PERFORMANCE OF PLASTIC FILTER CLOTHS AS A REPLACEMENT FOR GRANULAR FILTER MATERIALS

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This paper describes an investigation of the performance of plastic filter cloths used to replace granular filter materials. Laboratory or field performance data or both are given on 8 cloths. Laboratory tests were conducted on 7 cloths to determine their chemical and physical properties (e.g., opening size, percentage of open area, strength, absorption, resistance to weathering, and reaction to various chemicals) and their filtering abilities. Information on uses and performance of filter cloths at Corps of Engineers projects is given. Recommendations are made for filter criteria and physical characteristics of cloths for use in the design of drainage systems and the procurement of the filter cloth.

•GRANULAR filter material must meet 2 basic requirements: (a) The filter material must be fine enough to prevent infiltration of the material from which drainage is occurring (base material), and (b) the filter material must be much more permeable than the base material to permit free drainage. The Corps of Engineers (CE) and other investigators have performed comprehensive investigations to develop criteria for the design of granular filter systems that will satisfy these 2 basic requirements. Through this research and field experience, filter or design criteria have evolved to the stage that the engineer can, in most cases, confidently design a granular filter system that will function properly. In many cases, a graded (multilayered) filter is required in which each layer must meet the filter criteria with respect to adjacent materials. This involves placement of several different granular layers and is understandably costly and difficult to construct. Since 1962 the CE has used plastic filter cloths in some installations to replace certain granular layers of graded filters in drainage systems and, in some cases, to completely eliminate any filter or bedding material beneath riprap, rubble, or other stone protection. Prior to 1962 filter cloths have been used in the United States and other countries (although not by CE for drainage applications) and found to be very effective in some coastal structures (1).

Prior to 1967 only 2 filter cloths were known to be on the U. S. market, and their use was becoming widespread. Because the performance of these cloths had been satisfactory, CE specifications generally required one of these cloths by name or some other cloth of equal physical properties. Around 1967 other cloths were becoming available, and the CE had no standard acceptance criteria for use in specifications and no standard filter design criteria. In 1967 the Office of the Chief of Engineers and the U. S. Army Engineer Division, Lower Mississippi Valley (LMVD), authorized a study by the U. S. Army Engineer Waterways Experiment Station (WES) to develop acceptance specifications and design criteria for CE use of filter cloths. Eight different filter cloths were investigated, and some of the results of this study (2) are reported in this paper.

Sponsored by Committee on Surface Drainage of Highways and Committee on Subsurface Drainage and presented at the 50th Annual Meeting.

DESCRIPTION OF FILTER CLOTHS AND RESULTS OF LABORATORY TESTS

Table 1 gives some of the physical properties of 7 of the cloths investigated. The cloths will be referenced in this paper by the letter symbols given in Table 1. With the exception of cloth G, all of the cloths were manufactured in the United States. Cloths A, B, and C were made by the same manufacturer; the others were made by 4 different manufacturers. Six cloths were made of predominately polypropylene yarns, and one was made of polyvinylidene chloride yarns. The yarns used in the manufacture of the cloths varied considerably. Three cloths had round fibers and three had flat fibers. The round fibers varied in diameter from 0.003 to 0.015 in. The dimensions of the flat fibers were about the same for all cloths. Cloth F, the only unwoven cloth, was made by entangling fibers by needle punching and bonding by heat fusion. Cloth E was made of monofilament yarns in the fill direction and multifilament yarns in the warp direction.

Neither cloth E nor cloth F had distinct openings, and in fact cloth F had the appearance of felt. The other cloths that were woven of monofilament yarns had distinct rectangular openings. Because there were some variations in the opening sizes of the individual cloths and the openings were generally rectangular, the average opening size did not necessarily indicate what size of soil particle would pass the cloth. Because of this, a test procedure was developed to establish for each cloth an equivalent opening size (EOS) that is expressed in terms of a U. S. standard sieve number. The procedure is as follows: Approximately 150 gm of each of the following fractions of a rounded to subrounded sand was obtained:

U. S. Standard Sieve Number		U. S. Standard Sieve Number	
Passing	Retained On	Passing	Retained On
10	20	50	70
20	30	70	100
30	40	100	120
40	50		

Starting with the smallest size fraction of which more than 5 percent of the sand passed through the cloth, each successively coarser fraction was dry-sieved over the cloth for 20 min to determine that fraction of which 5 percent or less by weight passed the cloth. The EOS was taken as the finer or "retained on" size of this fraction. The equivalent opening sizes varied from the No. 30 to the No. 100 sieve. Open areas of the 5 cloths with distinct openings varied from 4.3 to 36 percent.

The tensile strengths of the cloths as determined by ASTM Method D 1682 varied considerably. The weakest cloth had a strength in the warp direction of only 31 lb, while the strongest cloth had a strength of 399 lb in the warp direction. Burst strengths of the cloths varied from 180 to 625 psi as determined by ASTM D 751-66T. Water absorption (CRD-C-575) was less than 1 percent for all cloths.

