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MARINE CLAY – JUTE GEOTEXTILE FILTER SHEATH SYSTEMS

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ABSTRACT

Ecofriendly woven jute geotextile can be utilized as channel sheath in pre-assembled vertical drains (PVDs) which are introduced in immersed clayey soils like marine dirt to speed up union. The PVDs produced using regular materials can be utilized as a substitute framework to polymer based PVDs. One of the fundamental worries in utilizing woven jute geotextile as channel in marine earth is the fine part maintenance capacity of jute sheaths. As the woven jute geotextile has more extensive pore sizes contrasted with polymer channel sheaths, there is a trepidation of obstructing of center of the PVDS. To comprehend the marine mud maintenance capacity and filtration similarity of picked woven jute geotextile with marine dirt, lab Apparent Opening Size (AOS) tests on geotextiles and long haul filtration tests on marine mud – geotextile channel frameworks were led. The tests were completed on three sorts of woven jute geotextiles having distinctive AOS utilized in making of normal PVDs other than one polymer channel sheath utilized in polymer based PVDs. Exact soil maintenance measures were found from the AOS tests and contrasted and the recommended standards of past scientists. The framework porousness was assessed from the filtration tests. The greatest framework porousness achieved in the underlying time of the test in all the frameworks was same. All the frameworks arrived at stable stream condition yet at various time. The outcomes showed that two of the marine earth - woven jute channel frameworks accomplished the steady framework porousness condition around the very time as that of marine dirt - polymer channel framework. It is reasoned that with the appropriate pore sizes and jute fiber network structure, woven jute channel sheaths can have great filtration similarity with marine dirt.

KEYWORDS: woven jute geotextile; marine clay; prefabricated vertical drain; filtration test; system permeability; filtration compatibility.

INTRODUCTION

Prefabricated Vertical Drains (PVDs) with surcharge loading provide effective vertical drainage for accelerating the consolidation of saturated clayey soils such as marine clay. The PVDs form vertical drainage paths for the excess pore water generated due to surcharge loading of soil to dissipate rapidly. The PVDs are made of outer filter sheath to filter the soil water and inner core material to carry the water. The core and filter sheath material of PVDs available commercially are made mostly from non-degradable polymers. With the geo-environmental protection consciousness, non-degradable core and filter sheath materials of PVDs can be replaced by bio-degradable natural materials such as jute, coir, straws etc. Since in certain ground improvement projects, it requires shorter time for the primary consolidation of soil with PVDs to the desired degree, the technical utilization of ecofriendly materials is justified and viable. The usage of natural materials becomes economical when available abundantly.

The selection of suitable filter sheath plays an important role in making of PVDs. The filter sheath should work on three following major principles to have adequate water flow through the PVDs: 1) retain majority of the soil particles (retention criteria) so that core of the PVDs should be prevented from clogging 2) provide sufficient flow capacity (permeability criteria) and 3) provide enough pore openings of a sufficient size so that if some of the smaller soil particles enter the filter, they should pass through instead of getting trapped inside the filter (clogging resistance criteria).

Soil Retention Criteria

Most of the geotextile filter design methods especially for soil retention ability are based on the relationships developed between characteristic pore size of the geotextile and particle size of the soil. The characteristic soil particle sizes considered by various researchers are D_{85}, D_{10} (D_{85}, D_{10} = soil particle size such that 85 % and 10 % respectively, of the soil is finer than that size).The common methods to find the pore size and pore size distribution of filters are based on numerical, volumetric, sieving and theoretical modeling [Fischer et al. (1993), Koerner (1994), Bhatia and Smith (1996a, 1996b), Bo et al. (2003), Aydilek et al.(2007)]. Although numerical and volumetric methods represent pore size and pore channel size better, the method widely used by the geosynthetic manufacturers is dry sieving method. Also, many of the empirical design criteria based on performance tests in the laboratory have been developed considering largest effective opening in a geotextile i.e., Apparent Opening Size (AOS or O_{95}) found by dry sieving methods.

Christopher and Holtz (1984) and Bergado et al. (1996) have given filter sheath design criteria which can be applicable in general to polymer based PVDs. Bergado et al. (1996) have conducted laboratory tests on different geotextiles used for filter sheaths on PVDs in Bangkok clay. They conclude that the AOS (O_{95}) as determined in accordance with ASTM D 4751 of the PVD geotextile filter sheath should not be greater than 0.090 mm and the ratio of O_{95} to D_{85} should be less than or equal to three in order to satisfy the soil retention function.

