A Filtration concept for woven geotextile with glocculated fine grain soil

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ABSTRACT:The conventional retention and filtration guideline of geotextile mainly focus on the non-woven geotextile and granular soil. Based on conventional retention criteria, the fine grain soil is not possible to be retained by the woven geotextile. It implies that excessive piping of fines through the opening of geotextile will take place. Thus, for the fine grain soil to be effectively retained by the woven geotextile, flocculation process, to form a large floc size, with the aid of chemical accelerant or flocculent is critical. This is an essential key to determine the success of the dewatering application of geotextile tube infilling with fine grain soil slurry. This paper presents a conceptual filtration mechanism and modified retention criteria for flocculated-clay to be filteredby woven geotextile and remain throughout the service life. To account for the final size of resulting floc formed from the fine-grain particles, an equivalent diameter "$D_{90,eq}$" of the resulting floc is introduced. This floc size with "$D_{90,eq}$" will be able to bridge across the opening of woven geotextile, O_{90}, and form a stablefilter cake that subsequently intercept the migration of fines. The equivalent diameter "$D_{90,eq}$" of the flocculated-clay particle can be estimated based on the settling velocity from a column settling test. The woven geotextile designed based on this "$D_{90,eq}$" is found to be able to effectively retain the flocculated-clay in a simulation test called Modified Geotube Dewatering Test (M-GDT) with expulsion of clear supernatant after short period of fines-piping.

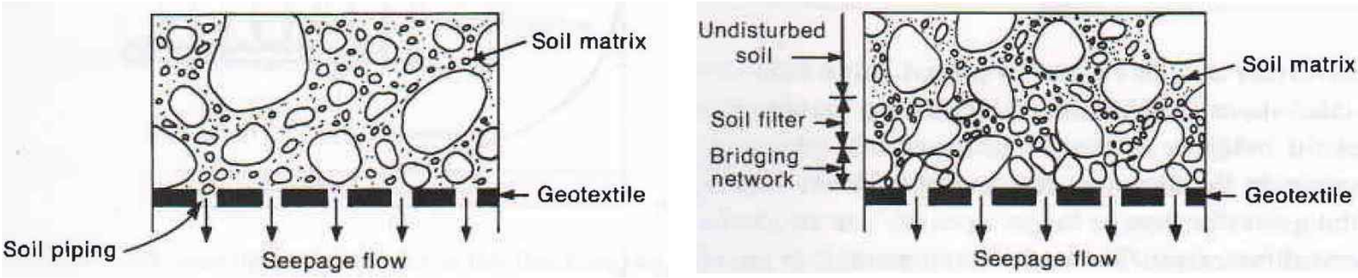
Keywords: Fine-grain soil, flocculation, geotextile filtration theory, woven geotextile

1 INTRODUCTION

To guarantee the geotextile performs satisfactorily in filtration application, "solid retention" and "water permeability" are the essential criterion. The capability of the retention depends on the openings of the geotextile. The opening of geotextile must be small enough to prevent the mitigation of the base soil. Whereas the permeability of the geotextile must be high enough to allow free drainage of water. To prevent clogging and ensure sufficient permeability after some time, the opening size of geotextile filter has to be carefully selected, such that the solid particle has to be effectively retained and yet water flow across smoothly after some initial state. Many guidelines of selecting the appropriate type, criteria and properties of geotextile according to the base soil were developed (Haliburton and Wood, 1982; Ingold, 1985; Lawson, 1990; Luettich et al., 1992; Giroud, 2010). The focus of these guidelines was to guarantee a permanent, consistent flow across the geotextile filter, and to retain the soil effectively after achievement of the equilibrium conditions in the soil-geotextile interface. However, these conventional retention and filtration guidelines of geotextile focus mainly on the non-woven geotextile and granular soil. These criteriamay not be suitable to assess the fine grain slurry with smaller particle size, and extremely high-water-content. Therefore, a further discussion and development of a new filtration criteria for filtration performance of geotextile in fine-grained soil are needed.

1.1 *The conventional geotextile filtration mechanism for granular soil*

For a geotextile to act as filter, an equilibrium condition must be established at the soil-geotextile interface as soon as possible after installation, to prevent soil particles from being piped indefinitely through the geotextile. When a geotextile is placed adjacent to a base soil (the soil to be filtered), a discontinuity arises between the original soil structure and the structure of the geotextile. This discontinuity allows some soil particles to migrate through the geotextile under the influence of seepage flows (Shukla, 2012). The condition of soil-geotextile interface right after the installation is illustrated in Figure 1(a).Figure 1(b) shows the condition of the same interface after equilibrium is achieved. The time taken to establish this equilibrium conditions varies. Thus, the structure or stratification of the soil immediately adjacent to the geotextile at the onset of equilibrium conditions dictates the filtering efficiency of the system. The stratification is dependent on the type of soil being filtered, the size and frequency of the pores of geotextile, and the magnitude of the seepage forces present.



