RESEARCH ANALYSIS OF PLASTIC FILTERS

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Introduction

Plastic filters are fabrics made from synthetic fibers. They can be of two types: either a woven filter featuring distinct open areas, or nonwoven filters that consist of a homogeneous fibrous mass with tortuous paths through the fabric. The fiber structure of these filters consist predominantly of polyvinylidene chloride, nylon, polyester, and polypropylene yarns, filaments, or fibers. These components give rise to the term "plastic." However, the terms filter fabric and cloth filters are synonymous with plastic filter.

Filter fabrics are used by some engineers as a replacement for granular filters. Being both economical and durable, filter fabrics can be viable alternatives to a graded filter. They are economical because costs of stone and construction are increasing. Also, plastic filters are durable because they have their own tensile strength. Like granular filters, plastic filters are designed to be permeable to water and yet be constraining to the soil particles.

The majority of filter usages lie within the realm of erosion control and drainage. Plastic filters have been applied as bedding material beneath riprap, protection for river revetment, and as scour protection in various locations around the country. Plastic filters have also been used in subdrainage systems as replacements for gravel packs. The ease of placement warrants their usage. Foundation protection is a growing field for filter cloth applications. Many roads through swampy lands would be nonexistent if it were not for plastic filters stabilizing the soil when surcharged by vehicles.

Test Objectives

A correlation exists between the plastic filter, soil type used, and the particular ground-water conditions. In analyzing the efficiency of a filter fabric, the performance mechanism must be investigated as to the aforementioned correlated variables. In establishing a testing environment, it is possible to study the hydraulic properties of plastic filters associated with various soil types and waterhead.

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In the past, most plastic filters were selected in a random process. This was due to the lack of knowledge associated with the hydraulic properties of the filter fabrics. With time, plastic filters will be selected for individual merit and environmental factors rather than by trial and error methodology. Only through research testing can this be accomplished.

Hydraulic Characteristics of Filters

A filter system must serve two purposes. First, it must be permeable to water so that there is not a hydrostatic water pressure buildup. This is accomplished by allowing the water to pass through the filter without significant head loss. Second, it must also constrain the soil so that the soil does not leach out from underneath structures. Once a filter, conventional aggregate or plastic, is installed, the filter system could become plugged or clogged with soil particles, depending on installation techniques and fabric-soil characteristics. In this text, plugging is defined as the decline in rate of water movement through the filter system; whereas, clogging is defined as the closing of filter openings to such an extent that the filter system becomes essentially useless.

By using permeameters in a controlled test environment, the plugging and clogging phenomenon, with respect to plastic filters, can be investigated. In measuring water discharges through a soil column and plastic filter, plugging effects are analyzed. In measuring the pressure within the soil column with time, clogging effects can be determined.

Test Setup

A square wooden box with 8-foot (2438-mm) long sides and a 2-foot (610-mm) depth was built to intercept the city water supply. The purpose of the tank was two-fold. The tank was fitted with a network of steam lines, so that the cold water could be heated to a warmer temperature. The tank was large enough that random flow currents were greatly reduced as characterized by a reservoir. The net effect of heating and stilling of the city water was a reduction of air entrainment.

A 2-inch (51-mm) diameter waterline delivered the warmer water by gravity to a rectangular head box, 2 feet (610 mm) in width, 4 feet (1219 mm) in length, and 2 feet (610 mm) in depth. The wooden head box consisted of three chambers. The water entered the head box through the first chamber and was allowed to pass through a porous boundary into the second chamber. The porous boundary was designed to collect particulates and to dampen any turbulence upon water entrance. The second chamber housed 12 outlets to the permeameters. In order to maintain a constant head within the box, the third chamber was set up as an overflow for the second chamber. Excess water was allowed to exit the system from the third chamber.

Flowing with a nearly constant head, the water was transported by plastic tubing to the 12 permeameters. The cylindrical permeameters were constructed of clear lucite(R) pipe, 12 inches (305 mm) in diameter, with three distinct sections (see fig. 1). The top section of each permeameter consisted of a gate valve to regulate incoming waterflow, a sprinkler head to spread the flow once the water entered the permeameter, and a standpipe to allow air to escape before air accumulations developed within the permeameter. The test section, containing a 4-inch (102-mm) soil column, a plastic filter with support screen, and five pressure taps fit flush with the top section. The pressure taps were drilled and secured within the lucite(R) walls. The first pressure tap was located 1 inch (25 mm) above the soil surface. The second, third, and fourth pressure taps were placed at 1-inch (25-mm) increments within the soil depth starting at the soil surface. The plastic filter along with a support screen was positioned directly below the soil column. The fifth pressure tap was located immediately above the plastic filter tested. The bottom section of the permeameter was sealed and bolted to the test section. This section closed the permeameter from the surroundings so that air could not enter the system from beneath the plastic filter. The sixth pressure tap as well as an outlet was placed within the wall of the bottom section.

The six pressure taps were connected by plastic tubing to a large manometer board. The difference in pressure between the first and sixth pressure tap reading represented the total head on the soil and plastic filter. By maintaining this difference for the duration of testing, pressure fluctuations within the soil could be analyzed.

Plastic tubing was strung from the outlet tap located in the bottom section of the permeameter, up through a tubing rack to assure a positive head, and then down through a permeameter support rack. From beneath the support rack, the permeameter discharges were measured with time.

Testing Procedure

The testing procedure began with the heating and chlorination of water in the large holding tank. The steam lines within the large wooden box were set so the water temperature within the system was approximately room temperature, 68 °F (20 °C). The chlorine concentration was kept at 10 p/m by weight (mg/L) in order to minimize the bacterial activity except for the first soil tested. The soil to be tested was baked in an oven at 450 °F (232 °C) for 8 hours to destroy any organisms that may have initially existed except for the first soil tested. Once sterilized, 25 pounds (11.4 kg) of soil were placed in each of the 12 permeameters and compacted to a thickness of 4.16 inches (106 mm). This corresponded to a soil density of 100 lb/ft^3 (1602 kg/m^3).

Disks of fine mesh screen were glued to the face of the pressure taps to minimize tested soil leaching from the system. The manometer lines were then connected to the pressure taps and the plastic transport lines were connected from the rectangular head box to the permeameter outflow taps located within the bottom permeameter sections. The soil was then ready to be saturated. The permeameters were filled in an upward direction to approximately 1 inch (25 mm) above the top soil surface. The saturation process usually required 8 hours, depending on soil composition. Once the saturation process was completed, outflow tubing was strung from the permeameter outflow taps through the tubing support racks, as earlier described, and the transport line was connected to the permeameter inlets. Water entered the system in a downward direction and sprayed against the inside permeameter walls through the sprinkler heads. The inch of water above the soil depth during saturation guaranteed dissipation of the incoming water energy. This eliminated soil surface erosion and other soil disturbances. The permeameters were allowed to fill and the pressure readings to stabilize. Once the systems reached stabilized conditions, water inflow was adjusted so that a constant head was applied upon the soil depth in each permeameter. After adjustments were made, a further increment of time was necessary for pressure and flow stabilizations. When all of the permeameters indicated the required constant head, testing began.

Each of the permeameters for any one particular test, were subjected to the same head and consisted of the same soil type. Therefore, by placing different filter fabrics in each permeameter, the filters would theoretically represent the only variable. However, a certain degree of experimental deviation would naturally exist. Hydraulic testing of the filter fabrics consisted of a five-phase analysis. These five phases included a filtration or water discharge analysis, a water pressure analysis, an analysis of sediment discharges through the plastic filters, an analysis of permeability changes, and a bacteria as well as fabric fiber analysis.

Discharge measurements were collected on a daily basis from each of the permeameter outlet taps. The measurements were plotted against time and analyzed with respect to fluctuation and magnitude for possible plugging of the filter system. Six pressure readings for each permeameter were also recorded on a daily basis. The pressures were analyzed with time in order to correlate with discharge results. The readings served as an indicator for denoting filter clogging and for denoting the plugging of soil voids which is independent of the plastic filter. Once all discharge and pressure measurements were terminated, the permeameter systems were dismantled. The bottom section of the permeameter served as a sediment trap for the fine particles which passed through the filter fabric.

