GEOMEMBRANE LINER SYSTEMS ON SLOPES IN NAVIGABLE CANALS: ON-SITE EXPERIMENTAL STABILITY STUDY

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ABSTRACT: The experiment presented here is part of some general studies of the stability of Geomembrane Lining Systems (GLS) on slopes. The aim is to monitor, taking the example of a navigable canal, the behaviour of three types of protection anchored at the top of the slope: metal gabions, concrete blocks fixed onto a reinforcement geotextile, and concrete blocks held in place by metal cables. Measurements of the anchor forces required and the water pressure under these protections over a period of ten months are given. These measurements show that the method of determining friction angles at the interfaces on an inclined plan is satisfactory and that the most unfavourable case for determining the anchor force was probably not detected by the in-situ measurements. This observation justifies continuing the measurements to achieve a better definition of this worst case linked with hydraulic conditions. Besides this, observation of the experimental panels when the canal was emptied 5 months after installation showed the good behaviour of the protections being tested.

1 INTRODUCTION

The experimental research work presented here is part of a study entrusted by the CETMEF (Center of Maritime and River Technical Studies, previously named STCPMVN) to the Cemagref on the possibilities and conditions of use of Geomembrane Lining Systems (GLS) for navigable canals.

The aim of this experiment was to provide full-scale validation of the results of general studies conducted on the stability of GLS on slopes and to check, in the particular case of navigation canals, the hypotheses adopted to take the influence of hydraulic conditions into account: filling and emptying the canal and the effect of waves assimilated to very rapid part drawdowns of the canal.

3 types of protection anchored at the top of the slope were tested: metal gabions, concrete blocks fixed onto a reinforcement geotextile and concrete blocks held in place by metal cables. As it was impossible to empty the canal during installation, only protections that can be installed underwater were chosen. In addition to the stability study of these protections, their general behaviour is also examined.

Before describing the experimental study and giving its results, the general research works conducted are recalled.

2 PREVIOUS RESEARCH WORKS

Since 1996, we have conducted, on the one hand, general studies into the stability on slopes of Geomembrane Liner Systems (GLS) under low normal stress and, on the other, 3 specific studies on the use of these systems in navigable canals:

- theoretical study of the stability of GLS on slopes for 3 types of canals (Freycinet, medium and wide canals),
- technical–economic aspects and proposal for experimental study,
- dimensions of anchors at the top of the slope.

Figure 1 Location of the experiment

The experiment presented in this paper follows on from the first two of these studies (POULAIN, 2000) and is also based on our general studies (BRIANÇON, 2002a, 2002b).

The theoretical stability study led us to propose a calculation method taking into account the different actions of water that concern navigation canals: rapid drawdown and waves. The technical study highlighted three zones of the canal profile that are particularly affected: the bottom, the lower part of the slope and the upper part; the main systems currently in common use to protect the top of the banks were listed: concrete slabs, treated gravel, gravel and rock and suspended systems. Among the latter, we can mention gabions and concrete blocks anchored at the top of the slope using a geosynthetic or cables, which are the subject of the present *in-situ* experiment.

3 IMPLEMENTATION OF THE EXPERIMENT

3.1 *Protection materials used*

The main properties of the selected materials are presented in Table 1.

The structure of the gabions (material M1) is composed of wire netting and filled with 30/120 aggregates to a thickness of 15 to 17 cm and for a weight evaluated to be about 250 kg/m^2. Materials 2 and 3 are concrete blocks with a

