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Comparison of 1-D and 2-D Tests in Geotextile Dewatering Applications

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Abstract

In this study, two different one-dimensional tests (only vertical flow) (Pressure Filtration Test and Suction Filtration Test) were compared to determine variability in the results due to different forms of pressure application. In addition, an innovative Two-Dimensional Filtration Apparatus (with both vertical and radial flow) was developed in order to determine the effect of radial flow on the results. This apparatus will more accurately imitate the real-life dewatering application of geotextile tubes. Unlike on-site “hanging bag” and “Pressurized Geotextile Dewatering” tests, this laboratory apparatus was designed in a form that will facilitate the studying of dewatering rate vertically and radially separately. It will also be used by mathematicians, as its geometric form will be more conducive to the analysis of dewatering. This will aid in the creation of a simple and fast mathematical model to determine geotextile dewatering rate, which will reduce the need and cost of experimental testing prior to actual dewatering in the site.

Keywords: Geotextile, geotextile tube, dewatering rate, one-dimensional, two-dimensional, dredging, filter cake

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1. Introduction

Geotextile tubes have been widely used around the world to contain and dewater high water content contaminated slurries [17], mine tailings, fly ash [6], and industrial and municipal sludge [17]. Dredged sediment from water bodies is pumped into geotextile tubes where the water freely drains while sediments are retained. After multiple fillings and subsequent dewatering, the filter cake formed from the retained sediments is allowed to consolidate. Following the consolidation, the geotextile tubes are left in place and capped, or hauled to the landfill facility for disposal.

Various types of performance tests have been conducted to understand the dewatering performance of the slurry at full scale. The performance tests are small-scale laboratory tests performed on small representative samples of the slurry; or medium scale that may be performed in the lab or field [3]. These tests not only help to characterize the sample and provide information about dewatering efficiency, but also aid in finding the optimum dose of chemical conditioner keeping in mind the project guidelines and specifications. The small scale tests that have been widely used are the Pressure Filtration Test (PFT), Suction or Vacuum Filtration Test, and the Falling Head Test (FHT). PFTs have been used by many researchers to assess dewatering performance [1, 6, 7, 8, 10, 11, 12, 14]. Some studies using Vacuum Filtration tests have also been performed [9]. Others have used Falling Head tests to simulate dewatering through the geotextile [4]. The PFT setup consists of a cylindrical acrylic reservoir and threaded base plate that holds the geotextile and directs the filtrate flow. Air is applied to the reservoir using compressed air in the laboratory. The effluent is measured using a digital scale, and following dewatering, the filter cake properties such as solids content and height are measured. Vacuum filtration tests have also been used to assess the dewatering performance in the lab [10]. Typical vacuum filtration setup is composed of a plastic permeameter that holds the geotextile in place, and a vacuum pump that supplied the required vacuum pressure below the geotextile-slurry interface. In both PFT and Vacuum Filtration Tests, the flow through the geotextile is only vertical. As a result, these tests help to predict only the vertical dewatering rate. However, in real dewatering application the flow takes place both vertically and radially. Hence, a test setup that can incorporate vertical and radial flow can help to better understand the dewatering rate as well as filter cake properties.

Some of the commonly used medium-scale tests are the hanging bag test (HBT) and geotextile tube dewatering test (GDT). Hanging bag tests and pilot tube tests have been used in-situ to determine the filtration rate, soil loss, and filter cake properties of the site-specific sediment [3]. Hanging bag tests are commonly used in the field to predict dewatering performance [2, 6, 7]. They are open to the air at the top, where the slurry is added and dewaters radially and vertically by gravity while filtration rate is recorded. To simulate real dewatering applications, a second filling is added at the same volume and concentration after the first filling ends. After the two fillings, filter cake properties including solids content, soil loss, and turbidity are recorded.

More recently, GDTs have been more commonly used to assess the dewatering performance as it imitates the dewatering process well, and simulates the transport of flocculated sediment through pipeline elbows and valves. In addition to creating representative samples of filter cake and the filtrate, this test confirms the chemical conditioning dose of full scale application. Grzelak et al. [3] compared the lab scale tests (FHT and PFT) with medium scale tests (HBT and GDT) using a woven geotextile and silt slurry at 33% solids concentration. It was found that the dewatering efficiency was similar for the PFT, HBT, and GDT, while filtration efficiency was similar for the HBT and GDT. However, FHT was determined to be a poor indicator to assess the dewatering performance compared to other test methods studied. The dewatering efficiency is defined by the following relation

$$\text{Dewatering efficiency} = \frac{(\%\text{Solids}_{final} - \%\text{Solids}_{initial})}{(\%\text{Solids}_{initial})} * 100\%$$

However, the dewatering efficiency provides information about the final solid content of the filter cake as compared to the solid content of the slurry. Information about the dewatering rate (vertical or radial) is not compared.

In order to understand the vertical as well as radial flow during dewatering, a new laboratory two-dimensional filtration apparatus at Syracuse University was developed. The apparatus is geometrically designed to separate radial from vertical drainage areas in order to determine the ratio and rate of radial vs. vertical dewatering. The results from the test will be of great use in the laboratory, as it will provide for more accurate dewatering rate and filter cake property analysis. The two-dimensional filtration apparatus more successfully imitates large scale dewatering in geotextile tube dewatering as compared to the one-dimensional dewatering test. This apparatus aims to address some of the limitations of the PFT and Vacuum Filtration Tests used in the laboratory.

