A DESIGN METHOD BASED ON CASES STUDIES TO TAKE IN ACCOUNT CREEP BEHAVIOUR OF GEOSYNTHETICS IN A REINFORCED SEGMENTAL WALL

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Abstract: Nowadays creep behaviour of geotextiles is a very important subject. Recent results predict durability of 100 years using security coefficients, which in general divide tensile strength of the polyester products by 2. The proposed solution consists in using Nixes-Trolls software, which can help civil engineers to calculate the stability of geosynthetic-reinforced segmental walls with concrete block facings, by giving the global safety factor using "Bishop" method for circular slip-circle and "perturbation" method for non-circular failure curves. With the ability in the software to also introduce a displacement field, the behaviour of the geosynthetic can be more accurately followed. Moreover, this software can give the tensile level of each geotextile layer, which is important data to determine creep safety factors based on standard creep tests done by the geotextile producers.

Working on an example of two equivalent soil configurations reinforced with different polyester geotextiles (one had half tensile strength compared to the other to represent creep behaviour), an analysis was carried out to obtain the same global safety factor by adjusting the length of the layers (for friction), number of layers and material type. It shows that it's possible to take in account creep durability of the geotextiles in soil reinforcement design. It also opens the last part dealing with other development fields to include geotextile creep in reinforced retaining walls design. With the proposed approach, it is possible to make a design of a geotextile reinforced soil project including creep durability.

Keywords: Geotextile, segmental retaining wall, creep, geotechnical design, computer simulation.

INTRODUCTION

Creep behaviour of reinforcement geotextiles is a sensitive issue. Most of building owners and designers don't know how to use this solution because of the difficulty for them to take into account creep and to predict hundred years of durability for their projects. They consider that it is safer to build slope reinforcements and foundations using classical solutions such as reinforced concrete walls, nailing systems, gabions, blocks with steel plates, etc. Moreover, a lot of different mathematical and research models exist and describe creep behaviour of geosynthetics but it is difficult to obtain practical information on how to take into account creep to design a specific case.

Building reinforced retaining walls presents so much interest regarding economical, technical and environmental points that it is a challenge to find design methods, which can ensure perfect stability of constructions for many years including creep behaviour of reinforcement geotextiles. The approaches and experiments explained in this document try to give some answers to this problem.

GEOTEXTILE CREEP BEHAVIOUR AND FRENCH STANDARD APPROACH

Geotextile creep test

Creep in geotextiles is strain of the product under a constant tensile load, during a long period. In the French standards, reinforcement geotextile creep must be studied to prevent long-term collapse of retaining structures. NF EN ISO 13431: « Determination of tensile creep and creep rupture behaviour » enables the user to define the products. This test is quite simple. It is done on 200 mm long and 50 mm wide geotextile samples and in standard atmospheres for testing (ISO 554). Loads are applied during 1000 hours but can be extended if needed. These loads are percentages of the tensile strength at break, 4 loads are chosen in following list: 10%, 20%, 30%, 40%, 50%, and 60%.

Table 1. Example of tensile test report

Load	ε 100h (%)	ε 1000h (%)	Break Time
20 %	2,85	2,93	No break
30 %	4,13	4,20	No break
40 %	5,36	5,41	No break
50 %	6,57	6,67	No break

Of course it is possible to have more results but the report shows these typical values. What is difficult is to make a good analysis of these values. In this standard it is considered that measurements between 100h and 1000h are sufficient to characterize the geotextile tested.

State of the art in geotextile creep (short situation)

The standard NF EN ISO 13431 model is probably not sufficient to describe creep behaviour. A lot of research programmes try to characterize creep, mostly using accelerated test methods because results are needed now. One of the most well-know methods is the SIM test method (Stepped Isothermal Method). It consists of using viscosityelasticity polymer behaviour to represent ageing with temperature and model long time strains with temperature strains. Explained in simple terms (Mailler *et al.* 2004), the sample is put under constant tensile load with a reference temperature. Increasing temperature step by step brings measurement of successive new deformations. It can be considered that every step is an increase in loading time. With specific mathematics models (such as Arrhenius' formula), predictions of long-term behaviour of geotextiles can be made (Greenwood & Friday, 2006).

