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Estimating the dewatering time in geosynthetic tube dewatering projects

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ABSTRACT: While the use of geosynthetic tubes in dewatering projects is rising steadily and the dewatering results are promising, there is still a lack of knowledge in predicting the time needed until a certain dewatering level is achieved. Also the choice of an optimal tube size is still depending on the practical experience of the project executives. This is mainly due to the fact, that the dewatering of fine grained sludges such as some dredged materials and industrial sludges depends on various factors including the particle size distribution, the contents of organic material, and salts, the pressure distribution within the sludge body and the flow path length to the tube surface. So the total modeling of the dewatering process is difficult and may not be efficient for the size of dewatering projects where geosynthetic tubes are usually applied. After a short introduction to cake filtration theory a simple method to estimate the dewatering time is presented using data from pressure filtration tests.

1 INTRODUCTION

Geosynthetic tubes have been used in a variety of coastal protection applications, wetland restoration projects and for the dewatering of various sludges. Used as construction elements geosynthetic tubes are mainly filled with incompressible and highly permeable materials such as sand which simplifies the prediction of the dewatering and consolidation of the filling material. However in dewatering projects the materials to be dewatered are often fine grained sludges (industrial waste water sludges or dredged materials). These are usually highly compressible materials for which the modeling of the dewatering behavior is very complex (Alles et al. 2003).

There is a variety of models for the separation and consolidation processes of highly compressible materials (compare Tiller et al., 1987; Alles, 2000). These complex models necessitate data from different laboratory experiments such as the permeability under triaxial loading, the compression behavior, sedimentation velocity, and others. To reduce the experimental effort a simple estimation method using the results of pressure filtration tests similar to those described by Moo-Young et al. (2002) is presented here. Pressure filtration testing is a common experiment to determine the viability of geosynthetic tube dewatering. The comparison to more complex models will be presented in the future.

2 DEWATERING IN GEOSYNTHETIC TUBES

2.1 *Parameters of dewatering*

The dewatering in geosynthetic tubes is basically a low pressure cake filtration system, so the dewatering result is dependent on the following parameters:

(1) The sludge properties like the particle size distribution, the void ratio, the amount of organic compounds, and salts (salts have major influences on the possibility to extract water from the sludge).
(2) The pressure distribution inside the sludge body.
(3) The flow path length inside the filter cake.
(4) The geotextile properties: A high permeability leads to a high initial dewatering rate. This is mostly due to a large AOS, which also allows a larger amount of fines to pass the geotextile before a filter cake has formed. An AOS too large may impede a filter cake to form which leads to a constant high dewatering rate together with a very high content of fines in the filtrate. A small AOS value mostly comes with low water permeability. While this helps the building of a filter cake, it also reduces the initial filtration rate drastically which will directly affect the filtration time.
(5) The structure of the geotextile and its tendency to blinding.
(6) Additional external pressure can improve the dewatering process. If only initially applied,

external pressure can accelerate the dewatering process but will not improve the dewatering result (Moo-Young et al. 2002).

(7) The evaporation is the main external factor with respect to the dewatering result and is not considered in this study.

2.2 *Two major processes*

The dewatering can be divided into two major processes, the first being the dewatering by self weight and the top pressure on the tube, the second being the “drying” through evaporation. The first dewatering process is a cake filtration process and it may be influenced technically during the project design; the second is dependent on the weather conditions and the cross-sectional shape of the tube. There is a variety of hydrological evaporation models that may be applied to model the dewatering of fine grained dredged materials, e.g. the Penman-Wendling method (Bauer et al. 2004). This paper focuses on the cake filtration stage.

3 CAKE FILTRATION

3.1 *Theory*

Cake filtration theory divides in the global and the local approach. The global view is the most common to define filtration processes (Alles et al. 2003). Here the cake is seen as one uniform package with a constant porosity and filtration resistance. The filter cake is commonly seen as incompressible. Then Darcy’s law can be applied.