2. Materials

2.1 Soils

The soils used for this study were obtained from Clarks Aggregate Co., a local quarry located at Tully, NY. The coarse soil, identified as Tully sand, was prepared by removing fractions coarser than US sieve No. 4. The sediment contains 92% sand and silt, and about 8% clay particles. The sediment was found to be non-plastic and classified as SP-SM. The properties of soil are given in Table 1.

Table 1 Tully Sand Properties

Property	D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	C_u^*	C_c^*	S_o^* (m^2/kg)	USCS Classification
Tully Sand	0.007	0.077	0.13	18	6.51	438.12	SP-SM

$^*C_u$: coefficient of uniformity = D_{60}/D_{10}; $^*C_c$: coefficient of curvature = $(D_{30})^2/(D_{10})(D_{60})$
$^*S_o$ is the specific surface area

2.2 Flocculant

Zetag 8185 anionic polyacrylamide copolymer was found to be the optimum flocculant for Tully sand, at a dose of 200ppm. A Phipps and Bird PB-700 Jartester with four large paddle mixers were used to mix the sediment, DI water, and polymer together. All tests were mixed with polymer to enhance flocculation.

2.3 Geotextile

A high strength polypropylene (PP) woven monofilament geotextile commonly used in dewatering was selected for this study and was provided by TenCate. This geotextile has an apparent opening size (AOS) and permittivity compatible with the Tully sand when flocculated. The physical and hydraulic geotextile properties are presented in Table 2.

Table 2 Physical and Hydraulic Geotextile Properties

Material	Polypropylene (PP)
Fabric Structure	W[a], MF[b]
AOS[c] (mm)	0.42
Permittivity (s^{-1})	0.37

Mass per Unit Area (g/m^2)	585
Thickness (mm)	1.04
Tensile Strength (kN/m)	96x70

[a]W: Woven; [b]MF: Monofilament;
[c]AOS: Apparent Opening Size

3. Test Methods

3.1 Pressure Filtration Test

The Pressure Filtration Test (PFT) setup has been shown in Figure 1. PFT consists of a cylindrical reservoir (72mm diameter, 170mm height, and 600mL volume capacity) and threaded container that secures the geotextile in place. A 547.17mL slurry at 20% solids concentration of Tully sand and optimum dose of zetag 8185 flocculants was mixed together in a Phipps and Bird Jartester at 220rpm. After mixing, the slurry was quickly transferred into the cylindrical reservoir and the cap was screwed. The reservoir was placed into the holding apparatus and the pressure hose was connected using lab supplied compressed air at 5.51-6.89 kPa, and this pressure was held constant throughout the test. This pressure represents the internal pressure during dewatering of geotextile tubes. To begin, the dewatering valve was released to initiate dewatering. After the first filling, the air pressure was reduced, the cap removed, and the second filling of the same concentration and volume was added; after which the system was returned to its dewatering state and filtration continued. Effluent volume was measured during both first and second fillings using a 500mL graduated cylinder. At the end of the PFT, the filter cake was immediately taken from the reservoir and the filter cake height was measured. The samples were weighed then were oven dried for 24 hours to measure their moisture content and percent solid of the filter cake.

3.2 Suction Filtration Test

The suction filtration test has been used in the lab to simulate dewatering of pulp using a nylon mesh filter [13] and has been shown in Figure 2. Within the drainage basin there is a geotextile housing unit that holds a removable threaded metal plate. A large metal filter is below the geotextile to keep it steady, and then a metal topper is screwed down onto the geotextile in the plate to secure it in place. The cylindrical metal plate can then be added into the housing unit. The apparatus also consists of a voltage reader held at the top of the apparatus above the cylindrical reservoir to record voltage measurements as slurry level drops which can be converted into height measurements after testing. A drainage basin is used to connect the cylindrical reservoir and funnel to fill the second reservoir and top off the geotextile housing unit with DI water before addition of the slurry. Slurry can be added directly into the cylindrical reservoir which has clamps to release and snap it down onto a rubber component on top of the geotextile housing unit to ensure a water tight apparatus. Data is recorded as the rubber stopper is removed to initiate dewatering.

A 547.17mL slurry at 20% solids concentration of Tully sand was mixed together in a Phipps and Bird Jartester at 220rpm. The slurry was then added quickly into the apparatus and sits at the bottom of the first cylindrical reservoir. The rubber stopper at the bottom of the second reservoir was removed to initiate dewatering through suction. As water drains into the second reservoir, volume does not change, therefore suction pressure was constant. After the first filling, the second filling of the same concentration and volume was added. Effluent volume was measured continuously during the tests. Filter cake properties and quality of effluent were recorded at the end of the test.

Both the pressure filtration test and suction filtration test accomplish dewatering through application of a known pressure in vertical direction only. However, instead of air being supplied at the top of the apparatus as in the PFT, this method uses a suction pressure of 5.51 kPa over the second reservoir to dewater the sediment. This is done by filling the second reservoir with de-aired water, creating a constant pressure head throughout the entire test. In this study the results will be compared.

3.3 Two-Dimensional Filtration Test

The Two-Dimensional Filtration device has been developed at Syracuse University to measure dewatering rate of the slurry in radial and vertical direction in a laboratory environment and is shown in Figure 3. Radial results were those recorded from filtering through the sides of the geotextile, while the vertical results are those recorded through the bottom of the geotextile, as well as through the filter cake once it has formed. Unlike a hanging bag test used in the field, this test allows the determination of radial and vertical dewatering rate as well as filter cake properties. The apparatus consists of a woven geotextile molded to an outer supporting structure. The geotextile is designed at a height of 60cm to create a pressure of 5.51 kPa only through the addition of slurry at the start of the test, which lessens as dewatering proceeds. The apparatus is 15cm in diameter, housed 3cm below the top of a drainage basin that is 30cm in diameter. The drainage basin is raised above the ground on four legs. Two center drainage pipes collect vertical effluent that collects into a beaker, while four drainage pipes in the drainage basin collect radial effluent that collects into a large container on top of a balance to record measurements.

