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# Execution and quality control applied on the construction of soil-cement embankments

## Exécution et contrôle qualité appliqués à la construction de remblais sol-ciment

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**ABSTRACT**: The use of cement in the treatment and stabilization of soils *in situ*, using high-power equipment, allows the optimization of the existing natural resources from the sites, resulting in less expensive suitable technical solutions. Given the performance of these new technologies, it becomes necessary to have innovative methods for quality control of built-up layers in addition to the traditional laboratory tests, which are performed on site laboratories, in order to ensure the binomial deadline-quality of the construction in effective terms. This paper presents both the solution adopted in the design phase and the methodology applied in the Quality Control during the construction of large embankments (with a maximum height of approximately 70 m) on the stretches of the motorway A4 that access to the Marão tunnel, in the North of Portugal. This solution made it possible to incorporate an important volume of materials obtained from the excavation works of the line and the tunnel, and to optimize surface occupation, due to the fact of being possible to adopt steeper slopes with the cement treatment of the embankment. The solution adopted in the construction of these embankments is deemed sustainable since it maximises the usage of local resources (excavation volumes) and is better integrated in the natural landscape.

**RÉSUMÉ**: L'utilisation du ciment dans le traitement et la stabilisation des sols in situ, à l'aide d'équipements de forte puissance, permet d'optimiser les ressources naturelles existantes des sites, aboutissant à des solutions techniques adaptées à des conditions financières avantageuses. Compte tenu des performances de ces nouvelles technologies, il devient nécessaire de disposer de méthodes innovantes de contrôle qualité des couches bâties en plus des essais traditionnels en laboratoire, qui sont effectués dans les laboratoires de chantier, afin d'assurer le binôme délai-qualité de la construction en termes efficaces. Cette communication présentera la solution adoptée dans la conception et la méthodologie utilisée dans la perspective du contrôle de qualité pour la mise en œuvre de grands remblais, d'une hauteur maximale d'environ 70 m, sur les tronçons de l'autoroute A4 qui accède au tunnel du Marão, au Nord du Portugal. L'adoption de cette solution a permis d'incorporer un volume important de matériaux provenant des excavations de la ligne et du tunnel, en maintenant une occupation raisonnable du terrain grâce à la possibilité d'adopter de fortes pentes dans le remblai, constituant ainsi une solution durable compte tenu de la rentabilité des ressources locales et intégrées dans le paysage.

**Keywords:** Embankments; soil-cement; road works; soil stabilization.

## 1 INTRODUCTION

In this article it is presented the solution adopted in the design and construction of the large embankments (with a maximum height of approximately 70 m) located in the stretches of the A4 motorway that approach the Marão tunnel, in the North of Portugal.

This solution, based on the use of cement in the treatment and stabilization of the embankments, was developed for the construction of the embankments that approach the East and West portals of the Marão Tunnel. It was applied in 4 places, having been designated as walls M14, M24, M40A and M41. The solution consisted in executing reinforced backslopes with soil-cement (with a cement rate of approximately 4%) with a slope of a 1:1 (V:H) and benches at every 15 m in height. The maximum heigh obtained for these embankments was 69 m.

The adoption of this solution made it possible to incorporate an important volume of materials obtained from the excavation works of the line and the tunnel while allowing a lower surface occupation due to being possible to adopt steeper slopes in the embankment face. The maximisation of the reusage of local resources (excavated volumes) and the better integration in the natural landscape makes it a sustainable solution.

Figure 1 shows a photograph with an overview of the M24 reinforced embankment after the completion of the works, highlighting its good landscape integration.

*Figure 1. General view of the M24 embankment, reinforced with soil-cement.*

This case study also intends to present a synthesis of the methodology used in the perspective of Quality Control, which was defined in the design phase and implemented during the construction stage.

## 2 GEOLOGICAL SETTING

The A4 motorway is mainly located in eruptive terrains of a granitic nature and metamorphic terrains that are essentially schist. The first occurs from between the beginning of the motorway up to about km 12, where the embankments concerned on this paper are located. Metamorphic terrains are predominant in the remaining motorway length. Both eruptive and metamorphic terrains can provide sub-rocky embankment materials (soils rich in rock fragments/blocks), suitable for the construction of embankments.

The granites are interwoven by multiple joint families and posess thick layers of residual soils which are derived from a deep weathering of the rock.

From a geotechnical point of view, and according to the nomenclature of the International Society for Rock Mechanics (ISRM), schists are moderately weathered (W3), and intensely fractured (F4-5).

