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Experimental and numerical studies of the geosynthetics reinforced platforms laid over soft subgrade soil

Nisrine ABOU CHAZ[1,3*], *Laurent* BRIANCON[2], *Pascal* VILLARD[1], *Claire* SILVANI[2], *Alain* NANCEY[3], Abdelkader ABDELOUHAB[3]

[1]Univ, Grenoble Alpes, CNRS, Grenoble INP, 3SR, 38000 Grenoble, France
[2]INSA LYON, GEOMAS, 69621 Villeurbanne, France
[3]TENCATE GEOSYNTHETICS FRANCE, 95870 Bezons, France

Abstract. Six full-scale unpaved test sections were constructed to investigate the benefit obtained from inclusion of geosynthetic layer. Two geotextiles were placed at the interface between the base layer and the subgrade. The results allowed the estimation of reinforcement efficiency. In addition, a numerical model coupled between the discrete element method and the finite element method has been calibrated based on the experimental results.

1 Introduction

Poor subgrade is a widespread issue in unpaved roads construction. The geosynthetic is considered one of the most innovative solutions since it was used in the late 1970's. Indeed, research applications shows that a properly designed and placed geosynthetic can improve the performance of the unpaved sections by: reducing the ruts under traffic load [1-2] and / or reducing base course thickness [3].

Depending on the type of the geosynthetics used, one or many functions among the separation, the reinforcement and the confinement can be ensured. Several questions remain in the literature regarding the part of each mechanism in the overall improvement. In order to answer these questions, many authors have attempted to relate the influencing parameters and the performance of reinforcement through experimental studies. Among these parameters, we will discuss the base course thickness, the subgrade bearing capacity, the geosynthetic type, properties and location.

Hufenus et al. [1] observed that the geosynthetic placed at the interface between the subgrade with a CBR less than 3, and a base course layer is effective up to $h \leq 50$ cm. In contrast, Khoueiry [2] concluded that the geosynthetic placed at the interface between a subgrade with a CBR=2 and the granular layer with thicknesses equals to 35 cm did not provide additional effectiveness under vertical cyclic loading. For thinner base course, around 20 cm, Khoueiry [2] showed the geosynthetic effectiveness on subgrade with a CBR equal to 3.

The observations of a full-scale experimentation performed by Hufenus et al. [1], reinforcement geosynthetic should have a tensile strength at 2% of axial strain $T_{2\%} \geq 8$ kN/m in both longitudinal and transverse production direction. Furthermore, Cuelho and Perkins [4] corelated the geogrid tensile strength at 2% and 5% strain in the transverse direction with the thin platform performance in the case of deep rutting and a rolling loading. Khoueiry [2] verified that the geogrid with a stiffness at 2% of axial strain equal to 2500 kN/m, was more

* Corresponding author: Nisrine.abou-chaz@univ-grenoble-alpes.fr

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effective in reducing settlement in the case of thin platform, compared to a geogrid with a stiffness at 2% of axial strain equal to 1000 kN/m.

Hufenus et al. [1], Cuelho and Perkins [4], and Khoueiry [2] showed the effectiveness of geosynthetics (geogrids and geotextiles) placed at the interface between the subgrade and granular platform. In contrast, other type of geogrid placed at mid-height of the thin granular platform over soft subgrade (CBR=2) was less effective as compared to the case where it was placed between the two layers [2].

The various factors and parameters affecting the mechanisms involved, its relative contributions to the improvement of the platform and their dependence explain the need for more investigations on this subject. Besides the experimental studies and based on them, numerical studies can provide access to additional information which is difficult to be quantified during the experimentation.

The methods used in geosynthetic reinforcement structure model should be able to describe:

1. the large deformation of the granular soil layer,
2. the mechanical behaviour of the geosynthetic and
3. the interaction between the geosynthetic and its surrounding soil

Villard et al. [5] have proposed coupling techniques to use DEM for the granular material and FEM to describe the geosynthetic behaviour. The used calculation code is the SDEC software (Spherical Discrete Elements Code, Donze and Magnier [6]) developed by Frédéric Donzé, then adapted and validated for soil reinforcement applications by geosynthetic sheet [5].