(a) (b)

Figure 1. (a) An idealized soil-geotextile interface conditions immediately following geotextile installation; (b) Idealized interface conditions at equilibrium for well-graded base soil (after Shukla, 2012)

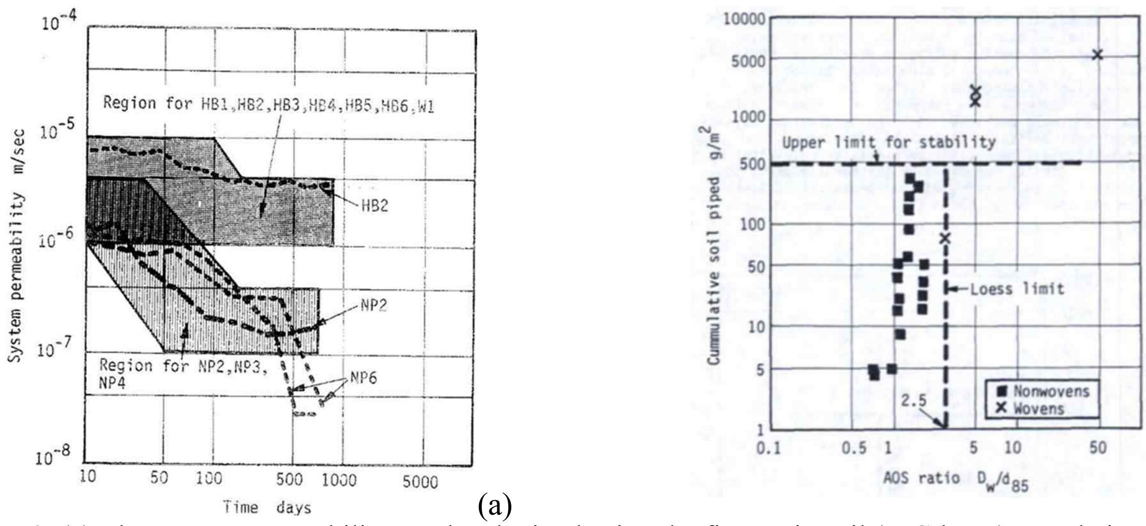
At equilibrium, three zones of soil particles can be identified as shown in Figure 1(b).They are: (a) the undisturbed soil zone at some distance from soil-geotextile interface, (b) a 'soil filter' layer, which consists of more and more progressively smaller particles as the distance from the geotextile increases, and (c) a bridging layer near the opening of geotextile, which is a porous structure formed by the coarser particles.No fines will be found in this "Bridging" layer. These three zones form the "filtration system".The migration of fines is effectively intercepted within this "filtration system".

Currently, a number of retention criteria were developed, and they are derived using different definition of opening sizes of the geotextile, such as O_{95}, O_{90}, O_{50} and O_{15}, and different definition of diameter of soil particles, such as D_{90}, D_{85}, D_{50} and D_{15}. Most retention criteria are given in the form of O_i/D_j ratio not exceeding certain value. Typical ranges of this limiting value for O_{95}/D_{50}, O_{95}/D_{85} and O_{90}/D_{90} are 1-to-6, 1-to-3, and 2-to-5 respectively. These conventional filtration criteria are proven to work effectively with granular base soil. For fine grain soil, with much smaller soil particle, these limiting value is almost impossible to achieve, and there is limited reference on the filtration performance of geotextile with fine grain soil.

1.2 *The filtration performance of geotextile in fine grain soil*

Lawson (1990) presented an important study on the geotextile performance with fine-grained soils. Three types of geotextile, namely (a) heat-bonded nonwoven geotextile (labelled as HB1 to HB6), (b) needle-punched non-woven geotextile (labelled as NP1 to NP6), and (c) monofilament woven geotextile (labelled as W1 to W3) were used to evaluate their filtration performance on fine-grained soils.Figure 2(a) shows the measurement of the filter system permeability over time. Lawson (1990) reported a dense cake of soil had formed within the structure of the non-woven geotextile NP6. This dense cake was found to have eight (8) times the unit weight of the geotextile, which was enough to blind and tremendously reduce the system permeability.

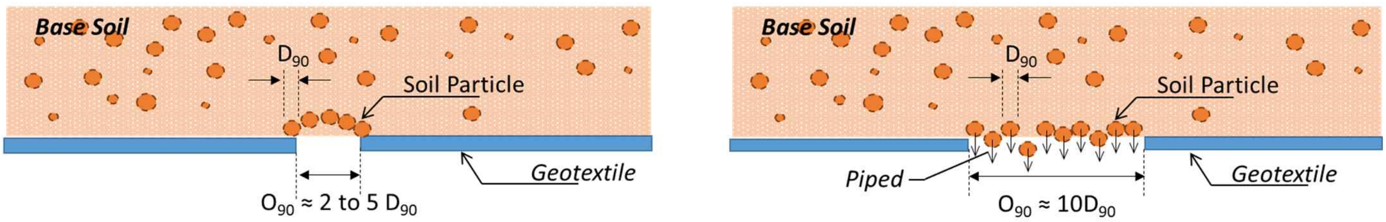
Lawson (1990) reported that if the cumulative amount of soil piped through the filter system exceeded 500 g/m^2 then the internal stability could not be attained. Therefore, an upper limit for stability was set at this value for non-woven and woven geotextile. As seen in Figure 2(b), the AOS ratio O_{90}/D_{85}limit is proposed to be 2.5 corresponding to this stability limit to attain internal stability.Figure 2(b) also shows that the woven geotextiles were experienced piping problem due to instability of the filter system at the soil-geotextile interface.Moo-Young and Tucker (2002) also proposed similar retention criteria for woven geotextile to filter clayey slurry. The criteria were given as O_{95}< 0.3 mm or O_{90}/D_{90} = 2 to 5.



