CONTRIBUTION TO THE CONSTRUCTION METHOD OF REINFORCED SOILS WITH GEOSYNTHETIC FIBRES

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Abstract: The optimal mixture of soil and small size reinforcing elements randomly oriented constitutes a three-dimensional soil reinforcing system, and is usually designated by Microreinforced Soil. A review of the literature revealed that only a relatively few full-scale experiments on microreinforced soils were reported, which seems to fully justify the subject of this paper.

The Microreinforced Soil with geosynthetic fibres, namely randomly oriented short polypropylene fibres of small diameters (diameters lower than 0.05mm), showed to be a very promising soil reinforcement technique to improve the shear strength and bearing capacity of soils with no reduction in its permeability, although its potential applications are presently not properly explored. It is necessary to understand the general behaviour of this composite material to adequately support its applications. In this context, a contribution for the improvement of the construction method of microreinforced soils was made, based on the first hand experience taken during the construction of a full-scale experiment.

This paper is part of a joint research project to study the behaviour of microreinforced soils under static and dynamic loads. A full scale trial embankment was constructed in the University of Beira Interior campus, using a representative soil of the region reinforced with short polypropylene fibres. The trial embankment is 50m long, 10m wide and 0.6m high. It is composed of five test sections, each one 10m long, either unreinforced or fibre reinforced with different characteristics, in order to conduct comparative behaviour studies. The construction technique and quality control of the trial embankment, with special consideration on mixing technique, is described. Up to now, a good behaviour of the trial embankment left under natural weather conditions has been observed, in particularly during very hard rains that have been occurred.

Keywords: Construction, embankment, fibre reinforced soil, polypropylene, full-scale test, field observations.

INTRODUCTION

The optimal mixture of soil with small size reinforcing elements randomly oriented constitutes a three-dimensional soil reinforcing system, and is usually designated by Microreinforced Soil (Pinto 2000).

A review of the literature revealed that only a relatively few full-scale experiments on microreinforced soils were reported (Andrawes *et al.* 1986, Lindh and Eriksson 1990, Foose *et al.* 1996, Gregory and Chill 1998, Casagrande *et al.* 2002, Tingle *et al.* 2002), including the use of monofilament fibre type of very small diameter, which seems to fully justify the subject of this paper.

The Microreinforced Soil with geosynthetic fibres, namely randomly oriented short polypropylene fibres of small diameters (diameters lower than 0.05mm), showed to be a very promising soil reinforcement technique to improve the shear strength and bearing capacity of soils with no reduction in its permeability (Pinto and Falorca 2005), although its potential applications are presently not properly explored. However, it is necessary to understand the general behaviour of this composite material to adequately support the potential applications. In this context, a contribution for the improvement of knowledge about the construction technique with microreinforced soils was made. This was based on the first hand experience taken during the construction of a full-scale experiment briefly described herein. The main objective of this paper is to describe the field experimental work, namely the construction technique and quality control of the embankment layers of the trial embankment, with special consideration on the soil fibres mixing technique.

FULL-SCALE EXPERIMENT DESCRIPTION

Site location

A number of possible locations for the full-scale experiment offered by the University were studied and ranked, based on some conditioning factors to the project: easy access for the heavy construction machines, security during both construction and field test stages, proximity of a relatively homogeneous soil mass for extraction and use in the embankment construction, distance from the site to the Geotechnical laboratory of the Department of Civil Engineering and other minor aspects. The site was finally selected and it is located in the campus of the University. Figure 1 shows the location plan of the experimental site.

Geotechnical characterization

The published geology map of Portugal (1:50 000 scale), shows for the experimental site a geological unit designated by granite, recognized as Covilhã granite. Typical Covilhã granite formation is a chalk-alkaline rock, coarse grained with mega-crystals of feldspars and two micas.

