Bearing ratio of a fine soil reinforced with geosynthetics: influence of the reinforcement type and the soil water content

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ABSTRACT: This paper reports an investigation on the effects of reinforcing a fine soil with three different geosynthetic solutions and their behaviour under loading. The effectiveness of the reinforcement was investigated through California Bearing Ratio, CBR, tests. The reinforcement solutions tested were: geogrid (GGR), geocomposite (GCR), association of geogrid and geotextile (GGR + GTX). The response of the unreinforced fine soil was compared to those of the same soil with one layer of reinforcement. The influence of the initial water content of the soil on the bearing capacity was analysed using five different values (11.9%; 13.9% (optimum); 15%; 17% and 19%). Including a layer of reinforcement improved the bearing capacity ratio and the stiffness of the samples. The best improvement in bearing capacity was found for GGR, followed by GGR + GTX and then GCR, and can be explained by the differences in stiffness and structure of the reinforcements. The mobilisation of the reinforcement depended on the type of reinforcement, the initial water content of the sample and the penetration induced to the sample. The soil initial water content affected the response significantly. Higher initial water contents lead to lower CBR values, for both unreinforced and reinforced samples. However, the effectiveness of each reinforcement varied with the initial water content; for GGR and GGR + GTX an initial water content of 17% lead to the higher bearing capacity ratio, while for GCR this occurred for the lowest value of the initial water content considered (11.9%).

Keywords: Geogrid, Geocomposite, Geogrid and geotextile, reinforcement, Bearing capacity ratio

1 INTRODUCTION

Currently engineers are under pressure to deliver adequate technical solutions, which contribute to a low carbon future and sustainable construction. Using locally available soils and improving their properties may contribute to reducing carbon emissions and meeting sustainability requirements. Reinforcing such soils with geosynthetics can contribute to reducing whole-life costs and emissions of construction.

For example, geosynthetics have been successfully used to build unpaved roads, extend the service life of pavements, reduce base course thickness for a given service life and delay rutting development (Abu-Farsakh et al. 2015). Furthermore, within transportation infrastructure, geosynthetics can reinforce weak subgrade layers, the base-subgrade interface or the base layer. Although very controversial, the California Bearing Ratio (CBR) test is widely used in the design of transportation infrastructure. The CBR test can be performed with most types of soils, ranging between a medium gravel to a heavy clay material (Head 1994). However, despite having been used for a wide range of natural soils and compacted fill materials, the significance of the CBR tests is often questioned (Magnan and Ndiaye 2015). According to Kamel et al. (2004), despite the limitations of the CBR test, it allows analysing the benefit of adding reinforcement under similar conditions. Other authors, such as Adams et al. (2016), have used CBR tests to assess the influence of parameters such as plasticity index and gradation of soils on the bearing ratio of reinforced soil. The CBR of particulate materials depends on several factors, such as the soil type and its density, the initial moisture content and the method used to prepare the sample (Carter and Bentley 1991). Therefore, these factors are likely to affect the response of reinforced soil samples. Other authors have studied the response of reinforced soil using CBR tests, such as Moayed et al. (2013), Vinod and Minu (2010), Ghosh and Dey (2009), Naeini and Ziaie-Moayed (2009).

This paper summarises data from a wider research project focused on designing new solutions for building and rehabilitating small dykes using local fine soils reinforced with geosynthetics. The dykes form boundaries between saltpans and canals in a tidal lagoon and are often utilised as unpaved roads for vehicles used in salt production. This paper reports an investigation on the beneficial effects of reinforcing a fine soil with three different geosynthetic reinforcement solutions and their behaviour under loading.

2 TEST PROGRAM

2.1 *Overview*

This paper reports results from CBR tests on a fine soil reinforced with geosynthetics. The materials used (geosynthetics and soil) were characterised in laboratory. The results presented in this paper are part of a wider research project.

2.2 *Materials*

Three different reinforcement solutions were studied: 1) geogrid, GGR; 2) geocomposite, GCR; 3) GGR+GTX, association of geogrid GGR with geotextile GTX (GGR on top of GTX). Geogrid GGR is a woven geogrid composed of high modulus polyester (PET) fibres knitted in a flat orientation and covered with a protective polymeric coating. Geocomposite GCR is a uniaxial materials composed of high modulus PET fibres attached to a continuous filament nonwoven geotextile backing. Geotextile GTX consists of continuous thermo-bonded polypropylene (PP) filaments. Table 1 summarises nominal properties of these geosynthetics: tensile strength (T), in machine direction (MD) and in cross machine direction (CD); strain for the tensile strength (ε), for both machine and cross machine direction; thickness (d).

