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RESEARCH ARTICLE

New Method to Measure Soil-GCL Interaction

Mustapha Kebaili, *Abderrahim* Bali, *Nabil* Abou-bakr, *Said* Taibi, *Nabil* Kebaili, *Lazazi* Menaa

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Abstract

The present study presents a new experimental technique to measure friction angle between soil and Geosynthetic Clay Liner (GCL). The method in question avoids some deficiencies observed on the inclined plane and pullout tests. Moreover, the technique allows observing the GCL tensile behaviour. The experimental frame is easy to build in usual geotechnical laboratory. The one employed is made-up in civil engineering Department of Ouargla University (Algeria). It is usable for testing both GCLs and other geosynthetic materials. Also, it permits to apply various experimental conditions (like slide velocity, confining pressure and water content) to the tested materials. The present method highlights that the soil-GCL interaction is, actually, a combination of two loading forces: soil-GCL interface friction and pure traction of the GCL material. The obtained results allow evaluating both soil-GCL angle of friction and intrinsic stiffness of the GCL in relation with the confining pressure.

Keywords

Interface friction · geotextile · stretch · GCL · stiffness · experimental model

Mustapha Kebaili
Laboratory EVRNZA, Kasdi Merbah University & ASAG, BP 511, 30000, Algeria
e-mail: m_kebaili@yahoo.fr

Abderrahim Bali
Laboratory of Construction and Environment, High Polytechnic National School, 10 rue hassen Badi, 16200, Algeria

Nabil Abou-bakr
Tlemcen University, EOLE Laboratory, BP 230, 13000, Algeria

Said Taibi
Laboratory LOMC, University of Le Havre & CNRS, UMR 6294, France

Nabil Kebaili
Laboratory EVRNZA, Kasdi Merbah University, BP 511, 30000, Algeria

Lazazi Menaa
Civil Engineering Department, Yahia Farès University, BD de L'A.L.N Ain - D'heb 26000, Algeria

1 Introduction

The implementation of sealing layers, such as GCLs and GMBs, on slope is most often practised in the geotechnical installations of water storage. Waste stocking centres, lagoon basins, dams and hill reserves are examples of such employment. In fact, slope represents existing depression where hold materials (solid or liquid) can be stored.

The installation of GCLs in inclined position requests, obviously, to check equilibrium of these materials, as well as of all the materials and parts related with them. The mechanical equilibrium of the slope with respect to a whole sliding failure is largely treated in soil mechanics. The own equilibrium of GCL is considered as a chief part one of the geotechnical facility itself. Many works [1], [2] sustain that improper evaluation of soil-geosynthetic interaction parameters has yielded to slope failures along that interface.

The common and most essential checks to undertake in relation with the GCL to be set in place are:

- sliding stability of the soil layer above the GCL,
- stability against the pulling up of GCL in anchoring zone,
- tear resistance of the GCL; i.e. tensile strength.

Each of the last two failure mechanisms generates sliding of GCL and protecting soil (together) on the supporting soil layer. In all the quoted cases of failure, the shear strength of soil/GCL interface must be quantified to be taken into account in the design of clay liner waterproofing (or sealing) system. The surface type of the GCL is generally mentioned on the product data sheet (type of material, method of fabrication, roughness, tensile strength, maximum stretch ...). However, the soil set in contact with the GCL varies from a site to another. This imposes to make, for each case, measurements of friction between soil and GCL, represented by an angle noted δ.

The measurement of the δ angle implies adoption of an experimental technique. The chosen procedure leads, all over its methodology, to more or less acceptable results. If, for example, the test conditions are mainly different from those of the site and of the material functioning, the obtained results will be very debatable and often not much accepted. A suitable experimental evaluation of shear strength parameters must imitate the best possible, site specific conditions and the planned structure working conditions. According to [3], factors influencing soil-geosynthetic interface strength are mainly material properties (geosynthetic and soil), testing apparatus (design and size), confining stress and shearing rate. The δ value is, therefore, recognised dependent, among others, on the adopted test procedure.

