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The application of soil and slurry filled geotextile tubes – an analytical survey on their behavior under a variation of magnitudes of influence

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ABSTRACT: In this article horizontally lying, hydraulically filled geotextile tubes are described. Examples for applications in coastal engineering and sludge dewatering are reviewed. The different existing calculation and design approaches are compared and valued. Calculations which were carried out using a selected approach are mentioned. A finite element model is presented in detail. This model covers the mechanical and hydraulic behavior of geotextile tubes under load and during the consolidation stages. Finally some ideas for a design guide in German language are given.

1 INTRODUCTION

Geotextile tubes - also called sand tubes or sand sausages - are tubes made of woven or non-woven geotextiles. They are produced with diameters ranging from one to several meters and with theoretically infinite length. They are filled hydraulically with a soil water mixture (slurry). The tube is permeable and thus enables the water to drain but it retains the soil material inside. The fill material consolidates and so the construction is individually stable. The tube shell reinforces the structure.

Fields of application of slurry-filled geotextile tubes are the following: Coastal protection, flood protection, beach management, construction of dikes and islands, groins and berms, restoration of marine sediments for ecological purposes, permanent or temporary constructions for the creation or restoration of wetlands, deposition of contaminated dredged material, foundations, etc.

The construction method has been applied internationally for over 35 years and it has been increasingly in use during the past ten years. However there is a lack of experience for several special applications, especially in respect of long term performance. Particularly the dimensioning of stable stacking of such geotextile tubes still embodies problems to be solved.

There are several calculation methods, including two computer programs, that describe the behaviour of a tube during the filling process (see Liu 1981, Kazimierowicz 1994, Leshchinsky 1996, Plaut & Suherman 1998). These approaches are all based on the assumption, that the highest circumferential tension in the tube occurs during the filling process.

There are few approaches to calculate the consolidation behavior all of which are based on large approximations and simplifications. One method assumes, that there is only a change in construction height (Leshchinsky 1996). Another one is programmed in Palmerton's computer program SOFFTCON.

For the stacking of tubes there are only two analytical approaches which imply large simplifications (Miki et al. 1996, Plaut & Klusman 1999).

First the fields of application are described. Calculation methods are reviewed and compared in short. For the fields of consolidation and stacking finite element models are presented for mechanical and hydraulic boundary conditions. Design diagrams based on a particular calculation method are presented to determine the most important design parameters for the filling process. Finally some ideas for a design guide in German language are given.

2 APPLICATIONS

There is a wide range of applications for geotextile tubes at present. Some examples of the most important application fields – coastal engineering and sludge dewatering – are given below.

2.1 *Coastal engineering*

As early as the 1960s, woven PE-tubes were used in Norddeich at the North Sea Coast in Germany as retaining structures for dredged material disposal (Erchinger & Snuis 1972, Janssen 1988).

In the late 1970s continuous retaining dikes (9 km in length) were built to upgrade the ground level for a new settlement in New Cubatao, Brazil (Bogossian et al. 1982).

In the 1990s an artificial oyster reef was constructed out of huge geosynthetic tubes in Chesapeake Bay, USA (Fowler & McLellan 1997).

After the disastrous El Nino phenomenon in 1997/98 geotextile tubes were installed in Ecuador for erosion protection (Martin 1999).

Between 1998 and 2000 geotextile tubes were applied in Cancun, Mexico. The tubes were used as offshore breakwaters in a large beach reconstruction project (Porraz 2001).

2.2 *Dewatering of sludges*

Geotextile tubes were used to dewater sedimental sludges in Japan. The dewatered material was used for the construction of embankments (Miki et al. 1996).

Limy sludges from Vicksburg water treatment plant were dewatered using geotextile tubes (Fowler, Bagby & Trainer 1997).

Tannery waste sludge was dewatered in Maryland, USA. Deposition on the local landfill requires a water content of less than 83 %. This was achieved successfully (Skelly 1999).

Highly organic sludges from a food production plant were pumped into geotextile tubes for dewatering. For the boundary conditions given this technology proved very useful (Gaffney & Wells 2000).

Dredged material from Nacote Creek, New Jersey, USA, was successfully dewatered in 1999 using geotextile tubes (Gaffney & Moo-Young 2000).