For each filling, two sets of 4,956mL slurry (a total of 9,912mL per filling, 9 times more than used in PFT and Suction Filtration tests) at 20% solids concentration was mixed together in two separate containers, as this was more practical for such a large volume. For the first filling, the slurry was added to the apparatus in two stages in quick succession. After dewatering slows to almost zero, the second filling was mixed and added. Measurements of the radial dewatering rate were taken continuously during the tests, while vertical dewatering rate was recorded every minute. Filter cake properties and turbidity were measured after the end of the test. The volume used for all three tests have been summarized in Table 4.

Table 4 Test Volume Comparison

	PFT	Suction Filtration Test	2D Filtration Test
First Filling – V1	547.17mL	547.17mL	9,912mL
Second Filling – V2	547.17mL	547.17mL	9,912mL

4. Results and Discussion

4.1 Pressure Filtration Test

Two trials of PFT were performed in order to ensure reproducibility. The dewatering curve has been shown in Figure 4. The first filling dewatered in approximately 9 minutes, where almost 450 mL (40% of the total volume) dewatered. Once the dewatering slowed, the second filling of same concentration and volume was added. The second filling dewatered at a slightly slower rate, taking between 20-26 minutes, about three times more than the first filling. However, the same amount of water (450mL, 80% of the total) was dewatered in the second filling compared with the first filling. The reason behind slow dewatering during second filling is due to the formation of the filter cake from the first filling. The filter cake reduced the permeability of the system, and subsequently the dewatering rate decreased. It can be seen that after the formation of a stable filter cake, the dewatering rate is governed by the permeability of the filter cake rather than the geotextile. The variability in test results is a result of the disturbance of the apparatus from air reduction and cap removal done to add the second filling. After the end of second filling and dewatering, filter cake properties were measured. The dewatering performance of the PFT has been summarized in Table 5. It can be seen that the average solids content of the filter cake from three tests was 69%. The height of the filter cake ranged from 4.8 cm to 5.3 cm. The percent of soil loss was 0.2% However, it was observed that the soil loss happened only during the first filling. The soil loss during the second filling was almost zero due to the formation of filter cake. The turbidity of the filtrate collected at the end of the test was below 50 NTU, and ranged from 27.1-41.2 NTU.

Table 5 Dewatering performance from the PFT

	Test 1	**Test 2**
Solids Content (%)	69	69
Height (cm)	5.3	4.8
Soil Loss (g/m^2)	86.5	72.3
Soil Loss (%)	0.20	0.20
Turbidity (NTU)	41.2	27.1

4.2 Suction Filtration Test

The dewatering curve has been shown in Figure 5. The first filling of the Suction Filtration Test took about ten minutes to completely dewater. Once dewatering slowed at around 490mL (44% of total), the second filling of same concentration and volume was added. The second filling dewatered at a slightly slower rate, taking twenty-five minutes, about three times more than the first filling. Slightly less water (440mL, 85%) was dewatered in the second filling as opposed to the first filling. Filter cake properties were recorded at the end of the second filling. The dewatering performance from Suction Filtration Test has been summarized in Table 6. The solids content of the filter cake ranged from 69-70%. The soil loss was significant and ranged from 221 to 314 g/m^2 which corresponds to 0.56-0.80%. The turbidity of the filtrate ranged from 80.2-112.4 NTU.

Table 6 Dewatering performance from the Suction Filtration Test

	Test 1	**Test 2**
Solids Content (%)	69	70
Height (cm)	4.1	4.4
Soil Loss (g/m^2)	221.6	314.4
Soil Loss (%)	0.56	0.80

Turbidity (NTU)	80.2	112.4

4.3 PFT vs Suction Filtration Test

Results from both one dimensional tests were similar in solids content of the filter cake. Both dewatered in about eight minutes for the first filling, while the second filling took about twenty five minutes to dewater. However, while the PFT setup dewatered the slurry in about 25 minutes, it took the same slurry to dewater in the Suction Filtration setup in about 35 minutes. Hence, it can be said that PFTs dewater slightly faster on average. It was also seen that the soil loss in Suction Filtration test (average of 268 g/m^2) was much higher than seen from the PFT (79.4 g/m^2). As a result, turbidity of the filtrate collected from the Suction Filtration Test was higher than from the PFT.