Permeability and Clogging Criteria

To satisfy permeability criteria, Christopher and Holtz (1984) suggest that the geotextile filters must remain more permeable than the surrounding soil to satisfy permeability criteria. For critical applications, they recommend that the permeability of geotextile filters should be at least ten times greater than permeability of soil. Bergado et al. (1996) have suggested that the permeability of geotextile filters used for PVDs installed in Bangkok clay should be more than two times the permeability of the soil.

Although several empirical methods have been proposed to evaluate the clogging resistance of geotextile, the most realistic approach is to perform laboratory filtration tests on soil-geotextile system by gradient ratio test or long term flow test or hydraulic conductivity ratio test. Generally gradient ratio tests are conducted on soils having permeability more than about 10^{-5} m/s. For soils with permeability less than 10^{-5} m/s, long-term filtration tests or hydraulic conductivity ratio tests are conducted. Bergado et al. (1996) proposes that the geotextile filter sheath used in PVDs should have the ratio of O_{15} to D_{15} greater than or equal to 1.5 to prevent clogging (O_{15} is the geotextile opening size such that 15 % of the pores are smaller than that size).

Mechanism of Filtration in Fine Grained Soils

The mechanism of migration of soil particles in coarse and fine grained soils and soil-geotextile filter stabilizations are explained by various researchers such as Lawson (1982), Rollin and Lombard (1988) and Chang and Nieh (1996). As the flow of water happens through the soil-geotextile filter system the soil particles get deposited on the geotextile forming structures such as bridge network or vault network or blinding (caking) and get entrapped inside the geotextile blocking the pores (phenomenon referred as “clogging”). These mechanisms depend on the type, thickness, size of pore and pore size distribution of geotextile, fine content and density of soil, hydraulic gradient and steady or dynamic flow conditions [(Koerner and Ko (1982), Carrol (1987), Rao et al. (1992, 2000), Christopher et al. (1993), Bergado et al. (1996), Kossendey (1999), Lee et al. (2010), Hong et al. (2011), Weggel and Dortch (2012a, 2012b)].

The mechanism of filtration in fine grained soil – geotextile filter system is somewhat different from the coarse grained soil - geotextile filter systems. Sherard and Decker (1977) notes that very fine-grained, low permeability soils rarely present a filtration problem unless they are dispersive or subject to hydraulic fracturing, such as might occur in dams under high hydraulic gradients. As described by Giroud (1982), the cohesive soils are more stable in filtration process and the stability of the soil structure is influenced by cohesion (which governs attraction between particles), density and grain size distribution (which help in interlocking between particles). Chang and Nieh (1996) explain that the movable particles in fine grained soils are in the form of small clusters or peds. These clusters or peds are semi microscopic fabric units formed by aggregation or flocculation of individual clay particles. The movement of particles through the geotextile pores causes sediment to form within short distance and there is subsequent decrease in system discharge rates and an increase in the stability of the particle structure above geotextile. As the soil above the geotextile is stabilized by the sediment, the movement of fines is gradually slowed to the point where it stops altogether.

Very few research works provide the guidelines and the information on filtration potential of clay-jute geotextile sheath system. Lee et al. (1989, 1994, 2003) had designed and studied the laboratory and field performance of PVDs made from jute and coir to improve soft clay deposits. They had used two layers of jute burlap as filter sheath. The AOS of the filter sheath was in the range of 200-600 microns. Their study shows that clay of near liquid limit (70%) did not enter the drain core during installation as well as consolidation process, but were retained by the two burlap layers. From the series of permeability tests, they conclude that the AOS of the jute filter layers need not be too small to prevent clay intrusion into the core, but a larger AOS of the order of 200-600 microns is beneficial in tapping pervious seams and lenses in clay deposits. Bergado et al. (1996) have observed under hydraulic gradient of 1, the variation of flow rate for duration of maximum 8000 minutes for one layer of jute geotextile filter sheath having AOS of 0.6 mm used in making of PVDs. They conclude that the jute filter sheath quickly reached quasi-stable flow condition, but the loss of soil particles continued which could eventually clog the PVD core.