3 CALCULATION METHODS

Several analytical approaches exist to calculate the shape of the filled tube and the stresses in the geotextile. The first calculation methods published were derived by Liu & Silvester in the late 1970's at the Royal Military College in Australia (Liu 1981).

The authors found a dependency between the circumference of the tube, the pressure head (e.g. pumping pressure), the contact length with the foundation and the height of the tube after filling. These approaches are the basis for several further surveys all over the world. Table 1 shows a selection of references for existing calculation approaches.

Table 1.Calculation theories for geotextile tubes

	Filling stage	Stacking/loading	Consolidation
1970s	Liu		
1990s	Kazimierowicz		Leshchinsky
	Leshchinsky	Miki et al.	
	Plaut & Suherman	Plaut & Klusman	Palmerton

In this article the author follows the approach of Plaut & Suherman (1998) for the analytical description of the filling stage. It is well suitable for the solutions needed and it proved best for programming in MathCAD.

The consolidation stage is described by Leshchinsky (1996) with a simple dependency. For the loading (e.g. stacking of tubes) Miki et al. (1996) found an empirical formula. Plaut & Klusman (1999) describe an approximate numerical approach for the stacking process.

There are also three computer programs available to aid the design process: Leshchinsky's GeoCoPS is a tool to calculate the geotextile strength parameters and the most important geometrical dependencies for different known boundary conditions. The consolidation is estimated with a simple formula. Palmerton's SOFFTWIN also calculates the geotextile strength and geometry parameters. He has also developed SOFFTCON for the determination of the consolidated geometry to estimate the maximum content of the tubes. It is possible to simulate multiple refilling.

4 CALCULATIONS

4.1 *Application of existing approaches*

The computer program GeoCoPS was used to produce results for later verification. For very high pressures and filling ratios in small tubes GeoCoPS sometimes varies the value of the circumference although it is a given constant for the calculation. The result is an underestimation of the tensile stresses for these critical states.

The methods of Liu, Kazimierowicz, Leshchinsky, and Plaut & Suherman were compared. They all lead to very similar results. Results from calculations based on the method of Plaut & Suherman were used to evaluate these different approaches.

This method was also used to generate an initial state for the finite element models described below. The original mesh in figure 2 shows the shape calculated in MathCAD for a tube with a circumference of 3.14 m and a pumping pressure of 10 kPa.

4.2 *Finite element modeling with ABAQUS*

The models presented here are based on the finite element method (FEM). They were designed to receive deeper knowledge about the behavior (dewatering behavior, stress- strain behavior) of the tubes during consolidation and loading.

4.2.1 *Load model*

Figure 1 shows the load model for the lower left tube in a 3-2-1 system of stacked tubes. The load was estimated with half the weight of the tube directly above plus a quarter of the weight of the top tube. It was applied along the interface of the tubes.

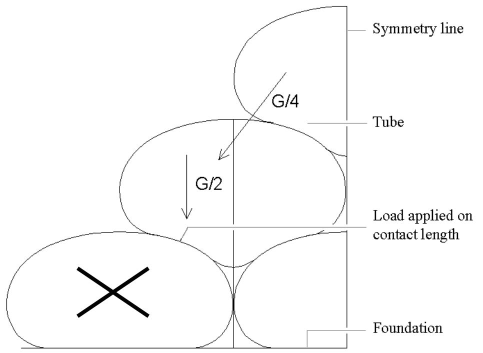

Figure 1. Load model for the stacking of tubes. Approximated example of a 3-2-1 configuration.

The calculations were carried out in ABAQUS and for the model generation and the post processing MSC PATRAN was used. Eight node elements were used because of the curved shape of the tube. For the filling material fully elastic material behavior was applied for the primary simulations.

The contact regions between the geotextile and the filling material as well as the ones between the tube and the foundation were modeled as friction planes. Simulations were carried out using different friction coefficients.

Figure 2. FEM-Plot of the calculated deformation – elastic modulus $E = 1 \cdot 10^{+5}$ N/m².

The elastic modules were also varied during the simulations to determine dependencies of the soil-geotextile system under load. Figure 2 shows the result plot for the deformation analysis with an elastic modulus $E = 1 \cdot 10^{+5}$ N/m². The maximum deformation calculated was f = 12.9 cm for a tube with a circumference of 3.14 m and an initial pumped height of 0.80 m.

An important result was the determination of the locations where the highest circumferential stresses occur: The highest stresses were derived at the points where the tube looses contact with the foundation (see figure 3).

