Geosynthetics, J. Kuwano & J. Koseki (eds)
 ISBN 90 5966 044 7

Geosynthetics lining design on slopes of water reservoirs in mountains

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Keywords: drainage, lining, geomattress, reservoir, mountain, snow

ABSTRACT: The paper describes the design and construction of large reservoirs under mountain climat conditions dedicated to artificial snow making for ski resorts. Typical stress conditions are listed. The design of the geosynthetic system comprises a protective drainage sub-layer called hereafter "geocomposite drain", then the lining geomembrane itself and then the protective and armoured top-layer called "geomattress". The paper describes the design of the different geosynthetic layers in respect with their main function. Parts of the design highligthed herebelow are such as anti-puncture, in plane drainage capacity, thermal behaviour of the geomembrane, strength and anchor on slopes. The friction angles inbetween the geosynthetic layers are considered. The hydrostatic stress above the geosynthetics is currently 100 kPa (10 m water) whereas the slopes reach 30 m with a 26° angle. The geomembrane is totally or partially covered with a 40 cm soil layer. The largest volume of storage considered here are about 100000 cubic meter situated at 2000 m above sea level in mountain climate and geotechnical conditions. Ice impact on the geomembrane is reported. The first project following that design was built in 1997 and behaves very well without any need of repair.

1 INTRODUCTION

Modern ski resorts need to guaranty their clients enough snow every day to practice their favourite winter leisure. The climate changes as well as the financial pressure on this "white gold business" requires heavy investments which are secured by artificial snow making facilities. The water reservoir generally located in or above the ski domain is a master piece of the snow installation which requires to remain waterproof and provide water when necessary. Being unable to operate the water ressource can lead to client losses and severe financial disapointment for the investor. Design is also critical because of geotechnical risk in case of leakage. Some snow makers, reservoir owners and political leaders of such equipments have faced bad experiences mainly because of constructions following a design and common rules for ordinary reservoir or basin less challenging. The market has more focused on the geomembrane type than on the associated layers under and above the geomembrane.

No specialized litterature has been found by the author.

Special puncture tests have been conducted with an experimental cell able to stress a 50 cm circular sample of product systems at 400 kPa in contact with various granular materials from the sites. In plane drainage capacity of the geocomposite drain has been analytically verified using the software Drainsoft® (e.g., Faure, Matichard. 1993). The behaviour of the exposed geomembrane has been observed on some projects in respect with the coefficient of thermal expansion. Friction angle is then considered to analytically compute the driving force above the protective geomattress layer.

2 ANTI-PUNCTURE AND DRAINAGE DESIGN UNDER THE GEOMEMBRANE

2.1 *Puncture*

Puncture sollicitations are of three types:

1. dynamic during construction stage
2. static under water weight
3. dynamic under ice and snow slidings

1 and 3 are considered to be the most severe but difficult to evaluate.

The experimental cell shown in Fig. 1 below has been constructed to test the products in contact with granular material under a 400 kPa pressure. The material of the site or typical material are used. The

Figure 1. Experimental puncture cell with 400 kPa load.

cell can be transported to the site for a quick check of the geosynthetics in contact with the soil. The geosynthetics samples are tested in between 30 cm of material each side.

The load is applied for a given period of time generally 1 hour before inspection of the products. Deformation and damage of the samples are visually evaluated: perforated filter of geocomposite drain, crushed geocomposite drain core, perforated geomembrane or definitive deformation of the geomembrane, perforated protection geotextile are negative results. Some family products cannot match the required criteria and must be rejected from design specifications.

Interactions between the geosynthetics in contacts are considered some drainage layers damaging the adjacent geomembrane.

In conclusion non woven needle-punched of virgin long fibers are selected with a mass area of above 800 g/m^2 up to 1200 g/m^2 as for protective layers. CBR test is not relevant for that selection nor cone drop test, all selected products displaying a 0 mm cone drop result.

2.2 *Drainage*

Drainage of the seepage groundwater under the geomembrane is necessary to stabilize the ground and to prevent from underpressure in excavated areas. It is also necessary as a security drainage of possible leakages through the geomembrane. A main drainage network with classical gravel trenches must be built in the bottom and on the slopes. like shown in Fig. 2

As to combine the protective anti-puncture function seen above and the drainage function, a geocomposite

Figure 2. Main drainage network beneath the geosynthetics.

drain made of a composite non-woven associated with an integrated small pipe parallel network shown in Fig. 3 teradrain® is a suitable geosynthetic structure type to fullfill both requirements.

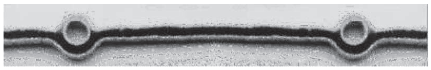

Figure 3. Cross section of the special geocomposite drain.

Water contained in the soil is filtered by the geotextile filter on each face of the product, accordingly to normal permeability (ISO 11058, 1999) shown in Fig. 4.