Permeability change within the soil column is also an indication of the extent of fine particle migration. Analysis of these changes depends upon the test data of discharge and pressure. Soil and filter samples were analyzed to determine the bacterial activity within the soil and the filter fabric. The bacteria analysis was performed by a microbiologist and the tested filter fabrics were analyzed with a scanning electronic microscope to determine filter clogging and/or bacterial activity.

Methods of Analysis

The filter system for testing the performance of different filter fabrics consisted of placing the fabrics in 12 permeameters with approximately 4 inches (102 mm) of soil placed on top. The discharge and pressure distribution were recorded with time for the 12 permeameters. To avoid confusion, the following terminology is used:

1. "Filter Fabric n" denotes the tested filter fabric identified by the name "n."

2. "Permeameter n" denotes a permeameter device for testing the filter fabric identified by the name "n."

Using the measured discharges and pressure distributions, the permeability coefficients based on the average and bottom inch pressure gradients were computed.

The governing equation for soil permeability computation was given by Darcy's law,

$$Q = KiA \tag{2}$$

where Q is the water discharge, K is the permeability coefficient of the soil, i is the hydraulic gradient, and A is the cross sectional area of the soil. Combining this equation with the equation of continuity, a more condensed form of Darcy's law can be developed and expressed as

$$V = Ki \tag{3}$$

where V is the average water velocity through the soil. Darcy's law is applicable only within the laminar region of flow.

The average velocity was determined by

$$V = \frac{Q}{A} \tag{4}$$

Where Q was the measured flow rate through the soil and filter fabrics. To determine the hydraulic pressure gradient within the soil, the pressures of the individual strata were measured as described in the testing procedure. The average gradient was computed by dividing the head applied to the filter systems by the 4.16 inches (106 mm) of soil depth. The bottom hydraulic gradient was computed by dividing the pressure recorded within the bottom inch of soil by the 1 inch (25 mm) of soil. Knowing the average water velocity and the hydraulic gradients, the permeability coefficients based upon the average and bottom pressure gradients were computed for each permeameter.

The gradient ratio is the index used by the U.S. Corps of Engineers to indicate when a filter fabric is clogging (Calhoun, 1972). The value is a ratio of the hydraulic gradient within the bottom inch of soil to the average hydraulic gradient. Due to the fact that the average hydraulic gradient for the four soils tested was maintained at a constant value during most of the testing time, the gradient ratio would, therefore, be an indicator of the pressure buildup within the bottom inch of soil.

The flow rate was affected by the temperature variations during testing conditions. To standardize the computed rates, the measured flow rates were converted to a temperature of 60 °F (15.6 °C) for the first soil test. However, it was found that the water temperature within the laboratory could be maintained more easily between 65 °F (18.3 °C) and

75 °F (23.9 °C). Therefore, the flow rates for the other three soil tests were standardized to 68 °F (20 °C). To standardize the computed rates the following relation was used

$$\frac{Q_s}{Q_t} = \frac{K_s}{K_t} \tag{5}$$

Where Q_s and K_s are the discharge and permeability coefficient at the standardized temperature (60 °F or 68 °F), and Q_t and K_t are the values at a measured temperature T. The changes in soil permeabilities can be related to water viscosity by using the relation

$$\frac{K_s}{K_t} = \frac{V_t}{V_s} \tag{6}$$

where V is the kinematic viscosity of water.

Upon dismantlement of the permeameters, a core sample of the tested soil was analyzed to determine the bacterial activity within the soil. The tested filter fabrics were observed using a scanning electronic microscope and analyzed to determine the extent of soil plugging and bacterial activity. The small amount of fine particulates that passed through the fabrics were weighed at this time. However, most of the soil testing considered large concentrations of particles that were finer than the opening sizes of the plastic filters. Therefore, much of the sediment passing through the fabrics occurred when the dry soil was placed in the permeameters. Furthermore, due to the fact that the water discharges were much larger than the sediment discharges and the sediment collection section of the permeameters were relatively small, some of the fines that passed through the fabrics were flushed through the outflow taps.

Tested Soil and Waterhead

Four soil types were used to analyze the filter fabric performance. These four soil types represent a variety of fine soils which many engineers feel are critical to plastic filter usage. The soils tested consisted of the following compositions:

- Soil Type 1 - 100 percent fine sand
- Soil Type 2 - 50 percent fine sand, 25 percent silica No. 290, 25 percent silica No. 395
- Soil Type 3 - 70 percent fine sand, 15 percent clay, 7.5 percent silica No. 290, 7.5 percent silica No. 395
- Soil Type 4 - 42.5 percent fine sand, 21.25 percent silica No. 290, 21.25 percent silica No. 395, 15 percent clay

The soil size distributions for the four soils are shown in figure 2. The fine sand used in each test was an Ottawa sand in which D_{50} = 0.0071 inch (0.18 mm). The silica used in testing was factory ground rather than naturally produced. Kaolinite was used as the clay component in testing. This type of clay was chosen for its insignificant swelling nature as well as for the addition of fine particulates.

A different plastic filter was placed within each permeameter. Table 1 lists the various filter fabrics used in the four soil tests and the corresponding equivalent opening sizes. The U.S. Corps of Engineers has adopted the EOS (equivalent opening size) as an indicator of the filter cloth open area (Calhoun, 1972). The EOS of a filter cloth is determined by placing the filter between a sieve of much greater openings and a pan within a sieve nest. Next it is necessary to obtain glass beads of known sieve intervals. Beginning with the finest of beads, fabrics are tested with successively coarser bead intervals by dry sieving for 20 minutes to find which sieve interval permits less than 5 percent by weight of the beads to pass through the cloth.

For Soil Type 1, the head difference between pressure taps 1 and 6 applied to the filter systems was maintained at 9.8 inches (250 mm). This head simulated 2.5 feet (750 mm) of water depth upon 1 foot (305 mm) of soil. For Soil Type 2, the head applied to the filter system was maintained at 1 foot (305 mm). In terms of hydraulic gradient, this head simulated 3 feet (915 mm) of water depth upon 1 foot (305 mm) of soil. For Soil Types 3 and 4, the head was maintained at 305 mm for 800 hours. After 800 hours the head was increased 6 inches (153 mm) each day until the head reached 3 feet (914 mm). The constant head tank was then raised 4 more inches (102 mm), to a head of 3.33 feet (1017 mm). This waterhead was equivalent to a hydraulic gradient of 10 feet (3048 mm) of water depth upon 1 foot (305 mm) of soil. To complete the test, the head was lowered to the original 305 mm.

Soil 1 Tests

For Soil 1 tests, it was found that each of the filter systems experienced a declining flow rate with time. Figure 3, plotted using discharge data from permeameter 2, shows a typical filtration response for Soil 1 tests. The discharges declined from the initial value of 600 mL/min to a final value of approximately 10 mL/min after 1,000 hours of testing. From all indications, it is quite possible that for a longer duration the flow rates for each permeameter would become negligible. The pressure distribution showed a definite increase in pressure difference after 50 hours of testing between the first and second inches of soil. Shortly after 50 hours a brownish-red soil layer developed within the top 2 inches (51 mm) of soil. After dismantling, this dark layer in the soil was found to be a heavy accumulation of two bacterial types, some mold particles, and small trapped silt and debris. The bacterial types were of a sticky capsular material which could retard the waterflow. The laboratory environment serves as an excellent atmosphere for bacterial activity due to the constant lighting, warm temperatures, and humidity. City water with a chlorine residual of 1 to 2 p/m by weight (mg/L) was used in this first test. Evidently most of the residual chlorine was dissipated within the large holding tank with the remaining chlorine unable to control microbial activity below the first inch of soil. The filter cloths had some bacteria attached but under a light microscope the cloths did not appear damaged or deteriorated. A scanning electronic microscope was used to evaluate each filter fabric for possible soil or bacterial blockage within the fibers. Each filter fabric tested showed no indication of fabric clogging. The microscopic photographs confirmed the findings of the light microscope for Soil 1 tests.

As the bacteria grew within the soil, the water velocity was greatly reduced, as indicated by the flow rate decrease. This decreased the soil permeability accordingly, as shown in figure 3. For the permeability coefficient based upon the average hydraulic gradient to reduce, the velocity must be decreased due to the fact that the head was a constant value of 205 mm for the entire test. The bottom inch of soil experienced a smaller reduction in permeability than the average soil permeability. It is believed that the plugging of the filter system mainly occurred because of bacterial activity in the top 2 inches (51 mm) of soil which caused a large pressure drop across the top soil layer. This is illustrated by the reduction in gradient ratio shown in figure 3. Initially, the gradient ratio was greater than 1.0 probably due to a greater compaction in the lower portion of soil. The ratio began decreasing as the pressure drop increased within the top 2 inches (51 mm) of soil.

