preventing the occurrence of swelling/collapse deformations due to suction changes, phenomena that could be exacerbated by the evolving nature of the employed marls. Besides the treatment, in which the percentage of added lime was 3.5% in dry mass, the designers adopted special procedures during the construction to ensure a good fragmentation of the large rock blocks (Cenorgeo, 2002). Placement with a vibrating sheepsfoot roller reduced their dimensions (high specific compaction energy). A minimum of 95% of relative compaction was also established (the compaction curve and interval are later presented in Fig. 5). High compaction energy is usual in road embankments but it can contribute to a higher swelling potential when marly materials are employed. In order to prevent this effect, compaction was carried out on the wet side of optimum (water content between the optimum value, $w_{opt,}$ and this value plus 2%) instead of being carried out on the dry side as is the current practice. This wetting process was prescribed to accelerate the physical degradation of the marl fragments during the construction because smaller fragments are less prone to break (Cardoso and Alonso, 2007). For this reason, future settlements that could affect the serviceability of the structure would be reduced. Strong breakage was achieved, as shown in the grade size distribution curves presented in Fig. 2.

3. Instrumentation

Extensiometers for measuring vertical displacements and sensors for measuring water content were installed during the construction. The data collected concerns this period and the 3 years after (the

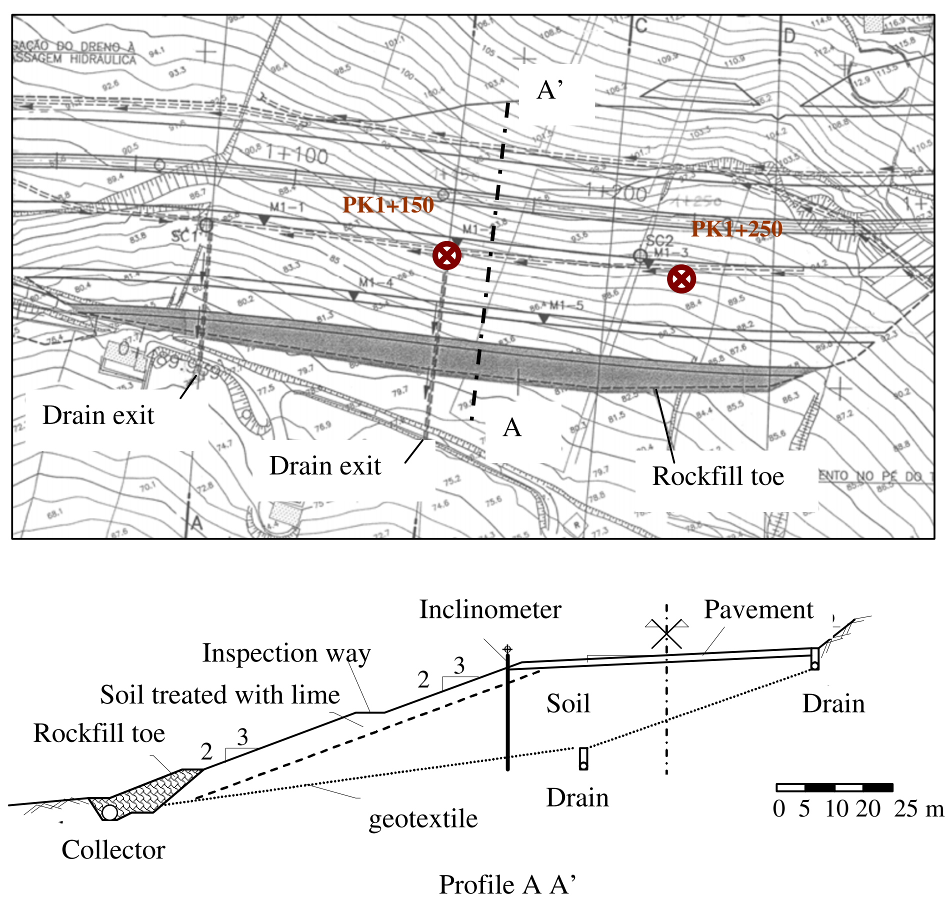

Fig. 1. Plan of the selected embankment and schematic vertical profile AA'. The cross marks the location of the two instrumented cross-sections.