Influence of Wetting after Compacting in the Behaviour of the Embankment from A10 Highway (BRISA)

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Abstract: The study presented in this work consists on settlement analysis of road embankments along the construction and in service. A case study was analysed inspired in the embankment AT1 from A10 Highway (Arruda dos Vinhos / Carregado), built with marls and marls treated with lime. It consists on a special case because the marls used for its construction are evolutive materials, therefore known for the degradation of their hydro-mechanical characteristics in time and also for presenting some expansive potential. Weather conditions are the main causes of marl degradation, being wetting-drying cycles the most important ones. A numerical model was done where the construction of the embankment was simulated to analyze the effects of the stiffness introduced by the marl treatment with lime. Wetting due to rain along exploration was also simulated to analyze the occurrence of possible deformations due to expansive phenomena. Code Bright was the numerical code used for calculation because it allowed a hydro-mechanical coupled analysis to include the deformations induced by wetting (suction variations). Model calibration was done with data from laboratorial tests performed at Instituto Superior Técnico (oedometric tests, measurement of the permeability coefficient, compression tests and unconfined triaxial tests). The main conclusion of the study, also corroborated by the data from the laboratorial tests, is that the marl treatment with lime may not be justified because the marls show a low expansible potential and the computed deformations were not relevant.

1 Introduction

The main purpose of this work was to analyze eventual effects of wetting on the settlements of the embankment AT1 from A10 Highway (Arruda dos Vinhos / Carregado) (Figure 1). This embankment has the particularity of being built with marls and marls treated with lime. In the supposition that the marls would be strongly expansive, the design project of the embankment predicted the treatment of the marls with lime in the area of the backs, trying to reduce its expansible potential. From the Design aspects, this study was focus on the analysis of the functionality of the structure and not on its stability.

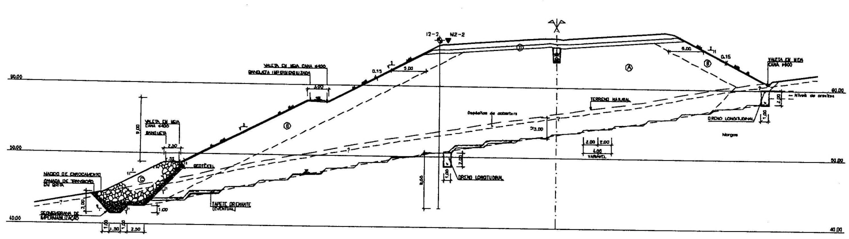

Figure 1 – Design project of AT1 embankment (Cenorgeo, 2002)

2 Compressibility, resistance and expansibility

Besides the expansibility of the material, it was necessary to understand other two factors such as the resistance and the compressibility because they are the main aspects to consider in the design of embankments built with fine soils. In chapter 2 (Lynce, 2007) it was analyzed these three concepts and the way that the constructive process can influence them. Once dealing with compacted materials, therefore unsaturated, it was also necessary to consider concepts of Unsaturated Soils Mechanics. The main conclusions of this analysis are presented as follows:

a) Expansibility

- According to Lawton et al (1989), mentioned by Alonso (2004), the expansibility of a soil depends on the side of the compactation curve on which it was compacted, presenting larger variations if compacted on the dry side. This behavior is justified for the existence of pores with great dimension. According to Alonso (2004), the pores of great dimension are related with the occurrence of volumetric instability by compression or collapse;

- According to Alonso et al (1990), and in agreement with Barcelona Basic Model (known by BBM), the expansibility of a no saturated moderately expansible soil depends on the trajectory of the tension in the planes (p,s) and (p,v) corresponding to the applied loading (tension / suction variation). This way, a compacted fine soil can suffer swelling or collapse according to its stress state in the moment when occurs the;

- Besides these factors, the expansibility also depends on the minerals present in the soil, especially if it shows the presence of expansive clayey minerals in high mass percentage.

b) Compressibility and Resistance

- As the water percentage (w) decreases, the compressibility decreases and the resistance increases. Such is due to the structure of the soil resulting from the compacting process;

- An increase of the compacting energy favors the parallelism of the particles, increasing the dry volumetric weight, contributing then to a decrease in the compressibility and an increase in the resistance;

- It is of general knowledge that a no saturated soil presents more rigidity than a saturated soil, so it presents less compressibility in elastoplastic regime than the same saturated soil. According to BBM, it is admitted that, in the elastic regime, both soils have identical compressibility;

- A soil more over-consolidated presents lower compressibility than a soil less over-consolidated because it presents a larger trajectory in elastic regime.