The most usually practised tests to measure soil/GCL friction angle are [4]: direct shear test, inclined plan test and pullout test. Each of these has some advantages and defects:

- The direct shear test on soil-GCL interface has been investigated by many authors. [5] highlight the scale representativeness defect, as well as that of the GCL stretch. Dimensions of the tested specimens are generally lower than 30 cm x 30 cm which is not sufficient to measure friction for most GCLs and GCL interfaces [6]. To address this limitation, large direct shear devices have been developed for specimens of more than 1m long [7], [8]; however, residual tangential stress may be not reached for some interfaces even after 200 mm of shear displacement [9]. Following to [10] and [11], friction on soil-geosynthetic interface, measured on direct shear test device, is overestimated comparatively to site measurements. Besides, [12], [13] and [14], also conclude for the same conclusion: ‘this kind of test may overestimate shear strength interface parameters’.
- The inclined plan test (also called ramp test) includes some obvious disadvantages. The following points are some examples of such defaults:
  - Considering of the applied normal stress as for constant value in spite of its reduction when the frame is inclined. The higher is the inclination the lower is the applied normal stress on sliding plan. Angle of failure is overestimated due, among other things, to this decreasing of normal stress [15].
  - Crumpling of the GCL at, mostly, downstream part of the sliding container. This leads to overestimate the measuring friction [4] and [16].
- The pullout test is also often used to measure soil-geosynthetic friction angle [17], [18] and [19]. This test is operated on two parallel GCLs to consider the resistance of each one of them as being half of the acquired measurement. [20] attest of non uniformity of stress and strain distribution. Also, friction between the two superimposed GCL layers has been evocated by [21] and by [22].

From experimental point of view, any experience must contain some unavoidable errors. These are acceptable as long as they do not sensibly affect the aimed result. The current method complies with such a situation. Boundary conditions and gripping system of the GCL specimen are examples of such master defaults [23]. Following to [6], the shear strength behaviour of GCLs is more complex than for any other geosynthetic material and proper care must be taken to achieve reliable results.

In this investigation the invented testing board, as well as the test procedures, are detailed. GCL characteristics and soil/GCL shear parameters are acquired.

2 Experimental methods

The new experimental frame is made-up of a container with lower surface covered by non-textured PVC GMB (Fig. 1). The latter is firmly fixed to the lower surface of the container so that its displacement relatively to the container is nil during all the test phases. The lower frontal part of the container is capped with a chamfer to avoid the moving box to thrust against underlying soil layer. The GCL layer to test is sealed to front part of the container, by means of a morsel, and covers all the lower part being sheltered by GMB (Fig. 1). GMB/GCL friction is neglected considering smooth state of the GMB compared to granular soil on the other side of GCL. Following to [4], the great part of tensile force is generated in the GCL. Therefore, when the container is pulled parallel to its base, tensile strength resisting force is almost produced on soil/GCL interface.

Container dimensions are 1 m x 0.5 m x 0.4 m (L x l x H). Therefore, the GCL has a width of 50 cm which is large enough to consider the underneath granular soil as a continuum media [24]. On the other hand, this width size allows observing possible differences between central and edge GCL behaviour. The container length is 1 m. Its height is of 40 cm so as to permit testing with large range of confining pressure (σ_N), fit in with that in practice (up to 50 kPa).

Moreover, in order to measure the displacement of GCL relatively to the vat, four rows of displacement sensors are set on soil-GCL interface at respectively 20 cm, 40 cm, 60 cm and 80 cm from the container upstream edge. Each sensor is made up of a non-stretchable yarn fixed to the down face of GCL (Fig. 1). The yarns go through the GCL, the GMB and the container base. Then they cross the granular material filling the container into thin tubes until to reach the upper part. Each yarn is, then, fixed to a light solid object placed on a horizontal carrier. In such conditions, relative displacement of GCL comparatively to the container corresponds to light solid objects displacement. Fig. 2 shows a simplified scheme of a sensor.

The lower face of the container, covered by GCL, is carefully deposited on the soil to be tested. Thickness of the latter is of 30cm as recommended in regulations [25], [26]. The container is then filled of material as a load charge until to reach the desired normal confining pressure σ_N.