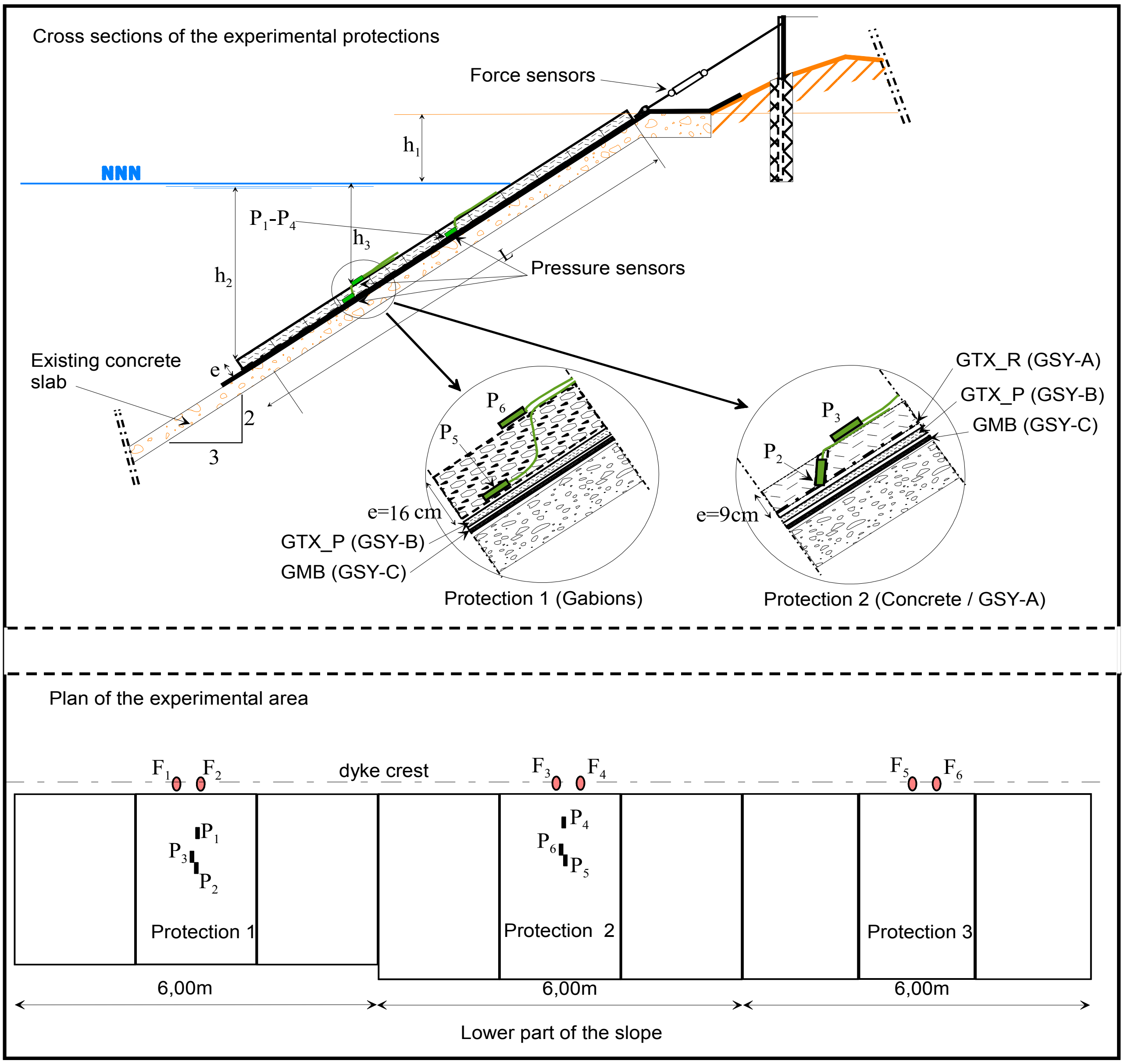

Figure 2 Cross sections and plan view of the 3 protections tested

low percentage of voids; in the case of material 2, these blocks (32 x 40 cm) are fixed onto a reinforcement geosynthetic (GSYA, Table 2) using plastic pegs cast into the concrete when the layers were manufactured; for protection material 3, the blocks (48 x 40 cm) are connected together by metal cables. The cables or the geotextile layer serve to hold the blocks together and to anchor them at the top of the slope.

Table 1. Main properties of the protection materials

Section N°	1	2	3
Protection material	M1 : Gabions	M2: Concrete / GSY-A	M3: Concrete / Cables
Supplier	France -Gabion	VDB Beton	Cimage
Reference	Matelas Reno	Betomat PE-VB 9	Dycel 101
Thickness	16 cm	9 cm	10 cm
Weight	250 kg/m^2	180 kg/m^2	215 kg/m^2

3.2 *Geosynthetics used*

The properties of the 3 geosynthetics used are given in Table 2.

Table 2 Geosynthetics Used

Material	GSY-A : Reinforcement geotextile	GSY-B : Protection geotextile	GSY-C : Geomembrane
Supplier	BIDIM		SIPLAST
Reference	ROCK PEC75	P70	TERANAP 331 TP
Type	Non-woven needle punched reinforced with wires	Non-woven needle punched	Elastomer bitumen
Mass per unit area	350	700 g/m^2	3,6 kg/m^2
Thickness	2,3 mm	5,7 mm	3 mm

3.3 *Setting up the experiment*

The experiment was set up on the Canal du Nord, reach 4-5, at kilometre point 13120, on the left bank, on 5 and 6 November 2002.