4.4 Two Dimensional Tests

As in the case of 1-D tests, two fillings were performed for 2-D dewatering tests. The filtrate and filter cake properties were measured at the end of dewatering from the second filling. It was observed that the first filling dewatered in approximately 15 minutes. Specifically, the dewatering occurred rapidly during the first 5 minutes and proceeded slowly thereafter because of the formation of vertical filter cake. During the first filling, 1150 mL dewatered from the vertical direction, whereas approximately 6195 mL dewatered from the radial direction. The dewatering curve for vertical and radial flow has been shown in Figure 6 and 7 respectively. The comparison of total flow with radial and vertical flow is shown in Figure 8. This is due to the fact that as flocculated slurry is poured in the test setup the soil settles forming a stable filter cake. Due to the formation of filter cake, the permeability decreases in the vertical direction. As a result, a majority of the dewatering occurs in the radial direction. The vertical and radial dewatering comprised 15.45% and 83.25% of the total volume dewatered during the first filling. The ratio of radial to vertical dewatering was 5.38. Hence, it can be seen that the radial component comprises the major portion of the dewatering in 2D dewatering setup. After the first filling, a second filling of the same volume and solids concentration (9912.03 mL at 20% solids concentration) was added to the setup. As seen in case of the first filling, dewatering was rapid during the first 5 minutes and proceeded gradually thereafter with total dewatering achieved around 35-40 minutes. However, during the second filling the volume dewatered from the vertical direction dropped significantly from 1150 mL to 220 mL compared to the first filling. It corresponds to an almost 80% drop in dewatering compared to the first filling. However, the volume dewatered from the radial direction increased from 6193 mL to 7434 mL during the second filling. The radial flow contributed to 98% of the total flow whereas the vertical flow contributed to just 2% of the total flow during the second filling. The ratio of radial to vertical flow during the second filling increased from 5.38 to 38.79 compared to the first filling. This is due to the reduced permeability because of the filter cake in the vertical direction.

Solids content of the filter cake ranged 67-72%. Soil loss was much lower than standards, with most occurring radially rather than vertically. Turbidity of the filtrate ranged from 19.1-26 NTU. Initially, turbidity was high as there was an initial soil loss, but it decreased as the filter cake formed. Soil loss was greater radially than vertically due to the lack of a large filter cake on the sides of the geotextile. The dewatering performance from the 2D tests has been summarized in Table 7.

Table 7 Dewatering performance from 2D tests

	Test 1	**Test 2**
Solids Content (%)	67-72	63-67
Height (cm)	19.5-21	19-20.5
Soil Loss (g/m^2)	331	102
Soil Loss (%)	1.7	0.3
Turbidity (NTU)	26.1	19

4.5 Discussion

The PFT and Suction Filtration apparatuses, while not similar in form, are similar in function. The PFT apparatus is designed to add pressure by air at the top of the dewatering column, creating an additional force to gravity to push water through the geotextile. It begins at a pressure of 5.5 kPa and naturally lessens throughout the test. This is because as dewatering proceeds, water leaves the system and the air can fill a greater area. This was compensated for by increasing pressure back up to 5.5 kPa throughout the test, to allow for suction test comparison. The Suction Filtration apparatus is designed at a specific height to create a pressure gradient of 5.5 kPa between the top and bottom of the apparatus through the removal of air. The height by which the pressure gradient is created never changes, so dewatering is done at a constant and regulated rate. The apparatuses are analogous as they are both one dimensional tests using a pressure of 5.5 kPa to facilitate dewatering, and their resemblance is apparent in the test results as discussed earlier.

Conversely, the Two-Dimensional Test apparatus dewaters both radially and vertically, and no pressure is exerted on the system other than gravity. The apparatus is designed at a height of 60cm, which produces a pressure of 5.5 kPa on the system when filled with slurry. The pressure can be dissipated radially as well as vertically throughout the test. As dewatering proceeds, similar to the PFT apparatus, pressure lessens on the system. With the addition of a second filling this can temporarily be brought back up to 5.5 kPa, but additional controls on the system are not possible. These conditions are favorable however, as the process of pressure attenuation creates conditions much more representative of real life dewatering applications.

Unlike the one-dimensional test apparatuses, the slurry in the Two-Dimensional test apparatus can dewater both vertically and radially. Radial drainage was determined to be a large factor in dewatering time, as nearly 80% of the total slurry dewatered through the sides. Dewatering will occur wherever the fastest and easiest path is present. Time of dewatering is governed by both the geotextile and the filter cake, but due to the lower permeability of the filter cake, most dewatering occurs radially. This explains why both 1st and 2nd fillings dewatered in the same time. Sediment on the sides of the geotextile would fall from the sides leading to the edges of the sediment being slightly higher than the middle. This may be the reason for the higher water content in the middle of the apparatus. These processes demonstrate a condition that is much more representative of real life dewatering applications, in which the filter cake is not a clean formation.

Solids content was on average 62% for one filling whereas it was 69% for two fillings. Dewatering was not as productive in the one-filling Two-Dimensional tests than the two fillings due to the added weight and pressure on the system. Using the two fillings test comparisons, dewatering rate was much faster with two-dimensional dewatering vs. one-dimensional due to radial dewatering.

5. Conclusion

The Two-Dimensional test is comparative in function to the hanging bag tests used on dewatering sites. However, unlike hanging bag tests, the Two-Dimensional test apparatus is designed to create results similar to real life conditions for additional testing in the laboratory. It is evident that the creation of a Two-Dimensional Filtration Apparatus for use in a laboratory setting can be of great benefit to a multitude of people, including researchers, mathematicians, and field operators. Because the Two-Dimensional apparatus can easily identify radial drainage from vertical drainage, a mathematical model may be produced that would reduce the need and cost of experimental testing in construction projects. However, at this time, a couple improvements on the apparatus need to be made, including a more structurally sound form and reproducible testing method. The form is currently not able to be replaced with a new woven geotextile simply. A simpler and easier method of slurry mixing and addition to the apparatus would also be of great benefit.