Even though bacterial activity dominated the hydraulic responses after 50 hours, during the early stage of testing the bacteria activity was negligible. By hour 50 the flow rates for the filter system had decreased to approximately 60 percent of the initial values. The pressure distribution within this time period was constant. Therefore, any instabilities within the permeameters can be neglected. The flow rate decline could be due to compaction and local fine particle migration throughout the entire soil column.

Due to data scatter, no definite correlation could be initially drawn between the EOS of the filter fabrics and the water discharges. The equation representing the weighted vertical permeability through multiple soils is

$$V = \frac{H}{\frac{D_1}{K_1} + \frac{D_2}{K_2}} \qquad (7)$$

where V is the measured velocity, D_i ($i = 1$ or 2) is the thickness of a soil layer of a permeability, K_i, and H is the head applied to the soil. The equation shows that if the thickness of an individual layer in a multiple soil system is small, the effect of this layer upon the measured velocity could be minimal. If this layer was that of the plastic filter, initially the filter fabrics would have negligible effect upon the filter system.

At the end of the testing duration the discharge response was independent of the filter opening size. This suggested that soil (after the growth of microorganisms) controlled the hydraulic responses of the filter system regardless of the type of fabric used.

The average sediment amounts that passed through the filter fabrics tested with Soil 1 were less than 15 grams (i.e., 0.1 weight percent of soil in permeameter). The mean sediment concentration for the Soil 1 tests was below 3 p/m by weight (mg/L). There is no indication that a relationship existed between EOS and passing sediment weight.

Soil 2 Tests

Filter fabrics Z, M, R, and 3-01 were added to Soil 2 tests to replace filter fabrics 4, 5, 6, and 11 that were used for Soil 1 tests. As shown in table 1, filter fabrics 2, 7, and 10 used in Soil 1 tests were changed to filter fabrics 2A, 7A, and 10A for Soil 2 tests. The corresponding filter fabrics were manufactured in the same manner and seemed the same by observation; however, they were manufactured at different periods of time. This could cause slight variations within the fabrics.

The initial discharge data for Soil 2 tests exhibited varying degrees of scatter. For the first 100 hours of Soil 2 tests, the outflows from the permeameters were collected in buckets as was the procedure for Soil 1 water collection. However, due to small flow rates through the Soil 2 filter systems, excess water that entered the buckets from wet equipment caused significant error. To minimize the data error, after 100 hours the water was collected using 1000-mL Ehrlenmeyer flasks rather than buckets. When Ehrlenmeyer flasks were used, the measured filtration rates were nearly constant with minor fluctuations. The varying degrees of discharge scatter measured in the first 100 hours of Soil 2 tests were attributed to the discharge collection method.

Despite the initial data collection difficulties for Soil 2 tests, the majority of the filter test systems were characterized by a nearly constant flow of about 100 mL/h. Most of the pressure differences were also approximately constant. Figure 4, plotted using data collected from permeameter 1, shows a typical example. However, permeameters 8, 10A, and 12 exhibited pressure distributions that consisted of either sudden rising or falling pressures. The discharge responses for the three permeameters were relatively constant throughout the tests. The variation in pressures was probably caused by a local disturbance of the soil particles near the pressure taps.

Figure 4 shows that the pressure drop measured between taps 2 and 6 approached that pressure drop between taps 1 and 6. The two most probable causes were that the soil above tap 2 was disturbed by air introduced to the soil from the manometer lines or the soil was disturbed when first saturated.

The pressure distributions were typically linear for all of the permeameters in the Soil 2 testing. However, the pressures recorded within the bottom inch were consistently low. It is believed that when this fine soil type was initially placed within the permeameters some fine particles immediately above the plastic filters passed through the fabrics leaving a layer of more permeable soil, as shown in the permeability curves in figure 4. When the bottom 1 inch (25 mm) of soil was more permeable than the other 3 inches (76 mm) of soil, the pressure drop within the bottom inch would be less.

Based on the same reasoning, the permeability coefficient of the bottom inch of soil was greater than the overall permeability coefficient. This feature was reflected by the changes of the gradient ratio with time. The initial value of the gradient ratio was below 1.0. However, the general increasing trend in the gradient ratio coupled with the reduction of permeability within the bottom inch of soil indicated that the lower portion of soil was slowly being compacted.

The bacterial analysis of Soil 2 showed that a negligible amount of bacteria existed within the soil with virtually no bacterial attachment to the filter fabrics. The bacterial activity was controlled in Soil 2 tests by boosting the chlorine concentration of the water to 10 p/m by weight (mg/L) and by initially baking the soil to kill any existing organisms. Not only was it determined that the filter fabrics were free of bacteria blockage, but it was also established by microscopic scanning that the fabrics were not clogged by soil particles.

It was found that the water discharge was independent of the filter fabric tested; therefore, Soil 2 controlled the hydraulic responses of the filter system. The initial and final filtration rates showed no correlation with the equivalent opening sizes for the filter fabrics tested under Soil 2. It was found that Soil Type 2 was less permeable than the filter fabrics tested. Within the tested EOS ranges, the plastic filters under Soil 2 performed the same. The sediment that passed the filter fabrics was not measurable due to the small amounts and very fine particulate.

Soil 3 Tests

Six permeameters were used for the hydraulic analysis of Soil 3 filter systems. The filter fabrics used for this test were filters 2A, 3-14-1, 9, 10A, 3-22, and 3-01.

Within the first 800 hours the Soil 3 tests were operated at the same head as Soil 2 tests, after which the head was increased and decreased as described under tested soils and waterhead.

The filter system was initially unstable, as shown by a typical example in figure 5, indicating the reduction in flow rate and the corresponding increases in pressure. After an initial time period of 80 hours, the flow rates fluctuated about the value of 200 mL/h. Between 300 and 750 hours of testing the flow rates for most of the permeameters dropped to values between 50 and 100 mL/h. This flow reduction was due to bacterial growth that developed upon the filter fabrics.

The bacterial analysis showed that a negligible amount of bacteria existed within the soil column; however, a significant amount of iron bacteria existed within the filter fabrics. This bacteria originally propagated upon the metal supporter, and then grew into the filter fabric directly above. In simulating this particular bacterial growth in a special laboratory under ideal conditions, it was found that the bacteria developed in about 8 days. This coincided with the reduction in the filtration rates. The amount of iron bacteria present within the filter fabrics had a significant effect on the flow rates through the permeameters. The same testing preparation used for Soil 2 was also used for Soil 3. However, the metal support screen used beneath the plastic filter in Soil 3 testing was painted with only one coat of galvanizing compound rather than five coats. This single coating of galvanizing compound was not sufficient in preventing rust accumulation upon the metal which then supported microbial growth.

The pressure distribution within the permeameters experienced more fluctuation than the previous two soil tests. As shown in figure 5, the pressure recorded by tap 2 increased to that of tap 1. This was attributed to a local disturbance of soil particles near pressure tap 2. The pressure recorded immediately above the filter fabrics increased after 80 hours of testing. This possibly reflects the initial stages of bacterial activity within the filter fabrics.

The head was increased after 800 hours of testing, as described earlier. As shown in figure 6, a direct correlation existed between the head change and the flow rate. However, at hour 1128, even though the head was maintained at 1017 mm, the discharge decreased. This reduction in discharge could be due to collapse or filling of small channels created upon head increasing within the soil. The pressures within the bottom 2 inches (51 mm) of soil were still increasing at hour 1128, even though the head was constant at this time. This was an indication of nonequilibrium encountered while constantly increasing the pressure head. Once the head was lowered at 1150 hours to the original height, the flow rate approached a constant value approximately equal to the discharge recorded immediately before the head increase.

The gradient ratio, as shown in figure 5, was initially below 1.0 for the majority of the permeameters due to a disturbance caused by saturation techniques before the test. At 48 hours the gradient ratio increased above the value of 1.0 while the permeability of the bottom inch of soil decreased. It is believed that as bacteria was developing in the filter fabric the water velocity reduced and the pressure drop within the bottom inch of soil increased. By hour 750 the bacteria had significantly affected the discharge, as shown by the flow reduction and the permeability reductions in figure 5. After hour 800 the head was raised. The permeability coefficients within this time range were relatively constant, as shown in the boxed area of figure 5. This indicates that the velocity through the system directly corresponded with the increase in hydraulic gradient. Although bacteria accumulated on the filter fabrics, the soil was virtually unchanged.