Present Study

In the absence of more information on filtration capabilities of woven jute geotextile filter sheaths in marine clay, laboratory AOS tests on geotextiles and long term filtration tests on marine clay - woven jute geotextile and marine clay – polymer geotextile systems were conducted. The two types of woven jute geotextiles considered for the tests are being used as filter sheaths in making of natural PVDs [(Asha and Mandal (2011, 2012)]. The polymer geotextile filter sheath considered for tests are from the polymer based PVD. The test results of marine clay – woven jute geotextile and marine clay - polymer geotextile systems are compared. The tests were carried out to understand the marine clay retention capacity of woven jute filters and the filtration behaviour of the marine clay – woven jute geotextile system.

MATERIAL PROPERTIES

Soil

The soil used in the long term filtration tests was marine clay obtained from Navi Mumbai area. The basic properties of marine clay sample are as given in Table 1.

Table 1: Properties of marine clay

Test property / unit	Value
Specific gravity	2.6
Liquid limit (%)	83
Plastic limit (%)	40
Plasticity index	42
Silt content (%)	33.7
Clay content (%)	51

Geotextile Filters

Three types of woven jute and one polymer geotextile filter sheaths are used in the study. The woven jute geotextiles have multifilament structure with different weights (mass per unit area) and pore sizes. They are labeled as WJT_{775}, WJT_{700} and WJT_{550} representing woven jute type having weight of 775 g/m^2, 700 g/m^2 and 550 g/m^2 respectively. The two types of woven jute geotextiles, WJT_{775} and WJT_{700} are used as filter sheaths in making of natural PVDs made from core of coir wrapped by woven jute sheaths called as natural PVDs (NPVDs). WJT_{550} woven jute geotextiles are included in the tests to understand the range of opening size and weight that can be considered in woven jute filters when used with marine clay. The polymer geotextile filter is non-woven and selected from commercially available PVD filter sheath which is utilized presently in soil consolidation projects. Figure 1 shows the structure of geotextile filters. Figure 1(a) shows the naked eye appearance of the geotextiles and Figure 1(b) gives the idea of intricate structure of geotextiles seen through a scanner. In closely woven WJT_{775} and WJT_{700} geotextile filter sheaths, the individual strands block the clear openings giving wide range of pore sizes .Whereas, WJT_{550} has open weave, almost same size wider openings. The polymer geotextile filter has well distributed uniform pore sizes. The physical and hydraulic properties of the geotextile filters are given in Table 2.