NF XP G 38064 recommendations

This standard is a French experimental project, which describes all factors involved in the design and implementation of a soil supporting structure reinforced with geotextiles. This standard is not finished yet and the Authors are working with the 2000 version. As the document should be probably improved, the aim is to show what are the ways taken to define creep. The annexe A of this document explains how to define creep behaviour for geosynthetics. The creep method is based on the NF EN ISO 13431 standard test but is extended to 10000 hours and practised with different temperatures. The NF XP G 38064 standard suggests a method to determine the creep coefficient of the product finding:

- The maximum tensile effort of the geosynthetic in service conditions without creep rupture, called T_{FR} (Ultimate Limit State)
- The tensile effort of geotextile producing a limited creep strain in using conditions, called T_{FS} (Serviceability Limit State)

Starting from the curves obtained with creep test, it is advised in the standard to draw the isochrones creep curves and decide on creep strain limitation.

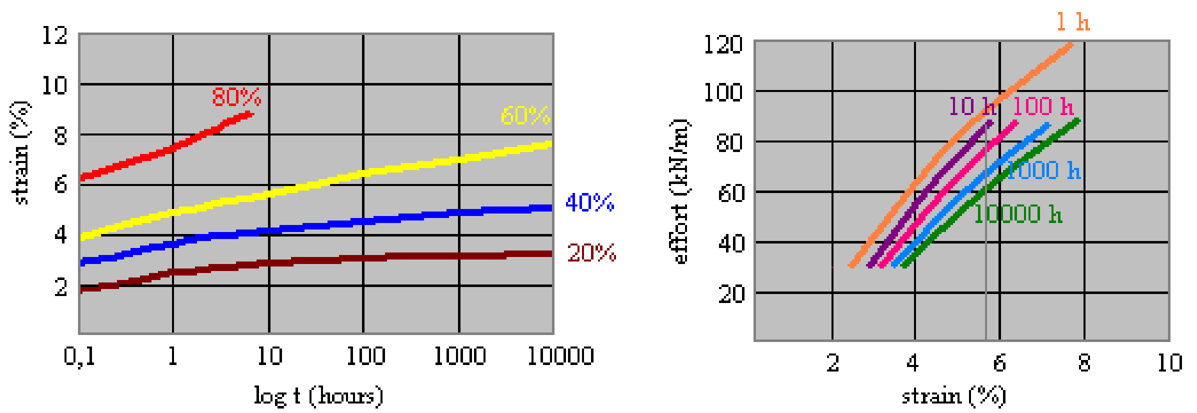


Figure 1. Standard curves – Strain limitation on isochrones curves

Then it is possible to obtain the effort diminution when creep occurs. The safety factor is defined in ULS with:

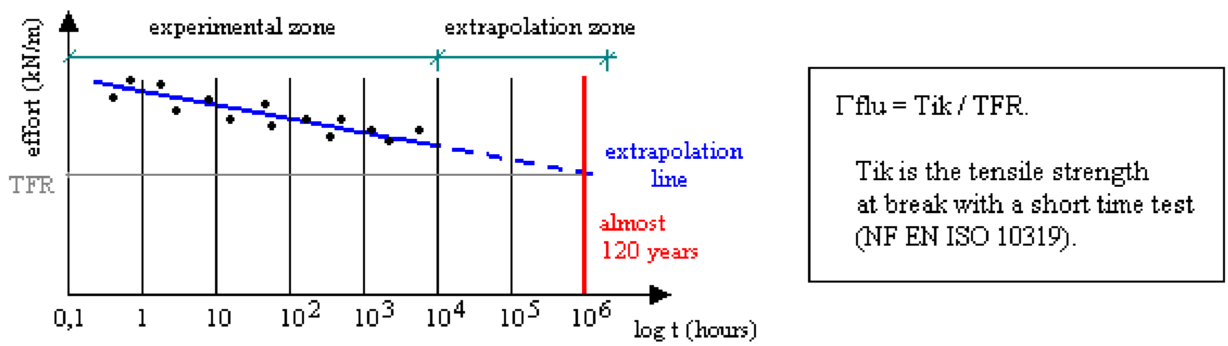


Figure 2. Long-term resistance evaluation

At completion of the calculation, the result obtained is very interesting but there is only one creep coefficient used to characterize a whole structure reinforced with many geosynthetic layers, differently loads and with different creep phenomenon. The Authors believe that production of the final standard version is important in order for users to find out what new criteria are introduced with regard to the geosynthetic creep definition. Moreover, designers of reinforced retaining walls don't apply this method at the moment (probably because of a lack of creep tests results) and use mostly for high tenacity polyester geotextiles a long time creep coefficient of 2,3 for all the layers (less than half of the short time tensile strength).