Table 1. Nominal properties of the geosynthetics studied

Property	Unit	Test standard	GGR	GCR	GTX
T (MD)	kN/m	EN ISO 10319	55	55	13.1
T (CD)	kN/m	EN ISO 10319	55	12	*
ε (MD)	%	EN ISO 10319	10.5	10	52
ε (CD)	%	EN ISO 10319	10	85	*
d	mm	EN ISO 9863-1	*	*	0.57

MD – machine direction | CD – cross machine direction | * Not available in the datasheets

The fine soil was collected from a saltpan wall in the Aveiro lagoon, Portugal, and characterised using laboratory tests. According to USCS, Unified soil classification system (ASTM D2487–

11), and AASHTO classification system (AASHTO M 145-91-UL), the soil is ML - sandy silt or A-4, respectively. Additional information is included in Table 2: percentage of fine particles (<0.074 mm); average grain sizes (D_{50}); liquid limit (w_L); plastic limit (w_P); plasticity index (I_P); unit weight (γ); compaction characteristics of the soil (obtained from modified Proctor tests ASTM D1557-12), maximum dry density (γ_{dmax}) and optimum water content (w_{opt}). Figure 1 illustrates the particle size distribution of the soil.

Table 2. Properties of the soil

<0.074 mm (%)	D_{50} (mm)	w_L (%)	w_P (%)	I_P (%)	γ (kN/m^3)	γ_{dmax} (kN/m^3)	w_{opt} (%)
65.7	0.0112	35	25	10.4	18.3	18.09	13.9

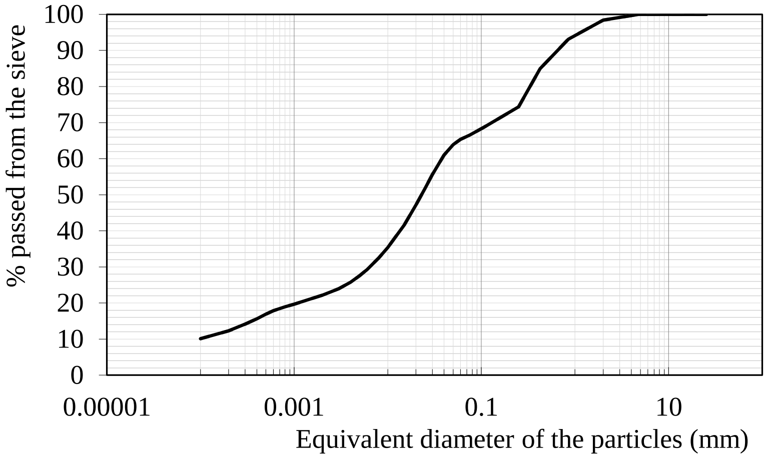

Figure 1: Grain size distribution of the fine soil tested

2.3 *CBR tests*

The test programme consisted of performing CBR tests of both unreinforced and reinforced soil samples. The CBR test procedure used is described in LNEC E198 (1967), which is similar to the procedure in ASTM D1883–07 (differing on the velocity of the test and the number of blows applied during compaction). The specimens tested were cylindrical, 125 mm high (H) and 152 mm diameter (D). The soil was prepared to the desired water content, w, of 11.9%, 13.9% (w_{opt}), 15%, 17% and 19%. Then the soil was allowed to rest for 24 hours, closed in plastic containers, in a standard atmosphere (temperature 20°C; relative humidity 65%). Each specimen was prepared in 5 layers. Each layer was 25 mm high and compacted with 25 blows using a plunger of 4.54 kg and a drop height 457 mm. For the reinforced specimens a layer of reinforcement was included at 2/5H from the top of the specimen (Figure 2). The specimens were soaked during 96 hours. The tests were performed at an imposed axial displacement of 1 mm/min.

