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EXPERIMENTAL AND ACTUAL USE OF GEOTEXTILE REINFORCEMENT OF A SLOPE

EXPERIMENTELLER UND TATSÄCHLICHER EINSATZ VON GEOTEXTILIEN BEI DER SICHERUNG EINER BÖSCHUNG

STABILISATION DE TALUS PAR RENFORCEMENT TOUT TEXTILE: OUVRAGES EXPERIMENTAL ET REEL

The early application in France of the geotextile reinforcement method in soil reinforcement is up to 1971 on A 15 motorway when horizontal layers of fabric were incorporated in soil as reinforcing element.
Since, others structures were constructed with various methods of design and construction techniques.
In 1984 an experimental embankment is constructed by the Laboratoire Central des Ponts et Chaussées aimed to appreciate the theoretical and practical design aspects. This paper reports on results from this experiments with informations on construction technique (mobile shutter, cubic pillow...) and observations on the deformation behaviour of the structure. It is completed by an application on site. The new technique developped in this case is the only-use of geotextile as reinforcing elements and facing unit wall (cubic pillows). Experience shows that this construction technique is a good response to produce economic structure of esthetic appeal.

INTRODUCTION

It has been demonstrated that geotextile-reinforced earth method can be an interesting construction technique. In the case of the geotextile-reinforced earth-retaining structures or reinforced embankment slopes, advanced developments of this applications necessary involve the improvement of appropriate construction method, the possibility of use of local materials and the better requirements for geotextile fitted for purpose.

Consequently, the Laboratoire Central des Ponts et Chaussées (FRANCE) was carried out at Rouen an experimental embankment in order to investigate the reinforcement mechanisms and the construction procedure. A construction procedure based on cubic gabion arrangement was used. Gabion arrangement was provided in this case the shutter and the face wall during and after the construction period.

Experimental investigation was followed by an application on the site of TROUVILLE SUR MER.

A - EXPERIMENTAL EMBANKMENT OF ROUEN

Since 1971, when was constructed the first geotextile reinforced structure (1), others similar structures were realized. However, according to various placement technologies and design methods used, many difficulties have been encountered, particularly the esthetic appearance.

The aim of experimental embankment is to point out a comprehensive knowledge of reinforcement mechanisms and to study some specific construction problems.

A-1- Description

Four test sections of 10 m length each were realized (photo 1). Each test section presented a 45° inclined slope and a vertical slope. The feature of this experimental embankment was the use of a weak soil at wet condition for fill material (figure 1).

photo 1 : Experimental embankment of Rouen : slope angle of 45°

Materials used

The soil tested is a loam with the following properties:

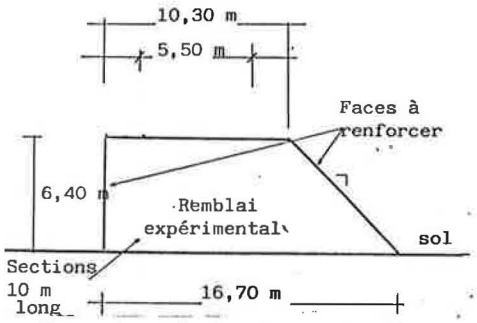

figure 1 : Embankment cross-section

Triaxial test results

C' =	0
Ø' =	30°

(CD test-Degree of compaction = 0,94 of max dry density)

Soil properties

W_L	30
W_p	20
I_p	10

Max dry density
γ_d = 18 kN/m^3
(standard Proctor Test)
Optimum moisture content
W = 14 %

Four geotextile types were tested in this investigation:
- a woven geotextile of polypropylène fibrilated tapes UCO 44 614
- a woven geotextile, closely-woven polyester TER 2013 R
- a woven geotextile, open-weave STABILENKA AJOUR 135
- a needle-punched non-woven geotextile bonded onto a polyester grid BIDIM R 2224

	α_f kN/m	ε_f %	module J(kN /m)	masse surf g/m^2
UCO 44 614	90	9 %	1000	500
TER 2013 R	120	17 %	700	300
STA AJOUR 135	130	11 %	1100	290
BD R 2224	70	15 %	450	500

Laboratory tests were achieved to determine the short term soil-geotextile coefficient of friction. Figure 2 gives test results. It is shown that one of geotextile was presented a low adhesion upon the saturated loam.

