Frictional Behaviour of Geosynthetics and Slope Stability of Lining Systems

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ABSTRACT: Studies carried out by several French laboratories on the frictional behaviour of geosynthetics in order to define a design method for slope stability of lining systems are described in the paper. The work programme, which has lasted since 1990, consisted of laboratory friction tests (large-scale shear boxes and inclined plan board) and of the improvement of an existing computer programme.

1 INTRODUCTION

The use of geosynthetics inside composite structures for the lining of domestic and industrial waste disposal facilities is widely spread in many countries and is growing in France. The design performance of such systems relies partially on the knowledge of all stresses suffered by the geosynthetic(s) during installation and throughout its/their lifetime(s), particularly on slopes.

Comparative tests have been performed by several French laboratories to analyse the different ways of measuring the friction angle between soils and geosynthetics and to assess the behaviour of the interfaces between these materials. Large-scale shear boxes and inclined plan boards were used for the laboratory friction tests performed. At the same time, studies were developed to improve a classic computer programme for slope stability analysis making it easily useful for geomembrane lining systems on slopes.

The first results of this work programme were published by Matichard et al. (1991). The tests performed, using 3 types of shear boxes and 2 inclined plan boards, dealt with the measurement of the friction angle between a standardized sand and four types of geomembranes for a range of normal, low stresses (0-25 kPa). Their results enabled the performance of a stability parametric analysis of the geomembrane lining systems on slopes using the ETAGE software. The continuation of the research programme, which is described in the present paper, dealt with the following points : use of a fourth shear box, use of new soils, analysis of the influence of various test parameters, improvement of certain instruments and improvement of the software.

2 EXPERIMENTAL STUDY

2.1 Materials tested - Apparatus used (improvements)

Among the soils used, the results given in this paper concern a 0.08/2 mm standardized, rolled sand, a sandy clay (including 44% of elements with a particule size under 80 µm, plasticity index Ip equal to 14 and optimum moisture content - W_{OMC}- equal to 16% determined at the normal Proctor energy) and a 0/25 mm crushed gravel. The sand and gravel were used dry ; the clay was subjected to tests with several moisture contents. These soils were compacted at 92 to 97 % of the maximum dry density obtained at the normal PROCTOR test.

The new tests concern 3 types of geomembranes : Bitumen (4 mm thick ; 1 smooth side and 1 rough side), HDPE (1 to 2 mm thick) and PVC (0.5 to 1.2 mm thick). Friction measurements of geogrids - geomembranes are also presented (3 types of geogrids with surface patterns of 1.6 to 5 mm in height).

5 apparatus were previously described by Matichard et al. (1991) ; in this paper, they are named :

- C1 : classic shear box - 10 x 10 cm (LRPC NANCY) ;
- C2 : half-box (25 x 25 cm) sliding on a rigid plane, with controlled shear stress rate (LRPC NANCY) ;
- C3 : classic shear box - 30 x 30 cm (CEMAGREF AIX) ;
- P1 : inclined plan board composed of a box sliding on a 50 x 50 cm rigid plan board (LRPC NANCY) ;
- P2 : incline plan board composed of two 100 x 100 cm boxes (CEMAGREF BORDEAUX).

A sixth apparatus was used for the present study ; it is the half shear box (25 x 40 cm) built by IRIGM in Grenoble, named C4. In this installation, the geomembrane is stuck on the rigid base which is subjected to a tensile stress ; the stresses dealing with the central zone and the lateral zones can be measured separately (Gballou, 1991).

The following improvements were made on various materials : installation of a distribution membrane of the normal stress on the C3 and C4 shear boxes ; on the P2 inclined plan board, possibility of keeping the angles of the upper box empty, of automatic monitoring of the measurements and of possibly measuring the strength required for retaining the upper box.

2.2 Influence of various test parameters

For data analysis, it should not be forgotten that the angle measured with the inclined plan board is a slippage angle ; the comparison between the two types of tests (shear box and inclined plan board) was made in the MOHR plane.

