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Geotextile Soil Drainage in Siphon or in Siphon-Capillarity Conditions

Drainage à l'aide des géotextiles travaillant comme siphon ou siphon capillaire

In some particular circumstances where the soil drainage is foreseen some geotextile types may perform in siphon or in auto-initiated siphon flow following the capillary rise. The consitions are discussed necessary to establish siphon function and the experimental method used is described.
The first testing results shows that the investigations should continue and used in drain designing with geotextile.

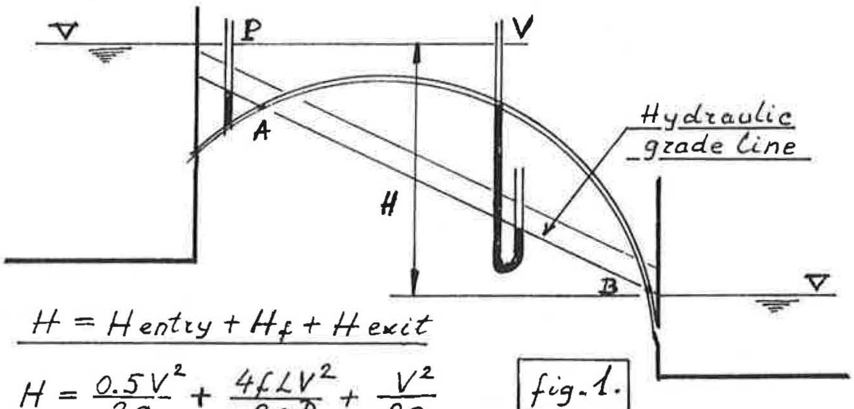
Dans certains cas particuliers où le drainage du sol est prévu, certains types de géotextiles peuvent travailler en siphon ou en siphon auto-amorçable grâce à la remontée capillaire.
Les conditions de siphonage sont discutées et le dispositif expérimental est décrit.
Les premiers résultats d'essais montrent que la recherche devra être poursuivie et exploitée dans le dimensionnement de drainage en siphon.

1. INTRODUCTION

Three principal functions of geotextiles have been clearly described by J.P. GIROUD in his valuable paper untitled : Design with geotextiles {1}. There are geotextile drains, geotextile filters and geotextile separators.
To perform any of these functions, a geotextile must have some mechanical resistance less or more in level depending on environnement forces balance. Nevertheless in some particular circumstances it would be useful to see a geotextile drain performs as siphon and especially as an auto-re-establish flow siphon.

2. SIPHON FUNCTION

It would perhaps be convenient to explain the siphon function shortly at this stage.
The figure 1 showsa water reservoir fed by another reservoir through a pipe, but the pipe joining them rise above the hydraulic grade line. So in this case, there will be a vacuum between the points A-B. The levels of the water pressure at P and of the vacuum at V are shown at this figure 1. But should the pipe crack at any point between A-B, air will be sucked in and the flow will stop.



$$H = H_{entry} + H_f + H_{exit}$$

$$H = \frac{0.5V^2}{2g} + \frac{4fLV^2}{2gD} + \frac{V^2}{2g}$$

fig. 1.

For the matter of that the flow will also stop when the lover reservoir is free of water and when the air pressure at the pipe end will be higher than the water max pressure in the pipe. But in some particular circumstances the flow in the pipe may be re-established or auto-re-established. In any way to re-establish the water flow, the water pressure in the pipe must become higher than air pressure. To do it, a pump for exemple can be used. But the capillary rise may also help to re-establish the water flow. This is the geotextile drain siphon function. We will see that some geotextiles and especially some types of needle punched nonwovens fullfilled the conditions to perform the siphon function.

3. DRAIN FUNCTION

It is now very well known that the application of man-made synthetic fabrics in civil engineering to solve geotechnical or hydro-geotechnical problems have incrased rapidly in last years.
As more theoretical knowledge and practical experience are gained on geotextile behaviour in soil wider developpement of its applications will result. Should a geotextile perform as auto-re-established flow siphon, it must at first perform well as geotextile drain.
In order to fullfil this first condition a geotextile must exhibit a high transmissivity.
When uniform (Darcy's) flow is considered, the drain discharge Q (m^3/s) is :

$$Q = A\, k_d\, t\, \frac{\Delta h}{L} \qquad (1)$$

where
L (m) and A (m) are respectively the length of the geotextile drain in the flow and in perpendicular to the flow direction;
t (m) is the geotextile drain thickness;
k_d (m/s) is its permeability; and Δh (m) is the hydraulic head loss.
If Δz (m) and Δp (Pa) are respectively levels and pressure differences between geotextile drain ends, the hydraulic head loss is :

$$\Delta h = \Delta z + \frac{\Delta p}{\rho_w\, g} \qquad (2)$$

where
$\gamma_w = \rho_w\, g$ is the specific weight of water that is the product of ρ_w (kg/m^3) the mass of water per volume unity and of gravity
g = 9,8066 m/sec^2

Thus the transmissivity of a geotextile drain is

$$t k_d = \theta \; (m^2/s)$$

Therefore the geotextile drain discharge per unity of its length perpendicular to the flow direction is directly proportional to its transmissivity and to hydraulic gradient :

$$\frac{Q}{A} = \theta\, i \; (m^2/s) \qquad (3)$$

Let us analyse now the work of this geotextile drain in siphon conditions following the soil settlement under an embankment.