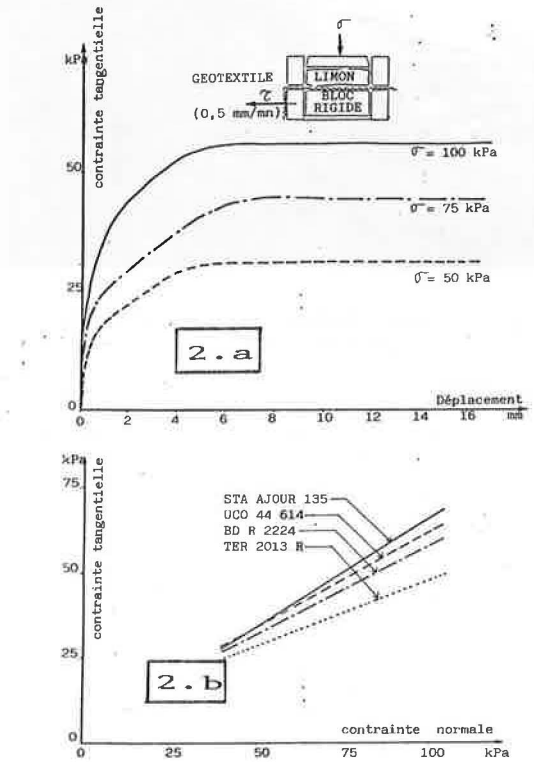

figure 2 : Friction test results
a - Typical curves : Force-displacement relationship of BD R 2224
b - Comparative test results

Design method

For design calculations, the thickness of the layer was fixed and equal to 0,80 m, according to specified compaction criteria for fill embankment and earthworks. Design with different method of analysis was achieved (2).

The results indicate a theoretical rate of tension developing in the reinforcement geotextile (the lowest mat) of :

	theoretical rate of tension
BD R 2224.....	35 % of the
TER 2013 R.....	27 % breaking
STA AJOUR 135.....	27 % load
UCO 44 614.....	30 %

Calculation was based on the long term triaxial test results of loam (C' = 0 kPa, Ø' = 30°). To take account of the geotextile anchorage at the fabric-soil interface, a coefficient of 0,67 was be applied to the tg Ø' value.

Instrumentation

All the test sections were instrumented (figure 3).

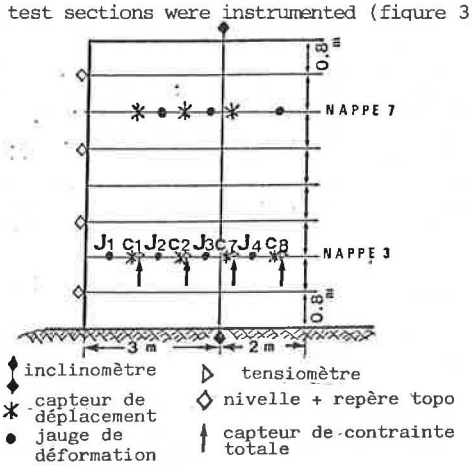

figure 3 : Vertical side-slope : location of the instrumentation

The observation and measurements were concerned with :
- the deformation characteristics of embankment by means of :
  * bench-mark
  * inclinometer
- the internal stability by means of :
  * displacement transducer focused at the Rouen Laboratoire des Ponts et Chaussées. Transducer was attached to the geotextile mat by sticking and bolted joint (photo 2)
  * strain gauges TOKYO SOKKI YL 60 large deformation (the calibration procedure was realized under the standard NF G 38014)
  * Glötz pressure cells
  * tensiometer : measurements of positive or negative pore water pressure.

A-2- Construction (3)

Three construction methods were tested in this experimental investigation (figure 4).

In the case of two sections BD R 2224 and UCO 44614 it was used a standard placement technique (type a) as it is shown in the diagram of the figure 5 :

mobile shutter hold by textile straps.
Two types of mobile shutter were used according to slope angle (photo 3).