Figure 3 Experimental area

This location (figure 3) was selected because there were plans to drain this section of the canal in the months following the experiment, thus making it possible to take measurements when the canal was empty; as well as this, this point has the advantage of being equidistant from two locks and in a straight line, favourable conditions for boats to generate waves that are even in size. This section of the canal is lined with concrete slabs; the experimental GLS were installed on these slabs. The layout, dimensions and cross-sections of the 3 test sections are shown in Figure 2. Each test section corresponds to a GLS installed on the existing concrete lining and composed of the bituminous geomembrane, the protection geotextile and the protection material in question.


Figure 4 Installation of the geomembrane


Figure 5 View of the concrete blocks suspended by cables

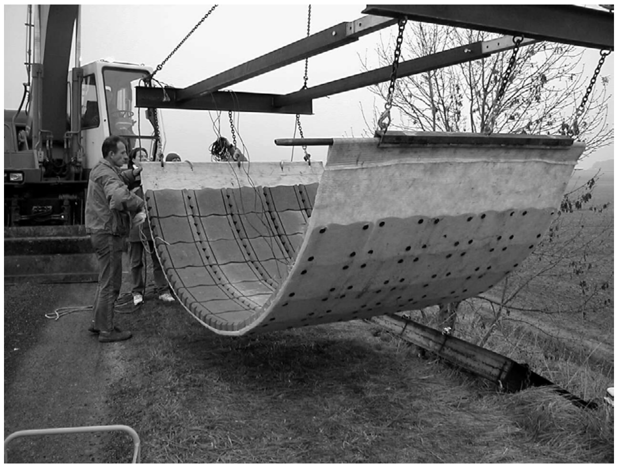
Figure 6 View of the concrete blocks fixed on a geotextile with pegs

Each of the sections comprises 3 identical panels, each of which is 2.00 m wide; the measurements are performed on the central panel so as to avoid interference of edge effects. Each test section is thus installed on an existing concrete slab 6.00 m wide. This support does not constitute an actual base, but this is not a disadvantage for the measurements envisaged here, as the slipping will be occurring above the geomembrane. Depending on their type, the length of the protection layers running down the slope varied from 3.50 to 3.65 m. Figures 4 to 7 illustrate this layout.


Figure 7 Installation of a panel of concrete blocks

In order to ensure that the various materials were installed correctly under the water (laying down the protection geomembrane or geotextile and avoiding overlaps between the protective layers) a diver was called in throughout the installation process. The installation of the materials on the slope did not pose particular problems. It is important to remember that the bituminous geomembrane, which has a smooth side composed of a polyester film and a rough side with sand, was laid out with the smooth side upwards; it is therefore the angle between the upper side of the geomembrane and the protection geotextile that is the weakest of the various interfaces. This avoids the geomembrane being placed under tension with a view to increasing its longevity. The protection geotextile was anchored during installation and then left free; apparently, no strain was observed on it, or on the geomembrane.

3.4 *Measurements*

The objective of the measurements is to be able to check the theoretical calculations of the stability of the GLS used. To do so, it is necessary to know the water pressure on and under the protection, as well as the restraining forces; sections 1 and 2 were fitted with 3 water pressure sensors and 2 force sensors, while section 3 was equipped only with 2 force sensors; each panel was fitted with 2 force sensors to avoid the protection elements being tipped askew and the restraining force is of course given by the sum of these 2 measurements. Figure 2 and Table 3 specify the position of these sensors and their numbering.

Figure 8 Anchorage of the protections, including the force sensors

Table 3 Numbering of the sensors

Section/Protection	1/M1	2/M2	3/M3
Height of water in the canal	P3	P6	
Water pressure under the protection	P1 - P2	P4 - P5	
Restraining force	F12=F1+F2	F34=F3+F4	F56=F5+F6

Figure 9 Installation of a pressure sensor on gabion protection

The frequency of the measurements is an important factor since the aim is to monitor changes in water pressure in relation to waves. The time interval was set at 0,12 s to begin with and was then increased to 0,80 s after examination of the first measurements. Given the large volume of measurements to be stored and processed, it was agreed to limit the measurements at these frequencies to one day and to perform these measurements over 24 hours once a month; this solution allows measures at short intervals over a limited period while also monitoring changes in these measurements over time.