Like Soil 1, a correlation could not be established between discharge and the fabric EOS. The weighted permeability equation aforementioned shows that the filter fabric had negligible effects upon the filter system. Therefore, the soil initially controlled the hydraulic responses of the system. At the end of the testing, the soil also controlled the hydraulic responses. Even though the bacterial growth was initiated on the metal support screen, the activity spread through the filter fabrics to the adjacent thin layer of soil above.

The average sediment weight that passed through the filter fabrics was less than 10 grams (i.e., 0.09 weight percent of soil in permeameter). No relation could be established between the measured weight and the filter EOS.

Soil 4 Tests

The Soil 4 tests were conducted simultaneously with Soil 3 tests. Within the first 300 hours of testing, the majority of the permeameters sustained discharges that ranged between 80 and 100 mL/h as shown in figure 7. However, after 300 hours the filter systems experienced a drop in discharge. This discharge reduction was mainly attributed to the same bacterial accumulations on the fabrics as were experienced during Soil 3 tests. Because the particle sizes of Soil 4 were very small, the average velocity through the soil was less than that for the Soil 3 tests. The bacteria could develop more rapidly in an environment with smaller velocities. Also, the smaller the velocity, the less chance of the chlorine protecting the soil from such activities. This is due to chlorine dissipation within the filter system. These factors caused the discharge drop during Soil 4 tests to occur about 100 hours earlier than in Soil 3 tests. The fine particulates of Soil 4 also affected the pressure responses within the permeameters, as shown in figure 7. This figure indicates that the head applied to the permeameters was about 400 mm for the first 350 hours. The 400 mm was a result of water level instability due to the length of the manometer line associated with tap 6, and corresponding air entrainment. The filter system remained stable as shown by the filtration curve in figure 7. Once the water level within the tap 6 manometer line had stabilized, the pressure drop decreased. This apparent hydraulic gradient reduction caused increases in permeability and decreases in gradient ratio, even though this was not the true phenomenon. In order to eliminate the effects of the manometer instability, the permeabilities and gradient ratio were adjusted accordingly.

Figure 8 illustrates the flow rate changes with head once the head was changed after hour 800. In general, the discharges increased and then decreased following the changes in head. During this test period the soil permeability remained approximately constant as shown in figure 7. This indicates that the variation in head within the tested ranges did not significantly affect the soil characteristics. However, figure 8 shows that the discharge reduced when the head was maintained at the peak height. This was attributed to the localized movement of fines within the soil which reduced soil voids and decreased the discharge. This effect was reflected by a slight reduction in soil permeability.

Permeameters 2A and 9 did not record discharges until the head was raised at hour 800. This was attributed to overcompaction of the soil during the test preparation which reduced the discharges to such a small value that they could not be measured by the techniques used in the study. The minimum measurable discharge was about 5 mL/h. When the head was increased at 800 hours, flow became measurable. Measurable flow persisted even after the head was lowered to the original 305 mm. Evidently, as the pressure increased, the overcompacted soil in permeameters 2A and 9 was probably loosened and small channels were formed.

Generally speaking, the pressures measured in the soil sections after hour 800 lagged behind the head changes. When the head was maintained at 400 mm for over 100 hours, the meaured pressure within the soil was still increasing, as shown in figure 8. This difference was due to delay in the response of manometer lines. Although the measured pressure within the manometer lines had not reached equilibrium, the filter system had stabilized before discharge measurements were taken. As shown in the boxed area of figure 7, the permeabilities within the soil were nearly constant during the head changes. This illustrates the fact that the filter system was stable in that the water velocity increased proportionally to the increase in hydraulic gradient.

No relationship could be established between the EOS of the filter fabrics and the flow rates for Soil 4 testing. The average sediment weight that passed through the filter fabrics was less than 15 grams (i.e., 0.1 weight percent of soil in permeameter). Again, no apparent relation existed between sediment passing and filter EOS.

DISCUSSION OF RESULTS AND CONCLUSIONS

Representative figures were used in this text to indicate the response of the plastic filters to the four different soil types tested. Individual filter responses show insignificant variations (Demery 1979).

The experimental data were analyzed to determine which elements in a filter system, the tested soil and/or the plastic filter fabrics, controlled the hydraulic responses of that system. In all the tests conducted in this study, it was determined that the soil controlled the hydraulic responses regardless of the type or the opening size of the filter used.

The compaction of soils at the beginning of testing was sufficient enough to decrease the flow rate with Soil Types 1 and 3. This caused some reduction in soil permeability for the two tests. Soil Types 2 and 4 experienced insignificant fine particle migration due to the initial control established by the soil. The chlorine controlled the bacterial activity so the soil properties and filter fabrics were virtually unchanged for Soil 2 tests. Even though the soil properties remained about the same for Soil Type 4, bacteria grew in the soil immediately above the fabric.

Even though laboratory testing encountered bacterial activity, a question arises as to whether or not bacterial accumulations exist in a field environment. In the field, soil is not exposed to constant light, temperature, or ground-water head. Furthermore, the soil occupies much larger areas than that tested in the laboratory, so that if a bacteria was developing it could be a long time before a soil layer would clog. However, in many field situations, soils contain an abundance of nutrients and the water is not chlorinated. It is possible that bacterial accumulations can be responsible for localized plugging of a disturbed field soil, similar to that experienced in the Soil 1 test. Many subdrainage systems contain perforated iron pipe. It has been shown in Soil Tests 3 and 4 that bacteria derived from metal can attach to the filter fabrics and may penetrate and spread through the soil. Bacteria have been responsible for plugging the fabric openings along a toe drain located within an earth dam as well as plugging fabric openings around a perforated iron subdrainage pipe.

In the laboratory testing the soil was saturated slowly in an upward direction. This method was designed to uniformly displace the air voids with water. It is impossible to remove all of the air; however, if the soil is saturated very slowly, most of the air can be removed.

In a field situation cold water contains dissolved air. Furthermore, with fluctuations of ground-water head, the soil will not remain uniformly saturated. It is possible that large air pockets can develop within the soil and become compressed with time. This air pocket could inhibit flow and increase pressures behind the filter fabric within a localized area.

Based on the analysis of the laboratory tests using a variety of filter fabrics, the following conclusions are drawn:

1. If the permeability of the soil is less than the permeability of the filter fabric, the soil controls the hydraulic responses of the system.

2. Bacterial activity within the soil or upon the filter can control the hydraulic responses of a filter system.

3. For 1,000 hours of continuous testing the filter fabrics had no detectable effect upon the hydraulics of the filter system.

4. The larger the fine particle concentrations within a soil, the higher the probability of the soil controlling the hydraulic responses. In this case, different fabrics will perform the same.

5. If the permeability of a particular soil layer within a multiple layer soil system is less than that of the filter fabric, this particular soil controls the hydraulic response of the entire soil system, regardless of the particular soil layer location within the system.

6. The gradient ratio developed by the U.S. Corps of Engineers to indicate filter clogging should be analyzed for long term effects rather than short-term effects. In using a short term analysis, system instabilities could be experienced that are especially prevalent in using finer soils.