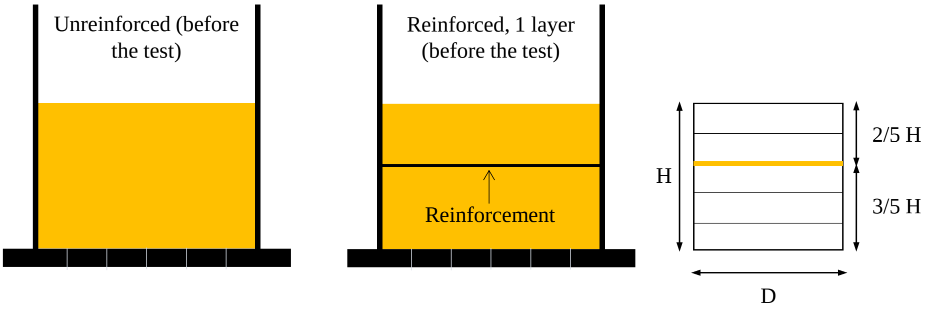

Figure 2: Position of the reinforcement in the CBR tests

3 RESULTS AND DISCUSSION

3.1 *Summary of results*

Table 3 summarises the CBR tests results and includes: desired and real (measured before soaking) water content, w and w_{real}, respectively; CBR values for penetrations of 2.5 mm, $CBR_{2.5}$, and 5.0 mm, $CBR_{5.0}$; maximum measured penetration force, F_{max}. $CBR_{5.0}$ was higher than $CBR_{2.5}$, for most specimens tested. The unreinforced soil CBR values for penetrations, s, of 2.5 mm and 5.0 mm, respectively, are: $CBR_{2.5}$=4.67 and $CBR_{5.0}$=4.73 (obtained for specimens prepared to the optimum water content, w_{opt}=13.9%). Such values are in good agreement with the expected range for this type of soil.

Table 3. CBR tests - summary of results

	Soil					Soil + GGR				
w (%)	11.9	13.9	15.0	17.0	19.0	11.9	13.9	15.0	17.0	19.0
w_{real} (%)	11.9	13.8	15.1	16.8	18.8	11.8	13.6	14.8	16.8	18.8
$CBR_{2.5}$ (%)	9.5	4.7	3.2	1.5	0.9	14.2	5.0	3.5	2.6	1.5
$CBR_{5.0}$ (%)	10.0	4.9	3.5	1.6	0.8	14.6	5.5	4.3	3.0	1.4
F_{max} (kgf)	374.4	185.8	142.2	58.6	29.7	534.7	233.0	204.0	122.3	53.3
	Soil + GCR					Soil + GGR+GTX				
w (%)	11.9	13.9	15.0	17.0	19.0	11.9	13.9	15.0	17.0	19.0
w_{real} (%)	11.9	13.6	15.0	17.1	19.1	11.7	13.7	14.6	16.6	19.0
$CBR_{2.5}$ (%)	12.3	4.7	3.4	1.6	0.9	13.7	4.8	3.4	2.0	1.1
$CBR_{5.0}$ (%)	12.2	4.9	3.7	1.7	0.8	13.8	5.2	4.1	2.3	1.0
F_{max} (kgf)	464.0	192.6	161.1	64.6	30.9	492.2	235.5	187.6	99.8	37.3

The bearing capacity ratio (Equation 1) was calculated as the ratio between the between the maximum penetration force of the reinforced specimen ($F_{max,r}$) to that of the corresponding unreinforced one ($F_{max,u}$). Those results are illustrated in Figure 3. The results are discussed in the following sections, analysing the influence of the type of reinforcement used and that of the initial water content of the samples.