FIRST NUMERICAL EXPERIMENTATION (STATIC APPROACH)

"Nixes et trolls" software

History

"Nixes et Trolls" is a software developed for slope stability since 1975 (Faure *et al.* 1976). This code was improved with the perturbation method (Faure, 1985) and adapted for specific purposes (soil nailing, rain fall simulation, etc.). Its last development was for segmental walls reinforced with geotextiles and the use of displacement measurements (Faure *et al.* 2007). It can be used to support testing of new approaches as the one presented in this paper.

Technical information

The program allows definition of all the parameters needed (construction geometry, different soils and their parameters, many concrete block facings, different geotextiles, loads, groundwater, calculation parameters). It can work with 3 different geotextile lengths and 3 different spaces between geotextiles along the construction. These adjustments are very important to find the reinforcement configuration for a targeted level of safety. To take into account the tensile effort for each geosynthetic layer, the friction between soil and geotextile is used with the followings parameters:

$F_{friction} = \sigma_h \cdot \tan \varphi \cdot L_{anchorage}$ (kN/m)

- σ_h: normal stress at depth h in kPa.
- φ: friction angle between soil and geotextile in degrees.
- $L_{anchorage}$: anchorage length, most of time twice of the geotextile length beyond slip circle (2 friction zones above and below geotextile) in meters.

This effort is taken into account only when there is a minimal length for friction (0,3 m for the program). It is also limited to the tensile strength at break of the product and the anchorage effort with the special concrete block. This effort is included in Bishop or perturbation method by projection when a geotextile cuts a discretisation slice (NF XP G 38064).

Building sites support for our analysis

Site 1

Urban motorway in south of Nice (France): this site is very interesting because it shows the possibilities of this kind of supporting structures (excavation limitations, adjustment of the geotextile layers, etc…)

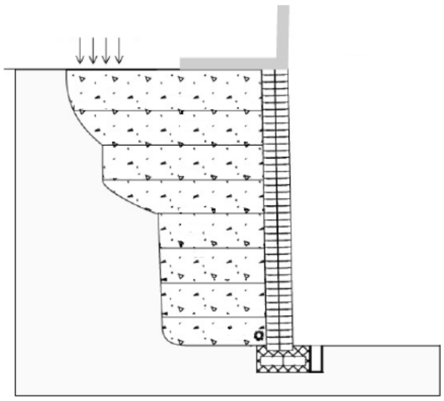



Figure 3. Nice building site

This construction was built for the Nice city technical services with the following parameters:

- Height: 5,20 m, inclined at 2°
- Filling materials: draining material, friction angle = 33°, density = 20 kN/m^3
- Loads: 50 kPa
- Wall and facing: Leromur®, special concrete blocks for reinforced walls (Betoconcept®)
- Reinforcement geotextiles: NOTEX® GX 200/50, 200 kN/m in machine direction (Texinov®)
- Space between geotextile layers: 0,40 m
- Lengths of geotextiles: 2 m, 3 m, 3,50 m

Site 2

Car park for a commercial centre in Grasse (France): This site was chosen to realize the creep studies because of its geometry and its simple reinforcement solution.