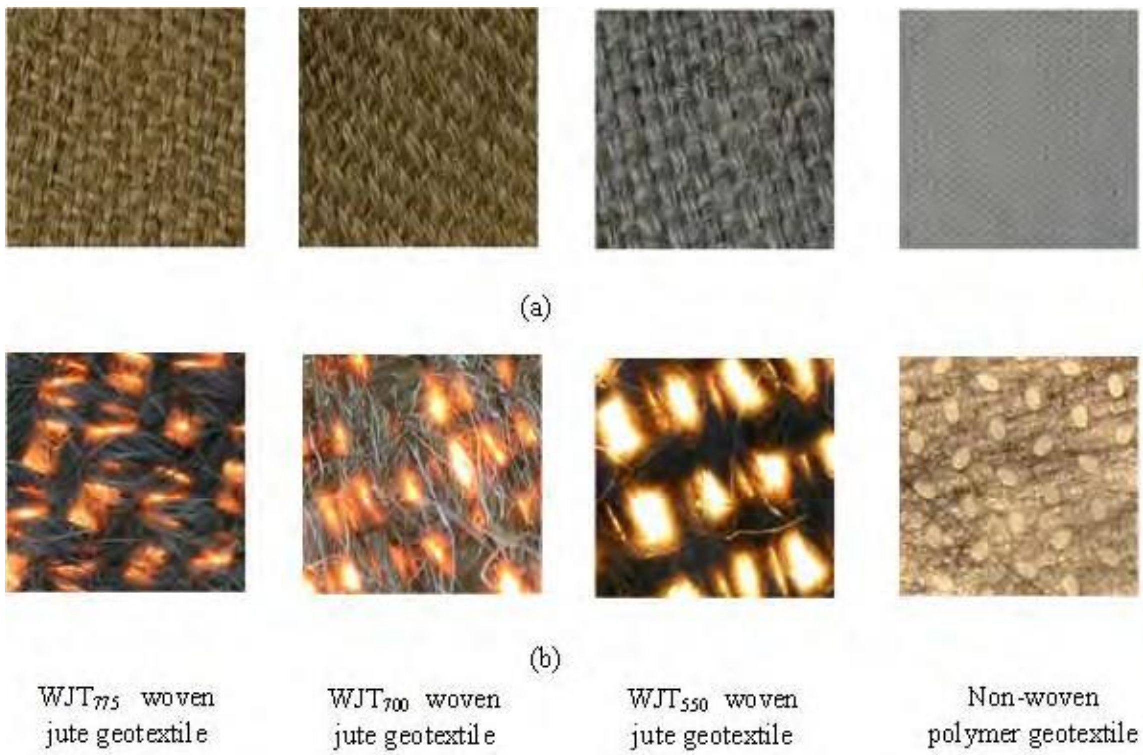

Figure 1: Appearance of different types of woven jute and polymer geotextile filters (a) as seen through naked eye (b) as seen through a scanner.

Table 2: Properties of geotextile filters

Test property/Unit	Value			
	Geotextile filter type			
	WJT_{775}	WJT_{700}	WJT_{550}	Non – woven Polypropylene
Weight (g/m^2)	775	700	550	100
Thickness (mm)	2	1.7	1.7	0.5
Permeability (m/s)	1.7E-04	2.0E-04	3E-04	1.1E-03

TESTS: METHOD AND PROCDURE

Apparent Opening Size (AOS) Tests

To find the generally adopted criteria for marine clay retention ability of woven jute geotextile filters, the AOS of geotextiles was determined based on standard ASTM D 4751 method. The AOS is a property that indicates the approximate largest particles that would effectively pass through the geotextile. The method adopts dry sieving the sized glass beads through the geotextile to determine the AOS. As per the standard, O_{95} is considered as the AOS of a geotextile. It means spherical glass bead size that would result in 5 % or less passing through the geotextile.

The tests were carried out on five samples of each geotextile filters. Figure 2 shows the different sized spherical glass beads used and sieve apparatus mounted on mechanical sieve shaker. To know the pore size distribution in geotextile, the geotextile sample was sieved through smallest to larger diameter glass beads until the weight of beads passing through was less than 5%. To eliminate built up of static electricity while sieving with glass beads, anti-static spray was applied on the geotextiles.

Figure 2: (*a*) Glass beads of different sizes used in the determination of Apparent Opening Size (AOS) of a geotextile (*b*) Sieving apparatus mounted on sieve shaker

Filtration Tests

To evaluate the filtration compatibility of geotextile sheaths in marine clay, the filtration test apparatus developed based on ASTM D5101 and ASTM D1987 standard was used. The apparatus which was basically used to measure the cohesion less soil-geotextile system clogging potential by the gradient ratio was slightly modified by providing silicone barriers at three locations on the inner wall to prevent possible flow of water along the wall. The apparatus has separable top, middle and bottom cylindrical transparent units made from Perplex glass. The internal diameter of the units is 100 mm. The description of apparatus is as shown in the Figure 3. It is equipped with brass support screen to place the geotextile and soil over it. Constant head water devices are connected to inlet and outlet valves to regulate water flow. Ports 1 and 6 are connected to manometer tubes fitted to a board having measuring rulers through plastic tubing to observe the hydraulic gradient through the soil – geotextile system.

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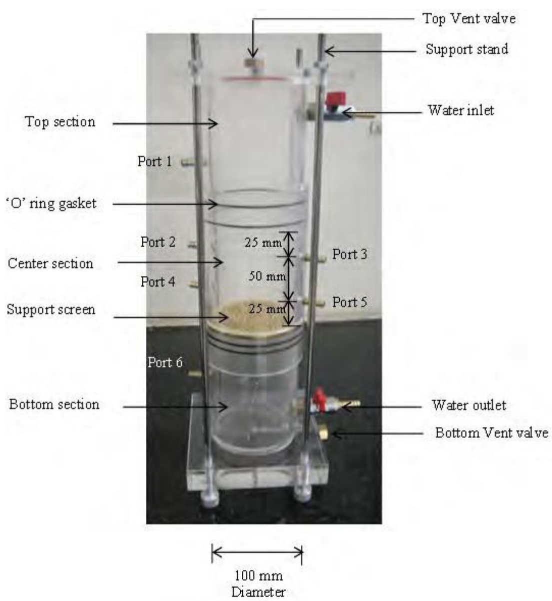

Figure 3: Filtration test apparatus

Figure 4: Filtration test in progress.