2 Scientific context and methodology

An experimental campaign, consisting of tests on reinforced and non-reinforced platforms over weak subgrade are carried out. The reinforcement performance is tested under vertical loading using two geotextiles with different tensile strength and two base course thicknesses. In addition, a numerical model using a Spherical Discrete Elements Code (called SDEC) and developed by [5] is used and calibrated with the experimental results.

This paper presents the results of six cyclic vertical plate loads tests on non-reinforced and geotextile reinforced platforms. This study highlights the benefit obtained from using geotextile at the subgrade-base course interface, the effect of the geotextile tensile stiffness at small strain on these benefits. In addition, the numerical model is calibrated after applying the static load of the first cycle applied experimentally. Results are shown in the following paragraphs.

3 Experimental study

3.1 Test setup and materials

An experimental box of 2 m long, 1,8 m wide, and 1,1 m high is used to build a 60 cm of subgrade layer thickness covered by a 30 cm or 50 cm of granular layer thickness (Figure 1a). The load is applied by a hydraulic jack on a circular plate of 32 cm of diameter placed at the granular platform surface. The applied cycles are shown in Figure 1b. The frequency of a cycle is 0.77 Hz. The maximum load is 45 kN chosen to obtain a pressure equal to 560 kPa which is equivalent to the contact pressure of a wheel. According to FHWA [7], the unpaved road is expected to support 10 000 ESAL passes, with a maximum rutting of 75 mm.

Hence, 10 000 cycles are applied to each tested platform except the test 1 because of the excessive rutting.

The artificial subgrade soil is composed of a mixture of 20% kaolin clay and 80% Hostun sand by weight. This mixture is installed with a water content of 13.0% to achieve, with a light compaction protocol, a CBR value of approximately 1.0 based on a series of Standard "Proctor" compaction tests and laboratory CBR tests. Non-treated (GNT 0 / 31.5), and poorly graded aggregates (Cu=20, Cc=5) were adopted as the base course materials and compacted with a 4 % of water content.

Two woven geotextiles (GTX1 and GTX2) made of an assembling of polypropylene filaments are tested. The mechanical properties of these two geotextiles provided by the manufacturer are shown in Table 1. At small axial strain (2% and 3%), the GTX1 and the GTX2 have a similar stiffnesses in the transverse direction, but the GTX1 has almost the triple stiffness of the GTX2 in the longitudinal direction. Since the vertical loading on the plate mobilizes equally the geosynthetic in both directions, we can assume an average stiffness that is equal to the mean of the stiffnesses in the two directions. In this case we can assume that the GTX1 is stiffer than the GTX2 at small axial strain (2% and 3%).

a) b)

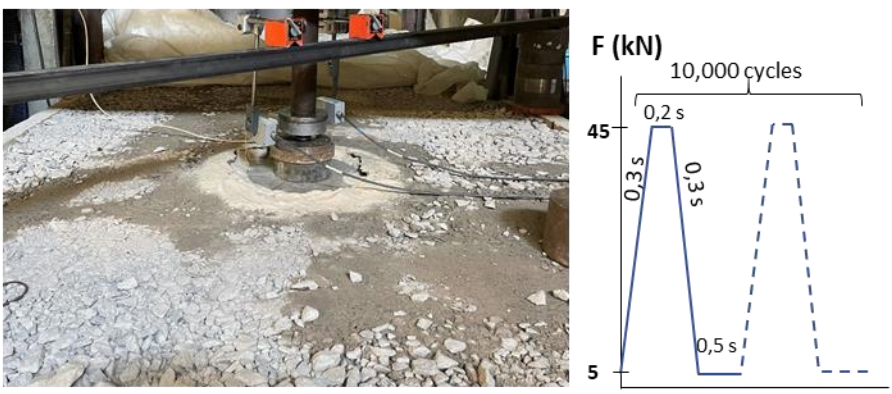

Figure 1: a) Plate load test setup, b) cycles applied.

Table 1: Mechanical characteristics of geotextiles.