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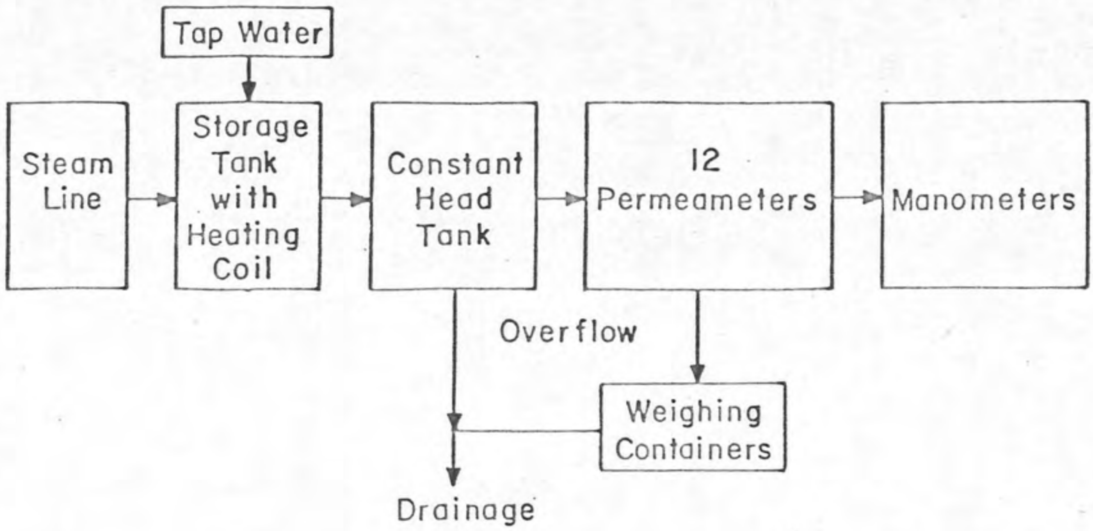
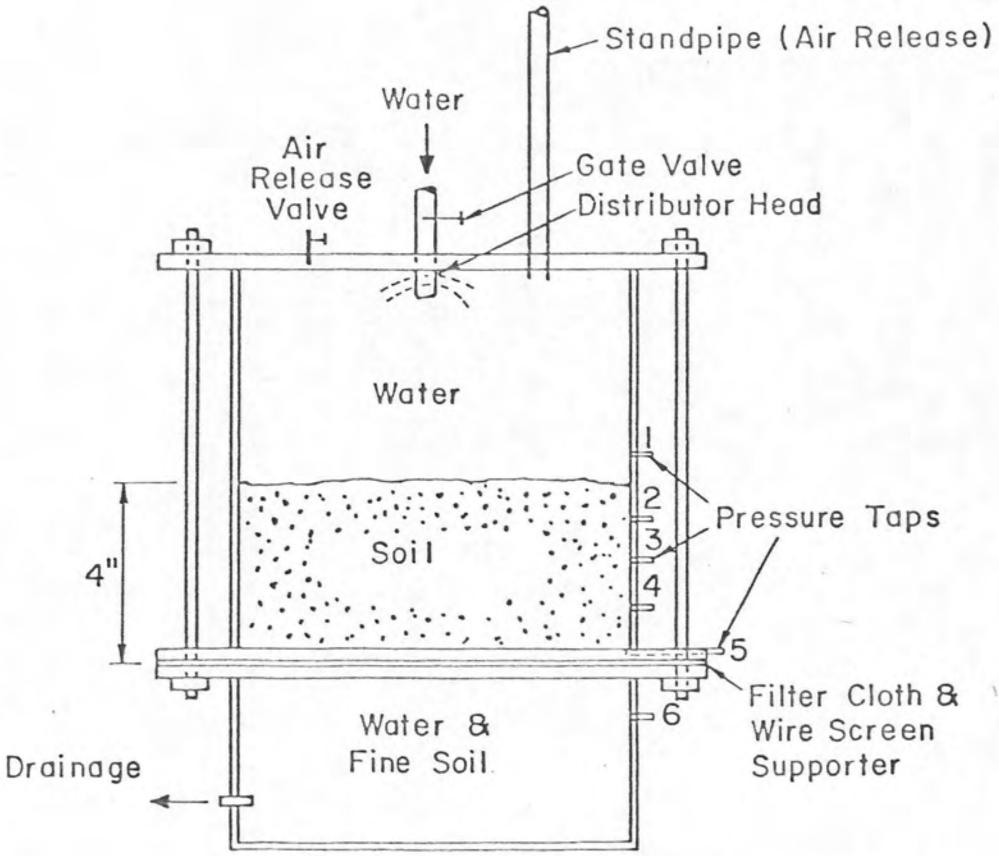
Table 1. - Tested filter fabrics

Soil test	Filter used	EOS Ranges U.S. standard sieve size	Mean opening size (mm)
1	1	70 - 100	0.18
	2	70 - 100	0.18
	3	140 - 170	0.10
	4	40 - 50	0.36
	5	80 - 100	0.17
	6	70 - 100	0.18
	7	40 - 50	0.36
	8	40 - 80	0.20
	9	40	0.42
	10	50	0.30
	11	100	0.15
	12	>200	0.07
2	1	70 - 100	0.18
	2A	70 - 100	0.18
	3	140 - 170	0.10
	Z	-	-
	M	-	0.01
	R	30	0.59
	7A	40 - 50	0.36
	8	70 - 80	0.20
	9	40	0.42
	10A	50	0.30
	3-01	20	0.84
	12	>200	0.07
3	2A	70 - 100	0.18
	3-14-1	100 - 120	0.14
	9	40	0.42
	10A	50	0.30
	3-22	100 - 120	0.14
	3-01	20	0.84
4	2A	70 - 100	0.18
	3-14-1	100 - 120	0.14
	9	40	0.42
	10A	50	0.30
	3-22	100 - 120	0.14
	3-01	20	0.84





Permeameter

Figure 1. - Test system.

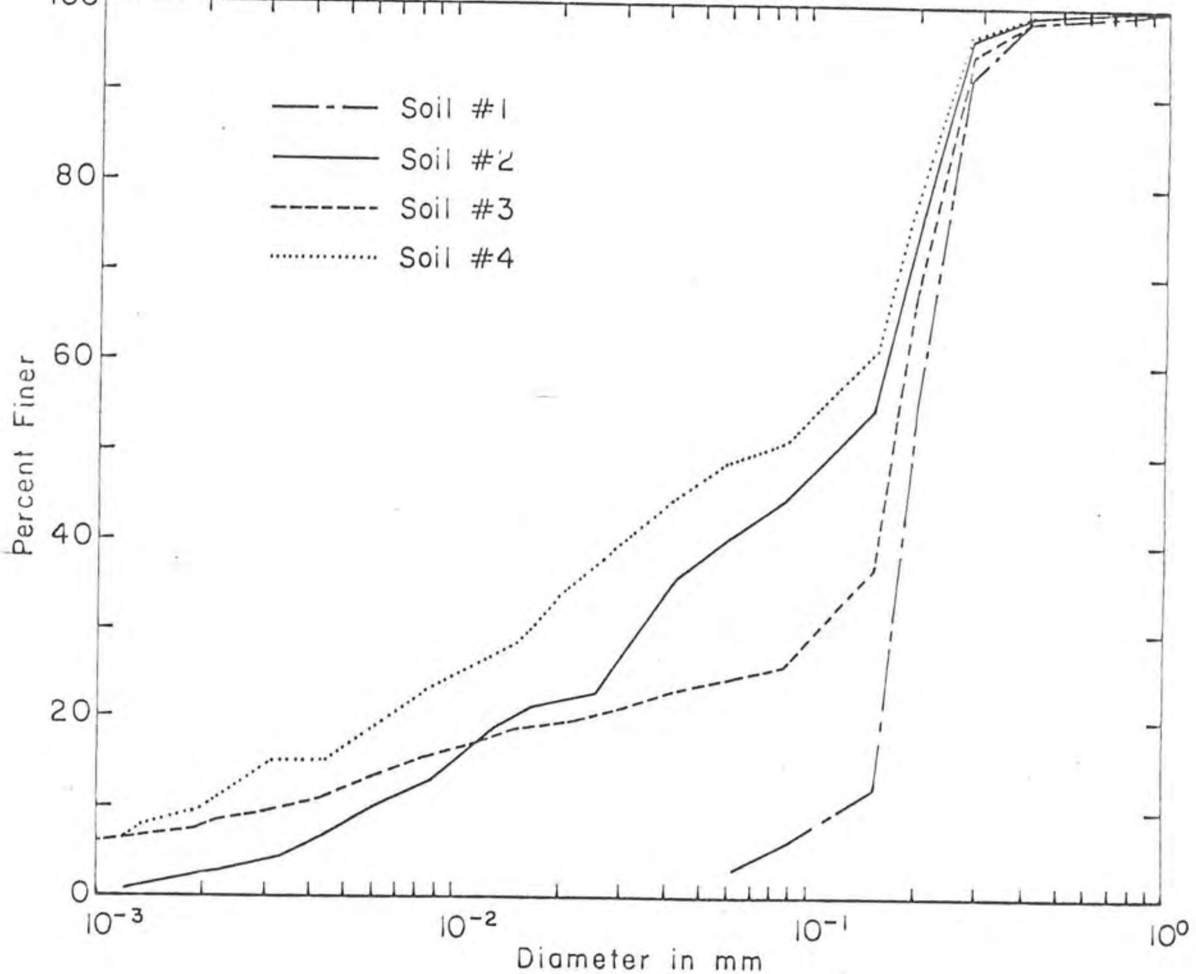


Figure 2. - Size distribution for the tested soils.