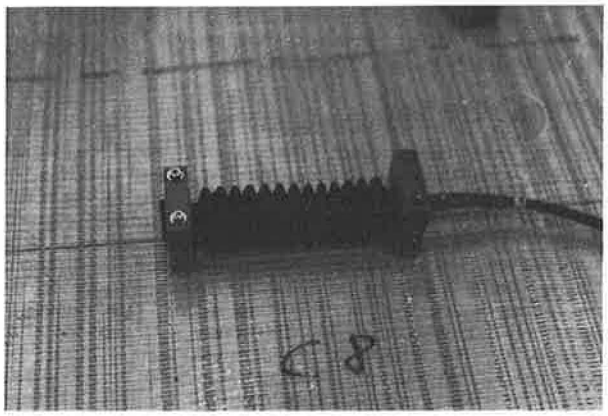

photo 2 : LCPC displacement transducer

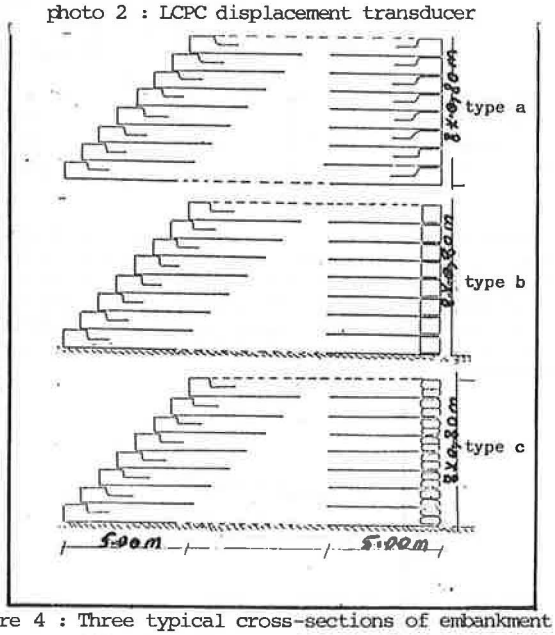

figure 4 : Three typical cross-sections of embankment

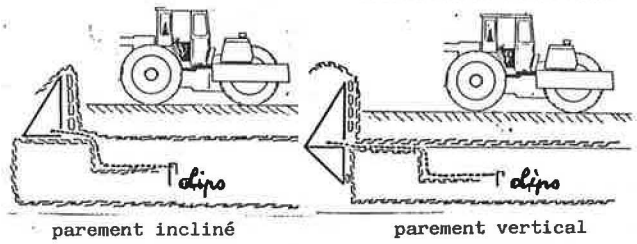

figure 5 : Standard technique : type a

In the case of the two others sections TER 2013 and STABILENKA AJOUR 135, the standard placement technique was used for the inclined side-slope construction and two special techniques were performed for the vertical facing construction. The latter consists of pillow and gabion arrangement playing the role of "shutter and facing" (photos 4 and 5).

photo 3 : Mobile shutter hold by textile straps (inclined side-slope)

The advantage of this method (types b and c) is to furnish the need of shutter during the placement stage (figure 6) and the permanent facing units of the wall at the completion of the embankment construction. This procedure was allowed to realize high fill embankments without contact of the underlying subsoil.

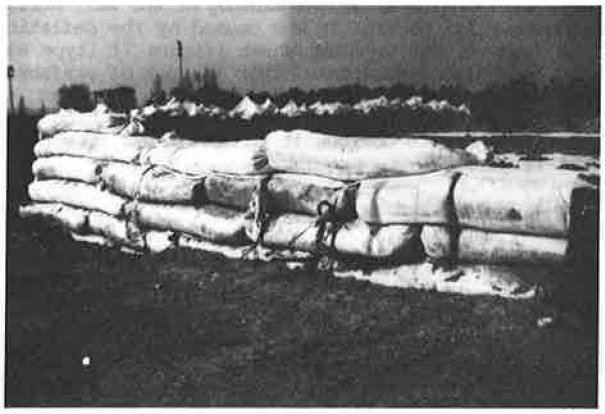

photo 4 : "Shutter and facing" : elongated-shaped container (ENKA procedure)

