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The efficacy and use of small centrifuge for evaluating geotextile tube dewatering performance

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A B S T R A C T

Geotextile tube dewatering technology has been widely used over the past two decades for dewatering high water content slurries. The dewatering process in geotextile tubes aims to decrease the volume of the dewatered slurry, which helps in the transportation, disposal, and reuse of the dewatered material. Several researchers have emphasized the effect of the retained sediment (filter cake) properties, in particular final solids content and volume (height) change, on the feasibility of geotextile tube dewatering projects. Retained sediment properties are often evaluated using small scale tests such as rapid dewatering test, falling head test, pressure filtration test (PFT), and field scale tests such as hanging bag test (HBT) and geotextile tube demonstrations test (GDT). In this study, centrifuge test is introduced as an alternative for the widely used pressure filtration and falling head tests to evaluate retained sediments properties. Centrifuge test provides a mechanism for understanding the response of slurries to externally applied pressure in geotextile tube environment. Centrifuge test was used to evaluate maximal solids content of the retained sediments and change in slurry volume of four soils that represent typical dredged soils. Tully sand, Tully fines, Elliott silt loam, and kaolin slurries were used at varying solids concentrations. Slurries were subjected to external stresses between 0.1 and 40 kPa by applying centrifugal speeds between 300 rotation per minute (rpm) and 1800 rpm. Both centrifuge test and PFT were conducted with unconditioned and cationic polyacrylamide conditioned slurries. Centrifuge tests results were compared with PFT results with respect to retained sediments final solids content and volume change. Tests results indicated that the maximal solids concentration of the retained sediments in saturated conditions is unique for each soil and is independent of the initial slurry solids concentration. Tests results also indicated that there is linear relationship between the initial concentration of the slurry and the final volume change at any externally applied stress. Finally, a relationship between the total pumped slurry volume and the final height of the dewatered sediments in a geotextile tube is presented.

1. Introduction

Geotextile tube dewatering technology has been widely used over the past two decades for dewatering high water content slurries. The dewatering process in geotextile tubes aims to retain sediments and at the same time allows for the release of liquid effluent through the geotextile pore openings. This results in an increase in the solids content of the dewatered slurry and allows for a larger volume of sediment to be contained in a geotextile tube. Generally, in geotextile tubes, four major sediment-water (slurry) processes occur simultaneously: (1) water seepage from the opening of the geotextile pores; (2) sedimentation of solid particles; (3) filter cake formation; and (4) filter cake compression and consolidation.

Small-scale tests such as rapid dewatering test, falling head test, and pressure filtration test (PFT) are widely used to assess geotextile tube dewatering performance. Small scale tests are complementary tests for field tests such as hanging bag test (HBT) and geotextile tube demonstrations test (GDT). The PFT, however, is the most commonly used test for evaluating dewatering performance of geotextile tubes in laboratory settings (Khachan et al., 2014; Kutay and Aydilek, 2004; Moo-Young et al., 2002; Muthukumaran

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and Ilamparuthi, 2006; Satyamurthy and Bhatia, 2009). Parameters such as retained sediments (filter cake) solids content, retained sediments height, effluent quality, and dewatering rate that are obtained from the PFT are used to assess the dewatering performance of geotextile tubes prior to full-scale implementation.

While dewatering rate and effluent quality are essential parameters for determining the dewatering time and the retention performance in geotextile tube dewatering projects, determining the retained sediments final solid content and geotextile tube final volume (height) in the design stages of geotextile dewatering project is critical for the feasibility study of the project in terms of number of the geotextile tubes needed for the project, the dewatered slurry volume, and sediments consistency. In geotextile tubes, the final solids content and the final sediments volume are mainly controlled by the sediment properties and the externally applied stresses. The externally applied stresses to geotextile tube originate from the filling pressure, water head during multiple filling stages of the geotextile tubes, self-weight of the sediments, and stacking of geotextile tubes. Therefore, understanding the response of slurry to the externally applied stresses is necessary for determining the final solids content and retained sediment height change in multiple filling stages.

Several geotextile tube researchers (e.g. Kim et al., 2016; Koerner and Koerner, 2010; Lawson, 2008; Shin and Oh, 2003; Yee et al., 2012) have performed field scale tests such as GDT, HBT, and large scale prototypes to determine retained sediments solids content and the slurry volume change at the end of the dewatering process. Shin and Oh (2003) evaluated geotextile tube dewatering behavior using large scale field tests. Dredged sand ($d_{85} = 2$ mm with 5% < 0.075 mm) at 37% initial solids content and dredged silty clay ($d_{85} = 0.065$ mm with 90% < 0.075 mm) at 19% initial solids concentrations were used in their study. The geotextile tube used was 8 m in circumference and 25 m in length which allowed for maximum filling height of 1.22 m. The geotextile tube filling time for the dredged sand was only one hour and the dewatering time was less than two days. Whereas, the filling time for the dredged silty clay soil over four filling and drainage stages was 10 h, and the total dewatering time was more than two weeks. Shin and Oh (2003) evaluated the change in geotextile tube height during dewatering and related it to the solids content of the dewatered sediments, comparing observed values with the respective estimated values. It was found that the prediction of the change in geotextile tube heights using conventional consolidation theory (0.44 m for dredged sand and 0.19 m for dredged silty clay) was significantly lower than the experimental data. The reason for this difference was attributed to deviations between the theory and the real behavior of the tube.