## 3 DESIGN SOLUTION

The design solution was developed for the construction of the embankments that approach the East and West portals of the Marão Tunnel. The solution was applied in 4 sites, designated as walls M14, M24, M40A and M41. In general, the solution included the execution of embankments with 1:1 (V:H) slopes, presenting along its development 1 to 5 embankment slopes separated by 3 m wide benches and at every 15 m of heigth. For slope stabilization, a mixture of soil-cement with a cement rate of approximately 4% was employed.

Figure 2 shows a typical section of the solution adopted.

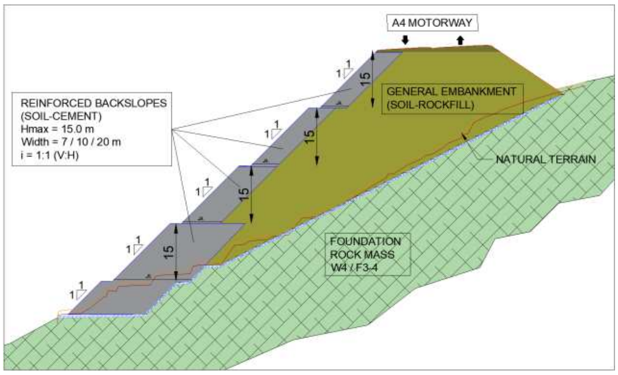


*Figure 2. Typical section of the solution.*

Table 1 shows the main characteristics of each of the embankments considered in the present case study.

*Table 1. General characteristics of the executed soil-cement embankments.*

| General Characteristics | Embankment | | | |
|---|---|---|---|---|
| | **M14** | **M24** | **M40** | **M41A** |
| Length (m) | 558 | 413 | 304 | 336 |
| Max. height (m) | 69 | 55 | 24 | 52 |
| Nº of benches | 4 | 3 | 0 | 2 |
| Max. Side slope width (m) | 20 | 16 | 7 | 10 |
| Soil-cement volume (m3) | 175.000 | 125.000 | 30.000 | 85.000 |
| Embankment volume (m3) | 510.000 | 175.000 | 20.000 | 210.000 |

Regarding the embankment foundation, a 1m deep over-excavation of the natural terrain was required in order to obtain good support conditions (W4 rock or better) throughout the embankment area.

It was considered the need to reinforce the backslope foundation whenever, after over-excavation, W4 and F3-4 rock mass (or better) was not detected. This reinforcement consists of over-excavation of about 2 m in the width of the backslope and later filling with cyclopean concrete and / or a concrete slab with two vertical nailing alignments.

# 4 CONSTRUCTIVE ASPECTS

## 4.1 Materials

The characteristics of the embankment materials, mainly soil-rockfill mixtures derived from schists and granites, should comply with the requirements of the Design's Technical Specifications. Additionally it was defined that the values presented in Table 2 must be achieved after the compaction of treated and untreated embankments.

*Table 2. General characteristics of soil-cement embankments.*

| Parameters | Embankment | |
|---|---|---|
| | **Soil-rockfill** | **Soil-cement** |
| Friction angle (°) | 36 | 38 |
| Specific weight (kN/m$^3$) | 20 – 22 | 20 – 22 |
| Cohesion (kPa) | 5 | 200 |
| Passing the #200 sieve (ASTM) (%) | < 25 | < 25 |
| Max. Diameter (m) | 0.25 | 0.25 |
| Uniaxial compressive strength (MPa) | N/A | 1.0 (7d) 2.0 (28d) |
| Diametral compressive strength (MPa) | N/A | 0.25 (28d) |
| Deformation modulus (MPa) | N/A | 2000 (28d) |

The control of these parameters was carried out during the quality control process defined for the construction phase, using laboratory and *in situ* tests.

# 5 QUALITY CONTROL

Special attention was given to the definition of the quality control for the execution of embankments right from the design phase (with a large emphasis on the reinforced zones). Thus, the 2 main phases to ensure proper execution of the design solution were identified in the Design phase:

- Study Phase;
- Construction Phase.

The studies, methodologies and tests to be carried out in order to guarantee the strength parameters that guarantee the stability and safety of the structure were defined in the Design phase.

## 5.1 Study phase

During the study phase, in order to define the mixture of cement soil to be applied on site, as well as its application technique, the following methodology was adopted (*Figure 3*).

### 5.1.1 Mixing study

Before commencing work, a laboratory study was carried out to formulate the mixture to be applied *in situ*.