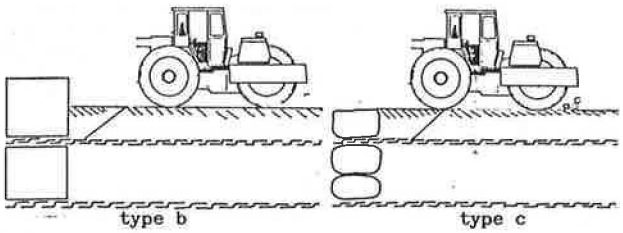

figure 6 : "Shutter and facing" construction procedure in the case of the vertical facing
Type b : Cubic container
Type c : Elongated-shaped container

photo 5 : Cubic container

Control at placement

The density and moisture content measurements are realized after each soil layer was laid and compacted. The results shown a compaction degree of 92 % to 95 % of the maximum dry density (standard Proctor test) and a range of moisture content of 19 % to 21 % (Optimum moisture content + 5).

In the case of the vertical slope, the levelling measurements were displayed an overturning of the wall during the construction period. It was caused by the deflation of the edge of the layering sheet (figure 7) (type a). It has been also demonstrated that the use of prefabricated textile gabions was provided a good manner to solve this problem. In other respects, the gabion must be well designed to obvious it to move under compaction effort (figure 8).

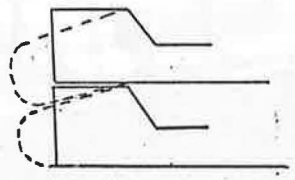

figure 7

A-3- Internal stability control

Displacement

Strains recorded show that a large part of total deformation of geotextile was developed during the construction. The reason of these displacements, which were raised to about ten centimeters near the vertical facing, was explained in the diagram of the figure 8.

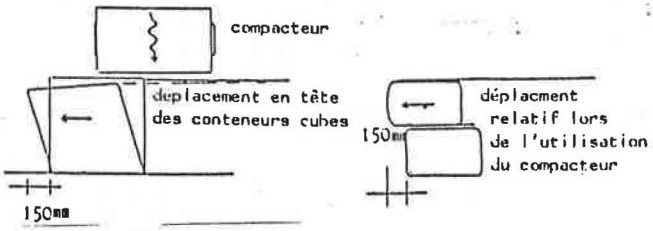

figure 8

In the case of the test section equiped with the lowest adhesion geotextile (figure 2) it was observed a slip displacement of geotextile within the soil (for the lowest geotextile mat) caused by a low degree of the mobilization of the short term geotextile-soil friction. The geotextile used has not allowed to dissipate the excess pore water pressure generated by compaction effort and overburden pressure.

Relative deformation

It has been noted that the displacement transducers (photo 2) were more suitable for the measurements of geotextile deformation while the strain gauges were often rendered inoperative at the placement stage. For the latter, a scattered difference between imposed strain deformation and measured deformation has been occured during the laboratory calibration test. Figure 9 gives the rates of relative deformation of the geotextile sheets n° 3 measured in the case of vertical face (figure 3). The following table summarizes maximum elong eltaon measured values and calculate tensile force based on the stiffness value of geotextile at the laboratory tests.

	Déformation maximale ε %	Tension maximale kN/m	Pourcentage de la force de rupture
UCO 44 614	3 %	30	33 %
TER 2013 R	3 %	21	18 %
STA AJOUR 135	2,7 %	29	22 %
BD R 2224	2 %	9*	13 %

* Calculate tensile force developed in the BD R 2224 was probably under-estimated. The comparaison with the tensile force developed amont the steel reinforcement used in reinforced earth indicates that the take-up load in the two cases was comparatively close while the stiffness of steel strips bed was 50 times as high as the stiffness of geotextile.