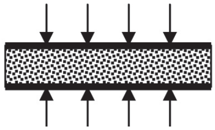

Figure 4. Permeability measure of the geocomposite drain.

Once inside the panel the water chooses the easiest path in the direction with the highest head loss that is to say perpendicular to the perforated small drainage pipe hereafter called mini-drains.

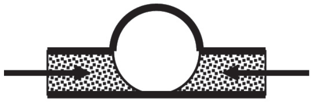

Figure 5. Perpendicular to mini-drain in plane flow rate (ISO 11058, 1999).

The water flows into the mini-drains instantaneously thanks to head loss entering the small pipes very low as shown by laboratory tests (LIRIGM, Grenoble Université, Faure) as shown in Fig. 6.

Figure 6. Measurement of head loss entering the mini-drains.

The flow rate capacity of the mini-drains has been measured (LIRIGM, Grenoble Université, Faure) and follows the experimental law (1) below Fig. 7.

$$Q = \alpha \cdot i^{n+1} \text{ where } \alpha = 2{,}36.10^{-4} \text{ m}^3\text{/s } n = -0{,}461 \quad (1)$$

Where :
Q = the flow rate;
α = constant;
i = hydraulic gradient;
n = constant;

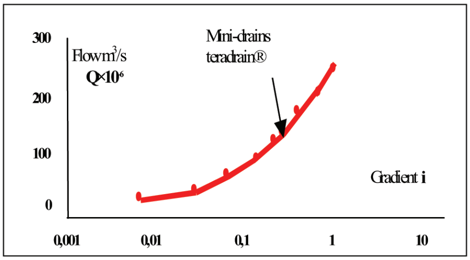

Figure 7. Measurement of flow capacity of the mini-drains.

2.2.1 *Application to slopes*

On slopes under the geomembrane the geocomposite drain must prevent from excessive pore pressure and uplift of the geomembrane. The worst condition regarding uplift is given when the reservoir is empty and the worst condition regarding drainage capacity of the geocomposite drain is given when the reservoir is full with maximum heigth of water. Thus we consider the geocomposite drain under the max compression load and the uplift condition in the most critical case and we consider that the mini-drain pipe network must operate in unsaturated conditions all over their length from top to bottom of the slope.

Typical project parameters:

Slope length = L = 30 m

Angle of slope with horizontal = 22°

In plane flow capacity of the non-woven inbetween the mini-drains under compression of 200 kPa = 5×10^{-5} m^2/s

Flow condition into the mini-drains = unsaturated
Spacement between the mini-drains = 1 m

Acceptable saturation in the geotextile inbetween the mini-drains = 0,02 m

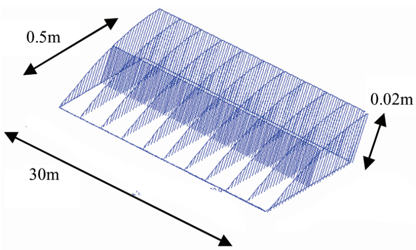

Figure 8. Hydraulic pressure inbetween half the minidrains distance

Calculus result with software as shown in Fig. 8:

$\mathscr{T} = 0.88.10^{-5}$ m^3/s/m^2

Thus $q = \mathscr{T} \times L = 2.6.10^{-4}$ m^3/s/ml = 0.94 m^3/h/ml

2.2.2 *Application to bottom*

The product is laid horizontally or with very little slope and then the mini-drains are considered saturated inbetween the main drainage trenches. We still verify the non-uplift condition of the geomembrane with an hydraulic pressure less than the soil weight above the geomembrane.

Drainage length = L = 20 m

Angle of slope with horizontal = 0

In plane flow capacity of the non-woven inbetween the mini-drains under compression of 200 kPa = 5×10^{-5} m^2/s

Flow condition into the mini-drains = saturated
Spacement between the mini-drains = 1 m
Acceptable saturation in the geotextile inbetween the mini-drains = 0.13 m,

Then $\mathscr{T} = 2.7.10^{-6}$ m^3/s/m^2

And $q = \mathscr{T} \times L = 5.4.10^{-5}$ m^3/s/ml = 0.19 m^3/h/ml

Compatibility with the soil permeability and with the global main network drainage capacity has then to be checked.

3 GEOMEMBRANE

Some of these mountain lakes have been rebuilt because of a non appropriate geomembrane design. A dark color geomembrane with high thermal expansion coefficient installed under shinny weather will raise in temperature (about 60° to 80°C) and expand proportionnaly. When cooling in winter (–20°C) severe shrinkage occurs that lift up the geomembrane from its foundation pulling very hard on joints and on mechanical fixings into concrete. On exposed geomembrane most damages are due to ice impact and rock falls. It often generates more than hundreds of puncture holes in one season demanding maintenance work with possible weldability problem of the geomembrane.