For compressible cakes however (as for many fine grained sludges), the liquid flow is superimposed by the solid particle flow and the sedimentation process. Therefore a more complex equilibrium of forces has to be found. After Alles (2000) the following governing equations apply for one-dimensional flow (1. gradient of fluid pressure; 2. gradient of solid pressure):

$$\frac{\partial p_w}{\partial x} = \alpha\varepsilon(1-\varepsilon)\eta\rho_s\left(\frac{q_w}{\varepsilon} - \frac{q_s}{1-\varepsilon}\right) - \rho_w g \tag{1}$$

$$-\frac{\partial p_s}{\partial x} = \alpha(1-\varepsilon)\eta\rho_s(q_t - u_s) + (1-\varepsilon)\Delta\rho g \tag{2}$$

With α = mass specific flow pressure
ε = porosity
η = viscosity of fluid
ρ_S; ρ_w = density of solids/fluid
$\Delta\rho = \rho_S - \rho_w$
q_S; q_w; q_t = solid/water/total flow
u_S = average velocity of solids
g = gravity.

Additionally boundary conditions and material properties are needed (see Alles, 2000).

3.2 *Modeling and input parameters*

The model used by Alles (2000) is a numerical solution of the above equilibrium equations. A layer discretization ($\partial x = \Delta x$) of the sludge suspension and the filter cake is used to solve them numerically. Boundary conditions are the filter resistance of the geosynthetic and the cake, the mass continuity of the total solids, the initial pressure on the filter cake and the pressure gradient in the fluid above. Sedimentation and drainage are modeled in parallel.

3.3 *Conclusions*

First experiments in 1D using equations (1) and (2) are indicative of the method being suitable to model geosynthetic tube dewatering problems. It will be expanded into a two-dimensional model which may be suitable to approximate the whole dewatering process inside a geosynthetic tube.

However, it is a very elaborate approach and the determination of the experimental test data may be too costly and time-consuming for the model to be used in geosynthetic tube projects. Therefore it may be useful to use a simple direct test to roughly estimate the parameters of dewatering result and dewatering time. To determine the viability of the sludge dewatering pressure filtration tests using different sludge-geosynthetic-combinations are a common solution. So a method using this test has been used to estimate the dewatering time.

4 PRESSURE FILTRATION TESTS

4.1 *Test apparatus*

The pressure filtration test apparatus used for the experiments consists of two pressure cells (2) with a diameter of 19 cm and a height of 30 cm in which the sludge is filled. To these cells air pressure is applied

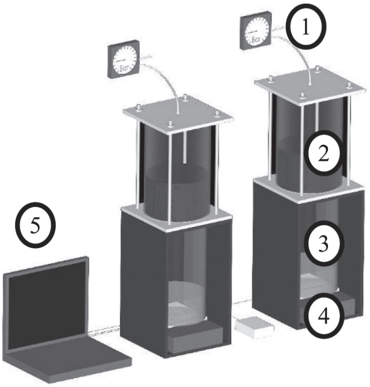

Figure 1. Pressure filtration test apparatus (1: Pressure gauge; 2: Filtration cell; 3: Filtrate; 4: Balance; 5: Data logger).

(1). At the bottom of the cells the geosynthetic is placed. The filtrate is collected in glass receptacles (3) which stand on electronic balances (4) to log the discharge continuously (5). The larger size compared to standard test apparatuses was chosen to receive a larger amount of filtrate and to remain a bigger filter cake for the analysis.

4.2 *Materials*

Tests were performed with three different geosynthetics and three different dredged materials. In this paper one combination is presented exemplarily. The geosynthetic is a woven polypropylene material with an AOS of 0.425 mm and a permeability of 0.04 cm/s. Table 1 shows the properties of the dredged material. d_{10} and d_{50} are the grain sizes, U the uniformity coefficient, w_0 the initial water content, e_0 the initial void ratio, and w_L the liquid limit. The material has comparably bad dewatering characteristics which is why it was chosen as one of the materials for the experiment.