2.2.1 Temperature (inclined plan board)

Tests performed at a low normal stress (3.5 kPa) using the P2 inclined plan board for the HDPE and the Bitumen (smooth side) geomembranes placed between the 2 boxes filled with sand did not show any significant deviation of the slippage angle in function with the temperature of the tests. For temperatures of 7° to 35°C, the deviation on the slippage angle did not exceed 1 degree : the slippage angles obtained were respectively 22° and 23° (HDPE) and 25 and 24° (Bitumen).

2.2.2 Rate of displacement (Box C4)

For example, tests conducted at rate of displacement of 1 mm/min and 6 mm/min between the rough side of a bituminous geomembrane and the sand showed that the friction angle increases with the rate (1.5 degree in this case).

2.2.3 Distribution of the normal stress (C4 box and P2 inclined plan board)

For the test with the inclined plan board, at the time of the slippage, the normal stress imposed on the geomembrane by the upper box is higher than the average value in the part below and lower in the part at the top ; in order to analyse the influence of better distribution of the normal stress, the lower and upper angles of the upper box were maintained empty by a shuttering at 26.5° (average of slippage angles) for several tests. For these tests it is noted that the slippage angle measured is higher by 1 to 2 degrees, namely when the stress on the geomembrane is assumed to be more uniform. This deviation increases when an overload is placed on the floor of the upper casing. This variation of the slippage angle could be explained by a hyperbolic shape of the "shear stress - normal stress" curve like the one proposed by Giroud et al. (1993).

In the case of the test with the shear box, poor distribution of the normal stress on the geomembrane during the shearing was reported ; to compensate for it, a membrane filled with fluid was placed between the application device of the normal stress and the soil ; as for the incline plan board, it can be observed that the friction angle is higher by 2 to 3 degrees when the normal stress is distributed better.

2.3 Examples of results obtained - Comparison shear box - inclined plan board tests

2.3.1 Sand - geomembrane interface

Most of the results concerning the case of normal stresses under 25 kPa were provided by Matichard et al. (1991) ; two complementary tests made with the P2 incline plan board and the C4 shear box for the HDPE confirm the first results obtained. The values of the friction angles measured with the various apparatus are close with a deviation under 2 degrees ; the average values are equal to 25° for the PVC, 24.5° for the HDPE and 38.5° for the Bitumen (rough side). The exceptions reported particularly corresponded to a test with box C3 for the PVC and a test with incline plan board P1 for the Bitumen (rough side). The first case confirms the difficulty of measuring the friction angle for normal stresses under 25 kPa with a shear box designed for reaching normal stresses exceeding 1 MPa ; the second case shows that the use of the incline plan board must be limited to the low normal stresses (10-15 kPa).

In a range of normal stresses from 25 to 200 kPa, the friction angle obtained with the large-scale shear boxes is close to the values given above for the HDPE (25.5° - box C4) and slightly lower for the PVC (21.5° - box C3) and the Bitumen (34° - rough side - box C4).

2.3.2 Clay - geomembrane interface

Few tests pertaining to this type of interface had been performed in France prior to this study ; these tests are important since the clay - geomembrane contact is quite frequent in waste disposal facilities.

Some tests were made with the P2 incline plan board and the C3 shear box. With the incline plan board, for a normal stress equal to 3.5 kPa, the values of the slippage angles range from 28° (HDPE - clay compacted at $W_{OMC}+3$), at

30.5° (PVC - clay at $W_{OMC}+3$) and at over 40° (rough side Bitumen - clay at $W_{OMC}+3$). A complementary test, made by wetting the surface of the clay compacted at $W_{OMC}+3$ by spraying, demonstrated a particular behaviour of the interface (Fig. 1) : whereas the slippage is brutal for the materials without cohesion, dry, in this case, a progressive slippage was observed as from a 30° incline, and at 45° (test stopped), the failure was not observed .