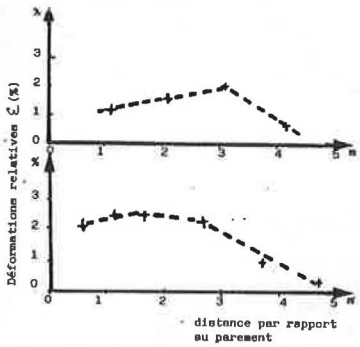

figure 9 : Relative deformation measured (geotextile mat n° 3 - vertical face)

Pore presures analysis

As it may be seen previously, an excess pore water presure was generated during the placement of the wet and plastic loam (coefficient of permeability of 10^{-9} m/s and in-situ moisture content near to the plastic limit W_p). Then it was measured, at the completion of embankment construction and at 4 m depth a pore water pressure value of 60 kPa. The ratio of the pore water pressure to the overburden pressure of 86 kPa was of 0,70. A year after, this ratio was decreased to 0,35. The tensiometer measures near of two geotextile sheets (figure 3) indicate the influence of geotextile

type. At 3,50 m from the wall face (figure 10 a) and in the case of STA AJOUR 135 section, positive pore water pressure of 20 kPa was observed at the completion of construction embankment it was dissipated in 350 days. For the same location and in the case of BD R 2224, negative pore water pressure was measured at the end of the construction period. The dissipation of excess pore water pressure was achieved by the non-woven geotextile during the construction period. At 2,50 m from the wall face, no significant differences in pore water pressure were observed (figure 10 b). At 1,50 m from the wall face (figure 10 c), the pore water pressure recorded values were greatly depended on the draining proportie of geotextile tested. In the case of the non-woven geotextile BD R 2224 with high coefficient of permeability, its contribution to the stability of the reinforced mass was concerned with :

1) the decreasing of the pore water pressure within the soil and consequently the increasing of its shear strength τ. ($\tau = C' + (\sigma - u)\ tg\ \phi'$)

2) the improvement of the geotextile-soil adhesion when excess pore water pressure can be rapidly dissipated.

In this way, the difficulties encountered and caused by an excess pore water pressure can be overcome in using the geotextile with high mechanical strength and high coefficient of permeability.

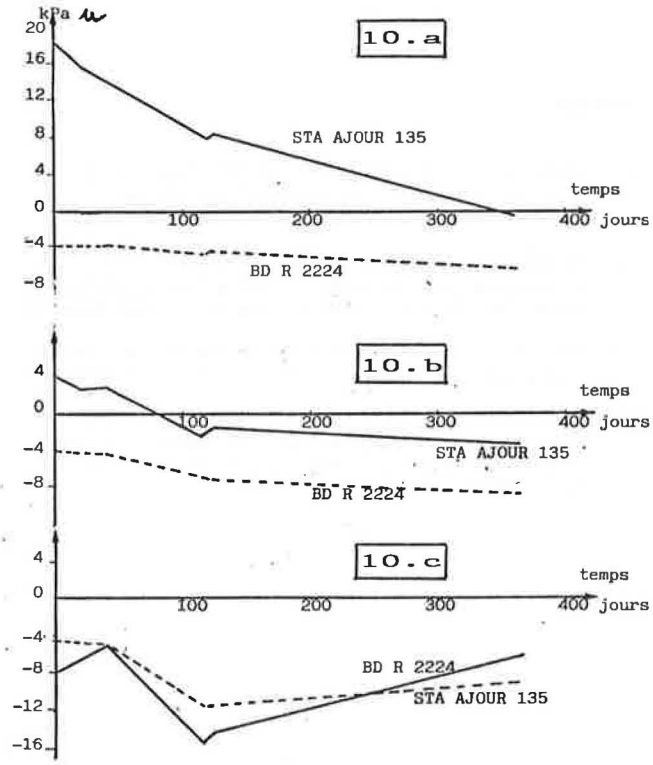

figure 10 : Pore water pressure recorded near of the geotextile sheet n° 3
a - at 3,50 m from vertical face
b - at 2,50 m from vertical face
c - at 1,50 m from vertical face

B - APPLICATION ON SITE : EMBANKMENT OF TROUVILLE SUR MER

B-1- Description

Slope stability analysis and calculations in the case of a draining mass provided a factor of safety of 1,50 m. It has been adopted the geotextile reinforced slope embankment technique with using local material for fill embankment (figure 11) (dredged sand from the Rivière TOUQUE). Cubic container procedure as it may be seen previously was used for construction.