Geotextile filter sheath test specimen having a diameter of 110 mm was taken and saturated in water for two hours. All the port openings of center unit were sealed from inside by a piece of impermeable tape to prevent water flow into the tubing. Center unit and all O ring gaskets were greased inside by silicone. The bottom unit of filter apparatus was filled with water up to the top of support screen by closing the outlet valve and geotextile test specimen was placed on the support screen. Center unit was fitted to the bottom unit and pressed to secure the screen and geotextile sample in place. Marine clay slurry having water content of 120 % was prepared in electrically operated mixer. The marine clay was poured into the center unit for a thickness of 100 mm over the geotextile sample in three layers and each layer was poked by glass rod to remove air bubbles. The density of soil was maintained at 13.5 kN/m^3.Top unit was fitted to the center unit and entire assembly was tightened by screws provided at top and bottom of the support stand. Top air vent valve was kept open and water was allowed to flow into the top unit from constant head water tank up to the inlet valve level. Outlet valve of bottom unit was opened. In order to expel air from soil through top vent valve, center unit was tamped at regular intervals. Once no air bubbles were found in the top unit, water was filled up to the top of unit. The inflow from the constant head water tank was adjusted to a hydraulic gradient of 3 and top air vent valve was closed. The marine clay - geotextile system was allowed to stabilize. The flow rate from the system was calculated at regular time intervals by measuring the quantity of water collected for a particular time interval. Figure 4 shows the filtration test in progress.

RESULTS AND DISCUSSION

Apparent Opening Size (AOS) Tests

The particle size distribution of marine clay and the results of AOS tests conducted on jute filter sheaths are shown in the Figure 5. The average O_{95} (AOS) and O_{50} (geotextile opening size such that 50 % of the pores are smaller than that size) obtained from the tests are as given in the Table 3. The AOS of the polymer filter sheath was less than 0.075 mm.

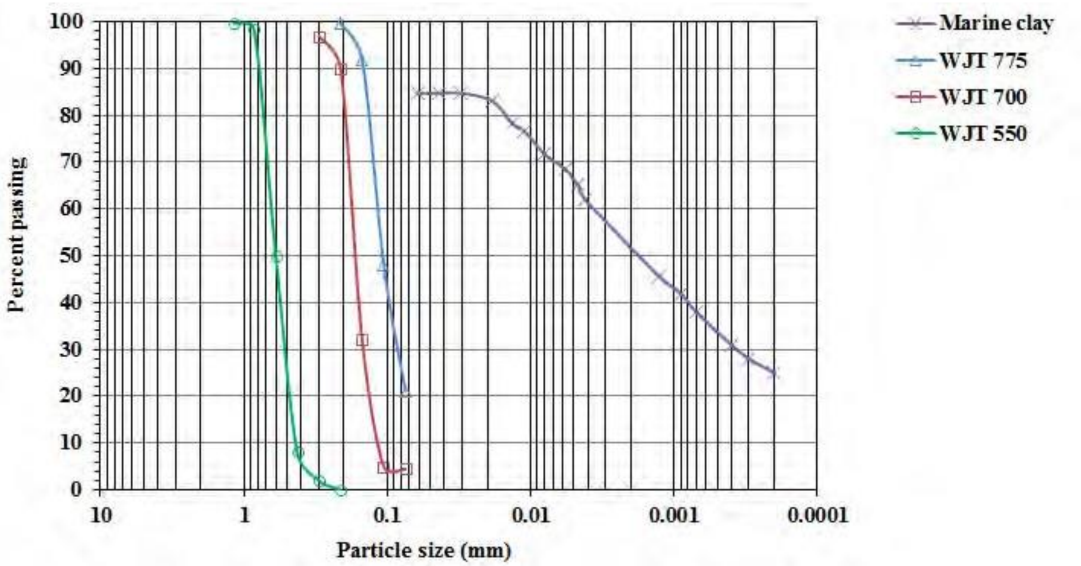

Figure 5: The particle size distribution of marine clay and the results of AOS tests conducted on jute filter sheaths

Table 3: Pore sizes of filter sheaths.

