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Dewatering fine-grained soils using geotextile tubes – An Australian case study

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ABSTRACT: The use of geosynthetic geotextile tubes for dewatering fine-grained soils have been used extensively around the world. Common geotextile tube applications include the dewatering of sewage sludge, contaminated mine tailings and dredged fine-grained soils. This paper will examine how a small-scale onsite dewatering system, utilizing high-strength woven geotextiles will be used to dewater fine-grained soils. The objective of the field study is to establish if the geotextile tube dewatering system will retain enough fines, and discharge the minimum amount of solids out into the natural environment. Furthermore, the practical aspects of dewatering tubes will be examined, including the manufacturing and operation of geotextile tubes highlighting the common pitfalls and misconceptions of dewatering tubes. Manufacturing issues mainly include seam and inlet construction and the type of polymer and geotextile to use, while operation issues include sludge pump-ability, pump equipment, drainage and secondary filtration and containment systems such as check dams, containment bunds and/or settling ponds. The design of a geotextile tube and a parametric sensitivity analysis for determining the maximum theoretical pumping height will also be briefly examined using a commercial design software program. Issues such as the rate of pumping into the tube; the seam design; the geotextile pore size; and the type of sludge to dewater will all impact on the performance of the tube. Observations from the field trial will also be briefly discussed with the emphasis placed on the benefits of using geotextile tubes and finding simple ways of improving the dewatering and filtration performance of encapsulated geotextile tubes.

1 INTRODUCTION

The use of geotextile encapsulated tubes for sludge dewatering has been utilized and well documented in recent years (Fowler et al. 1996; Gaffney et al. 1999). However, this paper will focus on some common misconceptions and pitfalls regarding the operation of geotextile sludge dewatering tubes. In addition, the paper will also investigate some critical design parameters affecting the design of encapsulated geotextile tubes. A sensitivity analysis on these parameters will be briefly carried out on a project-specific problem. The composition of fines will also be analysed for the typical sludge material to be used in the tube. In addition, the initial percent solids will be estimated from the Total Suspended Solids (TSS) of the filtrate immediately after pumping. The TSS in the filtrate should be below acceptable values set by government regulators. In addition, disposal of the dewatered sludge should be made easy once the tube is cut open at the end of its life cycle.

1.1 *Background*

The encapsulated geotextile tubes used in this project are made from biaxial woven polypropylene geotextiles. They are used for a variety of simple sludge dewatering applications and the fundamental concepts of sludge dewatering tubes may be better explained in some of the technical papers listed in the references below. However, in essence, the function of the geotextile tube is four-fold:

1. dewatering,
2. containment (or solid retention),
3. consolidation (through moisture removal), and
4. filtration (via the filter cake).

2 PROJECT DETAILS

On a site earmarked for residential redevelopment, sedimentation ponds are required to be dewatered. However, the client requested that the geotextile sludge dewatering tube initially have a trial run using a 5 m layflat (or empty) width by 5 m long tube. For environmental reasons, the filtrate coming out of the dewatering tubes had to have an acceptable maximum Total Suspended Solids (TSS). The trial involved the following:

- dewater a representative sludge sample
- collect filtrate during different times and at different locations
- calculate the TSS for the filtrates collected
- determine the particle size distribution of the initial sludge material
- to approximate the rate of pumping and to see how this affects the dewatering performance
- to determine the time between filling cycles.

The final dewatered sludge has yet to be analysed for its final percent solids and its solids concentration, and hence will not be included in this paper. The focus of this paper will be to reveal some of the pitfalls and the lessons learnt during the dewatering tube operation and some of the design issues affecting the geotextile tube.

3 RESULTS

The suffixes on the sample IDs have been defined as follows:

FF – filtrate from first fill
25 m – filtrate 25 minutes into first fill
SF – filtrate from seam area
SP – filtrate from downstream settling pond

Table 1. Total Suspended Solids (TSS) of the collected samples.

Sample ID	TSS (mg/L)
GWS02-FF	34,000 (3.4%)
GWS03-25 m	45,000 (4.5%)
GWS04-SF	38,000 (3.8%)
GWS05-SP	180 (0.018%)

The initial feed material was not analysed for its TSS, but it is assumed to be less than 5% solids. The particle size distribution for the initial feed material was found to be 52% finer than 63 microns in particle diameter. Therefore, the sludge material is predominantly made up of fines.