6. Acknowledgements

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8. Appendices

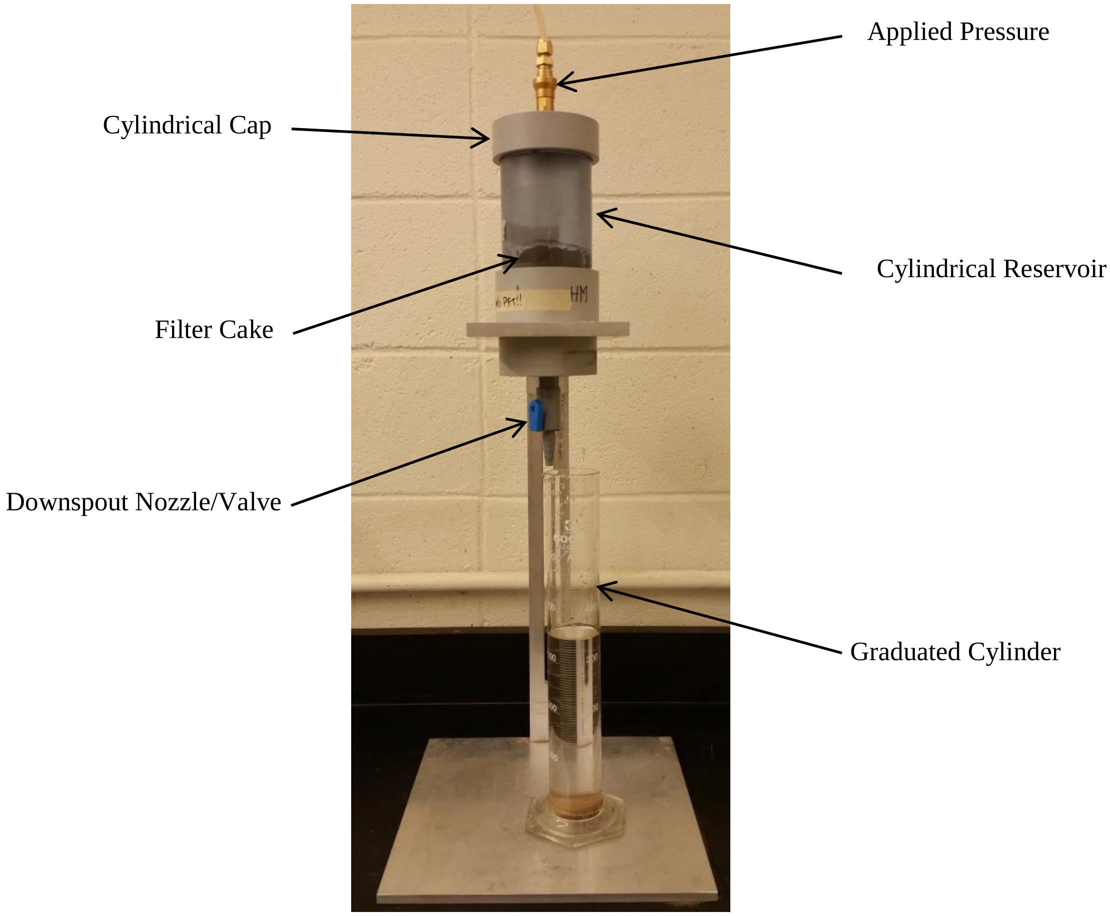

Figure 1 PFT Test Set Up [15]