(a) (b)

Figure 2. (a) The system permeability results obtained using the fine grain soil (WG loess) sample in geotextile performance study; (b) Relationship between geotextile AOS ratio and cumulative amount of soil piped for fine grain soil - WS loess. (After Lawson, 1990)

For geotextile tube dewatering application, the D_{85} or D_{90} of fine particles typical ranges from 0.002mm to 0.04 mm, and the O_{95} of the typical woven geotextile is about 0.4 mm. As shown in Figure 3, the minimum value of O_{90}/D_{85} is approximately 0.4/0.04 = 10, which is much greater than 2.5 and 5 that was proposed by Lawson (1990), and Moo-Young and Tucker (2002) respectively. Therefore, the fine grain particles like the clay slurry will not satisfy the above retention criteria for the dewatering application. As a result, the internal stability of the filter system will never be achieved to effectively intercept the mitigation of fines and piping will continue at the soil-geotextile interface.



(a) Stable (b) Unstable

Figure 3. (a) The retention criteria for fine grain soil proposed by Moo-Young and Tucker (2002); (b) the comparison of opening of typical woven geotextile to the fine grain soil.

To overcome the large size of woven geotextile opening, the usage of chemical accelerant in flocculating the fine grain particles were used in the real dewatering project. The large size of floc formed from the flocculated fine particles will be able to form a bridge network across the openings of woven geotextile.However, there is very limited literature on the filtration theory and mechanism of the flocculated fine grain soils bridge across the woven geotextile. Hence, this paper aims to establish a new concept of filtration mechanism with flocculated fine particles at the opening of woven geotextile.

2 NEW CONCEPT OF FILTER CAKE FORMATION FOR FLOCCULATED FINE GRAIN SOIL NEXT TO WOVEN GEOTEXTILE

For an effective dewatering of fine-grain soil in geotextile tube, the ability of the woven geotextile to retain the clay particles is the primary concern. Hence, flocculation of clay particle has to be done before approaching soil-geotextile interface. The flocculated-clay particles subsequently establish the effective “filter cake” formation(i.e. soil filter zone + bridging network layer) next to the woven geotextile-soil interface that subsequently promote an effective filtration and dewatering.

2.1 *The concept of equivalent diameter of flocculated-clay particles*

With the chemical flocculent, the fine grain particles are “captured” by theirlong polymeric chains, and subsequent conglomerated into a larger size of “particle” or floc. As seen in Figure 4(a), when the equivalent diameter, “$D_{90,eq}$” of this floc grows to a value close to $O_{90}/5$, a bridging network can be established, and be able to span across the opening of the woven geotextile. By adopting the criteria in Lawson (1990) and Mou-Young and Tucker (2002) works, the ratio of the opening size of geotextile to the particle size of the flocculated fine particle, O_{90}/"$D_{90,eq}$" is set to be 2 to 5. The fulfilment of this requirement will ensure that the internal stability near the soil-geotextile interface can be achieved and establish the "bridging network" at the opening of geotextile. Subsequently, the fines cease to escape or "pipe" through the opening of geotextile.

With the formation of the "bridging network", the subsequent floc growth will be deposited on top of this "particulate" structure. Segregation and rearrangement of these floc according to size, is similar to that of the well-graded base soil condition. This phenomenon results in formation of "soil filter" layer overlay the "bridging network". The fine particles are then intercepted within this "soil filter" layer, and the excessive piping is prevented. At this point (see Figure 4(b)), the internal stability of the soil-geotextile filter system is achieved with effective retention capability, and yet provide a high filtration/dewatering rate. As a result, the "bridging network" layer and "soil filter" layer is grouped to term as "filter cake" in this new proposed concept.