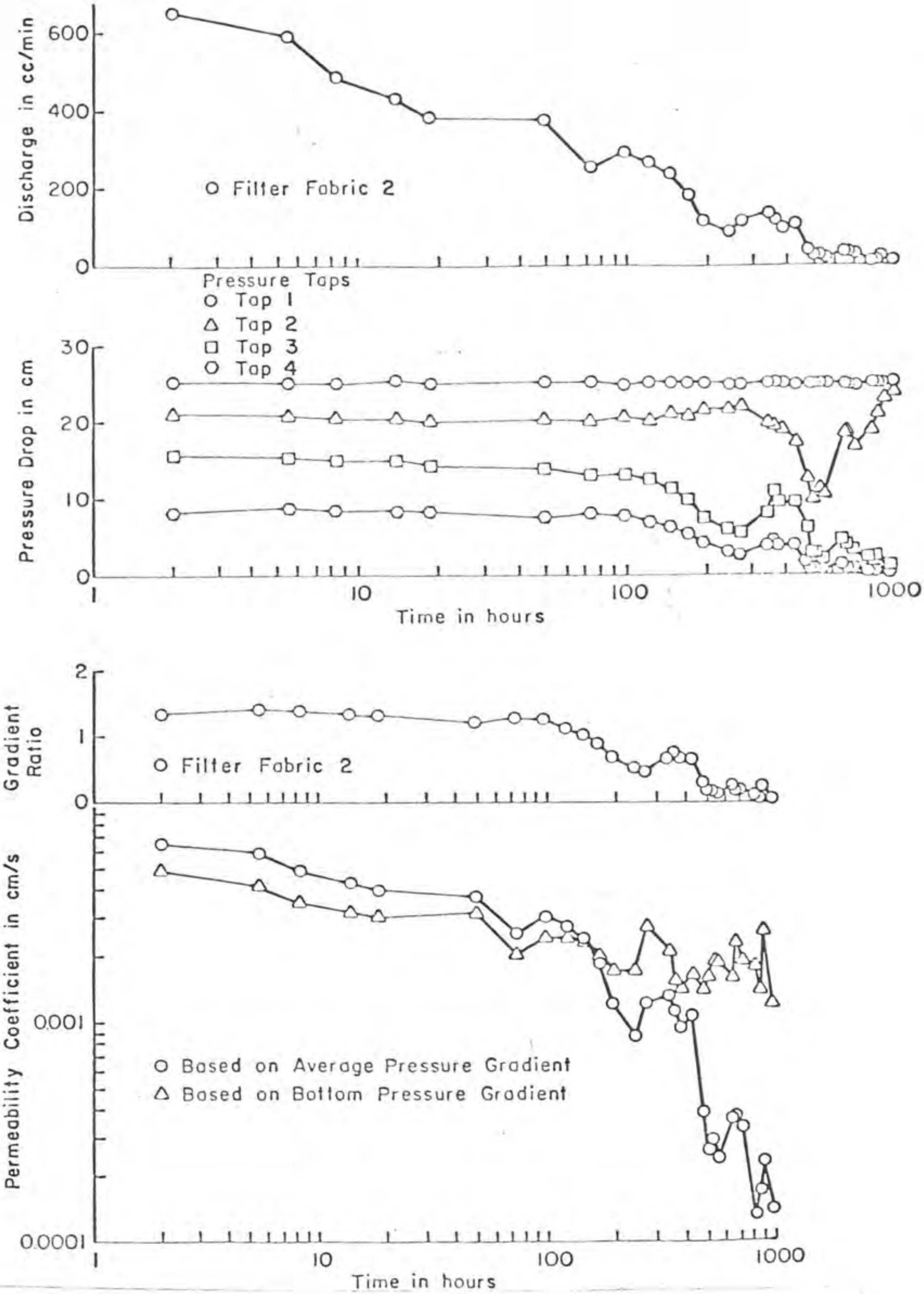


Figure 3. - Typical example of plastic filter response using Soil Type 1.

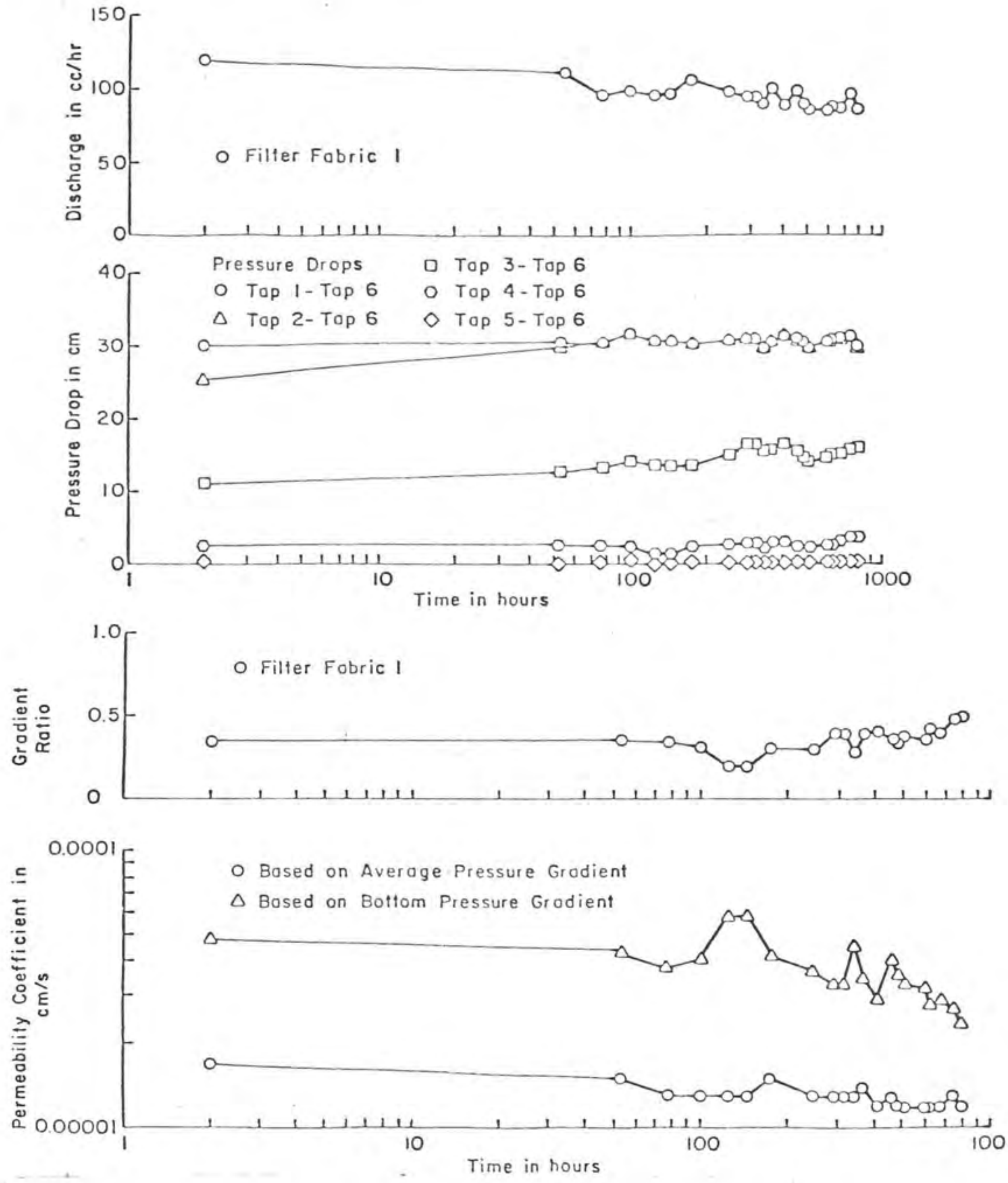


Figure 4. - Typical example of plastic filter response using Soil Type 2.