The force-displacement relationship of the container is obtained by fixing-on a load ring and displacement sensor. The load ring is attached, in one hand, on the container and, on the other hand, on speed controlled traction engine (Fig. 1). This testing model allows to measure:

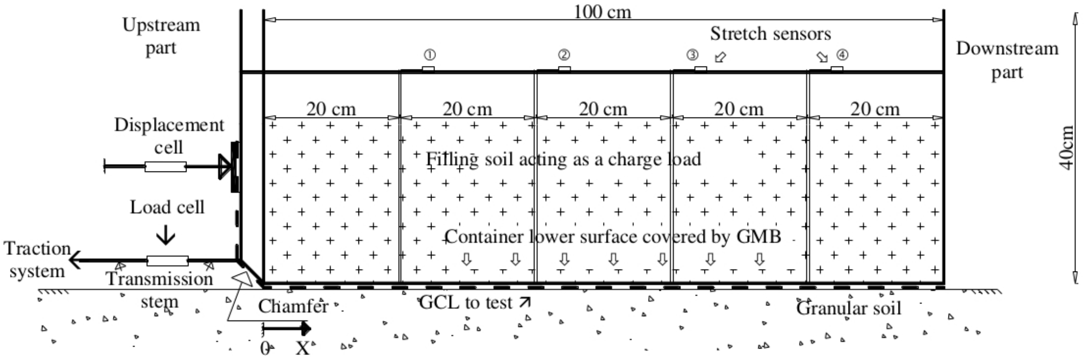

Fig. 1. Overview of the new trial frame

- the total displacement of the container. This is possible by means of the displacement sensor fixed to a stationary support and related to the sliding box. The recorded displacement of the container includes the soil/GCL relative strain and the GCL stretch relatively to the container.
- the tangential force developed between soil and GCL. This is simply read on the load ring, and allows deducing the tangential stress (τ) developed on soil/GCL interface. Friction on the upper face of the GCL (i.e. GMB/GCL interface) is considered small [4].
- the GCL stretch relatively to the container.

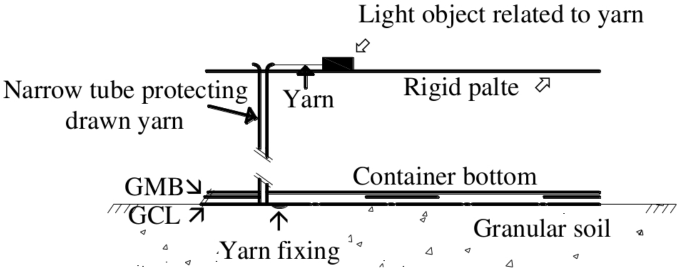

Fig. 2. Yarn system to measure the GCL stretch

3 Used materials

The tested materials are the supporting soil and the GCL. The other used materials, such as the GMB and the loading soil, are considered as props. GMB is set in place to reduce friction on the upper face of GCL [4]. The supporting soil is round gravel containing small quantity of sand. When extracting from field, particles smaller than 2 mm are eliminated. Geotechnical characteristics of this material are summarised in Table 1 and on Fig. 3. Table 2 gives the main characteristics of the used GCL.

The tested GCL is needle punched. The lower geotextile (GTX) is woven, the upper one is non-woven. It is so set in place in the experimental frame with manufacturing sense parallel to the sliding movement. Common physical characteristics have been measured (Tables 1 and 2). The two mechanical characteristics relative to traction are obtained from the product data sheet.

Tab. 1. Physical characteristics of used soil

Morphology: Round sandy gravel	
Physical measured parameters	Result
Dry unit weight: γd (kN/m^3)	16.1
Unit weight of solids: γs (kN/m^3)	26.3
$Cu = D60 / D10$	2.18
$CC = D_{30}^2 / D60.D10$	1.25
Angle of internal friction: ϕ	37°
Classification L.P.C. (U.S.C.S.)	Gm (GP)

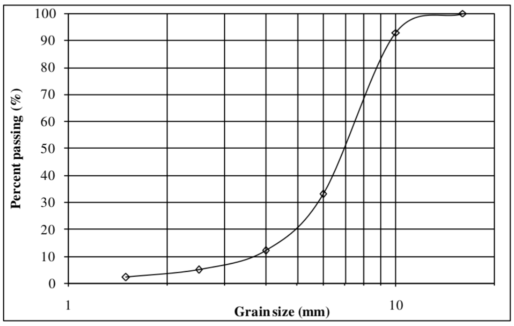

Fig. 3. Grain size distribution of used soil

Tab. 2. Common characteristics of used GSB

Needle punched GCL one side woven, the other non-woven	
Physical measured parameters	Result
Total surface mass (kg/m²)	5.12
Bentonite mass per unit area (kg/m²)	4.35
Thikness under $\sigma_N = 20\,kPa$ (mm)	7.7 to 9.1
Lack of bentonite at cutting (g/ml)	127
Mass of woven geotextile (%)	2.64
Mass of non-woven geotextile (%)	5.92
Mass of needling fibres (%)	5.81
From: Bentofix® NSP 400 data sheet	
Tensile strength (kN/m)	10
Maximum elongation (%)	10