The initial circumferential tension caused by the pumping pressure was calculated using the method of Plaut & Suherman. For the given example the initial tension was T = 7 kN. The initial stresses were compared to the results after loading. The result derived here was that the stresses caused by pumping may be much higher than those caused by the stacking of tubes.

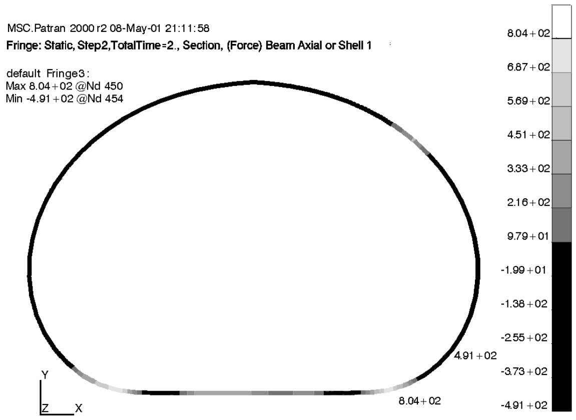

Figure 3. FEM-Plot of the calculated circumferential stresses – $E_{soil} = 1 \cdot 10^{+5}$ N/m²; $E_{tube} = 7 \cdot 10^{+9}$ N/m²

4.2.2 *Dewatering model*

Another model was designed to simulate the dewatering behavior of a sand-filled tube. The initial state at the tube top is either an excess pore pressure (directly after pumping) or zero pore pressure (for the following case: the high pressures due to pumping cause the water to drain quickly until there is zero pore pressure at the top of the tube. At this stage the simulation is started). A hydrostatic pore pressure distribution along the height of the tube represents the initial state.

Then water is allowed to drain along the free surface of the geotextile. The foundation is saturated, so no water will drain from the bottom of the tube. Figure 4 shows the pore pressure distribution for a badly draining porous material (fine sand or silt) after dewatering. At the bottom middle there is still an area where the material is not fully drained.

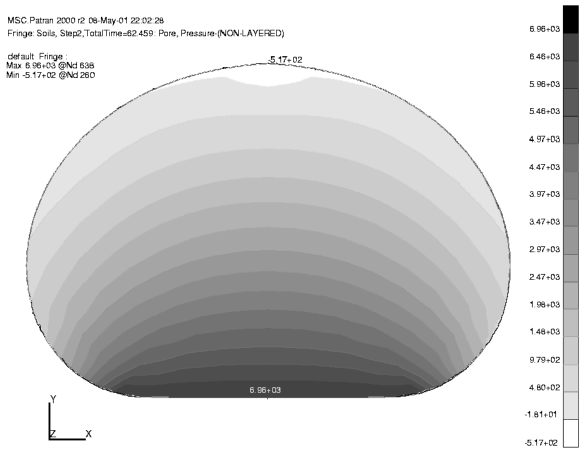

Figure 4. FEM-Plot of the calculated pore pressure distribution after consolidation.

First models with an octahedral shape were used to verify the boundary conditions and flow laws. After they proved acceptable the load model was enhanced and pore pressure was applied to the main nodes of the load model. The filling material was modeled with a simple Mohr-Coulomb approach for the simulation of the consolidation behavior.

Different dependencies of the permeability were modeled (e.g. the dependency on the saturation and the consolidation). The elastic modulus was also made dependent on the saturation, since at the beginning of the filling process the soil-water mixture is a fluid and becomes ever more solid the further the dewatering progresses.

The deformations caused by consolidation have not been simulated successfully yet. However the drainage approaches performed well.

It has to be stated that the models presented here are first approximations which show dependencies and tendencies. To receive reality-like results the models need improvement and experimental verification.

4.3 *Design diagrams*

Based on the dimensionless calculation method of Plaut & Suherman (1998) design diagrams were created for the most important magnitudes concerning the filling process of a geotextile tube. The diagram curves were calculated with the computer program MathCAD.

Using these diagrams parameters like the filled width (B), the contact length with the foundation (B'), the filling ratio, and the maximum circumferential tension (T) can be determined depending on the pumping pressure at the inlet of the tube (P_{top}) or the filled height (H) which are input parameters.