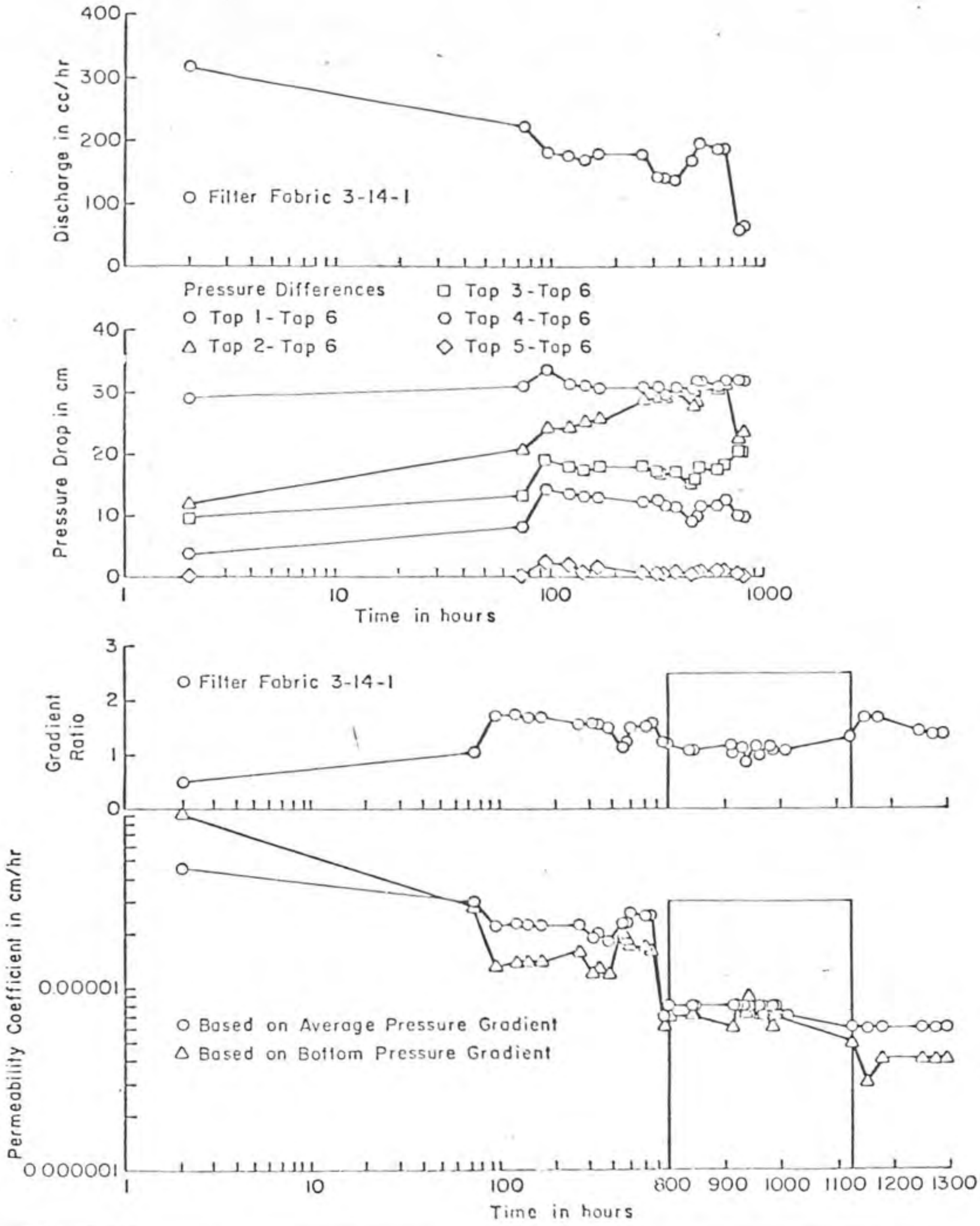


Figure 5. - Typical example of plastic filter response up to hour 800 using Soil Type 3.

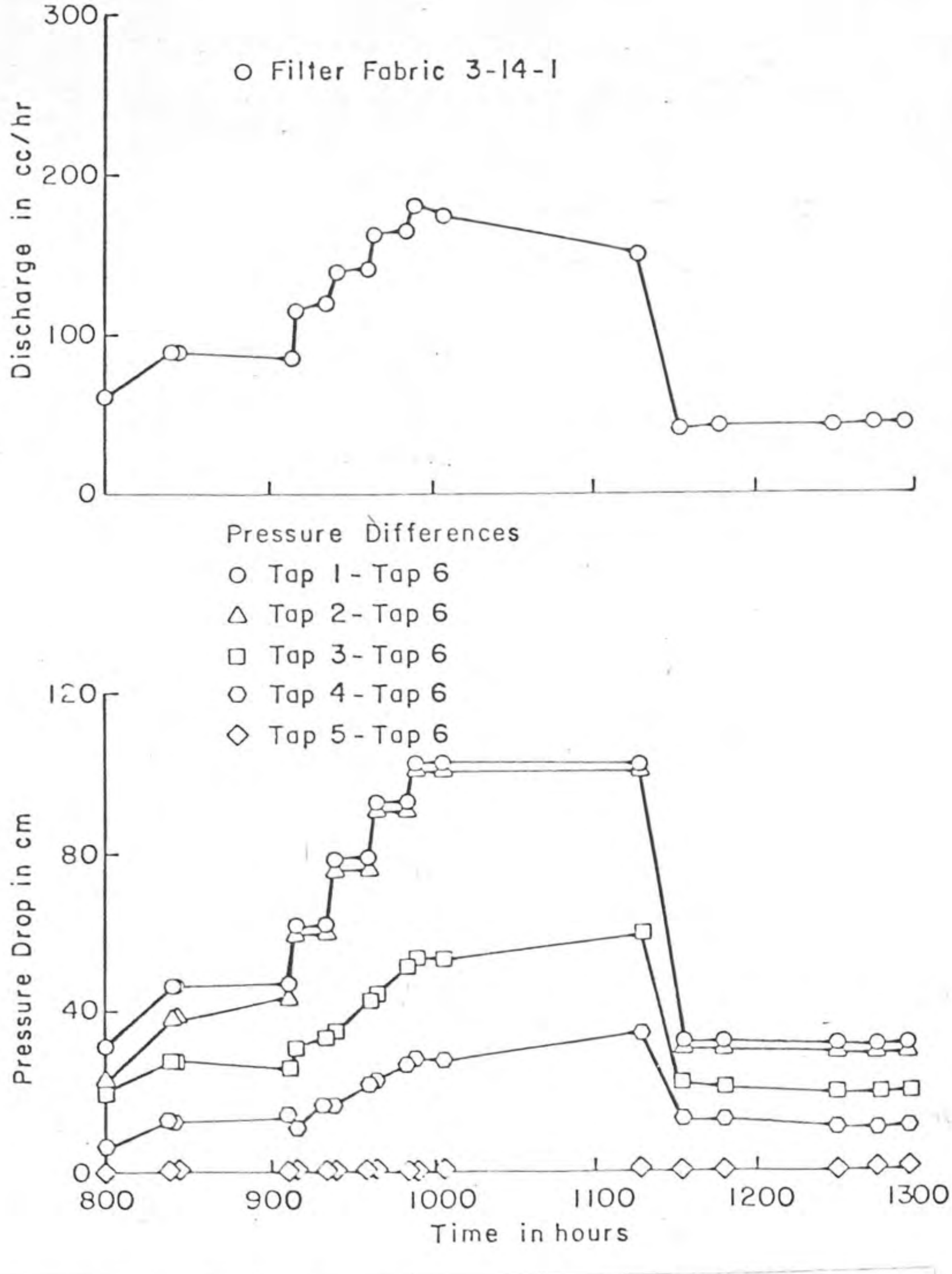


Figure 6. - Typical example of plastic filter response after hour 800 using Soil Type 3.