4 PROTECTIVE GEOMATTRESS

Protecting the geomembrane with a natural confinement layer is a solution but it requires a proper design as well as adapted installation methods since once covered the geomembrane is no more accessible for repair. The geomattress or geocell teracro® is an exclusive non woven product manufactured by terageos made of filtering retention ridges on a permeable and solid mat in four meters wide. Strengthening polyester wires are inserted into the mat to reach the appropriate modulus on sliding geomembrane slopes. This ready to use product is designed to withstand the weight of the soil and snow cover in Fig. 9.

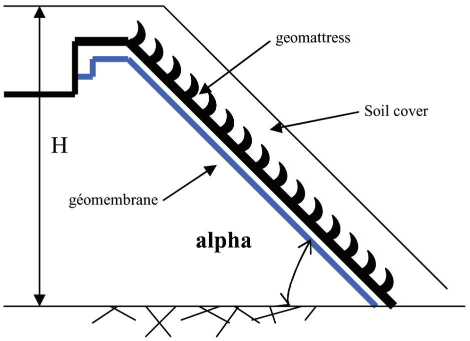

Figure 9. Geomattress laid onto geomembrane and anchored.

4.1 *Tension in the geomattress*

Height = H;
Slope angle = α;
Slope length = H/sinα;
Soil weight = Pv;
Soil thickness = Ep;
Snow weight = Sn;
Friction between product and geomembrane = φ;
Safety factor on snow = Fsn
Safety factor on friction = F(φ)
Safety factor on soil weight = Fw
Safety factor on tension = Fr
Driving force

$$Em = (Pv \times Fw \times Ep + Sn \times Fsn) \times H \quad (2)$$

Resistant force

$$Er = (Pv \times Fw \times Ep + Sn \times Fsn) \times tg(\varphi)/F(\varphi) \times L \times \cos\alpha \quad (3)$$

Tension into the geomattress

$$Tadm = (Em - Er) \times Fadm \quad (4)$$

Nominal tension of the product = T

$$T = Tadm \times Fr = 160 \text{ kN/m typically Fig. 10.} \quad (5)$$

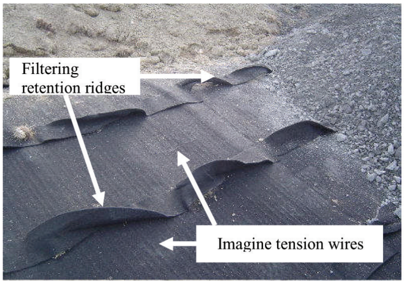

Figure 10. Detailed view of the geomattress.

4.2 *Anchor of the geomattress*

The anchor force available is computed considering only friction forces (Hulling et Sansone 1997) in Fig. 11.

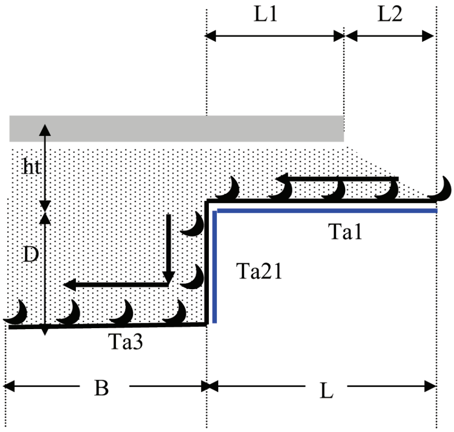

Figure 11. Anchor trench of the geomattress.

Friction between product and soil = φ';

$Tat = Ta1 + Ta21 + Ta3$

$Ta3 = 2\gamma\, B\, (D + ht) \times (\tan\varphi')$

$Ta21 = K_0\, \gamma\, D\, (ht + D/2) \times (\tan\varphi' + \tan\varphi)$

$Ta1 = \gamma\, ht\, (L1 \times \tan\varphi + L2/2 \times \tan\varphi)$

Typical values for B is 1.60 m; D = 1 m; ht = 0.50 m; L1 + L2 = 1.50 m.

5 CONCLUSIONS

In this paper it is shown that thermal expansion and repairability of an exposed geomembrane are critical parameters in mountain climate reservoirs. Sliding of ice together with erosion of the substrate are combined effects that damage the geomembrane with hundreds of holes by punching and tearing. A geocomposite drain composed of a thick non woven associated with an integrated small drainage pipe network prevents from erosion and puncture underneath; whereas a geomattress composed of filtering ridges welded onto a thick non woven reinforced with polyester threads maintains a top soil layer on the slopes. Such a design with appropriate installation methods appears to be a good solution for a successful geosynthetic lining system under a confinement soil layer; it can last many years without repair.

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