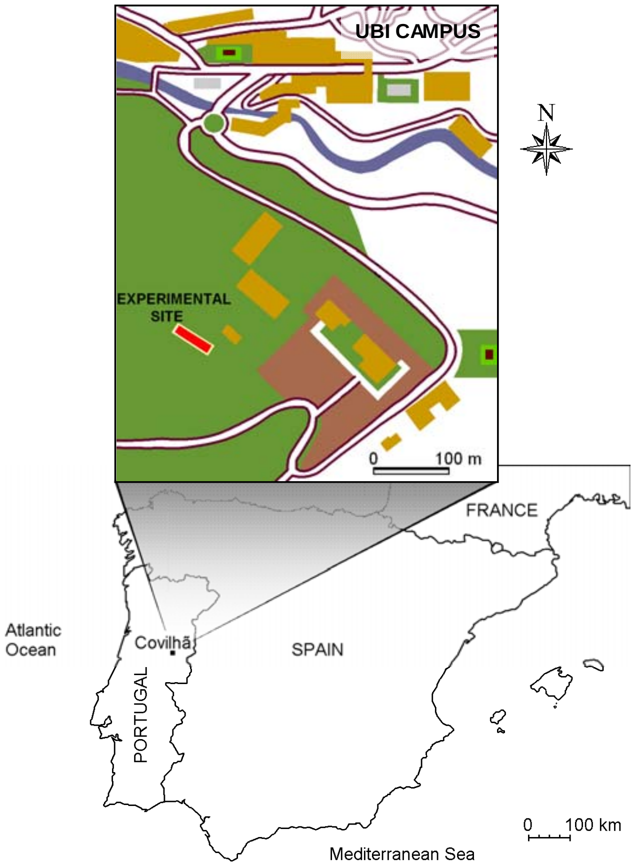

Figure 1. Location plan of the experimental site

The ground investigation stage comprised the application of several geotechnical and geophysical surface and borehole techniques, namely SPT, surface seismic and electrical resistivity, together with associated traditional laboratory tests. The geological-geotechnical model for the area under study is summarized in Figure 2.

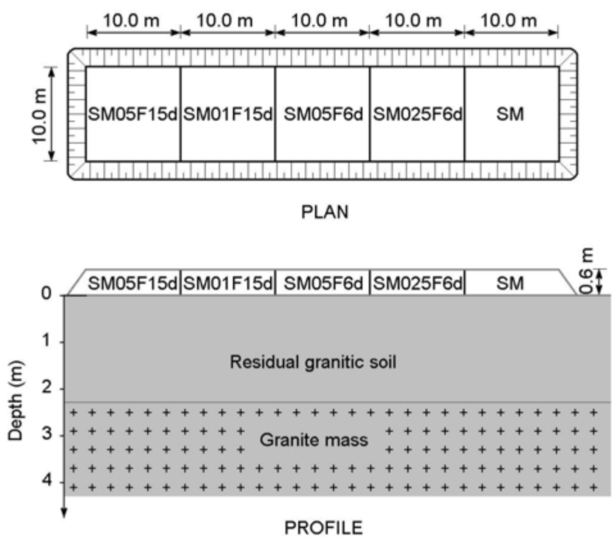

Figure 2. Plan and longitudinal view of the trial embankment

The geotechnical profile consists of a residual (saprolitic) granite soil layer overlying a granite mass. The hard stratum is located quite near the ground surface. The granite soil is a well graded sand with gravel and silt, of low plasticity, and can be classified as silty sand according to Unified Soil Classification System (ASTM D 2487-85). The main properties of the soil are summarized in Table 1. The groundwater level was found to be deeper than the investigated depth. As the data acquisition took place in May (end of rainy season), it is not expected interference between groundwater and embankment behaviour.

Full-scale trial embankment conception

The profile and plan of the trial embankment sections, including the identification of the selected mixtures, are also showed in Figure 2. All the full-scale experiment was designed to validate the laboratory behaviour of the fibre reinforced soil under static and dynamic loads and to obtain information concerning construction techniques, namely the development of an efficient technique for a homogeneous mixture of the fibres with the soil. Each of the 5 sections of the embankment is 0.6 m thick, 10.0 m wide and 10.0 m long. These dimensions were chosen because they are the minimum dimensions required to perform dynamic impact tests and plate loading tests.

Table 1. Soil properties

Property	SM
Natural dry unit weight, γ_d (kN/m^3)	14 - 20.5
Specific gravity, G_s (-)	2.66
Percent finer than #200 sieve (%)	18
Effective diameter, D_{10} (mm)	0.02
Mean grain size, D_{50} (mm)	0.75
Coefficient of uniformity, C_u (-)	60
Coefficient of curvature, C_c (-)	2.6
Liquid limit, w_L (%)	39
Plasticity index, I_P (%)	10
Maximum dry unit weight, $\gamma_{d,\ máx}$ (kN/m^3)	19.3
Minimum dry unit weight, $\gamma_{d,\ min}$ (kN/m^3)	13.7
Soil friction angle, ϕ' (º)	41
Cohesion, c' (kN/m^2)	12

The detailed description and respective nomenclature used to identify the selected mixtures of the different sections are presented in Table 2. As an example, for SM025F6d: SM stands for soil group classification, 025F for the fibre percentage (0.25% by dry weight of soil), and 6d for the fibre diameter that corresponds to 6 denier.