Geotextile	$T_{2\%}$ (kN/m)		$T_{3\%}$ (kN/m)		$T_{5\%}$ (kN/m)	
	SP	ST	SP	ST	SP	ST
GTX 1	23.9	26.3	37.3	37.7	61.2	56.3
GTX 2	8.7	27.8	13.0	43.8	23.7	72.5

SP: longitudinal direction, ST: transvers direction.

3.2 Instrumentation

The instrumentation system, shown in Figure 2, consists of Earth Pressure Cells (EPC), hydraulic settlement sensors (S), and laser displacement sensors (L). The EPCs are placed on the geotextile, within and on the top of the subgrade to measure the stress distribution. The maximum capacity of these EPCs is 500 kPa which is greater than the expected vertical stress at the interface between the base course and the subgrade. Each settlement sensor is positioned on an EPC, their range is 1000 mm allowing to detect a settlement of 1 mm. Laser displacement sensors are attached to a rectangular steel bar and placed above the circular plate to measure its penetration during the test with a great accuracy. A load sensor (F) of 8T of capacity and a displacement sensor (LVDT) are fixed to the hydraulic jack.

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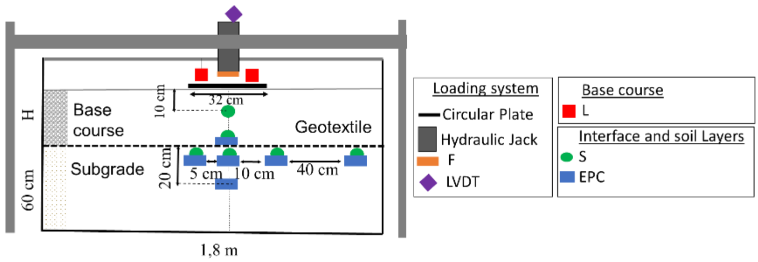

Figure 2: Instrumentation system

3.3 Experimental protocol

Several installation and compaction protocols were tested to reach a reliable and repeatable methodology to build a weak subgrade layer with CBR about 1%. The base layer is installed in 3 sublayers (w= 4%), and each sublayer was compacted using a vibratory plate.

The CBR of the subgrade layer is measured by a cone penetration test (CPT) before the granular layer installation and after its removal, since compaction of the granular layer increases the CBR of the subgrade layer. Moreover, a Clegg impact soil (CIS) tester is used to measure and control the base course strength and its consolidation level. The empirical equation 1 is related the CBR to the fourth drop impact value (IV4) obtained in the test [8].

$$CBR = [(0.24 \times IV4) + 1]^2 \quad (1)$$

In addition, Dynamic Cone Penetrometer (DCP) is used to characterize both the granular and subgrade layers after compaction. The IPI profiles (Figure 3) for the first 4 tested platforms were estimated using DCPI profiles based on the following formula [9]:

$$\text{Log } IPI = 2.632 - 1.28 \, log_{10}(DCPI) \quad (2)$$

Where DCPI = dynamic cone penetration index (mm/blow), which is calculated based on the penetration per each blow.

Table 2 provides a summary of the average CBR values for both the subgrade (measured by the CPT after base course removal) and the base course (measured by CIS), respectively, for all the test sections. The subgrade CBR values are around 1 showing the good repeatability of the initial conditions. The slight difference between the base average CBR values in the tests indicates a difference in the compaction level between the platforms in the 6 tests.

Figure 3 presents the IPI profiles for the base course test sections, and the CBR for the subgrade test sections estimated from the Dynamic Cone Penetrometer. The first 50 mm of the base course layer showed the lower IPI values because of the imperfections of the laboratory compaction machine and the difficulty to reach the level and quality compaction of the site. Overall, these profiles show a range of IPI between 4% and 17% in the granular layer and CBR around 1 in the subgrade, that is verify the average values of previous tests.