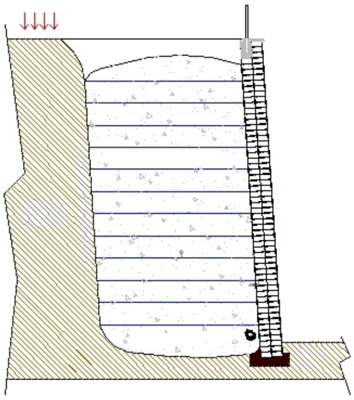


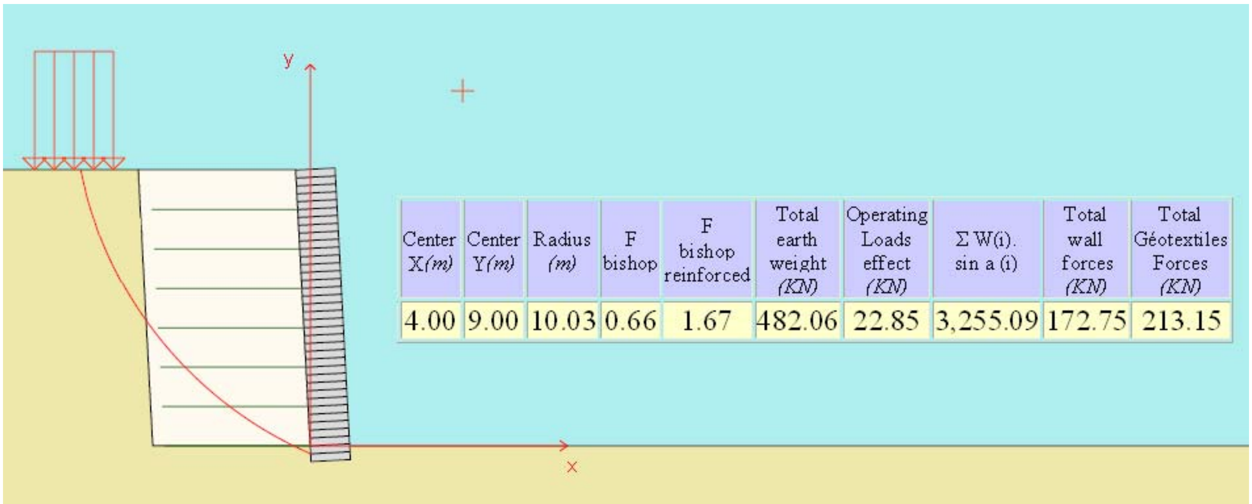
Figure 4. Grasse building site

This construction was built for the Grasse city technical services with following parameters:

- Height: 7 m (max), inclined at 3°
- Filling materials: draining material, friction angle = 30°, density = 18 kN/m^3
- Loads: 15 kPa
- Wall and facing: Special concrete blocks for reinforced walls
- Reinforcement geotextiles: 200 kN/m in machine direction
- Space between geotextile layers: 0,52 m
- Length of geotextiles: 3,70 m

Design configuration 1, short-term conditions

This is the classic situation with the same parameters as above but on a 5-meter high section. Slip circles that give the lower security coefficient for the construction must be looked for. With the method chosen, F (security coefficient) should be more than 1,5. In this case, the space between the layers is 0,65 m.



Center X(m)	Center Y(m)	Radius (m)	F bishop	F bishop reinforced	Total earth weight (KN)	Operating Loads effect (KN)	Σ W(i). sin a (i)	Total wall forces (KN)	Total Géotextiles Forces (KN)
4.00	9.00	10.03	0.66	1.67	482.06	22.85	3,255.09	172.75	213.15

Figure 5. Calculation configuration 1

This failure circle is used for demonstration and as one can see, cuts 3 geosynthetic layers. In reality, the user has to explore a great number of slip circles to be sure the most critical circle is found.

Design configuration 2, long-term conditions

Creep coefficient determination

With the geotextiles chosen in this study, creep test results are available and estimates of security coefficient to creep is made with NF XPG 38064 method. This method may have changed in recent times because alot of recent work has been done for this standard project. The aim here is to have an approximate value of the stress diminution. The creep test results for this geotextile product are quite good and the isochrones curves are very closed (so that they can not be differentiated when presented on a graph). The creep deformation limit chosen was 7,5% and the study was carried out without curves at different temperatures to ensure correlation. In these conditions, $T_{FR\ 120\ years}$ = 80,8 kN/m and Γ_{flu} = 150/80,8 =1,87. This coefficient should be given at a confidence interval (95% level) and increased with construction conditions (history of load application). The following study is done with Γ_{flu} = 2.