Table 2. Embankment sections identification

Description	Nomenclature
Unreinforced silty sand soil	SM
Soil mixed with 0.25% of fibres with 6 denier	SM025F6d
Soil mixed with 0.5% of fibres with 6 denier	SM05F6d
Soil mixed with 0.1% of fibres with 15 denier	SM01F15d
Soil mixed with 0.5% of fibres with 15 denier	SM05F15d

The fibres were supplied by a local manufacturer of nonwovens geotextiles in nominal lengths of 75 mm with round cross section and smooth surface. These fibres were studied at different diameters (6 and 15 denier, corresponding to diameters of 0.031 and 0.05mm, respectively) and different fibre percentages (0.1, 0.25 and 0.5% by the dry weight of the soil). The fibre length and fibre percentages were selected based upon previous results (Falorca and Pinto 2002, 2004, Pinto and Falorca 2005). The main properties of the fibres are summarised in Table 3.

Table 3. Fibre properties

Property	PP Fibres
Specific gravity, G_f (-)	0.91
Denier (g/ 9000 m)	6 and 15
Percentage (%)	0.1, 0.25 and 0.5
Length (mm)	75
Tensile strength, σ_t (MN/m^2)	200
Young's modulus, E (GN/m^2)	0.75
Elongation at break, ε_f (%)	250
Moisture absorption (%)	0
Colour	White

TRIAL EMBANKMENT CONSTRUCTION

Construction

The first stage of the trial embankment construction was the preparation of an adequate levelled foundation (Figure 3), clean of the any waste, organic soil and vegetation, which is always an essential preliminary action. A soil layer of 0.2 m average thickness was then placed and compacted all along the embankment area, and afterwards, the section boundaries were indentified over the horizontal platform by using vertical marks. These marks also allowed to work as a guide and thickness control of the microreinforced soil layers during embankment construction.

The trial embankment was constructed by using only conventional earthwork machines. Each section was constructed by placing and compacting a set of layers, up to a total embankment high of 0.6 m.

The unreinforced section (SM) was constructed by just placing and compacting a total of 3 layers of 0.2 m thickness each. For the construction of the fibre reinforced sections, special procedures were adopted. Starting with the experience achieved in previous laboratory investigations and combining that with the lessons learned in literature (Lindh and Eriksson 1990, Tingle et al. 2002), a preliminary in-situ mixing technique was selected.

The mixing technique used at the beginning comprehended the following main steps: first, a sandwich was prepared with a layer of fibres and a layer of soil; then a mixture of these two layers was made by mechanical means. The selected type of fibres were weighted and placed uniformly by hand over the section under construction (Figure 4) and then they were covered with a small quantity of soil by a bucket loader (Figure 5), to finally obtain the sandwich. After that, a recycler type mixer was driven along the section with slow speed combined with high rotation, in a regular pattern. Finally, the borderlines were further treated to obtain a uniform mixture all along the full section area (Figure 6). A simultaneous pulverization of soil particles and fibres was performed by the selected controls of the recycler type mixer, and a satisfactory homogeneous mixture was achieved (Figure 7)

Figure 3. Preparation of an adequate foundation

Figure 4. Manual spreading of the fibres

The procedure was repeated until a 0.2 m thick layer was achieved. When the entire length of the embankment was prepared in the described way, with distinct techniques for unreinforced and reinforced sections, a level measurement control was made and finally compaction took place along the full 50 m length. Compaction took place in two stages: it started with a static pass of the motor-scraper in a longitudinal regular pattern (Figure 8) and that was followed by six passes of a 4 t vibrating roller, transmitting a linear static load of 14.5 N/mm (Figure 9). After compaction, the required layer thickness of 0.15 m was attained. A correction of water content was performed during compaction stage using the necessary quantity of water for compaction and water evaporation compensation. A thin topsoil layer (of about 5 cm) was placed on top to protect fibres from UV oxidation.

Figure 5. Thin soil and fibre layers placed alternately

Figure 6. Mechanical mixing by means of a recycler type mixer

Figure 7. Microreinforced soil

Quality control

Mixture control

It was considered essential to check if a satisfactory homogeneous mixture was achieved at the end of the process.