Table 2: Average CBR Values

	H_{base} (cm)	Reinforcement	$CBR_{subgrade}$	CBR_{base}
T1	30	Unreinforced (U)	1.2	12
T2	30	GTX2	1.1	12
T3	30	GTX1	1.4	17
T4	50	Unreinforced (U)	1.2	15
T5	30	GTX2	1.3	12
T6	30	GTX1	1	-

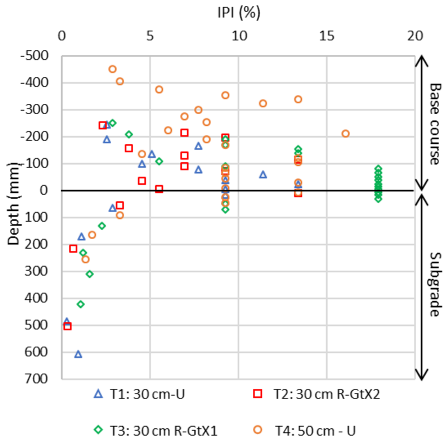

Figure 3: IPI profiles for base courses over subgrade

3.4 Results and discussion

Figure 4 presents the plate settlement evolution with cycles for six tests that measured in the unloading phases. The initial plate displacement is 30 (Test 1), 42 and 39 cm (Tests 2 and 5 respectively), 17 mm (Tests 3 and 6), 18 mm (Test 4). Among these tests, there are four repeatability tests performed on a reinforced platform with GSY 1 (tests 3 and 6) and GSY 2 (2 and 5). Each two identical tests show close initial settlement values and a similar settlement progression with cycles.

While the test 1 is stopped at 1000 cycles, due to the excessive settlement bringing the jack to the end of its course, tests 3 and 6, reinforced with GTX 1, reduce settlements at the 30-cm-thick granular platform surface by 58% and 55 % respectively compared to the unreinforced platform with the same base course thickness (30 cm) at 1000 cycles. GTX 2 reduce, to a lesser extent, settlements by 24% and 27% in tests 2 and 5 respectively at 1000 cycles compared to the unreinforced platform with the same base course thickness (30 cm). Test 4 performs on a 50-cm-thick unreinforced platform reduces settlement by 51% at 1000 cycles compared to the 30-cm-thick unreinforced platform at 1000 cycles (Test 1). Therefore, the 30-cm-thick platform reinforced by GTX 1 and the 50-cm-thick unreinforced platform has a close performance in the settlement reduction at 1000 cycles compared to the 30-cm-thick platform non-reinforced. However, after 1000 cycles, the settlement evolution for 30-thick GTX 1 reinforced base course surface stops but the settlement evolution at the 50-thick unreinforced base course surface keep rising until 5 000 cycles. That shows the effect of the reinforcement.

In order to neglect the influence of the initial settlement that can be eliminated by a heavy compaction in the site, Figure 5 presents the evolution of the settlements on the base course surface from the 3rd cycle (the settlement is set to zero at cycle number 2). The GTX 1 and The GTX 2 reinforced platforms show two close reductions in settlement compared to the 30-cm-thick unreinforced platform at 1000 cycles: 48% and 45% respectively. Similarly, GTX1, reduces settlements at the 30-cm-thick granular platform surface by 30% compared to the 50-cm-thick unreinforced platform at 10 000 cycles. GTX 2 reduces, to a lesser extent, settlements by 20% compared to the 50-cm-thick unreinforced platform at 10 000 cycles. Consequently, the GTX1-reinforced platform shows an ability to reduce surface settlement slightly more significant than the GTX 2-reinforced platform after removing the initial displacement.