$$BCR = \frac{F_{max,r}}{F_{max,u}} \qquad (1)$$

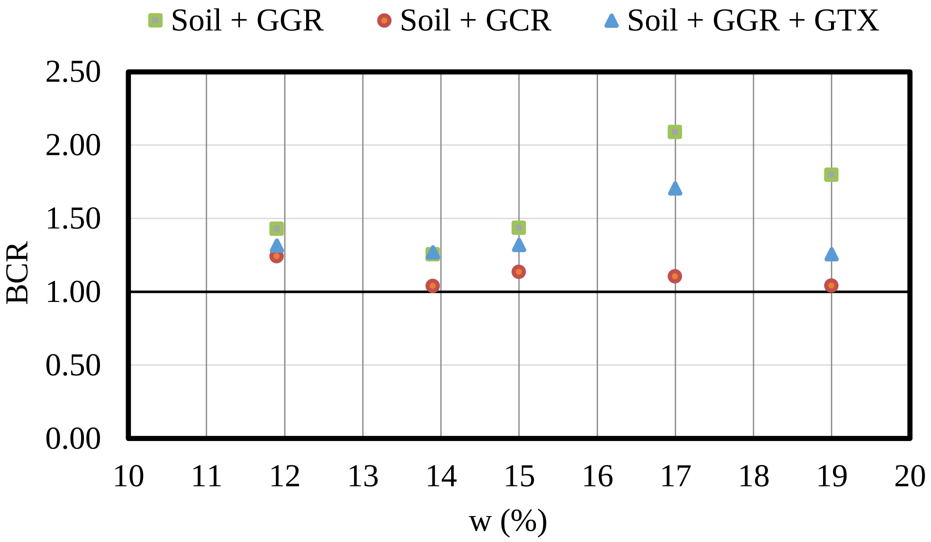

Figure 3: Bearing capacity ratio (BCR) of the reinforced samples

3.2 *Influence of the type of reinforcement*

Including a layer of reinforcement has improved the bearing capacity ratio of all samples, regardless of their initial water content (Figure 3). The least effective reinforcement solution is GCR, followed by GGR + GTX. The best improvement in bearing capacity was obtained using GGR. The differences observed are influenced by the initial water content of the sample (discussed in the following section).

The observation of the samples after the test allowed identifying permanent deformations (Figure 4). For the unreinforced samples, the soil below the piston became denser. For the reinforced samples, there were additional effects. The reinforcement layer deformed, following the deformations of the soil and assuming a concave shape (Figure 4b). Therefore, the reinforcement was mobilised; part of the stresses induced by the plunger were transmitted to the reinforcement and, thus, spread laterally in the soil. This lead to an increase of the bearing capacity of the reinforced samples relatively to the unreinforced soil.

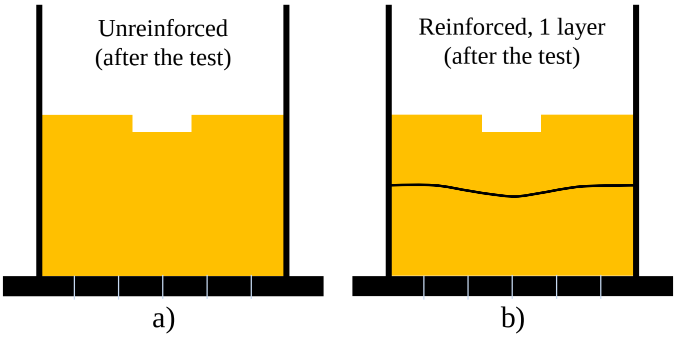

Figure 4: Schematic representation of the cross section of the specimens after the CBR test a) unreinforced and b) reinforced

GGR and GCR have the same nominal tensile strength. GGR is biaxial and has the same nominal strength and similar stiffness in both MD and CD. GCR is highly anisotropic, with significantly higher resistance and stiffness in MD, relatively to CD. These two geosynthetics have very different structures - the openings of GGR allow soil to move through them, while GCR, a sheet material, restrains such movements. As the loading applied during the CBR test is axisymmetric, the response of these two reinforcements is different; for GCR the direction of lower stiffness will be critical. Therefore, during the test, as tensile forces are transmitted to GCR, the reinforcement deforms, originating additional settlements and, thus, reducing the corresponding force measured (plunger). These deformations lead to densification of the soil below GCR. The samples reinforced with GGR + GTX exhibit an intermediate response. On the one hand, the high stiffness of GGR is important for the overall response (as this material is placed above GTX, during the test it is mobilised first). On the other hand, having a sheet material (GTX) prevents vertical movements of soil particles through the openings of GGR (which can occur when GGR is used on its own).

Figure 5 illustrates force-penetration curves obtained for samples prepared to an initial water content of 13.9% (optimum value). Including a layer of reinforcement improved the response of the sample. Particularly for penetration values higher than 2 mm, the response seems to be influenced by the type of reinforcement used, as discussed above. For the samples prepared to optimum water content, for smaller values of the penetration (<2 mm), the responses obtained with the different reinforcements are very similar.

The penetration s of the plunger into the sample as a function of the measured applied force F can be considered analogous to graphs obtained from triaxial tests (which, like the CBR test are performed at a constant displacement rate). The curves show that the stiffness of the reinforced specimens is larger than that of the unreinforced soil, particularly for higher penetration values. Thus, it is likely that the reinforcement layer is mobilised for penetration s > 1.5 mm.