During the full-scale trial embankment conception it was predicted that the required quantity of fibres would be mixed with soil to perform a 0.2 m thick layer in one single step, which corresponds to the maximum depth reached by the recycler type mixer. However, an unsatisfactory heterogeneous mixture was found to be achieved by this procedure. This was mainly due to difficulties of incorporating a great quantity of fibres placed over the soil layer, as big balls of fibres embedded in soil were found during quality control. In order to improve the quality of the mixture, a decision was taken to place thinner layers (sub-layers) of soil alternating with fibres, as described in section 3.1. Systematic visual inspections were carried out to control the randomness and uniformity of fibres distribution. The number of sub-layers was found to depend on the fibre characteristics. The experience showed that the in-situ mixing achieved by the described methodology becomes impracticable when the number of sub-layers is higher than 6.

The fibre percentage of each section was checked by sampling at the beginning of work. Based on the results, a more practical quality control was adopted: for a certain weight of fibres, a determined number of full bucket loaders were specified. As an example, as far as the amount of materials used in the present study is concerned, for each 1 m^3 of compacted SM025F6d material, about 4.5 kg of fibres are required.

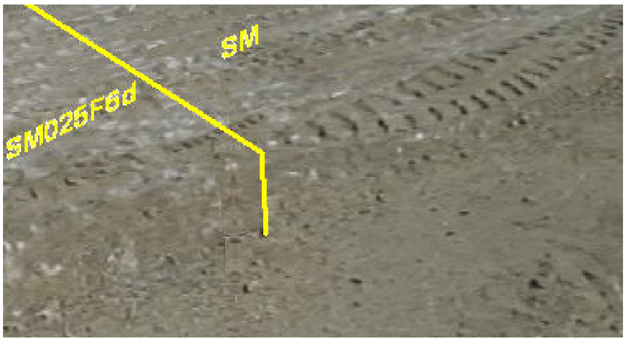

Figure 8. Compaction stage using a motor-scraper

Figure 9. Compaction stage using a vibrating roller

Compaction control

The traditional practice for compaction control, based on the dry unit weight of the materials, was adopted.

Representative samples of unreinforced and fibre reinforced soil were prepared for laboratory compaction tests in order to define the compaction parameters for each embankment section. Fibre reinforced samples were prepared by mixing the fibres with the hydrated soil by hand. A similar methodology to that described in Falorca and Pinto (2002, 2004) was adopted during the preparation of samples. Some results of the heavy (modified) Proctor tests performed are shown in Figure 10.

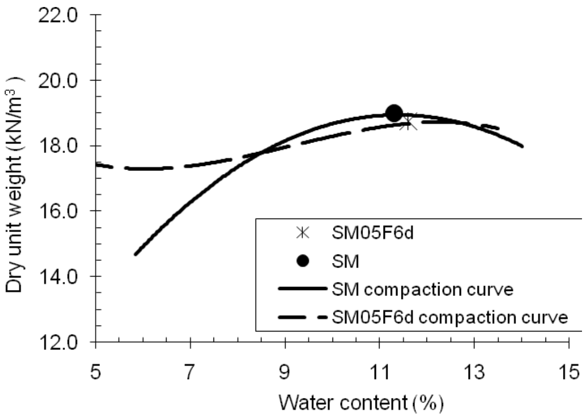

Figure 10. Laboratory compaction curves and results of the compaction control using water replacement method

The results indicated that the fibre reinforced soil exhibited the same overall compaction behaviour as that of unreinforced soil: the dry unit weight increases with water content up to an optimum value and then it decreases with further increase of the water content. However, adding fibres to the soil seems to flatter slightly the compaction curve, as the maximum dry unit weight decreases and the optimum water content increases.

Based on the reference values for each test section, an acceptance criterion for the compaction control was defined. According to current practice, a minimum value of the in-situ dry unit weight was specified, which corresponds to a relative compaction of 95%. For compaction control, nuclear moisture-density gauge, sand cone density test, Speedy method, and water replacement method tests were performed. Figure 10 also shows some results obtained from the water replacement method. Comparing these results with the corresponding laboratory Heavy Proctor test results, a very good agreement was found.

The compaction control was also carried out by monitoring the thickness of the layers. After compaction stage, a layer 0.15 m thick should be attained.