Table 1. Sludge properties.

	d_{10}	d_{50}	U	w_0	e_0	w_L
AF	< 2 µm	50 µm	~ 130	350%	8.5	261%

4.3 *Experiments*

Right before the test the initial water content was measured. Three different amounts of sludge were used: 10.6, 17.6, and 28.2 cm of fill height. After putting the sludge into the pressure filtration cell the pressure – 0, 0.1, and 0.5 bar respectively – was applied immediately. The 0.0 bar experiment simulates self-weight dewatering. 0.1 bar is an average value inside common sizes of geosynthetic tubes for dewatering while 0.5 bar stands for an additional pressure applied to the top of the tube (e.g. by pumping). The amount of filtrate was logged per minute, and the experiment had to be finished as soon as there was a decline in the logged filtrate volume, meaning the evaporation dominated the process. After terminating the experiment, the final water content and the grain size distribution were determined at different positions in the filter cake.

4.4 *Data processing*

The filtrate data was used to calculate both the average water content within the sludge and the specific discharge as functions of time. The actual evaporation was measured in parallel to correct the discharge data. Figure 2 shows the decreasing water contents for the sample dredged material. The calculated values (from filtrate data) match the experimentally derived water contents (after termination) very well.

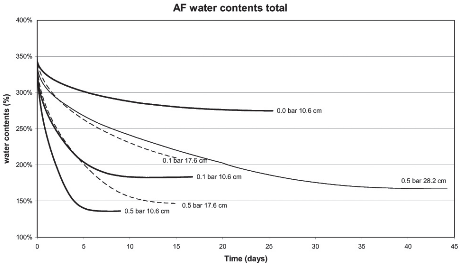

Figure 2. Decreasing water contents in the PF-cell.

4.5 *Additional results*

Additional to the filtrate data used to estimate the filtration time the following results could be derived from the experiments: Although usual soil filter criteria were not satisfied, the filter efficiency was 99.98%. A variation of the initial water content (w_0) showed a high impact on the filter efficiency: rising w_0 from 350% to 510% resulted in a minimum filter efficiency of 99.7%.

In filter applications the runoff is much lower than the (water-) permeability of the geosynthetic would have us expect. All experiments showed that for the fine grained sludges used (even those with very high water contents) the initial flow rate was very low compared to the geosynthetic properties.

5 A SIMPLE APPROACH

5.1 *Data evaluation*

From the pressure filtration data diagrams showing the dependency of flow path length and dewatering time could be obtained for different dewatering results. In the example the initial water content was 350%, and the four diagrams in Figure 3 show the dependencies for dewatering results of 300%, 260%, 233%, and 150%. The result of 150% water could only be realized with a pressure of 0.5 bar. The dewatering time was limited to 30 days. A simple quadratic extrapolation method was used to give an idea of the dewatering time for larger flow paths. This seems suitable since the dewatering time is an approximate function of the square flow path.

5.2 *Estimating the dewatering time*

The pressure inside the tube varies during the dewatering process: $p = p_0 + \gamma \cdot h$ (p_0 = pressure at the top of the tube, γ= specific weight and h = height of the tube). While the tube dewaters, the top pressure and the tube height decrease. Assuming an initial top pressure of 0.3 bar (e.g. Pilarczyk 2000), the pressure inside the tube is usually $p < 0.5$ bar. So the dewatering time can be found left of the respective curve in the diagram.

As an approximation for the flow path length inside the geosynthetic tube half the tube height was chosen. For high filling ratios and low pressures this may be an unsuitable approximation. However for low filling ratios and/or high initial pressures (and thus a relatively quick initial volume loss) the filled geosynthetic tube will be comparably flat and a rectangular cross-section can be assumed which makes the flow path approximation seem suitable. Horizontal flow has been neglected.

Figure 3 shows that for the given dredged material and a typical tube size of more than 5 m circumference dewatering results as low as 150% could not be obtained without the drying stage (evaporation). This may not be necessary since the liquid limit of this dredged material was $w_L = 261\%$ and so transportability of this particular material may be achieved within 15 days after filling the tube to a height of about 60 cm (see Figure 3, top right).