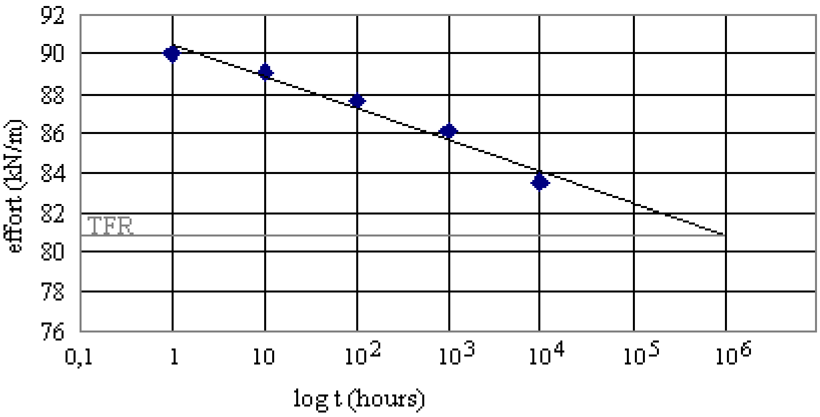


Figure 6. Creep coefficient determination

Results

This situation in long-term conditions is calculated with almost the same configuration and with the same geotextile product but a half tensile strength at break compared to the first design, so 100 kN/m. It represents the effect of geotextile creep for 120 years of durability. To ensure stability, F should be more than 1,5. To have the same global safety factor as above the space between the layers has been reduced to 0,52 m.

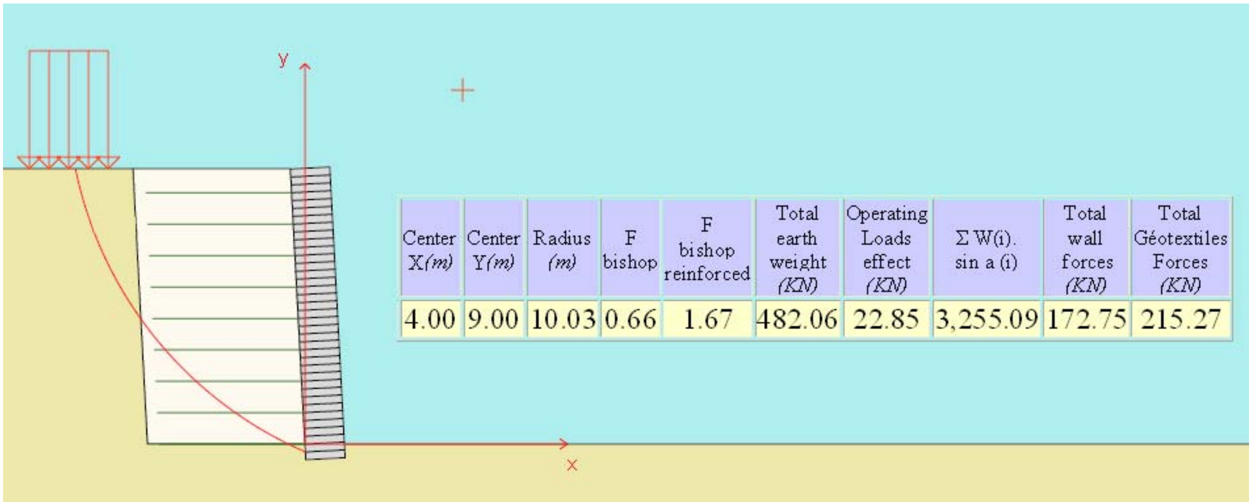


Figure 7. Calculation configuration 2

Comparison

The difference with the first calculation is the number of layers. 7 layers were used in the first case and 9 layers are needed now to have the same global safety factor. There is also an effect on friction with the new position of the layers. The area of reinforcements has increased of 29%. The total stress in geotextiles stays equivalent. This is a very simple case and of course it should be analysed in a global slip circle study, especially with upper slip circles and optimized upper layers. Nevertheless, it shows that geotextile reinforcement is very useful to optimize the design. It can be seen that the case is very closed to the real building site with this configuration, so this section is stabilized.

To ensure stability coming from a first short time design, 3 parameters can be adjusted: geotextile length, geotextile number, geotextile tensile strength. The geotextile length could be interesting if anchorage length is not sufficient or if the geotechnical configuration allows length adjustment. It is more interesting to work with a number of layers and geotextile tensile strengths to limit earthworks. With these parameters, safety conditions in short term and long term can be ensured.

Design configuration 3, short-term conditions with long-term reinforcements

To analyse the effect of long-term design on the construction, the short-term calculation (with short term geotextile tensile strength) is presented.