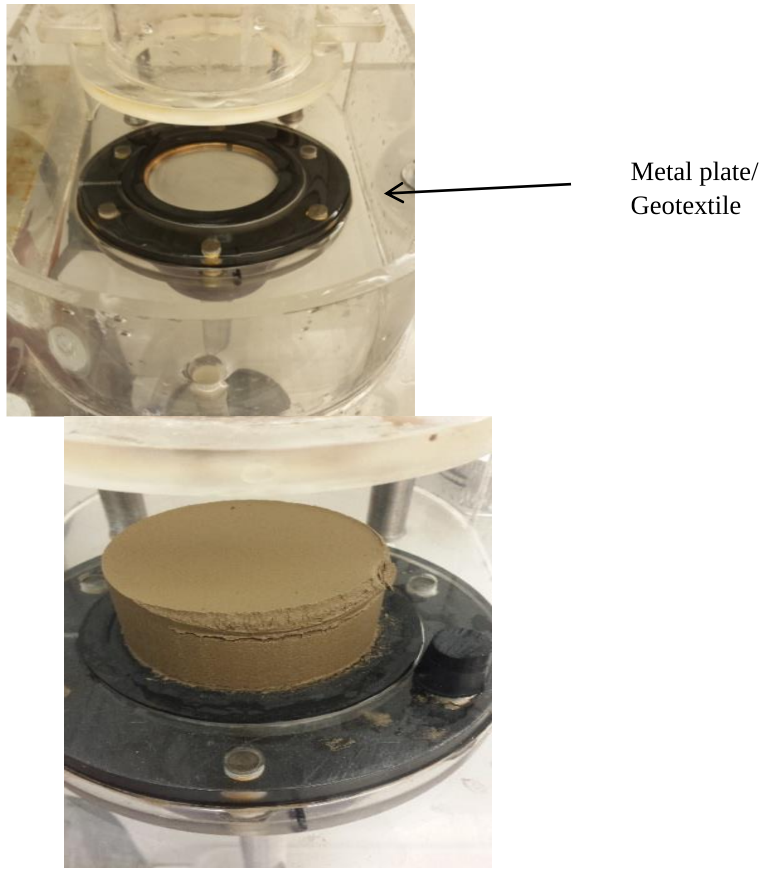

Figure 2 Suction Filtration Test Setup

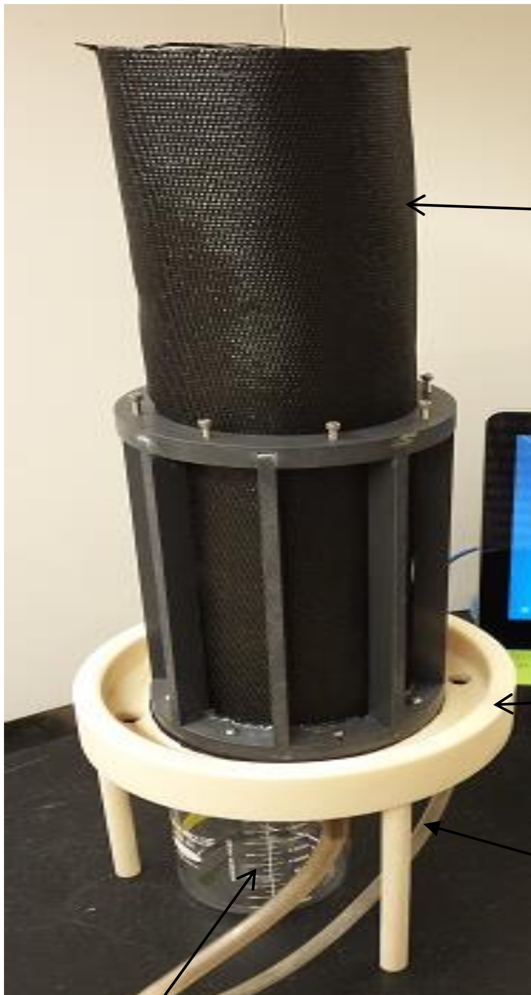

Figure 3 2-D Test Setup

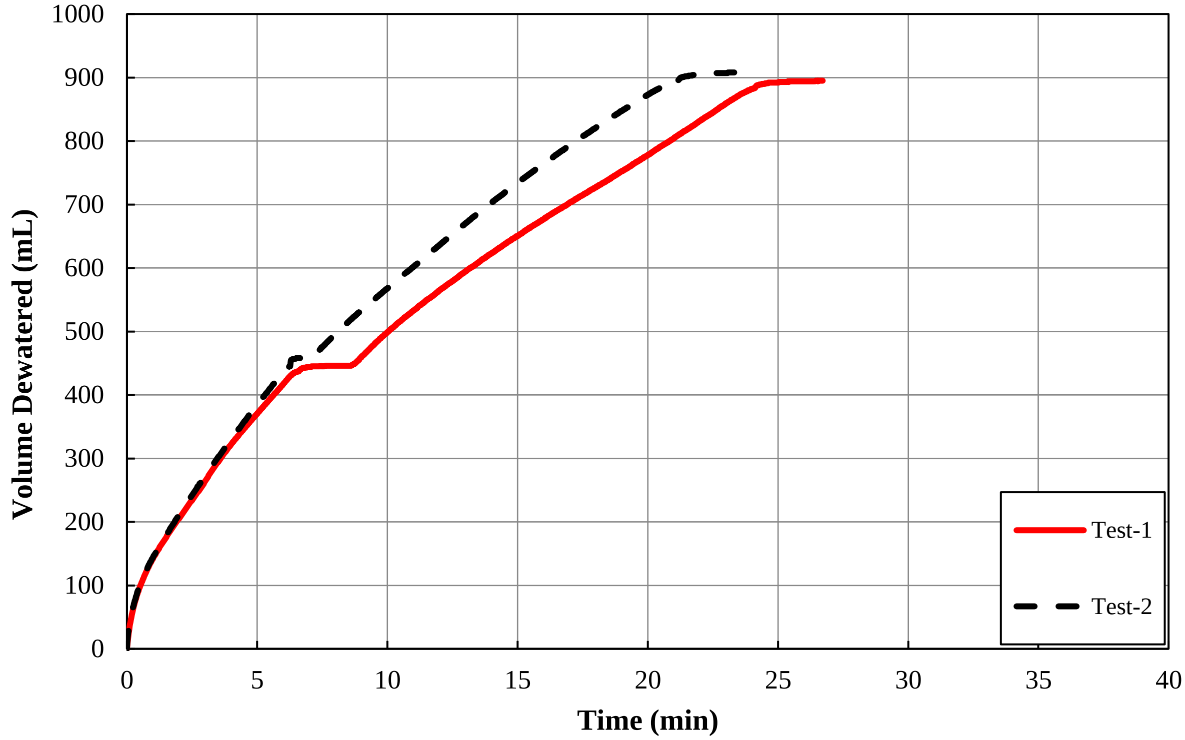

Figure 4 Dewatering curve from PFT test