4 Tests and results

Eight tests are performed on the experimental frame. Tensile force and container displacement are read respectively on force and displacement sensors. GCL stretch is measured at the end of tests. Adopted test rate is of 2 mm/min. [6] indicate that dry GCLs show essentially no displacement rate effects. The normal confining pressure (σ_N) varies from 5 kPa to 25 kPa. This permits to simulate wide range of confinement applied by covering soil layer in practice. Contrary to ramp test, σ_N remains constant during all steps of each test.

For every test carried out, the tensile force is recorded at regular steps of displacement of the container. Test is stopped when the maximum tensile force is reached. Fig. 4 shows the relationship between tangential force and displacement for each applied confining pressure. At first millimetres, rapid increase of the tensile force is noticed. The force continues to rise but following more and more weak slope. At relatively large displacement, the force decreases. Maximum force is obtained for a certain displacement depending on confining pressure magnitude. This displacement varies from about 15mm, for $\sigma_N = 5\,kPa$, to 60 mm for $\sigma_N = 25\,kPa$. Fig. 5 shows GCL stretch recorded on each sensor placed at respectively 20, 40, 60 and 80 cm for different confining stresses. We note that for any position, GCL stretch relatively to the container increases simultaneously with the normal confining pressure. Moreover, for any normal pressure, the stretch increases all with the sensor position (i.e. distance from container upstream).Slope of this relationship increases with normal confining pressure.

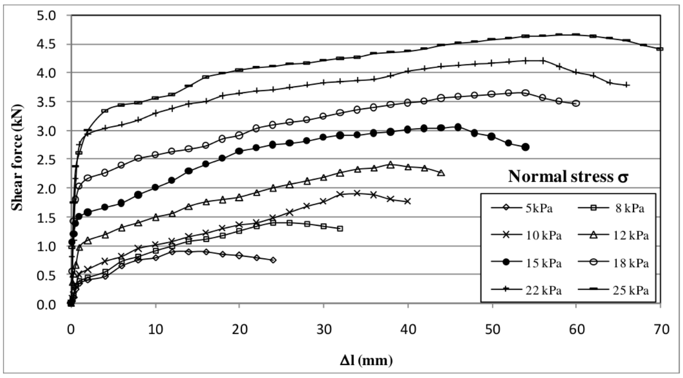

Fig. 4. Tangential force versus displacement of the container

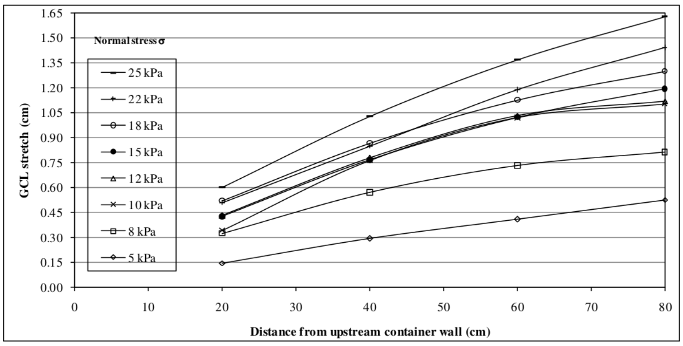

Fig. 5. Stretch of GCL corresponding to maximum tensile force

5 Interpretation of results

5.1 Soil/GCL Friction

According to many authors [27], [28], interface parameters between soils and geosynthetics are usually evaluated using Mohr-Coulomb failure criteria:

$$\tau = c + \sigma N. \tan(\delta) \tag{1}$$

where:

c the cohesion (considered nil)
σ_N the normal stress
δ the friction angle on soil-GCL interface.

Fig. 6 presents maximum tangential stresses in relation with their corresponding normal confining stresses. The curve characterising granular soil beneath GCL is also represented on this figure in extended line.