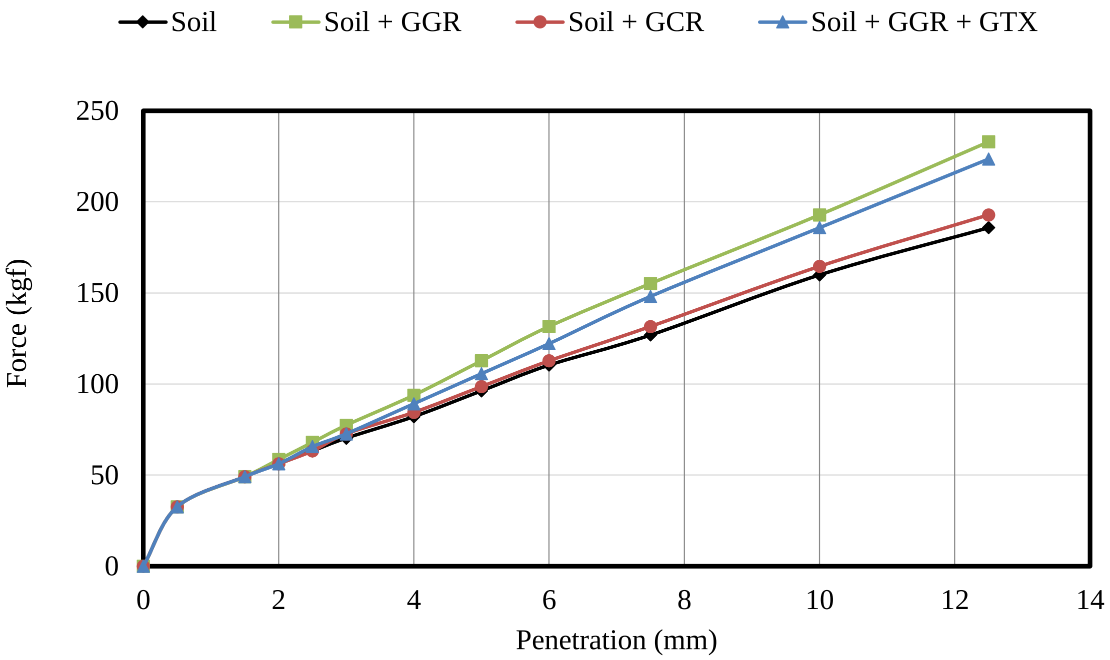

Figure 5. Force-penetration curves for specimens prepared to a water content of 13.9% (w_{opt}) - influence of the type of reinforcement.

Figure 6 illustrates the $CBR_{2.5}$ improvement ratio determined from Equation 2, where $CBR_{2.5,u}$ and $CBR_{2.5,r}$ and the CBR values for a penetration s=2.5 mm for the unreinforced and reinforced samples, respectively, tested under similar conditions.

$$CBR_{2.5} improvement\ ratio = \frac{CBR_{2.5,r}}{CBR_{2.5,u}} \qquad (2)$$

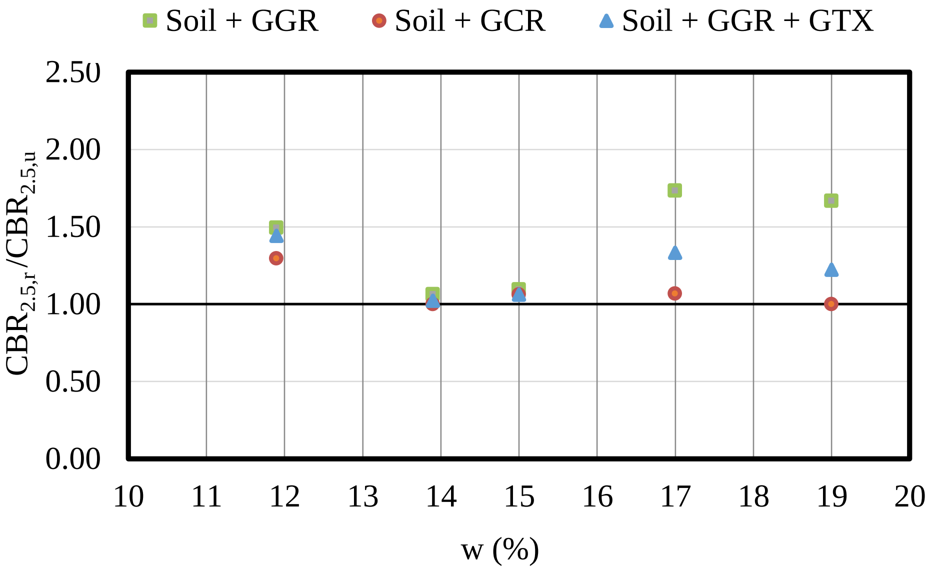

Figure 6: $CBR_{2.5}$ improvement ratio of the reinforced samples

For penetration s=2.5 mm, the $CBR_{2.5}$ improvement ratio (Figure 6) shows that the differences between types of reinforcement are less evident than for the BCR (Figure 3), particularly for initial water content values of 13.9% (optimum water content) and 15%. Additionally, for these initial water content values (13.9% and 15%) the deformations induced in the soil and reinforcement (for s=2.5 mm) were not sufficient to mobilise the reinforcements significantly (as the improvement ratio is close to 1).