It was concluded that the compacting process affects not only the mechanical behavior (compressibility and resistance) of a fine soil, but also its expansive behavior when subject to drying / wetting processes.

3 Experimental results

In chapter 3 (Lynce, 2007), and with data from experimental results obtained by several authors with marls used in the embankment under study (Maranha das Neves and Cardoso, 2006, Cardoso et al. 2008 and Oliveira, 2006), it was concluded that the marls characteristics (such as the mineralogy, for instance) allowed to predict some swelling potential, however lesser than the one that was initially foreseen.

In chapter 4 (Lynce, 2007), it was characterized the hydro-mechanical behaviour of the marls through oedometric and triaxial tests performed in the work presented. This chapter also presents the results obtained in similar tests of samples of marl treated with lime performed by Godinho (2007). Figure 2 presents the Mohr-Coulomb envelope obtained in the triaxial tests performed in marl samples compacted according to construction conditions.

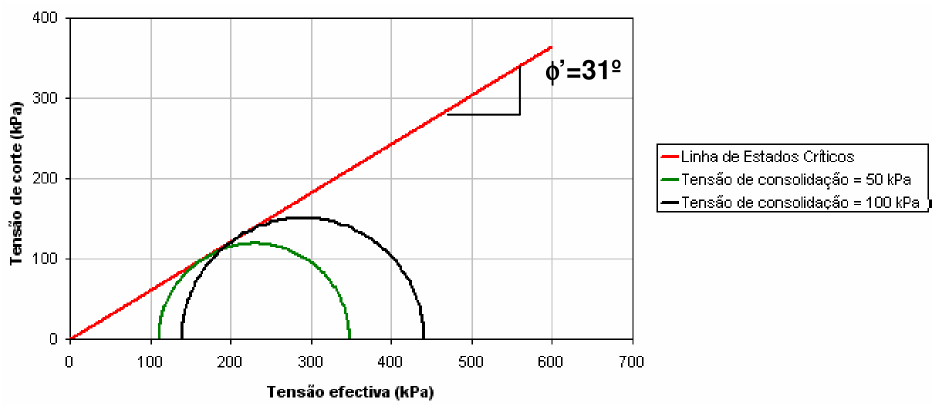

Figure 2 - Mohr –Coulomb envelope obtained in the triaxial tests of marl

The confirmation of the weak swelling potential of the marls was carried out also in chapter 4 (Lynce, 2007), after the analysis of oedometric tests with wetting under different vertical stresses that allowed to characterize its swelling potential, as well as its compressibility for different suctions. It was achieved that, in spite of the marls treated with lime have better hydro-mechanical behaviour (less swelling behaviour, lower compressibility, higher shear strength, etc.), the improvement concerning the swelling behaviour due to the lime treatment was not very important since the marl without treatment had shown also small swelling potential.

4 Numeric results

The characteristics of the materials obtained experimentally and collected in the mentioned bibliography, were used in the numerical model of the embankment from A10 Highway, presented in chapter 5 (Lynce, 2007). The numerical code Code Bright (Olivella et al., 1996) was used in the analysis, which allows the coupled hydro-mechanical analysis of geotechnical structures, assuming that the soil is porous, deformable and not saturated.

The model does not include the drainage systems that exist in the real embankment, allowing a conservative approach on the settlements calculation due to wetting. In fact, it can be admitted that the numeric model corresponds to the case when these systems are not in operation.

There were analyzed not only the deformations due to wetting (main objective of the work) but also the stresses (tensile stresses) in the body of the embankment for the purpose of identification of possible crack opening. Besides that, the displacements during construction were also calculated to understand the influence, in the behaviour of the embankment, of the different stiffness of the marls and the marls treated lime. The analysis allowed the following conclusions:

a) Analysis of the tensile stresses in the embankment

It was analyzed the tensile stresses in the embankment at the end of construction (figure 3) to identify the possible appearance of tensile stress because these can indicate crack occurrence that could turn into preferential trails for water entrance inside the embankment, which could led to swelling or collapse deformations. The development of this type of deformation was intended to be avoided with the lime treatment, therefore the cracking occurrence would questioning the adequacy of the treatment in this case study.