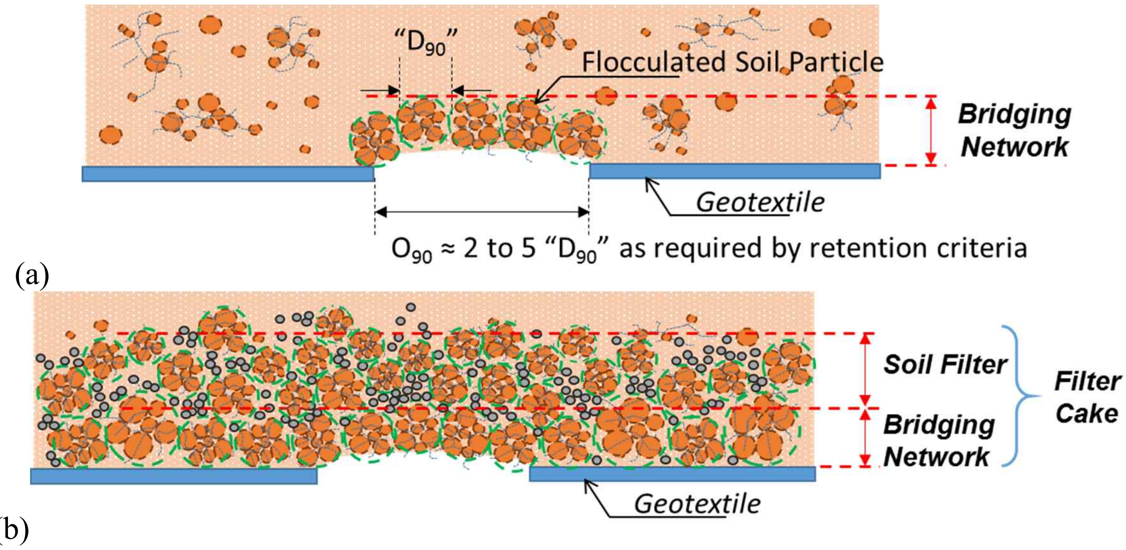


Figure 4. (a) The formation of bridging network by floc with equivalent diameter "$D_{90,eq}$"; (b) The filter system with internal stability established with filter cake formation.

2.2 *The settling phases of flocculated-clay particles in quiescent water condition*

The flocculated particle is larger and relatively heavier than its original unflocculated size.The settling behavior of this flocculated particles can be modelled using the conventional settling theory. According to Merckelbach and Kranenburg (2004a, b), the downward movement of the sediment bed interface at various settling phases is shown in Figure 5. The initial settlingbehavior of the slurry-soil consists of (a) suspension stage and (b) hindered settlingstage.

With application of flocculent, the suspension stage can be assumed to be negligible. Thus, the period $t = 0$ to $t = t_1$ will be dominated by hindered settling stage. At this moment, an observable interface exists between supernatant water and sediment bed interface. Time $t = t_1$ is also known as "gelling point" in fluid mechanic – sedimentation study. With time $t > t_1$, it is then rapidly developed into the transition settling stage. Subsequently, the soil particles come to intact with each other (a transition point) and the effective stress starts to become significant at time $t = t_2$.With $t > t_2$, it is dominated by effective stress, and is known as the self-weight consolidation stage.

Merckelbach and Kranenburg (2004) also reported that the period $t = t_1$ to $t = t_2$, which is labelled as "transition settling stage", can be identified from the profile of sediment height over time, plotted on a log-log scale. Reported experimental data (see Figure 5(b)) indicates that a linear line between sediment height and time can be found within this period of time. Hence, $t = t_1$ can be more accurately defined by drawing this straight-line. With that t_1 clearly identified, the "$D_{90,eq}$" of the flocculated clay particles can be estimated. This will be explained in the next section. Time $t = t_1$ is needed to compute the initial secant gradient of the settling curve.