Filter sheath type	Filter opening size (mm)	
	O_{95} (AOS)	O_{50}
WJT_{550}	0.8	0.6
WJT_{700}	0.25	0.18
WJT_{775}	0.16	0.11
Non-woven polymer geotextile	< 0.075	< 0.075

The general soil-geotextile filter system retention criteria relationships developed between a representative pore size of the geotextile and particle size of soil are calculated. The D_{85} and D_{50} of the marine clay are 0.06 mm and 0.0019 mm from the particle size distribution curve. The ratios of O_{95} / D_{85} and O_{50} / D_{50} obtained for different filter sheaths based on generally suggested criteria are given in Table 4. Also, the suggested criteria of Christopher and Holtz (1984) for U.S. Federal Highway Administration (FHWA) for drainage, filtration and erosion control applications in silt and clay, Bergado et al. (1992, 1996) and Bo et al. (2003) for polymer based filter sheath of PVDs are presented in Table 4 for comparison.

The ratio of O_{95} / D_{85} of all the woven jute and non-woven polymer filters is greater than the criteria suggested by Christopher and Holtz (1984). WJT_{775} and non-woven polymer filters satisfy the criteria suggested by Bergado et al. (1996). The value obtained for WJT_{700} filter falls under the range suggested by Bo et al. (2003). WJT_{550} filter did not satisfy any of the referred criteria.

Table 4: Comparison of retention criteria relationships obtained from present study with available literature studies

Criteria	Values from present study				Suggested values from literature study		
	Filter sheath type						
	WJT_{775}	WJT_{700}	WJT_{550}	Non-woven polymer geotextile	Christopher and Holtz (1984)	Bergado et al. (1996)	Bo et al. (2003)
$\frac{O_{95}}{D_{85}}$	2.7	4.2	13	< 1.25	For woven: ≤ 1 For non-woven: ≤ 1.8 $O_{95} \leq 0.3$ mm	≤ 3	4 - 6
$\frac{O_{50}}{D_{50}}$	58	94.7	315	< 39.5	-	≤ 18 – 24	-

The precise value of O_{50} / D_{50} for non-woven polymer filter could not be obtained as the pore sizes below 0.075 mm were not possible to be measured by dry sieving method. For all the types of woven jute geotextile filters tested, the ratio of O_{50} / D_{50} do not fall under the range suggested by Bergado et al. (1996). But later in the marine clay – geotextile filtration tests, WJT_{775} and WJT_{700} filters were able to retain the clay particles effectively similar to non-woven polymer filter.

Filtration Tests

To understand the long term flow behavior and the time required to reach stable flow condition in marine clay - geotextile filter systems, a graph showing the variation of system permeability with time as shown in Figure 6 was plotted. In all the tests, it required nearly 6 days for the flow to establish through the entire thickness of clay and geotextile filter system. Then the flow rate increased and reached maximum value in all the four systems in about 14 days. The maximum system permeability observed was around $1.4 * 10^{-8}$ m/s (Maximum flow rate = 30 cm^3 / day) in all the systems. Multiple increase and decrease pattern in system permeability with time were observed before reaching the stable flow condition in each of the systems. The increase in flow rate represents the soil loss phase through the geotextile filter and the decrease in flow rate indicates soil cake formation phase (Rollin, 1985, Bergado et al. 1996).

The system permeability in marine clay - polymer filter systems attained stable value around 47^{th} day from the commencement of the test. Whereas, marine clay - WJT_{775} / WJT_{700} filter systems reached stable flow condition by 55^{th} day. The system permeability was almost same in the marine clay - polymer / WJT_{775} / WJT_{700} filter systems measuring around $0.35 * 10^{-8}$ m/s (flow rate around, 7 cm^3 / day). In these systems, there was no considerable loss of soil particles after reaching the maximum system permeability. This is evident from the curves pattern; short ascends compared to lengthy descends. The water in the bottom unit of filtration apparatus was almost clear and negligible soil particles were settled at the bottom as could be seen in the photos taken at the end of the tests (Figure 7).