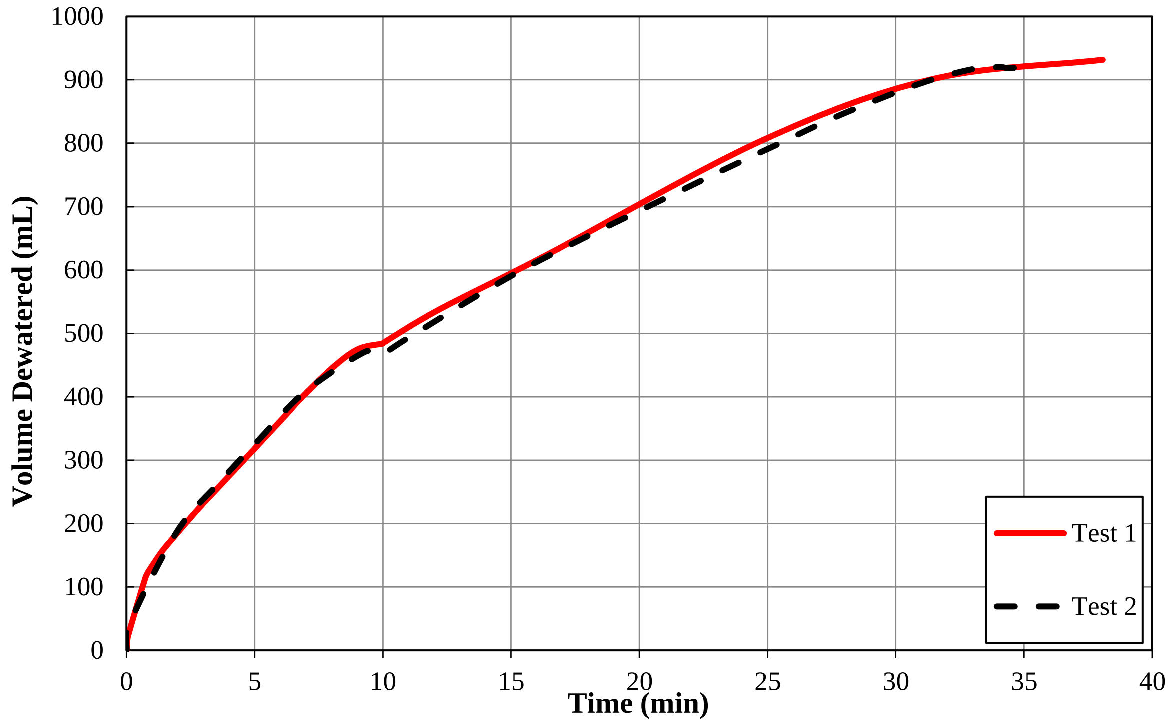

Figure 5 Dewatering curve from Suction Filtration test

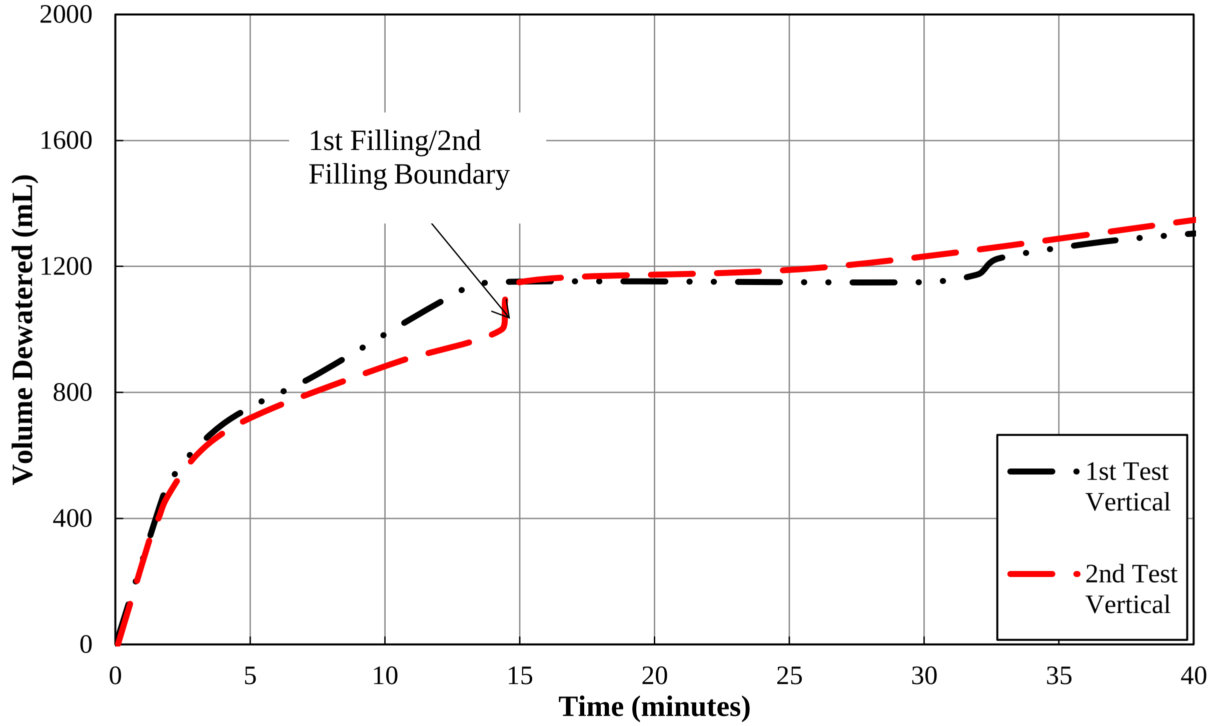

Figure 6 Dewatering curve for vertical flow in 2D test