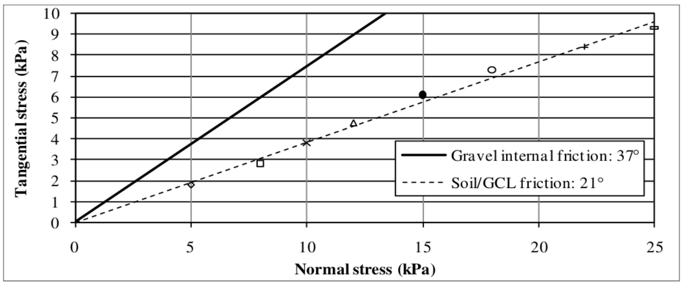

Fig. 6. Obtained results of soil/GCL friction on the new frame and representative curve of utilised soil

Extending of soil-GCL friction curve to zero confining pressure matches with the origin of τ axis. This attests of good precision of sensors used in the experimentation. Soil-GCL friction angle is found of 21°. The ratio of this angle in respect of intrinsic friction of soil is $\delta / \phi = 0.57$.

5.2 GCL Behaviour

Fig. 7 shows the GCL strain along GCL-container interface. This strain is defined as displacement recorded on a sensor fixed at x abscissa divided by the distance up to the precedent sensor. It is reminded that the four stretch sensors abscissas are respectively 20, 40, 60 and 80 cm.

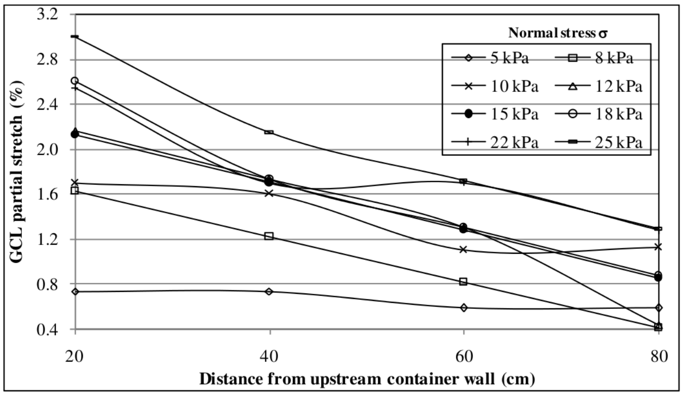

Fig. 7. Partial strains of GCL corresponding to maximum tensile forces

Fig. 7 shows that GCL strain decreases from upstream of the container to downstream. For any abscissa, this strain increases with the confining pressure. Besides, normal pressure seems not influencing the strain fall from upstream to downstream, even if curve slope of $\sigma_N = 5\,kPa$ is almost slight compared to the other curves.

Curves are as close together as the GCL abscissa increases. The extrapolation of curves up to zero strain corresponds to a mean position of 1 m to 1.2 m. This means that whole applied tensile effort is consumed within 1.2 m length of soil-GCL friction. This observation may contribute in optimising the experimental model and also for design of in-situ anchoring cuts.

The apparatus, set-up mainly for explore and measure soil-GCL friction, is also profitable as complement in characterising GCL behaviour. Therefore, Fig. 8 shows variation of tensile force (per unit width of GCL) versus strain recorded on sensors. Stiffness of GCL material being constant, only one curve has to be obtained whatever the position might be. Yet, this is not observed on Fig. 8 which shows different curves for different sensor positions.

This can be understood for that during the container displacement, GCL is not applied for pure traction, but for combination of traction and shear friction on granular soil. The measured tensile stiffness is, then, impeded of shear friction effects. The more the friction grows, the more this parasitic effect is emphasised. The measured friction depends, on the one hand, of GCL surface dealing with (that is sensor position cf. Fig. 9) and, on the other hand, of magnitude of normal confining pressure (Fig. 10).

Following to traction test standards [29], stiffness modulus is obtained with relating $T\text{-}\varepsilon$ origin point to maximum traction value. Fig. 9 shows calculated stiffness modulus versus GCL length relationships for different σ_N values. Fig. 10 expresses stiffness modulus versus normal confining pressure relationships according to GCL part position.

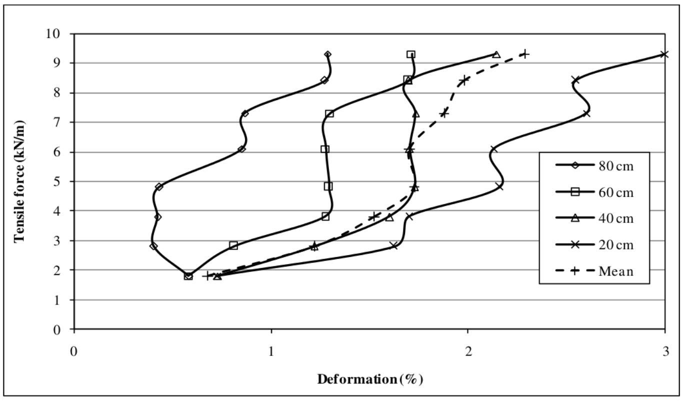

Fig. 8. Maximum tensile force vs GCL strain (80 cm curve not considered in mean curve)

In other words, the measured traction stiffness is more and more impeded from sensor 1 to sensor 4 and, also, when the normal confining pressure increases. For a result, the more reliable measuring of traction stiffness of GCL is that obtained of sensor 1 and for the less confining pressure (5 kPa).