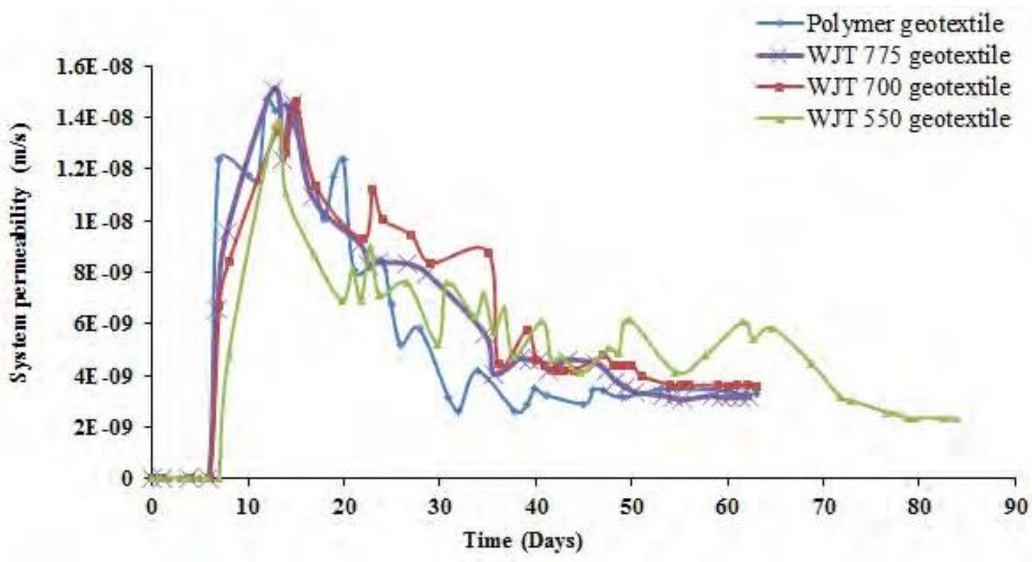

Figure 6: Long term flow behavior in different marine clay- geotextile filter systems.

The system permeability fluctuated excessively in marine clay - WJT_{550} filter for a longer time, compared to other systems. Considerable loss of soil particles was observed as shown in Figure 7. Stable system permeability of 0.25 * 10^{-8} m/s (flow rate around, 6 cm^3 / day) was observed after 75 days.

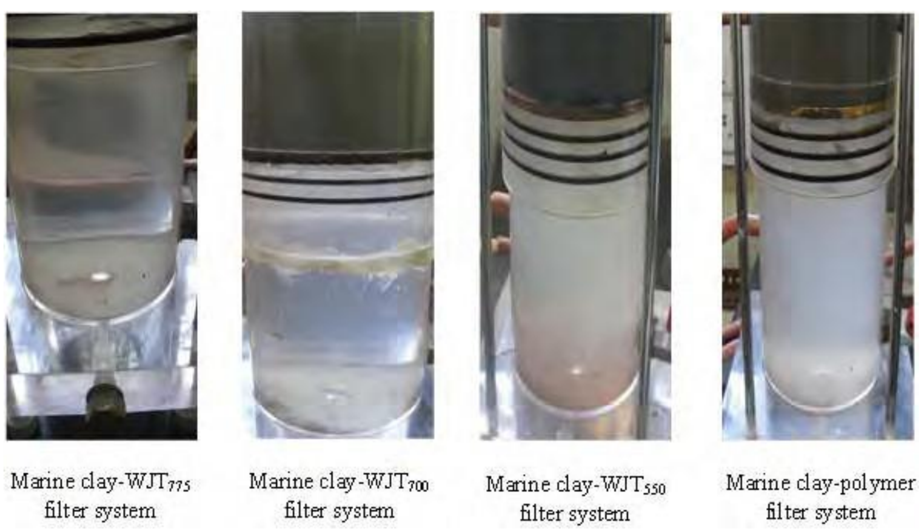

Figure 7: Quantity of fine clay particles settled at the end of test in bottom unit of apparatus in different marine clay- geotextile filter systems

From the variation of system permeability with time, it can be observed that the built up of stable clay cake formation was comparatively faster in marine clay- polymer filter system tending towards more stable flow condition much earlier compared to marine clay - WJT_{775} or WJT_{700} filter systems. Accordingly, the system permeability also decreased at a faster rate in marine clay – polymer filter system. The difference in system permeability pattern is mainly due to the pore size, pore distribution and structural variations in polymer and woven jute geotextiles. The polymer woven geotextile has smaller AOS, even smooth texture and well distributed openings, making the soil particles to settle evenly and uniformly building the soil cake after the initial loss of fine soil particles. Whereas, woven jute geotextiles have larger AOS and uneven openings with rough texture. These make the built up of soil cake on woven geotextile a little longer time, but once the stable cake forms, the system reaches stable flow condition as in the case of polymer filter system.