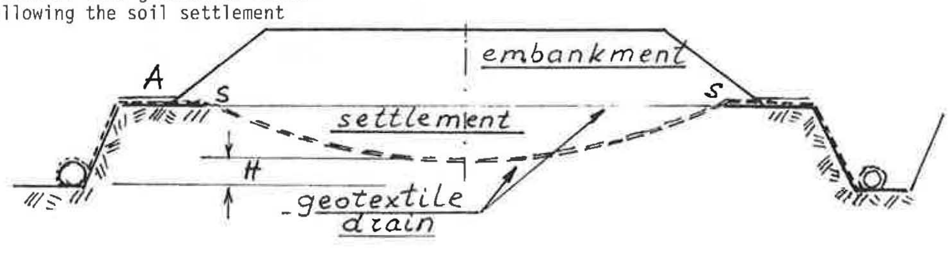


fig. 2.

The settlement proportions are exaggerated for the clearnece of description.
At the point A the geotextile drain is under vacuum and to establish a water discharge from the settlement area S-S the siphon flow must established.

4. DISCUSSION OF CAPILLARY RISE

The establishment of the siphon discharge through the geotextile drain is connected with its impregnation which may be accomplished by penetration or diffusion process or by both phenomenous acting simultaneously.
The force (N) normal to the capillary void cross section perpendicular to its length is :

$$F = 2\, \pi\, r\, T_s \cos \alpha \qquad (4)$$

where
r (m) is the radius of curvature of meniscus; in the capillary tube r may usually be taken as the radius of the tube;
T_s (N/m) surface tension of liquid; typical value for water is 7,5 x 10^{-3} N/m;
liquid-solid contact angle.
Thus F may be, depending of value, negative or positive, and we have respectively down stream or rise in the capillary tube {3}.

In this respect the pressure (Pa) in the capillary tube is {2} :

$$P = 2\, T_s \cos \alpha \,/\, r \qquad (5)$$

inversely proportional to the meniscus radius.
For α small and r = 10^{-6} m for exemple, the capillary pressure will be of 1,5 x 10^{-3} x 1 / 10^{-6} = 15 x 10^3 Pa and the capillary rise of ~ 1,5 m results.
Regarding the capillary flow through Poiseuille's equation, we have :

$$Q = \frac{dv}{dt} = \frac{\pi\, r^4\, P}{8\, L\, \eta} \qquad (6)$$

where
P (Pa) is the active pressure calculated above
η (NS/m^2) the dynamic viscosity and
L (m) the capillary length.

Introducing (5) to (6) we get :

$$Q = \frac{\pi\, r^3\, T_s \cos \alpha}{4\, L\, \eta} \qquad (7)$$

But capillary void is not straight so its tortuous form can be expressed by the ratio :

$$L_T = L_{actual} \,/\, L$$

Thus the number n of capillary voids of mean radius r per transvers cross section of geotextile drain caracterised by a porosity ε is :

$$n = \frac{\varepsilon}{L_T\, \pi\, r^2}$$

and the discharge through this section is :

$$\frac{dV}{dt} = \frac{\varepsilon\ r\ T_s \cos \alpha}{4\ L_T^2\ L\ \eta} \qquad (8)$$

Therefore the impregnated volume per unity of transverse cross section is :

$$V^2 = \frac{\varepsilon\ r\ T_s \cos \alpha}{2\ L_T\ \eta}\ t \qquad (9)$$

The validity of this simple model is restricted by the differences between r.
The FICK's second low describes the unidirectional diffusion :

$$\frac{\partial c}{\partial t} = D\ \frac{\partial^2 c}{\partial x^2} \qquad (10)$$

where
c : concentration of diffused matter (water) at a distance x, at the time t; and
D : is the diffusion constant.
It is assumed that the water and its vapour diffusion may play a role in the geotextile drain flow auto-re-establishement but for the moment the part of this phenomen in the flow process can not be surelly evaluated.
Nevertheless some interesting models was bild for study the impregnation process by diffusion {4}.

6. TESTING ARRANGEMENT AND RESULTS

The capillary rise of water in soil is depending of its nature, grain finesse and voids ratio. So it can be from few mm to few m.
The capillary rise in needle punched nonwovens is small in order of few mm but this figure changes for wet soaking material. The water molecules adsorbe to the fibers producing many meniscus and reducing voids volume. Than by capillary rise with aid of diffusion process, the water partly impregnated geotextile helps to establish a water flow. The true process of this flow should be rather complex one but some figures can be reached using a simple testing arrangement showed at the figure 3.