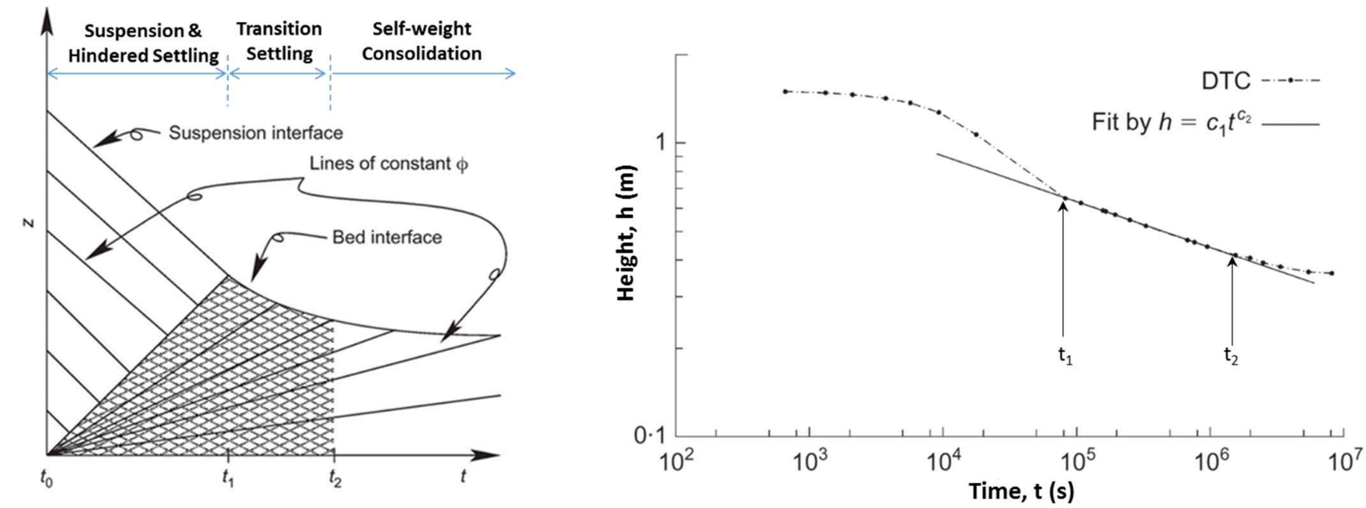


Figure 5. (a) A schematic Kynch-plot; (b) Reduced height of mud-water interface against time on double logarithms scales (After Merckelbach and Kranenburg, 2004).

2.3 *The estimation of equivalent diameter "$D_{90,eq}$" for a flocculated-clay particle*

To carry out the precise quantification of the size of the flocculated particles, advanced technologies (i.e. gamma ray scanning technique) are required. Therefore, this section discusses the application of the established classic settling theory (i.e. Stoke Law) in estimating the equivalent diameter "$D_{90,eq}$" of the flocculated-clay particle.

The equivalent diameter "$D_{90,eq}$" of the flocculated-clay particle is estimated based on the settling velocity. In this case, the flocculated-clay particle is assumed a sphere shape. The settling velocity is given in Equation (1).

$$v = \frac{g(\rho_s - \rho_f)"D_{90,eq}"^2}{18\mu} \tag{1}$$

where v = settling velocity, ρ_s= density of "solid" (in this case the $\rho_s$should be the density of the "flocculated soil cluster" which contain water within it. The value would be equivalent to "soil" bulk density rather than "solid" density), ρ_f = density of fluid, "$D_{90,eq}$" = diameter of sphere, and μ = viscosity of fluid. The settling velocity of the sediment bed interface during the hindered settling stage is adopted to estimate the equivalent diameter "$D_{90,eq}$" of the flocculated clay.

3 METHODOLOGY

This section presents the experimental procedures to derive equivalent diameter of a flocculated-clay particle from a column settling test. Subsequently, a simulation test of filling and dewatering process of fine grain soil in a miniature size of woven geotextile bag was performed to verify that this filtration criteria indeed works.

3.1 *Properties of flocculated fine grain particle slurry and woven geotextile*

In this study,Kaolin Clay is used as the fine grain soil. The surface characteristics of Kaolin clay are well understood and allowed for a more precise interpretation of sedimentation and rheological behavior in terms of particle interaction.A synthetic Polyacrylamide (PAM) polymer, given name as Clarifloc-1 was the chemical accelerant used to promote the flocculation and conglomeration of the fine particles to a larger aggregate as flocs. The optimum dosage for the chemical accelerant to react with Kaolin Clay slurry was determined from a series of Jar Test. In the subsequent Modified Geotube Dewatering Test(M-GDT), geotextileGT500 with opening size $O_{90}$of 0.25mmwas used as a filtration layer to retain the flocculated particles.

3.2 *Column settling test*

With the above concept, "D_{90}" of the flocculated Kaolin clay was derivedfrom column settling tests. These tests were carried out with and without the flocculation to compare the diameter of these clay particles. The Kaolin clay slurry was prepared at solid content (by weight), S = 10%, and mixed with the optimum dosage of the Clarifloc-1. Subsequently, this pre-treated slurry was poured into a 50mm diameter and 400mm long transparent cylinder. The experiment setup of this column settling test is illustrated in Figure 6. The downward movement of the sediment bed interface is recorded with time.