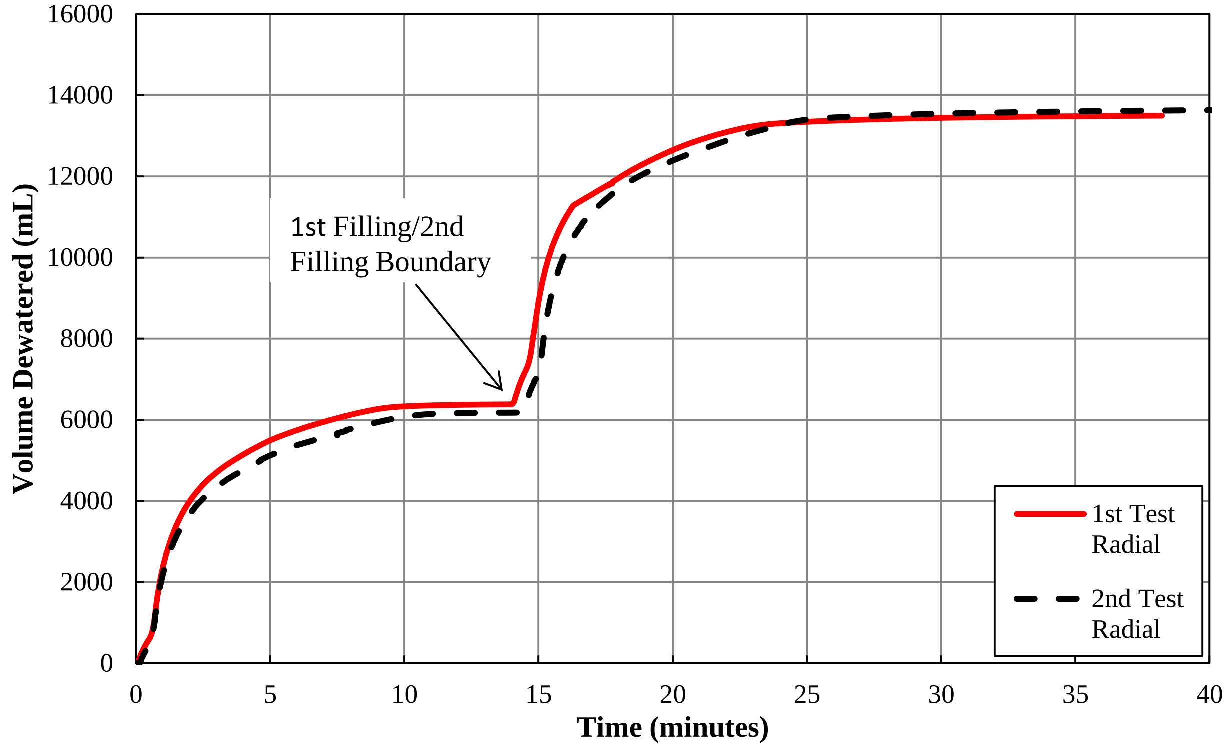

Figure 7 Dewatering curve for radial flow in 2D test

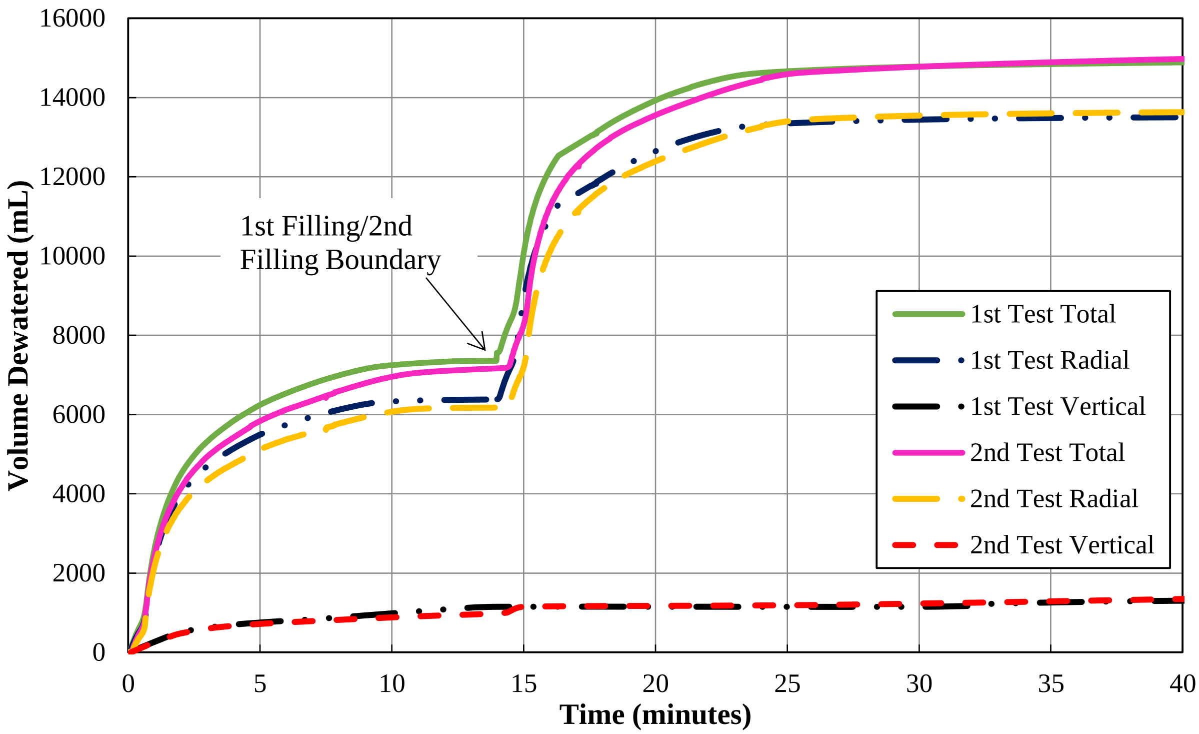

Figure 8 Comparison of total dewatered flow with radial and vertical flow