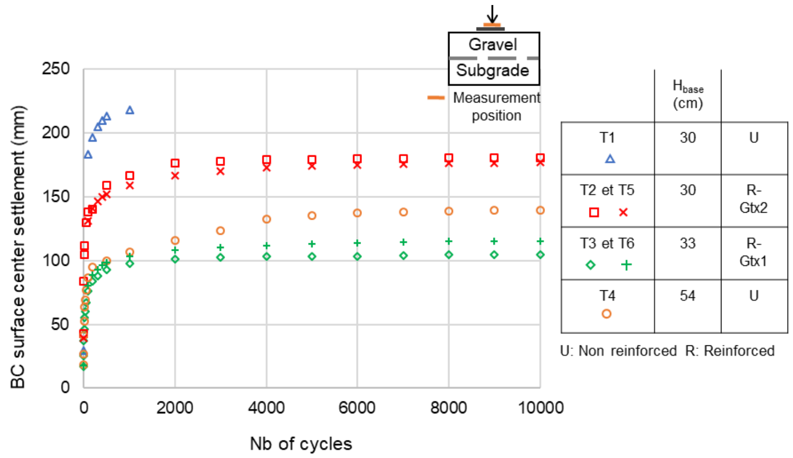

Figure 4: Base course surface centre settlement evolution with cycles

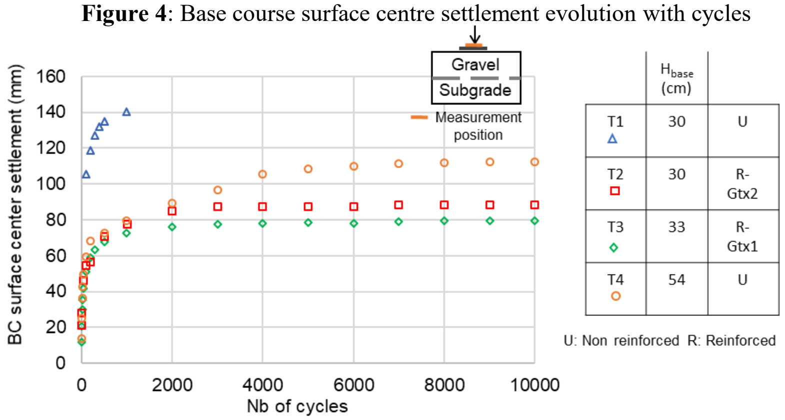

Figure 5: Base course surface centre settlement evolution with cycles starting from the 3rd cycle

4 Numerical Model

The 3D numerical model used in this study is based on a coupling that combines the finite and discrete element methods. This model considers the discrete nature of the granular material, the fibrous and continuous nature of the geotextile and the interaction at the interface between the soil particles and the finite elements used to describe the geotextile behaviour [5]. The used model (fig. 6) is 2 m long, 2 m wide and 0,36 m deep and includes, from top to bottom:

1. an assembly of clumps (composed of two overlapped and unbreakable spheres of same diameter D with d is the distance between the center of two particles, see Figure 6) describing the behaviour of the granular mattress and interacting through contact points (molecular dynamics method) [10],
2. thin, finite, triangular elements describing the membrane and tension behavior of the geosynthetic reinforcement under large deformations,
3. a layer of spheres regularly distributed in a square mesh at the base of the model and associated to springs to represent the supporting soil (which is supposed to behave elastically).

To calibrate the numerical parameters of the granular platform, several numerical triaxial tests are performed with different granular assemblies and the obtained macroscopic friction angles are compared to the one obtained with an experimental direct shear test (see Table 3). The interface friction parameters between the geosynthetics and the lower subgrade or the upper granular material are obtained by shearing tests using a shear box test 0.2 x 0.2 x 0,2 m^3 while the tensile parameters of the geosynthetic in x and y direction are deduced from traction tests performed by the geosynthetic manufacturer and presented in the section 3.1. The subgrade soil rigidity and its evolution with cycles are obtained by experimental cyclic plate load test performed on the subgrade soil placed in the experimental box described in section 3.1. All the micro and macro parameters of the different materials are summarized in Table 3.

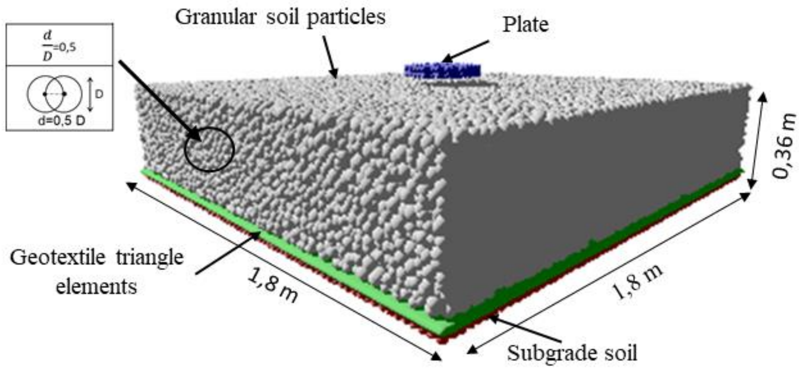

Figure 6: Geometry of the numerical samples

Table 3: Numerical parameters describing the granular platform, soil-GTX interface and the subgrade