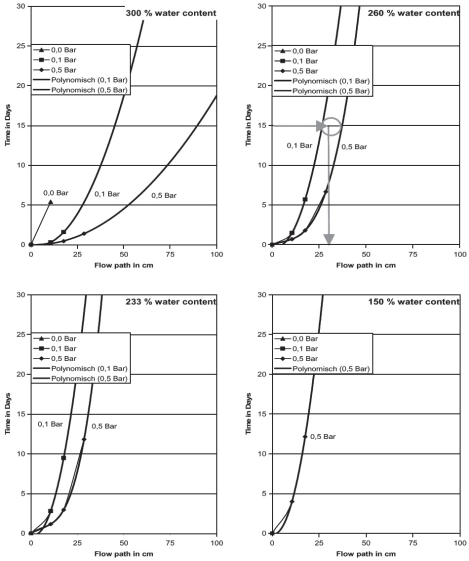

Figure 3. Diagrams from pressure filtration tests for the estimation of the dewatering time.

6 DISCUSSION

Although criticized in the application with compressible sludges (especially for press filtration processes), pressure filtration tests may be suitable to roughly estimate the dewatering result and time of the cake-filtration process in geosynthetic tube applications. But there are several pressure filtration tests needed – with both varying pressures and amounts of sludge – until estimations for the real tube can be made. In the example, nine tests were performed to gain the three curves for flow path and time. If the tests are run to the point where evaporation dominates the system, experiments may last more than one month for low pressures and large amounts of sludge.

As a time reduction measure the planned filtration result can be used as the termination value of the test. This may be the liquid limit or the legal limit for deposition. The first test should then be performed with a small amount of sludge and the maximum pressure suitable for the respective tube which can be derived from the formulation of Namias (1985) or simply by using a computer program like SOFFTWIN (Palmerton, 1998). If the desired result can be obtained, the other experiments need to be executed.

Still the work load for this very simple estimation approach is relatively high. Especially the time needed to carry out the tests may limit its application. Then a more precise model may be worth considering, even if it is bound to more sophisticated testing. Dependent on the project some of the tests needed for the modeling have to be performed anyway.

7 CONCLUSION

The simple method using the direct results from pressure filtration tests may help to find a suitable filling ratio or maximum height of the tube and helps to estimate the dewatering time up to a water content specified. However, the results still need interpretation and the many filtration tests needed may not fit into the time schedule of a dewatering project.

In prospect, the two-dimensional model based on the formulation of Alles (2000) will be developed and validated for the application in geosynthetic tube projects.

REFERENCES

Alles, C.M. 2000. Prozessstrategien für die Filtration mit kompressiblen Kuchen. Dissertation, University of Karlsruhe.

Alles, C.M., Anlauf, H. 2003: Filtration mit kompressiblen Kuchen: Effiziente Konzepte für eine anspruchsvolle Trennaufgabe. In: Chemie – Ingenieur – Technik. No. 75 (2003), 9, pp. 1221-1230.

Bauer, B. et al. 2004: Untersuchungen zur schnellen Feldentwässerung von Bremer Baggergut. In: Tagungsband zum 3. Rostocker Baggergutseminar vom 10.-11. November 2004.

Moo-Young, H.K. et al, 2002. Testing procedures to assess the viability of dewatering with geotextile tubes. In: Geotextiles and Geomembranes, 20, pp. 289-303.

Namias, V. 1985. Load-Supporting Fluid-Filled Cylindrical Membranes. In: Journal of Applied Mechanics, Vol. 52 (Dec), pp. 913-918.

Palmerton, J.B. 1998. SOFFTWIN. Computer program to calculate the shape and force equilibrium of geosynthetic tubes.

Pilarczyk, K.W. 2000. Geosynthetics and Geosystems in Hydraulic and Coastal Engineering. Balkeema, Rotterdam.

Tiller, F.M., Yeh, C.S. and Leu, W.F. 1987. Compressibility of Particulate Structures in Relation to Thickening, Filtration, and Expression – A Review. In: Separation Science and Technology, 22, 2/3, 1037-1063.