3.3 *Influence of the initial water content*

The CBR values for the different samples prepared to the five values of the initial water content considered is summarised in Figure 7. For each type of sample (unreinforced and reinforced), the best response was observed for samples prepared to the lower water content (below the optimum). This may indicate that the compaction characteristics of the soil were not always the same and/or that the soil sampled (mass ~2000 kg) had some heterogeneity. At the time of writing, the authors were unable to repeat the tests to determine the compaction characteristics of the soil, to verify if the initial values obtained could be confirmed.

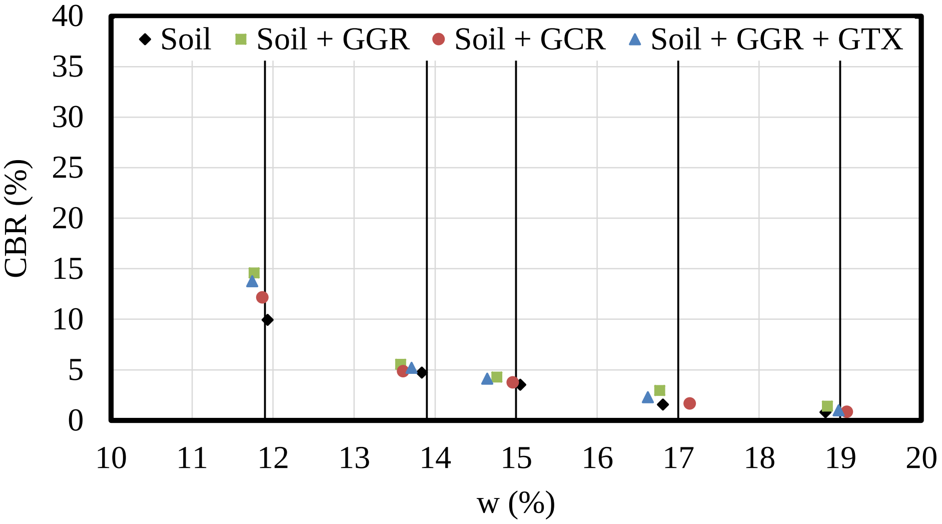

Figure 7. Influence of the initial water content on the CBR of the unreinforced and reinforced soil specimens.

The bearing capacity ratio (BCR), illustrated in Figure 3, shows that the reinforced samples performed better at water contents on the wet side of the optimum value. When GCR was used, an initial water content of 11.9% lead to the best contribution of this reinforcement. For GGR and GGR + GTX the best improvement due to the inclusion of one layer of reinforcement was obtained for samples prepared to a water content of 17%.

4 CONCLUSIONS

In this paper the bearing capacity of a fine soil was analysed using CBR tests. The performance of the soil was compared to that of reinforced samples using three different reinforcement solutions: GGR, GCR, GGR + GTX. From the results the following conclusions can be established:

- Regardless of the initial water content, including a layer of reinforcement improved the bearing capacity ratio and the stiffness of the samples; the bearing capacity ratio (BCR) ranged between 1.04 and 2.09;

- The best improvement in bearing capacity was obtained using GGR, followed by GGR + GTX and then GCR; the differences in stiffness and structure of the reinforcements explain the different performances observed.
- Independent of the reinforcement solution considered, for penetrations s=2.5 mm the reinforcements were not mobilised significantly, particularly for samples prepared to an initial water content of 13.9% (optimum) and 15%.
- Although all tests were performed with the soil soaked, the initial water content of the sample affected the response of the sample significantly. Higher initial water contents lead to lower CBR values, for both unreinforced and reinforced samples.
- The effectiveness of each reinforcement varied with the initial water content; for GGR and GGR + GTX an initial water content of 17% lead to the higher bearing capacity ratio, while for GCR this occurred for the lowest value of the initial water content considered (11.9%).

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