4 GEOTEXTILE DEWATERING TUBES

As mentioned in the introduction, sludge dewatering tubes perform multiple functions. However, the performance of the tube depends not only on the geotextile material, but also on the actual sludge infill. Typically, this simple technology requires no chemical additives or mechanical components for it to carry out its functions. However, tube operators have been known to use polymer additives (e.g. alum) to help flocculate and coagulate sludge materials. Mechanical assistance may also be employed to increase the rate of dewatering.

One of the keys to successful sludge dewatering using geotextile tubes is finding the right type of sludge to dewater.

Some of the basic physical and hydraulic properties of the woven polypropylene geotextile used in this project are as follows:

- flow rate (for water) – 49 L/m^2/s
- pore size (dry sieve) – 320 microns
- wide width tensile strength – 110 kN/m (machine & cross directions)

Geotextile tubes have been used successfully to dewater sludge from industrial and other waste sources. Local inland councils and small coastal towns have also shown interest in sludge dewatering geotextile tubes. The main benefits that encapsulated geotextile tubes can provide are as follows:

- they minimise the sludge from being re-saturated from sudden rainfall events
- they minimise odour emissions
- they minimise space requirements
- they can reduce earthworks requirements
- they are fast to install and easy to operate
- they are flexible systems, with respect to increasing its system capacity and layout

Photo 1 shows the "layflat" empty tube installed, ready to be filled.

Photo 1. "Layflat" empty geotextile tube with inlet sleeve.

Photo 2 shows the inflated geotextile tube in operation.

Geotextile sheets are stitched together, typically using a J-seam to form an encapsulated geotextile tube. The seam efficiency, S.E., is defined as:

S.E. = (seam strength)/(base geotextile strength)

The S.E. value is usually between 40 to 60% for woven geotextiles, depending on the manufacturer's seam, stitch and thread types. This suggests that the weakest structural link in the geotextile tube is the

Photo 2. Encapsulated geotextile tube in operation.

seam. Therefore, the design for the maximum allowable tensile strength in the circumferential or hoop direction will be governed by the seam strength. The design process will be briefly discussed in the next section.

5 DESIGN OF GEOTEXTILE TUBES

The design of encapsulated geotextile tubes may be carried out using commercially available design software. The computer program used to design the tube in this project was based on the research for GeoCoPS (Leshchinsky & Leshchinsky, 1996). This is abbreviated for Geosynthetic Confined Pressurized Slurry.

The basic design parameters required for a geotextile tube analysis are as follows:

- unit weight of the slurry
- circumference of the tube
- geosynthetic reduction factors
- ultimate wide-width strength of base geosynthetic in the circumferential direction

5.1 *Geosynthetic reduction factors*

Determining the reduction factors for the geosynthetic base material is considered to be the most critical, but is usually based on typical values and not on extensive product-specific test data. Although loading of the tube will be short-term and the design life is relatively short (usually less than 1 year), the application of geosynthetic reduction factors are necessary to ensure a conservative, but safe tube design. The four geosynthetic partial reduction factors to be considered are as follows:

- installation damage, RFid (= 1.15 say)
- durability, RFd (= 1.15 say)
- creep, RFc (= 1.5 say)
- seam strength, RFss (= 2.5 say)

The above values were multiplied together to form the cumulative geosynthetic reduction factor (RFcum). This value equalled 4.96 and was used as a reference point in the sensitivity analysis for this project. The slurry pH was assumed to be between 3 to 10, and the design life was less than 12 months. Furthermore, UV degradation was assumed to be minimal over its design life. The seam strength was also determined in a laboratory test, and a conservative reduction factor of 2.5 was adopted. The creep reduction factor used is also a minimum suggested value, but is considered to be conservative as the filling operation is relatively short-term.