As noted by Giroud (1982) and Chang and Nieh (1996) throughout the filtration process, under a specific hydraulic gradient, the stability of soil structure and cohesive nature of soil plays a significant role in soils such as marine clay. In WJT_{775} or WJT_{700} filters, the dense bridge network of the jute fibres help in retaining the fine clay particles settled on the filters and build up stable cake formation at earlier stage compared to WJT_{550} filter. In WJT_{550} filter although the filter system attains the stable condition, it requires considerable time to achieve stable cake formation. Even in marine clay - WJT_{550} filter system, after attainment of peak system permeability, formation of cake for significant time can be observed. But the coarse network of jute fibres in almost equal sized larger pores of WJT_{550} filter may not be able to retain the clay particles under the increased pressure drop across the filter. This lead to the detachment of clay particles adhered to fibres at few larger pores. But the cohesion in highly plastic marine clay particles helps in rebuilding the cake formation gradually leading to stable flow condition. Hence, while selecting the woven jute geotextiles as better filters in marine clay, it is essential to make jute geotextiles having good fibre network along with suitable pore sizes.

Comparison between clay retention criteria relationships and filtration tests are made. As mentioned earlier, the WJT_{775} and WJT_{700} filters did not agree with some of the referred soil retention criteria. But, WJT_{775} and WJT_{700} were able to retain clay particles effectively when filtration tests on marine clay – WJT_{775} / WJT_{700} systems were carried out. The retention criteria for WJT_{550} filter did not fall under any of the suggested criteria. Although the marine clay - WJT_{550} filter system reached stable system permeability after a long time compared to other systems, the loss of soil particles was more. It is concluded that, marine clay - WJT_{550} filter system is not a better filtration system compared to marine clay – polymer / WJT_{775} / WJT_{700} filter systems for the specified soil and hydraulic condition. If the empirical relation of $O_{95} / D_{85} \leq 4.5$ and $O_{50} / D_{50} \leq 100$ are considered for woven jute geotextile filter sheath selection, the filtration compatibility between marine clay – woven jute geotextile filter system can be achieved.

CONCLUSIONS

To understand the marine clay retention ability and filtration behaviour of three types of woven jute geotextile ($WJT_{775,}$ WJT_{700} and WJT_{550}) used as filter sheaths in making of natural PVDs and polymer geotextile used as filter sheath in polymer based PVDs, the Apparent Opening Size (AOS) tests on geotextiles and laboratory long term filtration tests on marine clay – geotextile system were carried. From the test results and further analysis, the following conclusions are made:

1. From the long term filtration tests, for the given soil and hydraulic condition, the maximum system permeability was almost same in all the four systems measuring $1.4 * 10^{-8}$ m/s. Multiple increase and decrease pattern in system permeability with time were observed before reaching the stable flow condition in all the systems.

2. All the marine clay – geotextile filter systems reached stable flow condition but at different time intervals. The system permeability in marine clay-polymer / WJT_{775} / WJT_{700} filter systems attained stable value of around 0.35 * 10^{-8} m/s by 47th and 55th day from the commencement of the test. Whereas, marine clay - WJT_{550} filter system took 75 days to reach the stable system permeability and it was around 0.23 * 10^{-8} m/s. The loss of clay particles during filtration process was more in marine clay - WJT_{550} filter system compared to other systems.

3. There exists good filtration compatibility between marine clay – polymer / WJT_{775} / WJT_{700} filter sheaths for the given hydraulic and soil conditions. Whereas, marine clay - WJT_{550} filter system is not a better filtration system. Hence, while selecting the woven jute geotextiles as better filters in marine clay, it is essential to prefer jute geotextiles having good fibre network structure with appropriate pore sizes as well.

4. The apparent opening size (AOS) tests revealed that polymer and WJT_{775} filters satisfied some of the suggested soil retention criteria adopted by other researchers. Although, WJT_{700} filter did not satisfy some of the referred criteria, it was able to retain clay particles in marine clay - WJT_{700} filtration tests similar to polymer and WJT_{775} filters within the test period. This illustrates that filtration compatibility between marine clay – woven jute geotextile filter system can be achieved with the ratio of $O_{95} / D_{85} \leq 4.5$ and $O_{50} / D_{50} \leq 100$.

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