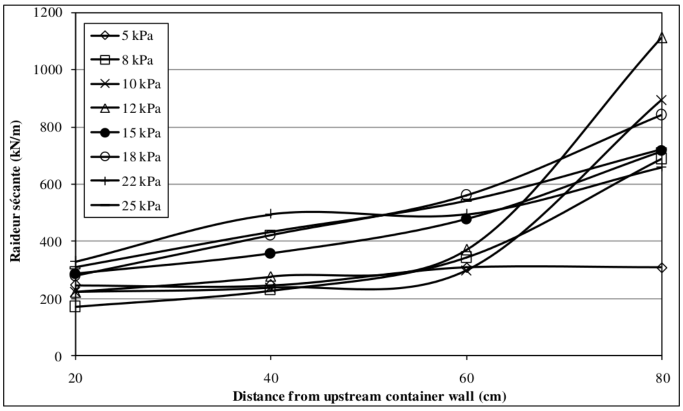

Fig. 9. Stiffness modulus - GCL length relationships

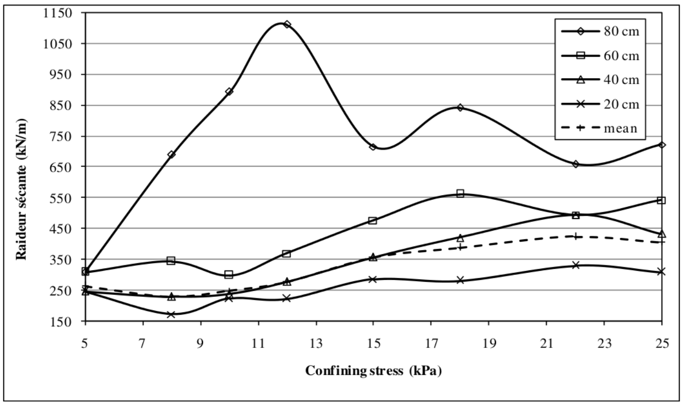

Fig. 10. Stiffness modulus vs normal confining stress (80 cm curve not considered in mean curve).

6 Conclusions

The proposed experimental model is of simple design. It is easily made-up for laboratory and in-situ applications, and on horizontal or inclined soil surfaces. This device allows evaluating soil-GCL friction and tensile strength in actual conditions.

The test procedure permits, in one hand, to measure soil-GCL angle of interaction and, on the other hand, to quantify the intrinsic stiffness of GCL against traction. The obtained results attest that the load applied to GCL tested specimen is a combination of straight traction and shear on soil-GCL interface and on GCL-container interface. Tensile behaviour is predominant in upstream part of GCL (i.e. small lengths), while shear behaviour on interfaces occurs noticeably in downstream part of GCL (i.e. relatively higher lengths).

The test procedure is conceived as to avoid some disadvantages known on other experimental techniques such as:

- wrinkles of GCL noted on ramp test. This increases the soil/GCL friction relatively to real situation,
- friction of GCL with other parts of the apparatus apart from the soil,
- decrease of confining stress during the test.

Consequently, the presented method simulates the soil-GCL sliding in manner close to site reality insofar as the ground slope remains constant.

Moreover, the experimental model permits measuring soil-GCL friction with taken charge of various parameters such as humidification, drainage conditions, geometrical sizes and rate of traction. It also allows checking observations made on other techniques: stretch of GCL during slide, decreasing distribution of tensile stresses and strains from upstream to downstream, zero cohesion on soil-GCL interface, etc. The obtained results may amend geotechnical actions such as anchor dimensioning and design of slops covered by GCL.

At last, the presented experimental model is evolving and parameterisable. It aims at contribution to improve existing techniques and standards, and also to provide profitable experimental data base allowing validation of soil-GCL behaviour models.

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