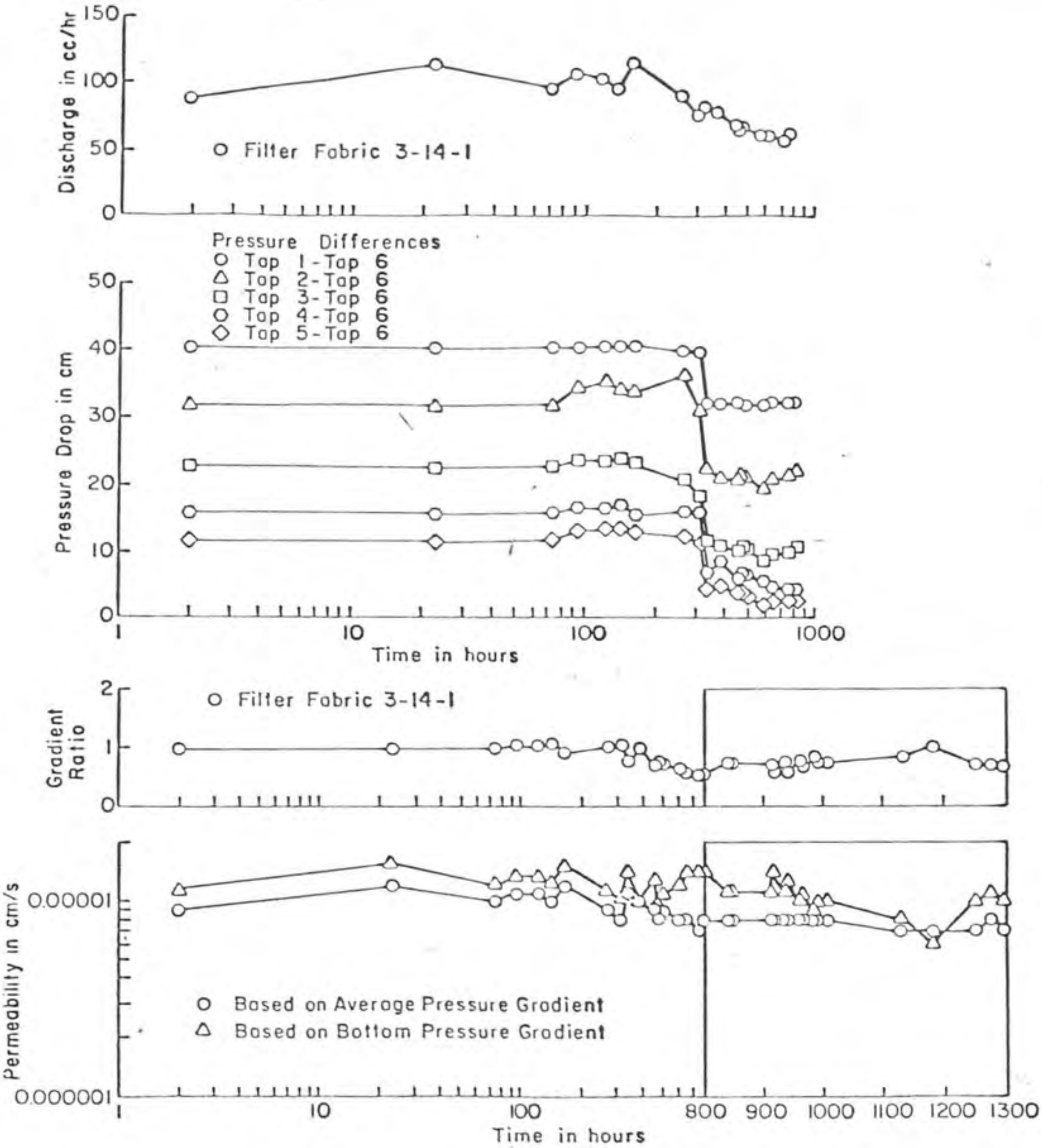


Figure 7. - Typical example of plastic filter response up to hour 800 using Soil Type 4.

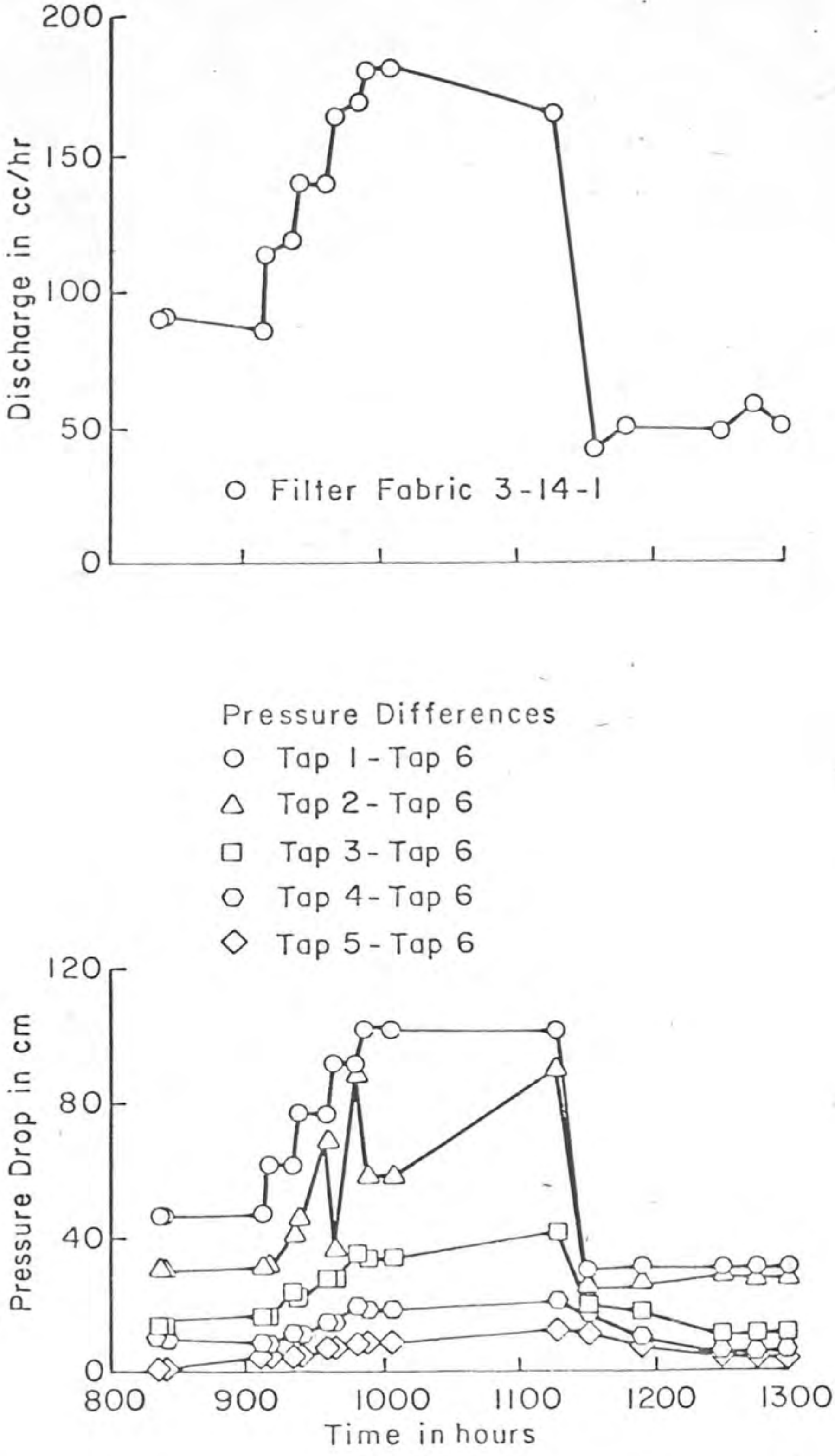


Figure 8. - Typical example of plastic filter response after hour 800 using Soil Test 4.

REFERENCES

Calhoun, C. C., Jr., "Development of Design Criteria and Acceptance Specifications for Plastic Filter Cloths," U.S. Army Engineer Waterway Experiment Station, Technical Report S-72-7, Vicksburg, Mississippi, June 1972

Dallaire, G., "Filter Fabrics Can Cut Costs of River-bank and Shore-Protection Structures," Civil Engineering (New York, vol. 47, No. 3, March 1977, pp. 74-79

Demery, P. M., "Laboratory Testing of Plastic Filters," Master Thesis, Colorado State University, May 1979

Ehlers, S., "The Selection of Filter Fabrics Re-Examined," Industrial and Engineering Chemistry, July 1961

Rosen, W. J., and B. D. Marks, "Investigation of Filtration Characteristics of a Non-Woven Fabric Filter," Transportation Research Board Record No. 532, 1975