4 DETERMINING THE FRICTION ANGLES

The calculations of the restraining forces of such protection systems anchored at the top of the slope are of course based, first and foremost, on the friction angle of the least frictional interface of the GLS. 2 tests were performed on the inclined plane on each of the 3 GLS used in the full-scale experiment. The apparatus used is described in detail by BRIANÇON (2002a); this publication showed the interest of carrying out this test simulating the present experiment, that is to say measuring the force required F_B to hold back the protection material as the plane incline angle β was increased; in this cases, there is no upper box. For each GLS, one test was performed in dry conditions and one test with water seepage but without pressure at the interface being tested, the friction angle in these wet conditions being likely to turn out to be lower; we did not simulate a rapid drawdown, for our earlier results showed that such cases are taken into account suitably by the traditional calculations (Briançon, 2002b).

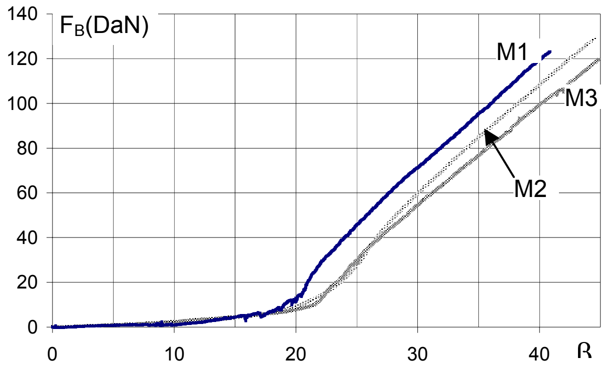

Figure 10 Examples of results of incline plane tests

Using the measurements performed during the tests on the inclined plane, the curves shown in Figure 10 were traced, with the same "virtual" weight (M3 weight), in order to be able to draw this curves on the same graph; these results can be used to determine the friction angles δ of the 3 GLS tested corresponding to the 3 sections in our experiment. In all 3 cases, the least resistant interface is that between the protection geotextile (GSY_B) and the smooth side of the bituminous geomembrane (GSY_C).

The test in dry conditions and the test with seepage performed on each of the GLS did not show up a significant variation for the tested interfaces, with the values of δ remaining within the ranges given in Table 4. The friction angles were obtained by determining the average of the values of δ calculated on the right linear part of the curve $F_B = f(\beta)$, when the plane angle β is over β_R, angle at which sliding was observed, using the relation given by BRIANCON (2002a):

$$\tan \delta = (W_P \sin \beta - F_B) / W_P \cos \beta \qquad (1),$$

with W_P = weight of the protection.

Table 4 Friction Angles δ of the GLS

Section	1	2	3
Protection	M1: gabions	M2: Concrete / GSY	M3: Concrete / Cables
δ°	15-17	16-18	17-19

When the tests were dismantled, the state of the surface of the geomembrane was examined; under materials M1 and M3 no particular marks or imprints were noted. However, under material M2, slight prints caused by the pegs were observed on the geomembrane, although apparently without having any impact on its water tightness; this point is worthy of careful analysis when the in situ experiment is dismantled.

5 EXPLOITATION OF THE MEASUREMENTS

5.1 *General*

The aim is to compare the values of the measured forces and the calculated forces, taking into account the water pressure measured on the site to examine the validity of the proposed calculation methods and hypotheses (see paragraph 2). Here, we have the first results of the experiment which is still going on.

5.2 *Effects of waves and water pressure*

We currently have at our disposal 10 days of measurements; the maximum waves recorded have an amplitude of 40 cm (± 20 cm in relation to NNN).

The measurements show that neither under the gabions nor under the two concrete-block protections there is any uplift when the wave re-descends: indeed, the curves of the pressure values given by sensors P1 and P2 on the one hand, and P4 and P5 on the other are parallel respectively to the curves given by sensors P3 and P6 placed on the surface of the protection systems. Figures 11 and 12 illustrate this result.

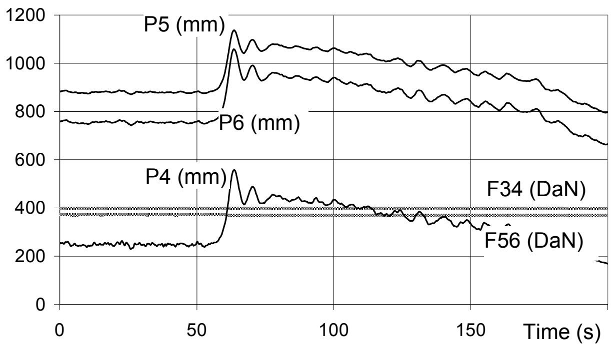

Figure 11 Measurements concerning concrete blocks during the drawdown of the canal (March 31st, 2003)