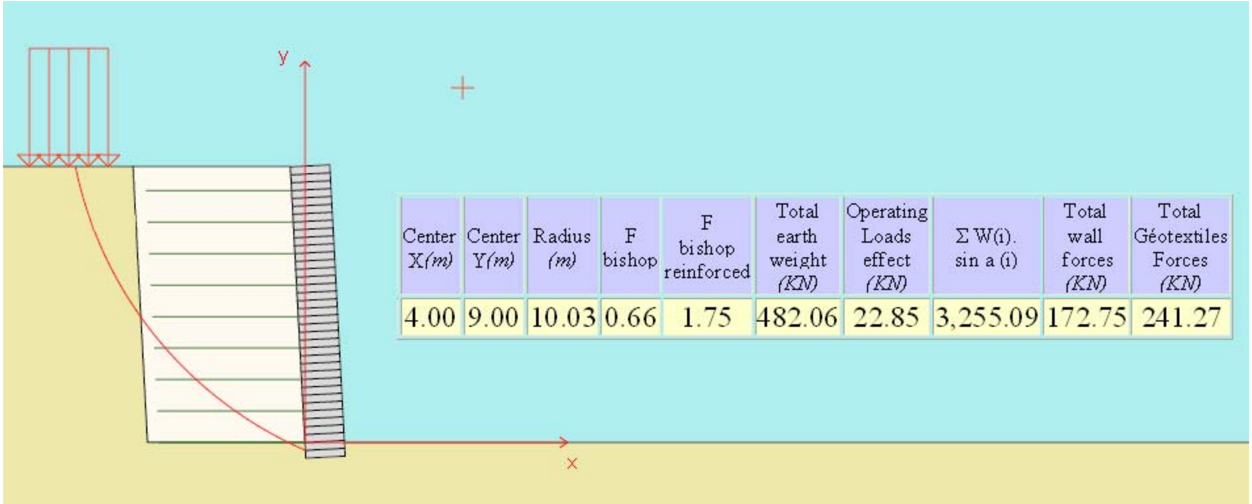


Figure 8. Calculation configuration 3

In this case, F is higher (1,75) and the reinforcement geotextile stresses are different than in long-term conditions. The forces distribution has changed and global geotextile effective force has increased going from 215,27 kN/m to 241,27 kN/m. It means that more layers or different surfaces contribute to reinforcement. It shows that probably the creep conditions imagined at long term will never be reached. There should be an optimization of the tensile stress of each layer and their creep behaviour. The next development step with the program is to use each layer force (it is calculated but not displayed yet) to analyse precisely what happens.

DEVELOPMENT WAYS

Another creep strain definition for geotextiles

Faure *et al.* (2002) proposed an interesting approach of creep modelling. On a log(t) – ε(%) graph, the results of the creep test give curves for each tensile load chosen. The following mathematic function can fit these curves:

$\varepsilon(s,t) = \lambda(s) + v_0(s) \sinh((s-s_1)t) (\cosh (t))^{\wedge(s-s_1)}/(s-s_1)$

- s: level of load for a creep curve
- s_1: level of load for constant speed creep curve
- λ(s): initial elongation when charging
- v0(s): each creep curve origin slope

For $s<s_1$ the creep vanishes, for $s>s_1$ the creep accelerates to break and for $s=s_1$ a constant rate creep is obtained.

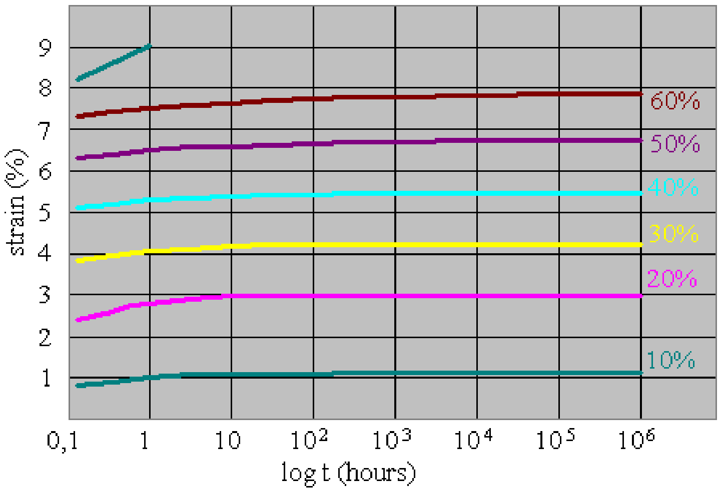


Figure 9. Geotextile used in this study fitted in creep behaviour with the function. Fitting is good.