It was observed that compaction due to the motor-scraper did not affect significantly the slopes of the borders of the reinforced sections in comparison with the SM section, as Figure 8 illustrates. Besides, no rutting was developed on the reinforced sections surface due to the motor-scraper in contrast to the unreinforced section. The effect of the subsequent compaction of the reinforced sections with vibrating roller was practically negligible, when compared with the unreinforced section. An abnormally behaviour was however identified, and that was the development of some fissures on the surface of the reinforced sections. This kind of anomaly usually indicates the presence of a soft underlying layer and constitutes a non acceptance criterion in conventional earthwork compaction quality control. This acceptance criterion was not considered in the present work because it was also observed that the reinforced sections exhibited very good bearing capacity and trafficability under the heavy construction machines. The fissures might be due to a slight increase of the volume of the mixture after discharge of the compaction load. Such fissures cannot be avoided by an extra compaction but the problem that they might create can be reduced by placing a slight surcharge on top of them. Foose et al. 1996 had made a similar recommendation for sand reinforced with shredded tires.

The experience obtained during compaction of the embankment layers in the present work seems to indicate that reinforced soil could be better compacted with a different type of equipment, like sheep’s foot roller or similar, rather than a vibrating roller. It is believed that a kneading action would give a better help to the fibres and soil particles to mix together and to achieve a denser state without the development of observed fissures.

Behaviour

The trial embankment was constructed in September 2006 and it has been left under natural weather conditions since then. Investigation based on visual observations of the behaviour of the trial embankment has been conducted. Up to now, very hard short-duration intensive rainfalls have been occurred, namely in Autumn 2006. A peak of 16.1 mm/h rainfall intensity with duration shorter than one hour was observed, which is considered an historical exceptional data.

The unreinforced section of the embankment (SM section) presented low resistance to the erosion by rainfall and overland flow. The initial geometry of the slope was significantly changed under the short-duration intense precipitation. The soil particles were washed away by the surface water runoff, and small eroded channels such as rills concentrated the runoff, which in turn eroded the small channels further, until finally ravines were created. The ravines are drawn out of the slope, and spread through the SM section of the embankment platform. Due to this erosion process a deposition of some material took place at the base of the slope, and that was responsible for the drainage system obstruction, thus, the erosion process was accentuated.

Comparing Figure 11 with Figure 12, it can be seen that the microreinforced soil (SM01F15d section) has significantly greater resistance against the erosion by rainfall and overland flow than the unreinforced section, as only a small number of soil particles on the surface of the slope were washed away. The ravines developed in the slopes of the reinforced sections could not spread through the embankment platform due to the reinforcing effect of the fibres (Figure 12). It was observed that the fibres bind the soil particles together, reducing significantly their susceptibility to erosion. This is clearly shown in Figure 13, where some particles of the top protective soil layer (of about 5 cm thickness) were eroded and as a consequence the fibres were exposed. Despite that, no evolution of the ravines towards the microreinforced sections were observed. This demonstrates that a substantial increase of the erosion resistance of young embankment slopes can be achieved by mixing the soil with a small quantity of short, randomly oriented polypropylene fibres.

Figure 11. Surface erosion in the unreinforced section

Figure 12. Surface erosion in the SM01F15d section

Figure 13. Anti-erosion effect of fibres in the SM025F6d section

CONCLUSIONS

Under the joint research project on the behaviour of microreinforced soils under static and dynamic loads, a trial full scale embankment was constructed. The construction technique and quality control of the embankment layers, with special consideration on the mixing technique, were described.

The selected in-situ mixing technique consists of putting together the soil and the fibres like a sandwich, and then mixing both materials with a recycler type mixer. This technique is in accordance with the results of a previous laboratory studies that demonstrated that spreading the fibres and the soil layer by layer in alternate mode, followed by a slight mixing, a satisfactory homogeneous mixture was achieved. The inclusion of short polypropylene fibres as soil reinforcing elements has shown to be a very promising technique to improve the properties of the soil since the fibre reinforced sections exhibited very good bearing capacity and trafficability under heavy construction machines in comparison with the unreinforced section.

Up to now, a good behaviour of this full-scale experiment left under natural weather conditions was observed, in particularly during very hard short-duration intense rainfalls that have been occurred. An important resistance against the erosion of young embankment slopes by short-duration intense rainfalls was achieved with just mixing the soil with a small quantity of short, randomly oriented polypropylene fibres.

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