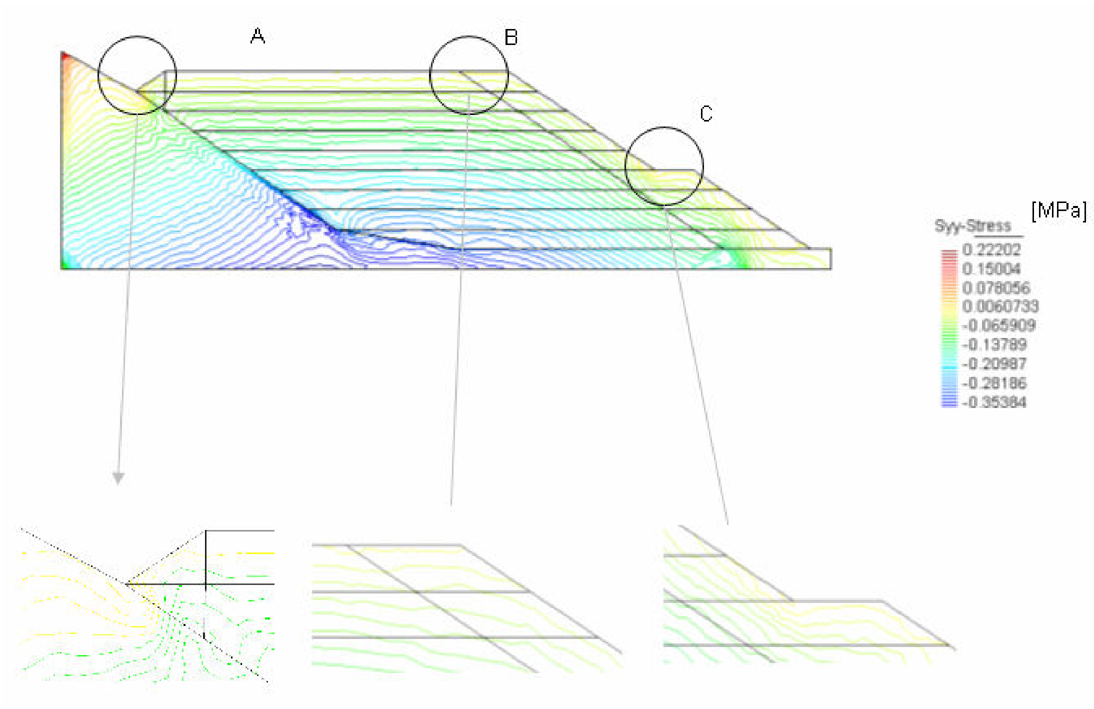

Figure 3 - Map of the tensile stresses calculated, enhancing the areas with the larger values found.

From the analysis it was verified tensile stresses in the junction between marls and marls treated with lime, in the re-entrance of the bench with the slope, and in the connection of the embankment with its foundation. It is possible that in the three cases detected there will not be severe consequences for the functionality of the embankment due to the following reasons:

- In the junction between the soil and the soil treated with lime, the tensile stress obtained was very small (5 kPa) and it should not lead to crack opening. On the other hand, this area is covered with a bituminous pavement and this material has waterproofing function in those problematic points;

- In the re-entrance of the hassock with the slope the traction tension is irrelevant (9 kPa), but in the connection of the embankment with the foundation (27 kPa) the traction tension is significant. Drainage solutions were introduced in these two places (a half-cane ditch was put in concrete and draining ditches were executed with geotextil). However these devices are mainly drainage systems and not waterproofing, therefore it is not ensured that they can eliminate the inconveniences related with cracking.

b) Displacements after wetting

Finally, the displacements caused by the wetting of the slopes were calculated. The largest displacements, vertical and horizontal, were almost zero. Considering the previous analyzes concerning the swelling potential of the materials, this result was expected.

The previous observations allowed concluding that the solution presented for the embankment AT1 of the A10 Highway (Arruda dos Vinhos / Carregado), can limit the deformations in service in a significant way. However, data from the swelling tests performed allowed to understand that the marl treatment with lime only to reduce its swelling potential would be dispensable.

5 Future developments

The evolution of the mechanical characteristics of the compacted marls subject to drying-wetting cycles was not considered in this work. A more rigorous prediction of the settlements in time should consider that evolution, however such analysis requests more complex constitutive models than those used in this work. To the present time it is ignored the existence of appropriate models to simulate the behaviour of compacted marls. The inclusion of these concepts would increase the possibilities of settlement prediction of the embankment during a longer life period, which is an important aspect in what it concern its functionality.

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