Lawson (2008) identified two major objectives for geotextile tube dewatering projects; reduction of slurry volume through reducing the amount of water in the dewatered material, and change in the consistency of dewatered material from liquid state to semi solid state (increasing solids content), which helps in the transportation and disposal of the dewatered material. Lawson (2008) proposed the use of Eq. (1) to determine the solids content in geotextile tube at any time during the dewatering process. Eq. (1) is derived from the mass balance between the inflow slurry and the outflow effluent.

$$\frac{V_t}{V_0} = \left(\frac{1-S_t}{S_t} + \frac{1}{G_s}\right) \Big/ \left(\frac{1-S_0}{S_0} + \frac{1}{G_s}\right) \quad (1)$$

Note that the mass balance Eq. (1) requires obtaining the change in geotextile tube volume to calculate the final solids content. However, such information is not readily available at the design stage of geotextile tube dewatering projects. It can only be obtained during the full scale geotextile tube dewatering process. Lawson also presented typical values for final solids content at the end of the dewatering process for several materials; final solids content in the range of 35%–70% was suggested for sediments such as sands, silts, and clays. This large range indicates that it is necessary to understand the properties of the dewatered sediments due to their significant effect on the achievability of the dewatering project.

Koerner and Koerner (2010) conducted GDTs to evaluate the efficacy of geotextile tubes for dewatering sand, silty clay, and clayey silt (SP, ML, and CL per Unified Soil Classification System, ASTM D2487-06). GDTs were conducted on unconditioned soil samples at solids contents of 16.6%, 14.2%, and 13.6% for sand, clayey silt, and silty clay respectively. The slurry was filled in the geotextile bags through port that is connected to a 1.4 m cylindrical tube. The extension tube is added to the test setup so that the test setup simulates the geotextile tube heights which are significantly higher than the small GDT setup. The extension tube allows for an initial head of about 15 kPa which decreases eventually as the water flows out from the geotextile bag. After 24 h of dewatering, the GDTs were cut open and the solids content of the retained sand, clayey silt, and silty clay were found to be 90%, 65%, and 62%, respectively. These values, however, were not compared to large scale dewatering test to determine if they are representative of field conditions.

Yee et al. (2012) presented a case study on the dewatering of 5 million m^3 of contaminated dredged sediments using geotextile tubes. The sediments were mixtures of silts and clays with high organic matter content. In this project, geotextile tubes were used as an ecofriendly method for dewatering sediments at 10% solids concentration. The dewatering effectiveness was evaluated using small-scale tests (rapid dewatering tests), geotextile demonstration tests, and large-scale tests (full scale prototype). GDTs results yielded a final solids content of the filter cake of about 30% after 13 days of dewatering. Based on the preliminary results, a full-scale geotextile tube prototype test was performed. Once the prototype geotextile tube tests were completed, the geotextile tubes were cut open to evaluate the final solids content. Yee et al. (2012) found a final solids content of 53% which was significantly higher than the 30% final solids content predicted by GDT. Such finding indicates that the final solids content obtained from conventional GDT significantly underestimated the final solids content in large scale geotextile tubes.

In a recent study, Kim et al. (2016) evaluated the dewatering performance of two field scale geotextile tubes. The geotextile tubes that have diameters of 3.0 and 5.0 m were filled with silty sand ($d_{85} = 0.07$ mm with 26.2% finer than 0.075 mm) slurry with an initial solids concentration of 40% and 37% respectively. The final solid content and the change in height were measured at the end of the first filling/dewatering cycle. For the 3.0 m geotextile tube, the average final solid content was 55% and the ratio of the final height (~0.9 m) to initial height (1.57 m) was 57%. For the 5.0 m diameter geotextile tube, the average final solid content was found to be 52%, and the ratio of the final height (~0.94 m) to initial height (1.7 m) was 55%. In addition, Kim et al. compared the drop in height of the geotextile tubes with one dimensional approximation method and two dimensional analytical solutions and found fairly acceptable agreement between the measurement and the numerical results. Kim et al. study, however, did not provide information about the use of flocculants, dewatering time, soil loss, and the volume of slurry that was pumped in each geotextile tube to reach the required maximum height.

In addition to field scale tests, many researchers (e.g. Cantré and Saathoff, 2011; Driscoll et al., 2016; Khachan et al., 2014; Liao and Bhatia, 2005; Moo-Young et al., 2002; Satyamurthy and Bhatia, 2009) have performed small scale tests, in particular PFT, to assess