This study, which should contain at least 3 different cement dosages, presented:

- Grain size distribution curve of the material resulting from the action of the "recycler";
- Cement content and its characteristics;
- Water content, which should be optimized in order to ensure maximum mechanical resistance;
- Results of the modified Proctor test on the "soil (aggregate) / cement" mixture;
- Proctor density corresponding to the water content of the installation;
- Results of strength tests on moulded test specimens with a degree of compaction of 98%, referring to the modified Proctor test;
- Simple and diametral compression tests at 7 and 28 days (or 90 days for CEM II);
- Workability period.

The study of the mixture was carried out, considering specimens composed by schist and granitic materials, with 3 different dosages of cement. The different mixtures were then subjected to simple and diametral compression tests at 7, 28 and 90 days, in order to assess whether the values obtained were in line with the design reference values.

The results showed that, in general, the use of materials of a schist-grade nature, made it possible to meet the established requirements, even for a 3% cement dosage.

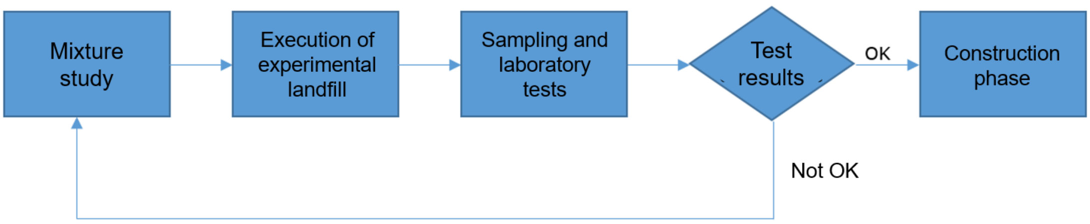


*Figure 3. Methodology to be applied in the Study Phase to define the mixture.*

In contrast, with the use of materials of a granitic nature, the minimum strength values defined were only achieved with a minimum cement dosage of 4%.

#### 5.1.2 Experimental embankment

After the study of the mixture, the phase of experimental embankment construction began, which allowed the design and study assumptions to be confirmed. It was particularly important to evaluate the obtained strength for the percentage of cement added and its temporal evolution, particularly in the early days.

The results obtained in samples from the experimental embankment tests confirmed the values obtained in the study of the mixture.

It was defined that the soil-cement mixture should contain a minimum cement rate of 4%, in order to obtain the desired resistance parameters, namely when the reinforced embankment is being carried out using materials of a granitic nature.

### 5.2 Construction phase

#### 5.2.1 In situ and laboratory tests

After the study and definition of the soil-cement mixture to be used, the construction of the reinforced embankments begins according to the assumptions defined during the study phase.

During the construction phase, the quality control carried out was based on the comparison between laboratory tests and on-site tests, when possible.

Thus, in addition to the tests that are usually caried out in order to ensure that the embankment is properly built, the following tests were carried out to validate the design parameters:

- Uniaxial compressive strength – Obtained by testing samples in a hydraulic press, in laboratory;
- Diametral compressive strength - Obtained by testing samples in a hydraulic press, in laboratory;
- Deformation modulus – Evaluated *in situ* with a portable impact deflectometer - PRIMA 100.

It is important to mention that, during the construction phase, it was essential to adjust the time necessary for carrying out the tests and obtaining the respective results to the production needs and on-site efficiency.

In order to solve this issue, it was defined that the laboratory tests to be carried out, namely for the evaluation of simple and diametral compressive strength, would be performed at young ages (≤ 7 days). Then, through the calibration obtained during the study phase, it was possible to carry out the projection of the results for the most advanced ages (28 and 90 days).

#### 5.2.2 Monitoring

In addition to the Quality Control works, the monitoring with geotechnical instrumentation (topographic marks / targets and inclinometers) allowed to evaluate in real time the response of the embankment, by controlling its deformations at the surface and in depth.

Throughout the construction work, and after its completion, the instrumentation showed a good behaviour of the embankments.

## 6 CONCLUSIONS

The solution developed for the stabilization of the M14, M24, M40 and M41A embankments, located in the stretches of the A4 motorway that approach the east and west portals of the Marão tunnel, allowed to incorporate an important volume of materials obtained from the excavation works. The use of reinforced backslopes in soil-cement allowed steeper slopes, which reduced surface occupation.

The combination of these two important initial premises resulted in the development of this innovative technique, allowing the execution of large embankments, both in height and in length. Thus, it was possible to make the best use of local resources and achieve a better landscape integration, resulting in an economically and environmentally sustainable solution.

The quality control of the construction works was, in our understanding, the main condition for the success of the Project's execution. The proposed methodologies guaranteed not only the quality of execution and consequent stability of the embankment but also the fulfillment of the established deadlines, especially since it is an innovative solution and, therefore, on which there was little experience and knowledge.

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