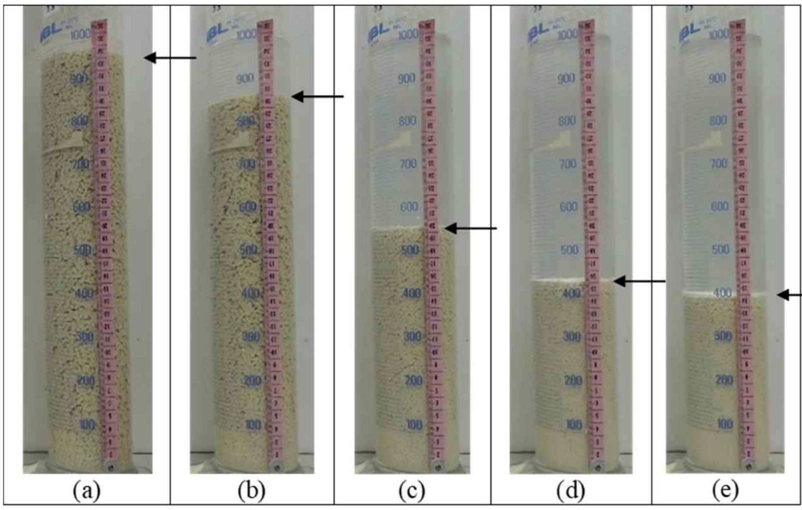
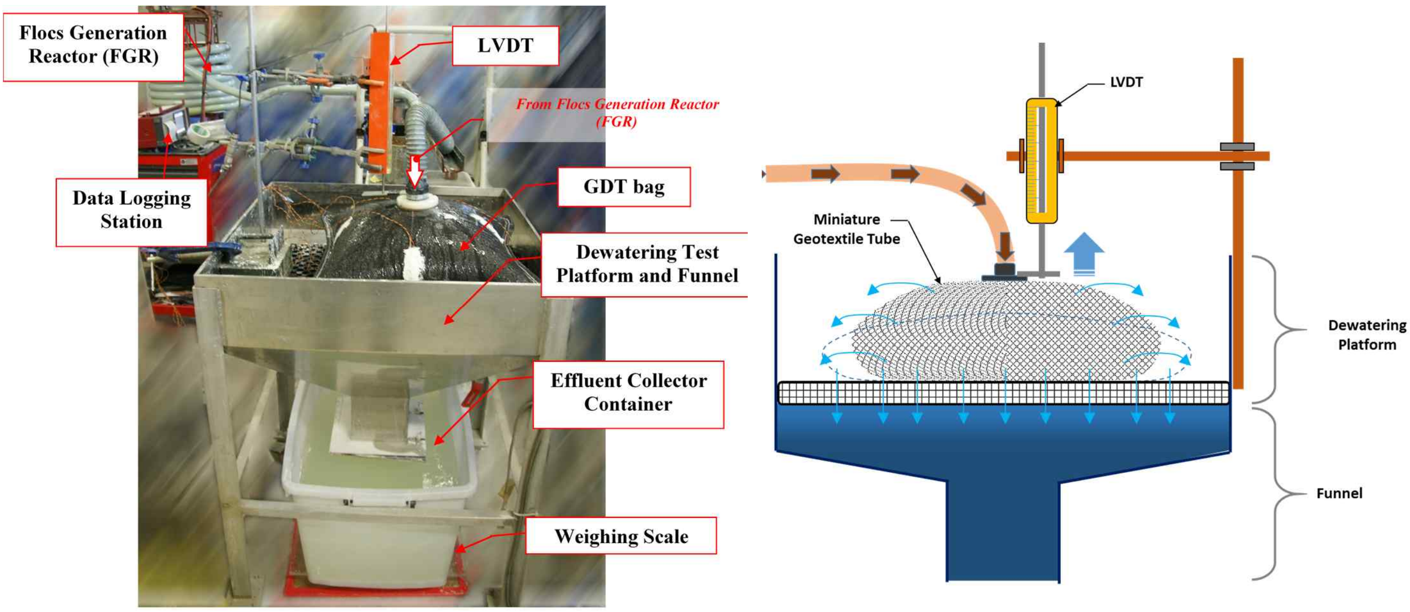


Figure 6. Column settling test with flocculated clay: (a) time= 0s; (b) time= 10s; (c) time= 60s; (d) time= 300s; (e) time= 3600s (After Eng, 2016)

3.3 *Modified geotube dewatering test (M-GDT)*

Dewatering Test (GDT) is originally developed by the geotextile manufacturer to estimate the final accumulated solid content within the geotextile tube at the end of dewatering stage. To quantify the overall dewatering behaviour of a geotextile bag, the original test setup of GDT was modified by Eng (2016) with additional measurement on the cumulative volume of the effluent. This Modified Geotube Dewatering Test (M-GDT) was developed to simulate the filling and dewatering stage with confining effect in geotextile tube. In this paper, M-GDT is used to verify that the flocculated-fine grain soil with proposed Equivalent Diameter (at optimum dosage)can beeffectively retained by the selected woven geotextile. The experimental setup of M-GDTis shown in Figure 7 but not discussed in this paper.



(a) (b)

Figure 7. The Modified Geotube Dewatering Test (M-GDT): (a) Laboratory setup; (b) Schematic diagram (After Eng, 2016)

4 TEST RESULTS & DISCUSSIONS

4.1 *The column settling test &equivalent diameter "$D_{90,eq}$"*

Two tests were conducted: "Control Test" with no flocculent added, and "Test 1", "Test 2", and "Test 3" with the same dosage of flocculent added. The downward movement of the sediment over time in Column Settling Testsare shown in Figure 8. According to Figure 8(a), a straight-line portion in the log-log scale of bed sediment height vs time can be drawn to identify the transition settling stage. The time $t_1$was found to 3000sfor the "Control Test", and 60s for Test 1, Test 2 and Test 3. Thus, the period of hinder settling stage is also identified once the time t_1 was found. In addition, the bed sediment profile for the period t = 0 to t = t_1 is also found to be a linear line in a normal-scale plot (see Figure 8(b)). The gradients of this straight line is deduced to be 0.00356 cm/s for "Control Test", and 0.2282cm/s to 0.3284 cm/s for Test 1 and Test 3. These are the settling velocities for the un-flocculated and flocculated clay particles respectively.To compute the equivalent diameter "$D_{90,eq}$" with the proposed Stoke's Law, several properties of the solid and liquid are required. Conservatively, the viscosity of the water is taken as, μ= 8.94E-4 kg/m.s. at 25°C. The density of "solid" and fluid are determined at 1600kg/m^3 and 1000kg/m^3 respectively. Hence, the equivalent diameter "$D_{90,eq}$" of the flocculated clay particle are deduced and tabulated in Table 1.