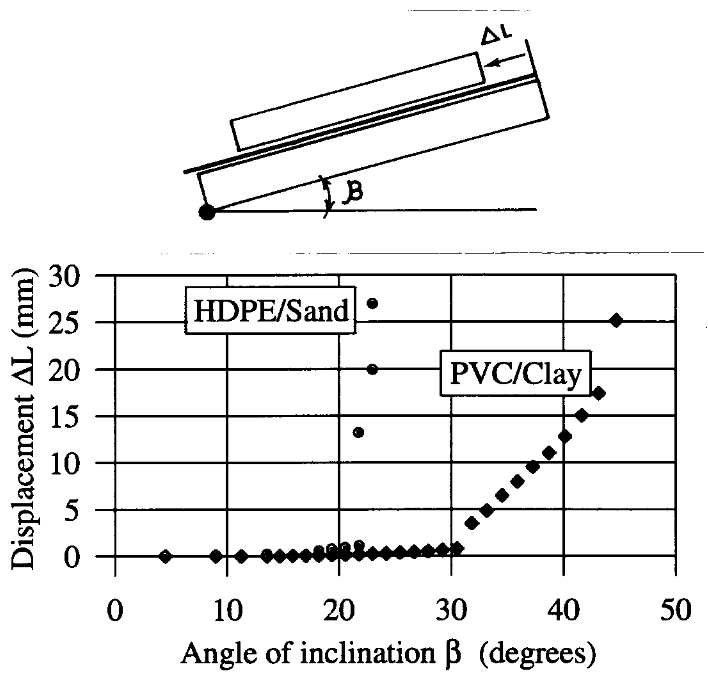

Fig. 1 Displacements measured at two interfaces with an incline plan board (P2)

For the clay compacted at W_{OMC}, the shear strength measured with the box is rather high with strong cohesion (24 to 36 kPa) and a friction angle of 16 to 18.5°; in the case of the clay at $W_{OMC}+3$, the resistance decreases with a low angle (7°) and a cohesion of 21.5 kPa.

2.3.3 Other interfaces

Tests pertaining to the "PVC and HDPE - geogrid" interfaces conducted with the C4 box demonstrated that the friction angles were from 19 to 20° for the PVC and from 16 to 17° for the HDPE.

Geomembrane - geotextile tests were also performed.

The measurements made on the PVC - crushed gravel interface produce an angle 5 to 7° over that measured with the sand for the two types of tests.

2.4 Assessment of the experimental study

The present study contributed to the development of 2 French standards that define an identification test with the shear box (NF P 84 - 505) and a performance test with the incline plan board (NF P 85 - 522).

These 2 tests appear to be complementary as far as the normal stresses applied are concerned (see paragraph 2.3.1). The results provided previously only constitute examples specifying the ranges obtained for the friction angles of the various interfaces. They can obviously not be applied to a given project, as each structure is a special case requiring specific tests for taking into account the real soils, their implementation and the geosynthetics used.

The research work carried out made it possible to specify certain test parameters (temperature, test rate, distribution of the normal stress) and to suggest an evaluation method of the friction characteristics between soils or geosynthetics in contact with a geomembrane. Nevertheless, for the study of the behaviour of geomembrane - clayey soil interfaces, a larger number of tests should be scheduled to specify the influence of the rate of displacement and of the moisture content of the soil : the first tests performed (paragraph 2.3.2) have shown a different behaviour than those observed for non-coherent soils. Also, additional studies should be planned concerning in particular the compacting of soils above the geomembrane (possible penetration of the soil).

Lastly, the aptitude of the incline plan board for dealing with clayey materials remains to be confirmed ; in this case, the comparison with the shear boxes is difficult.