Soil behaviour

Using the perturbations method which gives very realistic values of σ_n (static normal stress) at each point of the failure curve, it is possible to use the following stress – strain soil curve and so describe the soil behaviour.

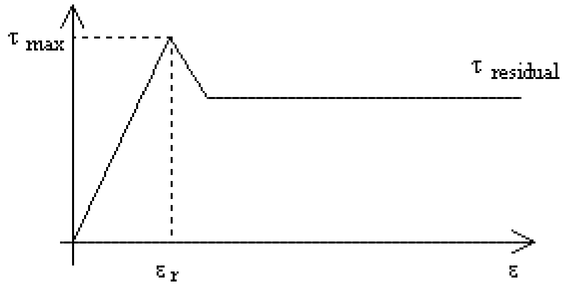


Figure 10. Soil behaviour

From direct shear tests or triaxial tests the following two parameters can be determined: R_f and ε_r

- τ_{max} = c'+(σ_n-u) tan φ' (Coulomb's law)
- $\tau_{residual} = \tau_{max}.R_f$, R_f is for ratio failure, most of time between 0,8 and 0,95. It can be considered as a soil parameter.
- ε_r = most of time 3%

The increasing and decreasing slopes on the curve are equivalent. For each deformation the curve gives τ in the soil and the behaviour (from elastic to plastic).

Displacement field use in "Nixes et Trolls"

The program allows the engineer to enter displacements on a regular grid of 16 points. With linear interpolation, the software calculates displacement for each point in the displacement field. The user will have to find the displacement for each point. Displacement can be measured now directly on sites with inclinometers or special optic fibre equipment for geotextiles (Nancey *et al*. 2006, Rossi *et al*. 2006)

In the program, the most important design condition is to enter the general form of the construction displacements. This general form should be beyond ultimate limit strain, and then the program calculates a security coefficient and a security margin (Faure *et al*. 2008), in 10 displacement steps. The user can judge which step brings the collapse and try another calculation to be more precise.

Design procedure

In order to use these opportunities, following procedure was chosen:

- Model construction geometry
- Model and search the possible slip circle with the software. In "Nixes et Trolls", parameters can be used to define automatically sets of slip circles and potential collapse conditions can be obtained, including the most probable case.
- Model geotextile behaviour using a NF EN ISO 10319 tensile test.
- Model geotextile creep behaviour (with the method above that uses curve fitting)
- Model soil behaviour (with the method above)
- Model displacement field (with the method above)

For the potential slip circle, calculations using displacements can b conducted. For each displacement step the soil shear resistance (soil behaviour curve) are known, as is the stress in the geotextile (geotextile short term tensile test). In addition the creep deformation at the effective stress level for each geotextile (geotextile creep behaviour) is known.

If a long-term failure is considered, the effort in the geotextile shall not be taken with short time tensile test but in long term. Comparing the two possibilities:

- Subtract the creep strain augmentation in time (difference between initial deformation in short term and deformation in long term for effective loading level) to evaluate tensile stress in the geotextile (with short time test). Then represent the stress diminution in each geotextile due to creep phenomenon and analyse safety factor and safety margin.
- Conduct another calculation with extra-displacement on displacement field (displacement coming from integration of creep phenomenon of each geosynthetic layer), analyse the new safety factor, safety margin and the moment of the collapse in the 10 displacements.

Currently the Authors are conducting calculations and trying to have first results to analyse the situation and to observe the method of interest. The aim is to determine if the displacement method allows accurate assessment of creep behaviour for each geotextile at each different stress. The previous design configurations 1, 2 and 3 will be compared to the displacement method. Then an analyse conducted to find a reinforcement configuration that could give safety conditions with interesting, well-defined and economic reinforcements. It is hoped that it will be possible to have good results and present more precisely the displacement method in the coming months.

CONCLUSION

Polymer geotextile creep can be compared with other reinforcement material creep behaviour. Composite materials with geotextiles are very low elongation products. Using security coefficients and adapted methods allow creep phenomenon to be taken into account and to ensure global stability of construction in time. The NF XPG 38064 provides interesting ways to continue and improve this kind of design. Release of the next version is impatiently awaited. This paper shows that it will be possible with current software to work with geotextile creep and ensure security. With adapted software a displacement approach can be used to analyse the phenomenon. New ways for development on geotextile creep phenomenon in design methods will soon be available.

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