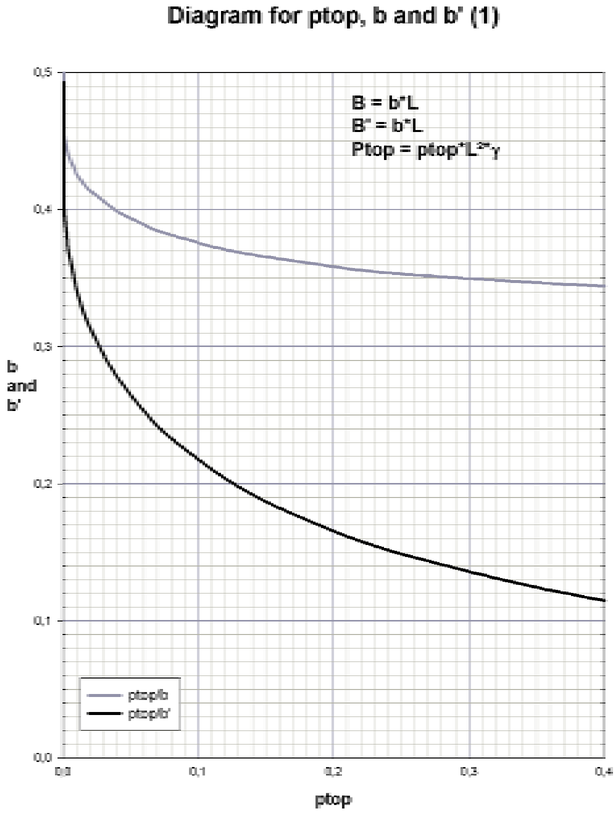

Figure 5. Diagram for the determination of Width B and Contact Length B' for known Top Pressure P_{top}.

For the dimensionless method the circumference L of the tube has to be known. All parameters only depend on the circumference except the tension and the pressure which additionally depend on the unit weight (γ). The simple formulas for the conversion of the parameters are given in the diagrams.

First the real values for H or P_{top} have to be converted into dimensionless ones. Then the dimensionless results for the needed parameters can be determined and at last these results have to be converted again into values with dimension.

Figure 5 shows the diagram for the filled width and the contact length with the foundation depending on the top pumping pressure.

5 IDEAS FOR A DESIGN GUIDE IN GERMAN LANGUAGE

In Germany there is not yet a published technical paper concerning the necessary design parameters for geotextile tubes. The GRI-Standards GT11 and GT12 (GRI 1999a and 1999b) may be helpful in preparing a German design guide.

There should be proposals about the selection of analytical design methods (filling, consolidation and loading). For the technical design, the following factors should be verified: The filling material, the choice of geotextile, the filling pressure and the filling ratio, the safety factors, the estimation of the height of the tube, the foundation, the filling process, and other factors.

Suggestions for the necessary design parameters to be used in a German manual were proposed by Cantré (2001). A manual has to be published soon to help local authorities and planners use the technology effectively. It may be an efficient technology for several working fields, along with other geotextile container technologies, but therefore the boundary conditions have to improve.

6 REVIEW OF THE DIPLOMA THESIS

The original diploma thesis reviews a wide range of case studies and experiments from the literature. In the thesis advantages and disadvantages of the technology and cost estimations are presented and commercial systems as well as existing patents are reviewed. The existing calculation methods are compared and valued. The calculations and modeling are shortly described above.

There is a large chapter about a proposed design guide in German language. In the appendix of the thesis you may find all the design diagrams, some ABAQUS input and output files, and a translation of the most important analytical basics into German.

7 PROSPECTS

Further development of the mathematical models is planned in the scope of a PhD program. Different approaches for the simulation of the mechanical and hydraulic behavior will be tested. Verifying experiments will be carried out in laboratory scale and in full scale. The simulation and experiments will lead into the development of design parameters for special applications.

Applications may be found in the province of Mecklenburg-Vorpommern in the north of Germany. It is a region with many big lakes and it is situated at the Baltic Sea coast. Thus a lot of dredging has to be done as channel maintenance and for ecological purposes. This may be a chance for the application of the relatively new technology of geotextile containers and tubes.

The tubes might also be used as temporary structures for flood protection. There are several systems for such temporary dams, including water filled hoses, and the use of small sand bags. Large sand containers or tubes might prove more successful because the filling material is more stable than pure water and a large container may be filled and placed quicker than many sand bags.

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