3 ETAGE SOFTWARE

3.1 Presentation of the software

ETAGE software, developed by the "Laboratoire Central des Ponts et Chaussées (LCPC)", has already been presented by Matichard et al. (1991). It is based on the computation software of PETAL slope stability that uses the method of perturbations and enables computation along non-circular surfaces of failures.

ETAGE software was developed for the study of the stability of geomembrane lining systems. It can take into account several layers of geomembranes, geotextiles and related products and soils, a possible overload (waste) as well as the hydraulic conditions and the friction characteristics of the various interfaces. The computation provides the factor of safety for each failure surface considered ; the software also indicates the presence of possible heavings due to uplifts and, in the case of an instable interface, it computes the complementary force that must be taken up at the top of the slope to ensure stability, in function with the factor of safety chosen.

The improvement of the ETAGE software, during the present study, dealt with taking into account hydraulic conditions and the computation of the possible anchorage force, as these two moduli gave rise to problems in some particular cases ; the determination of circular endings of the slippage plane were defined more accurately so as to obtain the minimum factor of safety more rapidly.

3.2 Computation validation

The results provided by the modified ETAGE software were first compared to those obtained with two existing manual methods (Giroud et al., 1989 ; Koerner et al., 1991) ; the three methods were applied to the designing of the lining system of an experimental cell of the MONTREUIL/BARSE waste disposal facility. This structure had been chosen because anchorage force measurements were foreseen and they should have been available during the present study to validate the software but due to delays in the achievement of this experimental structure, we do not have this data at present.

The slope of the cell concerned, composed of compacted sandy clay, has a height of 5.5 m and a slope of 1/1 ; it has a 1 m wide berm placed at 1.5 m above the bottom. The lining is ensured on the slope by a 1.5 mm thick HDPE geomembrane covered by a geotextile and a 20 cm thick layer of sand (Φ= 40°; c= 10 kPa). Tests performed with the P2 incline plan board made it possible to measure the friction conditions on the interfaces : Φ clay/HDPE = 28°; Φ sand/PEHD = 30.5°. For the protective geotextile, the following values were adopted for the computation : Φ geotextile/HDPE = 20° ; Φ sand/geotextile = 30°. For the three methods, only the case of the slope above the berm, before filling with the waste, was instable and called for taking up an anchorage force on the crest. The values of this force to be taken up by the geotextile, determined by the three methods, are very close : 4.2 kN/ml (ETAGE), 3.7 kN/ml (Giroud et al., 1989) and 4 kN/ml (Koerner et al., 1991). This result remains to be validated on the real data resulting from the experimentation as soon as it is available.

The ETAGE software was then applied to the case of a slippage which occured on a 15-m high dam (Girard et al., 1990) with a slope equal to 1/2.5 on which a lining system was installed composed of a PVC geomembrane. The geomembrane was separated from the main part of the backfill by an unwoven geotextile and a 20 cm thick layer of crushed gravel; it was covered by the same materials at the time of slippage. The following characteristics of shear strength were measured : Φ geotextile/PVC = 25° (test with incline plan board on the interface at the seat of the slippage) ; Φ gravel = 35°. The geomembrane and the upper geotextile were anchored at the crest by means of a pile of gravel corresponding to an anchorage force of 8 kN/ml. In these conditions, the ETAGE software indicates that the friction angle with the PVC/geotextile interface must be approximately 20 to 21° in order for the force exerted by the existing anchorage to be reached. This computation does not completely explain the slippage observed but it may make it possible to evaluate the accuracy of the method and the range of the factors of safety to apply for the designing of a structure.

4 CONCLUSION

The results of the present work programme primarily deal with the existence of more accurate laboratory tests defined for a wider range of materials and normal stresses. Data provided by these tests are generally suitable for use in an improved computer model and for forecasting the safety factor of lining systems on slopes.

The research programme is to be continued in the laboratory, in particular for the case of clayey materials, and in situ by measuring the anchorage resistance of the geosynthetics placed on the slopes of the experimental site, in order to complete the validation of the computation software.

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