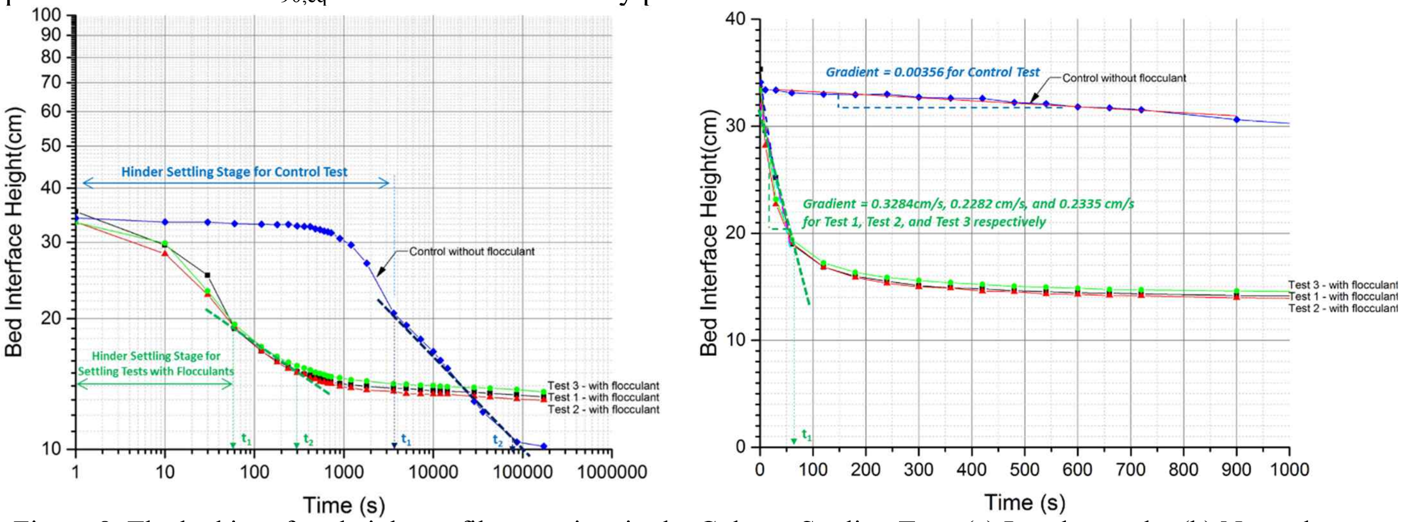


Figure 8. The bed interface height profile over time in the Column Settling Test: (a) Log-log scale; (b) Normal scale (After Eng, 2016)

Table 1. The estimated equivalent diameter of "$D_{90,eq}$" derivation from the settling velocities.

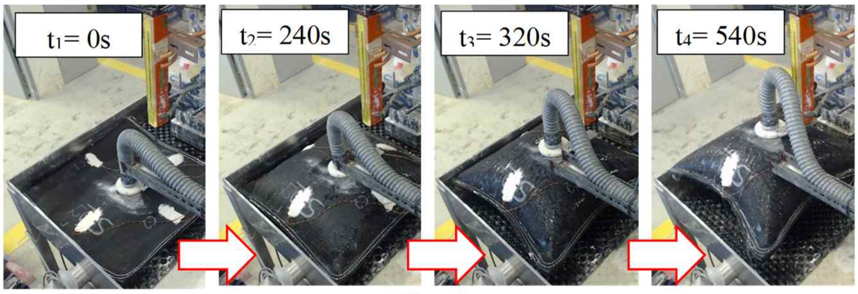
Parameters		Units	Test 1	Test 2	Test 3	Control Test
Settling velocity,	v_s	m/s	3.28E-03	2.28E-03	2.34E-03	3.56E-05
Equivalent diameter,	"$D_{90,eq}$"	mm	0.0948	0.0790	0.0799	0.0099

It can be seen that the equivalent diameters "$D_{90,eq}$" of the "flocculated-clay particles" are ranged from 0.079mm to 0.095mm, which is relatively much larger than the original particle size of the Kaolin clay (unflocculated size= 0.010mm). If the woven geotextile is having an opening size of 0.25mm, thus the value of O_{90}/"$D_{90,eq}$" will be in the order of 0.25/0.079 to 0.25/0.095 = 3.16 to 2.6. This satisfy the proposed retention criteria of effective filter cake formation of O_{90}/"$D_{90,eq}$" = 2-to-5. Thus, the flocculated clay will be effectively retained by the selected woven geotextile.