6 SENSITIVITY ANALYSIS

The sensitivity of each of the relevant design parameters with respect to calculating the maximum theoretical pumping height (H_{max}) and corresponding pumping pressure (P_{max}) were briefly investigated, with the circumference of the tube and the ultimate tensile strength of the base geotextile kept fixed. The following reference data was used:

- circumference of tube = 10 m (fixed)
- ultimate wide-width strength of base geosynthetic in the circumferential direction = 110 kN/m (fixed)
- unit weight of slurry = 12 kN/m^3
- RFcum = 4.96

Based on Table 2, it is clear that the effect of the slurry unit weight is much greater than the cumulative geosynthetic reduction factor, RF_{cum}. That is, a smaller percentage increase in the value of the slurry unit weight will yield the same decrease in maximum pumping height compared to the cumulative geosynthetic reduction factor. The values in brackets show the percentage differences relative to the reference data (shown in the top row in *italics*). In practice, the greatest variables designers will face will most likely be the slurry properties and the long-term design strength of the geosynthetic base material and seam.

A comprehensive parametric study can also be found in the documentation of the computer program used for the analysis.

Table 2. Sensitivity analysis of maximum pumping height.

H_{max} (m)	P_{max} (kPa)	Unit weight (kN/m^3)	RF_{cum}
2.1	7.9	12	4.96
1.7 (–19%)	5.3 (–33%)	23 (+92%)	4.96
1.7 (–19%)	2.4 (–70%)	12	10.28 (+107%)

7 LESSONS LEARNT

Although geotextile tubes are a simple technology, a few lessons have been learnt in relation to optimising the performance of these tubes. As mentioned earlier, chemical additives such as polymers may be employed.

However, it has been found to be a trial and error exercise, and sometimes even non-effective. Mechanical devices have proven to be effective and these may include; an automated or manually operated high-pressure water spray or mechanical "whacker" – this allows the geotextile pores to be cleaned out periodically (using a fluid such as water or perhaps air), and it also allows an externally applied pressure to be put on the tube to promote dewatering by breaking up the filter cake on the inside. This effectively prolongs the service life of the dewatering tube.

Failure of the geotextile tube is likely to occur at the seam during the filling operation. The seam strength is also found to be the weakest link and this will govern the structural design of the tube.

The type of slurry infill will determine the filtration and dewatering efficiency, and not the tube's geotextile mechanical and hydraulic properties. Non bio-sludge (or inorganic) infills are likely to dewater better than organic sewage sludge. The use of drainage materials (either gravels or a geocomposite drainage layer) under the geotextile tube has been found to be questionable. The popular belief that it will improve dewatering by increasing the available surface area for dewatering is logical. However, the filter cake formed at the base of the tube will inhibit any chance of water to pass beneath the tube. Experience has shown that since the filter cake cannot be externally disturbed on the tube base, the drainage blanket under the tube may be redundant. The filter cake formed inside the tube allows the filtrate to be "mechanically" filtered via means of a "filter bridge". However, over time, the dewatering rate will reduce towards zero as the sludge (containing moisture in its voids) becomes trapped within the tube as the filter cake hardens.

The rate of pumping may also influence the filtration and dewatering efficiencies. However, in practice, the commercial pumps available for use are usually too powerful for typical geotextile tube applications. Whenever pumps are used, always remember not to exceed the maximum allowable pumping height of the tube at all times!

8 CONCLUSIONS

In summary, we can conclude that:

- the design of geotextile tubes can be easily carried out using computer software
- a parametric study for encapsulated geotextile tubes show that the slurry unit weight has a greater effect on the maximum tube pumping height than on the cumulative geosynthetic partial reduction factor
- the cumulative geosynthetic reduction factor, RFcum, is governed by the long-term design strength of the seam
- from observations and past experience, non bio-sludge materials dewater better than organic sewage sludge
- additional research and field studies on why a particular sludge dewaters better relative to other slurry materials need to be carried out
- additional research and field studies on how to improve dewatering and filtration efficiencies using on-site methods (such as polymer additives and/or mechanical aids) need to be investigated
- the performance of a geotextile tube is more dependent on the sludge properties rather than on the geotextile's mechanical and hydraulic properties
- the drainage blanket under the geotextile tube is considered to be redundant
- encapsulated geotextile tubes is a very simple and cost-effective means of dewatering sludge
- the design of large geotextile tubes and its applications is relatively small and even unknown in Australia compared to the international arena, but its use is growing steadily in various industries

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