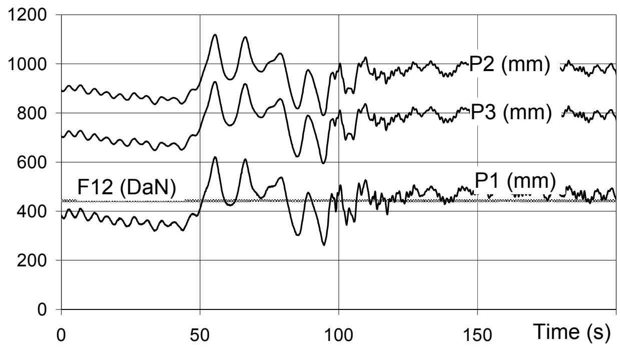

Figure 12 Measurements concerning gabions (February 5th, 2003)

This absence of reaction to the recorded, low-amplitude waves is confirmed by the measurement of the forces which do not vary instantly under the effect of the waves; this point also appears in Figures 11 and 12.

5.3 *Comparison of the measured and calculated forces*

As far as the measurements are concerned, 3 series are examined here corresponding to 2 situations at the normal navigation level before (NNN1) and after draining (NNN2) and to when the canal is empty.

The calculations performed are simple in this case where there is no abutment; the main difficulty resides in the choice of the hypotheses regarding the water pressure to be taken into consideration under the protection under the effect of the waves. The relations used are given by POULAIN (2002) for the following cases:

- A/ canal empty,
- B/ canal at the normal navigation level (NNN),
- C/ drop in level, without uplift,
- D/ drop in level, with uplift.

Tables 5 and 6 give the measured and calculated values. In cases NNN1 and NNN2, the heights of water measured above sensors P3 and P6, except during periods of waves, are about 0.90 m. The values given in Table 5 are average values, the maximum observed variations from these averages being in the region of 5 %.

The formulas used here to calculate the restraining forces are recalled hereafter for cases A and B, as no pressure was measured under the protections.

- Case A:

$$F_R = W_P \sin\beta - W_P \cos\beta \tan\delta \qquad (2)$$

- Case B:

$$F_R = W_P \sin\beta - (W_{P1} + W_{P2}) \cos\beta \tan\delta \qquad (3)$$

with W_{P1} = weight of the protection above the water level and W_{P2} = weight of the protection above the water level, W_{P2} calculated with the immersed unit weight of the protection.

Table 5 Anchor force measurements (DaN)

Water level	Area 1	Area 2	Area 3
NNN1 (February 5th, 2003)	449	348	327
Empty (March 31th, 2003)	497	400	372
NNN2 (October 21th, 2003)	552	424	423

Table 6 Anchor force calculations (DaN)

Water level	Area 1	Area 2	Area 3
Empty	510	393	429
NNN	371	294	322

Comparison of the values provides the following detailed information.

In the case of the empty canal, the calculated and measured values are very close for protection materials M1 and M2; in the case of M3, the measured values are 16 % lower than the result of the calculation.

The values calculated for case NNN are lower (case NNN1) or much lower (case NNN2) than the measured values.

The measured forces thus show an increase with time when the canal is in operation, while the calculated and measured values are close to each other for the empty canal. This increase was observed between installation and emptying of the canal and between emptying and the latest measurements.

Figure 13 View of the experimentation, 5 months after installation

Various hypotheses can be envisaged to explain this phenomenon:

- actions likely to increase the restraining force, such as greater-amplitude waves than those measured or variations in temperature, can have non-reversible effects that are accumulated; these actions would then lead to a displacement downwards which cannot be compensated by a return to the initial position when the strain is reduced: in this case, it would take a force orientated towards the top of the slope and greater than the action of the weight plus the resistance to friction; it should be noted that the *Center of Maritime and River Technical Studies* (STCPMVN, 1995) anticipates drops in the water level of 0.75 to 1.00 m under the effect of waves;
- wear on the interface under the effect of dynamic actions could reduce the friction angles at the interfaces;
- partial uplift in the upper part of the systems cannot be ruled out.

6 CONCLUSION

The present experiment already provides interesting information. In particular, the forces calculated for an empty canal, with a friction angle measured in wet conditions, can be lower than the actual forces which increase over time, probably until they reach a maximum value corresponding to the worst case, which is probably not the empty canal.

The measurement of the friction angle on the inclined plane is coherent with the “empty canal” force measurements.

The experimental set-up is still in place and the measurements are going to continue being taken, with attention being made to examining the effects of temperature and the effects of higher waves.

The observation of the experimental panels (Figure 13) when the canal was emptied 5 months after installation showed the good behaviour of the protections being tested, with no sign of displacement or damage, in particular.

7 REFERENCES

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