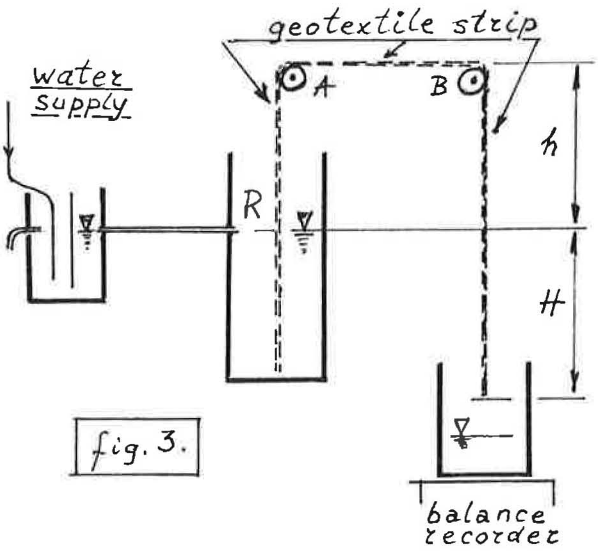


fig. 3.

A soaked wet strip of needle punched polyester nonwoven, 50 mm in wide (length perpendicular to the flow direction) is immersed in a constant level water reservoir (R), passed over two rollers (A)(B) and hangs down.
In view to avoid a drying of the strip the device is kept in a wet air (100 % R.H.).
Driving by the hydraulic head, H, the water flows through the strip and draps to the lover reservoir stayed on a balance recorder.

Thus, for a given type of geotextile, the strip width and the overhang, h, are kept constant.
Than the discharge is measured for some hydraulic heads H.
The results reached for some types of geotextiles are consigned in the Table 1.

6. CONCLUSIONS

This investigation shows that in some circumstances, some types of geotextiles can perform in a siphon function.
Other tests and a beter theoretical knowledge of the phenomenon of capillary rise are needed for designing.

REFERENCES

{1} GIROUD, J.P. "Designing with geotextiles". RILEM Materials & Structures, Paris, 1981, n° 82, 257-272.

{2} TERZAGHI, K. "Mécanique théorique des sols". Dunod (Paris, 1951).

{3} MORROW, N.R. "Physics and thermodynamics of capillary". Industrial and Engineering chemistry. Vol. 62, n° 6, June 1970, 32-56
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{4} JOST, W. "Diffusion in solids, liquids, gases". Academic Press (New York, 1960).

TABLE 1

Sample nr	Units	1	2	3	4	5
Mass per unit area	g/m^2	150	210	270	340	550
Porosity under : 0,5 kPa	%	93	92	91	91	91
2 kPa	%	91	90	89	89	89
200 kPa	%	82	81	81	81	81
Thickness under : 0,5 kPa	mm	1,5	1,9	2,3	2,8	4,4
2 kPa	mm	1,5	1,9	2,2	2,7	4,0
200 kPa	mm	0,6	0,8	1,05	1,3	2,1
Permeability (radial) in plane of geotextile under : 2 kPa	m/s	6×10^{-4}	6×10^{-4}	6×10^{-4}	6×10^{-4}	6×10^{-4}
200 kPa	m/s	4×10^{-4}	4×10^{-4}	4×10^{-4}	4×10^{-4}	4×10^{-4}
Transmissivity (radial) under : 2 kPa	m^2/s	9×10^{-4}	$11,4 \times 10^{-4}$	$13,2 \times 10^{-4}$	$16,2 \times 10^{-4}$	24×10^{-4}
200 kPa	m^2/s	$2,4 \times 10^{-4}$	$3,2 \times 10^{-4}$	$4,2 \times 10^{-4}$	$5,2 \times 10^{-4}$	$8,4 \times 10^{-4}$
Max force per unit width with 0,8 m width and 0,1 m lenght	kN/m	6,52	7,94	11,81	15,3	-
Discharge for H = 0,05 m	$10^{-6}\ m^3/s$	$0,113.10^{-6}$	$0,113.10^{-6}$	$0,272.10^{-6}$	$0,131.10^{-6}$	$0,186.10^{-6}$
0,1 m	$10^{-6}\ m^3/s$	$0,185.10^{-6}$	$0,247.10^{-6}$	$0,439.10^{-6}$	$0,258.10^{-6}$	$0,319.10^{-6}$
0,15 m	$10^{-6}\ m^3/s$	$0,237.10^{-6}$	$0,286.10^{-6}$	$0,528.10^{-6}$	$0,317.10^{-6}$	$0,400.10^{-6}$
0,2 m	$10^{-6}\ m^3/s$	-	-	$0,556.10^{-6}$	-	$0,385.10^{-6}$