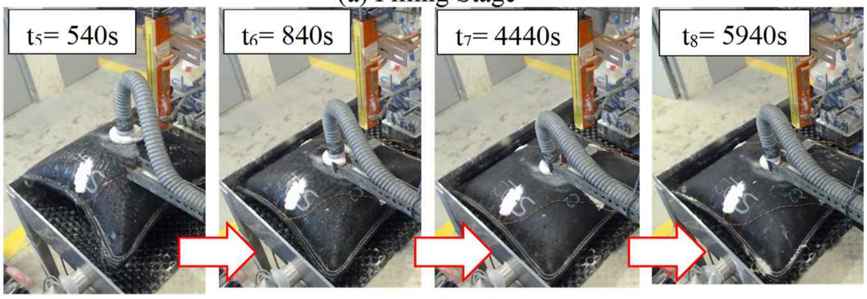
4.2 *Modified geotube dewatering test (M-GDT)*

In this test, Kaolin Clay slurry was prepared at solid content (by weight) at 10% and pumped through Floc Generation Reactor (FGR), which generated the flocculated clay particles to be filled into the miniature woven geotextile bag made from GT500. Upon the commencement of the filling activity, the height change of the miniature bag was monitored, and the effluent was collected under the dewatering platform. Figure 9 shows the changed of shape in miniature geotextile bag in the infilling and dewatering process with flocculated-clay particles.

At the initial stage of infilling activity (t_1 to t_2), some piping of fines was observed. However, the piping of fines was stopped after a short period of time andclear supernatant water was observed to be discharged out from the miniature bag during the filling activity. This continuous expulsion of the supernatant water allowed continuous filling of the miniature baguntil the control height was achieved.This observation verified thatthe flocculated-clay (with the designed equivalent diameter) could be effectively retained by this selected woven geotextile. The effluent became clear water droplets (after t_2). This observation indicates that the flocculated-clay was well retained by the geotextile GT500, and promoted the effective filter cake formation despite the hydrodynamic of filling activity.



(a) Filling Stage



(b) Dewatering Stage

Figure 9. The inflation of a square GDT bag in the filling and dewatering process (After Eng, 2016).

5 CONCLUSION

A concept and mechanism of filtration criteria was established for the woven geotextile with flocculated-clay slurry.The woven geotextile can establish an effective filter cake formation to promote the effective filtration and dewateringprocess if the opening size of geotextile over the Equivalent Diameter "$D_{90,eq}$" of the flocculated-clay (O_{90}/"$D_{90,eq}$") is kept within 2-to-5. The column settling test could be used to determine the equivalent diameter of the flocculated-clay, and hence help engineer in selecting the proper opening size of woven geotextile.It is worth to note that retention capability of the flocculated-clay under the woven geotextile could be deteriorated under extreme hydrodynamic condition and further study is recommended.

REFERENCES

Eng, Z.X. (2016). Modelling of Geotextile Tube Filled with Fine-grain Materials in Dewatering Process, Ph.D. Thesis, National University of Singapore, Singapore.

Giroud, J.P. 2010. Development of Criteria for Geotextile and Granular Filters. Paper presented at the Proceedings of the 9th International Conference on Geosynthetics, Guarujá, Brazil.

Haliburton, T.A., and P.D. Wood. 1982. Evaluation of Us Army Corps of Engineers Gradient Ratio Test for Geotextile Performance. Paper presented at the Proceedings of the Second International Conference on Geotextiles.

Ingold, T.S. 1985. A Theoretical and Laboratory Investigation of Alternating Flow Filtration Criteria for Woven Structures. Geotextiles and Geomembranes 2, no. 1 (1985): 31-45.

Lawson, CR. 1990. Geotextile Filter Performance with Fine Grained Soils.Paper presented at the Proc. Fourth Internat. Conf. on Geotextiles, The Hague.

Luettich, S.M., J.P. Giroud, and R.C. Bachus. 1992. Geotextile Filter Design Guide. Geotextiles and Geomembranes 11, no. 4–6 (1992): 355-70.

Merckelbach, L.M., and C. Kranenburg. 2004a. Determining Effective Stress and Permeability Equations for Soft Mud from Simple Laboratory Experiments. Géotechnique 54, no. 9 (2004): 581-91.

Merckelbach, L.M., and C. Kranenburg. 2004b. Equations for Effective Stress and Permeability of Soft Mud;Sand Mixtures. Géotechnique 54, (2004): 235-43.

Moo-Young, Horace K., and Wayne R. Tucker. 2002. Evaluation of Vacuum Filtration Testing for Geotextile Tubes. Geotextiles and Geomembranes 20, no. 3 (2002): 191-212.

Shukla, S.K. 2012. Handbook of Geosynthetic Engineering: Geosynthetics and Their Applications. ICE.