Granular platform parameters		
Normal contact stiffness (N/m^2)	K_n	1.0 x 10^9
Tangential contact stiffness to normal contact stiffness	K_s/K_n	1
Micromechanical friction coefficient	$\mu = \tan \delta$	1.1
Peak friction angle (°)	Φ_p	46
Young's modulus (MPa)	E	31
Porosity	n	0.34
Soil-geotextile interface friction parameters		
Angle between the clumps and the upper interface of the GTX (°)	$\Phi_{clumps\text{-}GTX}$	35
Angle between the subgrade and the lower interface of the GTX (°)	$\Phi_{sphere\text{-}GTX}$	25
Lower supporting soil		
Subgrade reaction modulus (MPa/m)	K	5

5 Comparison between experimental and numerical results

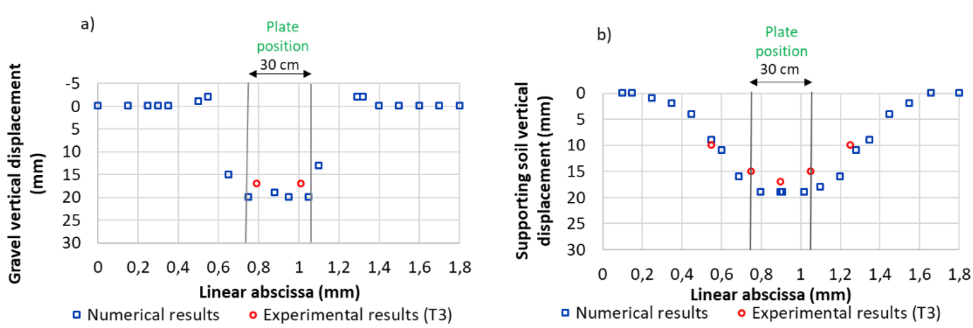

Figure 7: Comparison between experimental and numerical results a) base course surface displacements and b) subgrade surface displacements, both taken at the center of the model

A static load of 40 kN (560 kPa) is applied on a rigid plate placed at the center of granular mattress. The numerical results of the surface settlements of the granular platform and subgrade surface settlements after application of the first loading cycle are compared in Fig.7 to the experimental results (test T3, see section 3). The numerical results match well with the experimental results.

6 Conclusion

This paper presents experimental and numerical studies on a soft subgrade soil reinforced by a geosynthetic layer and granular platform. The experimental studies show the behaviour of two unreinforced base courses with two thicknesses (30 and 50 cm) and geotextile reinforced base with a thickness of 30 cm over the weak subgrade under cyclic loading. The following conclusions can be drawn from this study:

1) The two used geotextiles improve the performance in settlement reduction of the 30-cm-thick reinforced base courses over the weak subgrade as compared with the 30-cm-thick unreinforced base course, but the GTX 1, isotropic and with higher average stiffness at small strain, shows an ability to reduce surface settlement more significant than the GTX2.
2) The GTX1 reduces 30-cm-thick base course surface settlement compared to 50 cm thick unreinforced base course settlement.
3) After removing the initial displacement effect, the performance of GTX1 and GTX2 to reduce settlement at 30-cm-thick base course surface compared the two unreinforced base courses (30 cm and 50 cm) become approximately equal.

Moreover, a numerical tool based on the coupling between discrete and finite element methods is used to study the behaviour of granular platforms reinforced by geosynthetics over a weak subgrade. For the first loading cycle, this numerical tool provides relevant information on the soil surface settlement. The calibration of this model with further number of cycles will provide access to additional information which is difficult to be quantified during the experimentation. This work is in progress.

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