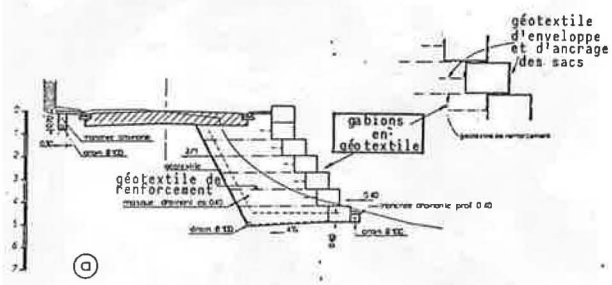

figure 11 : Wall face

Design procedure

Design calculation was based upon the standard method (2). The reinforced block presented two zones (figure 12). The active zone which attempted to slide but was retained by geotextile sheets and a passive zone which sustained the geotextile sheet anchor. In this case, the locus of the maximum tensile strength was the Rankine failure line. The theoretical rate of tensile force developed within the geotextile was of 20 % of the breaking load. The required length of the layering sheet (4 m) was determined according to the overturning stability analysis.

Test procedure

Control tests were performed on the reinforcement geotextile under the standard NF G 38014 :

	UCO 44 614	woven geotextile
. Mass per unit area		550 g/m^2
. Breaking load		96 kN/m
. Coefficient of geotextile-soil friction		$tg\ \phi'_G / tg\ \phi' = 0,8$

ϕ'_G : angle of geotextile-sand friction

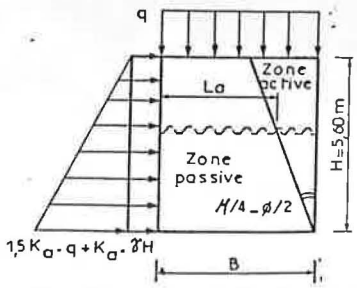

figure 12 : Principle of the design method

B-2- Construction

Embankment construction was split up into three steps :
- At the first stage : filling the gabions with sand and its stockpiling near the construction site.
- At the second stage : excavation and preparation of bedding course for gabions.

- At the third stage : construction of the reinforced-soil structure by laying of a 0,70 m thick each of soil. The construction of this embankment of 60 m length and 5 m heigth was taken one week (photo 6).

photo 6 : Placement : layering anchor sheets with cubic gabions to form the wall face

This manner of stepped construction was revealed as a great interest, according to the ease and the high speed of construction.

For this type of structure, it has been shown that the technique and construction method used was allowed to realize a wall face in good esthetic aspect (photo 7).

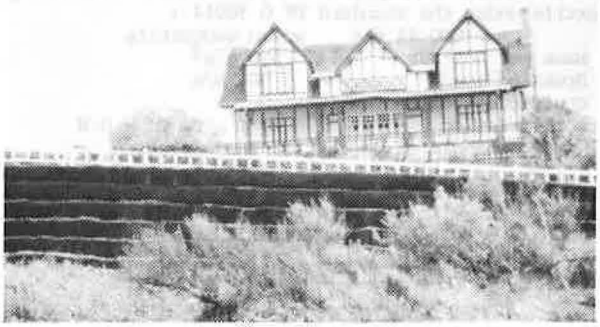

photo 7 : Embankment of TROUVILLE-SUR-MER

B-3- Conclusion

The geotextile reinforced slope embankment technique used in the case of slip failure of the Trouville-sur-Mer cornice was contributed to a low-cost structure with a satisfied esthetic appearance. The use of cubic gabions to form the wall face were allowed to dispense with the shutter, and can be considered as an original procedure.
This type of reinforced structure were advisable in order to reduce the land required for constructing the embankment and in the case of retaining wall structures.

C - AN ADVANCED TECHNIQUE

The construction of the ROUEN and TROUVILLE-SUR-MER embankments made the following may be concluded.

* Marginal or locally available soils can be used for fill materials. The range of suitable soils was wider than those specified for others techniques. However attention must be paid in the case of the use of weak soils. Laboratory test must be performed to measure the geotextile-soil adhesion characteristics at in-situ conditions.

* The cubic textile containers were shown as very interesting for the placement and the construction method of the geotextile reinforced embankment and its contribution to the general appearance was to be confirmed.

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