TABLE 1

PHYSICAL PROPERTIES OF FILTER CLOTHS

Cloth[a]	Color	Equivalent Opening Size[b]	Open Area (percent)	Avg Fiber Width (in.)		Avg Fiber Thickness (in.)		Tensile Strength (lb)		Elongation (percent)		Burst Strength (psi)	Absorption (percent)
				Warp	Fill	Warp	Fill	Warp	Fill	Warp	Fill		
A	Green	100	4.6	0.031	0.030	0.0085	0.0070	206	113	22.2	27.4	268	0.91
B	Black	70	5.2	0.031	0.029	0.0085	0.0070	388	257	22.4	26.8	542	0.13
C	Black	40	24.4	0.013[c]	0.014[c]	0.013[c]	0.014[c]	208	202	23.6	16.6	625	0.87
D	Black	100	4.3	0.030	0.028	0.0085	0.0070	399	244	17.0	24.6	528	0.38
E	White	—[d]	—[d]	0.003[c]	0.010[c]	0.003[c]	0.010[c]	127	231	10.6	26.3	316	0.08
F	Gray	—[d]	—[d]	0.003[c]	0.010[c]	0.003[c]	0.010[c]	31	104	11.3	40.3	180	0.31
G	Black	30	36	0.015[c]	0.013[c]	0.015[c]	0.013[c]	186	150	23.0	10.6	437	0.29

[a] Chemical composition of cloth A, polyvinylidene chloride, and of all others, polypropylene.

[b] U.S. standard sieve size.

[c] Round fiber.

[d] Could not test.

Tests were conducted to determine the effects of temperature (-60 to 180 F), acids and alkalies, oxidation, fuel spillage (JP-4), and sunlight (weatherometer). All the cloths were adversely affected by sunlight, particularly cloth F. Cloth F was also adversely affected by fuel spillage, and cloth A appeared to be affected by alkalies. All cloths withstood the other tests satisfactorily.

Filtration tests indicated that all 7 cloths evaluated would effectively retain sandy or silty soils in applications such as beneath riprap, although there was always some initial infiltration of fines. In these tests the filter cloth was secured in a permeameter and soil was loosely placed on top of the cloth. Water was then allowed to flow through the soil and filter cloth. The permeameter was instrumented such that hydraulic gradients through 1-in. increments of the soil and through the filter cloth could be measured. Special "clogging" tests were conducted where the soil above the cloth was composed of clean sands with various percentages of silt added for different tests. These tests indicated that cloths E and F tended to clog because of the migration of fines in a sandy soil. This tendency was measured by determining the ratio of (a) the hydraulic gradient through the cloth and the 1 in. of soil adjacent to the cloth to (b) the gradient through the entire sample. For sand samples containing 5 percent silt, this ratio was 1.67 for cloth. [(Gradient through 1 in. of soil and cloth)/(gradient through entire sample) = 1.67; e.g., head loss through the cloth and 1-in. thickness of soil above the cloth was greater than the average head loss per inch of soil for the entire sample.] Cloths A and E showed no measurable tendency to clog. For sand with 10 percent silt, ratios of 1.33 and 1.98 were measured for cloths E and F respectively. Visual inspections of these 2 cloths indicated a cake of fines had developed on the cloth. Although the ratio at 10 percent silt for cloth A was about 1.0, there was some caking of fines on the cloth, though not nearly to the extent observed on cloths E and F. Only cloths A, E, and F were subjected to clogging tests. Because there was no measurable clogging of cloth A, it was concluded that there would be no clogging of the remaining cloths that were similar to or had more open weaves than cloth A.

Filtration tests were also conducted to develop filter criteria for cloths used to wrap collector pipes where the backfill material will be a clean sand or gravel. These tests indicated that the sands would not pass the cloth if the 85 percent size of the sand was equal to or greater than the EOS of the cloth.

It is obvious from the variations in the cloths now available that an engineer would encounter difficulties in selecting a filter cloth to meet his specific need without guidance from a research program.

USES OF FILTER CLOTHS

An early phase of this study was to circulate questionnaires to CE offices to determine the filter cloths being used and their applications (3). Twenty-six of the 38 offices receiving questionnaires indicated that as of the latter part of 1969 they had used or would use filter cloths. Detailed information was received on uses of filter cloths at 46 projects. At 28 projects filter cloths had been used beneath riprap, rubble, articulated concrete mats, and other revetment materials. At 9 projects filter cloths had been used around pipes and well screens or for fabricating piezometer tips, and at 4 projects they had been used in drainage systems to prevent fines from soils being drained from entering granular filter layers. At 3 projects filter cloths had been used to stop grout, to protect slopes from erosion by surface runoff, or to bridge gaps in the concrete sheet pile wall. At the 46 projects, cloth A had been used 6 times; cloth B, 37 times; and cloths D and F, 1 time each. Cloths C and E had not been used at the time of the survey. Cloth G has not been used to date although a similar cloth, designated cloth Z, made by the same manufacturer was used at one site. (No laboratory tests were performed on cloth Z because its presence on the market was not known when tests were conducted on the other cloths. The EOS and the percentage of open area of the cloth appeared to be between those of cloth C and cloth G. Cloth Z is made of polyethylene yarns.)

Subdrain Systems

Both the Los Angeles and Ft. Worth Districts reported use of filter cloths to wrap subdrain pipes. In the Los Angeles District, filter cloth B was used to wrap individual joints of an open-joint subdrain pipe (1967), and in the Ft. Worth District perforated pipe was wrapped with cloth A (1966). In both instances the use of the cloth eliminated the necessity of a graded filter. A section of the subdrain in the Ft. Worth District (Sam Rayburn Dam) was removed during a visit by the principal author in February 1970, and the filter cloth showed no signs of deterioration or clogging, although the pipe perforations were partially clogged with an iron sludge. At the other installation, the subdrain system is functioning properly.

Figure 1. Installation of collector pipe and cloth A in subdrain system.

The Soil Conservation Service of the U. S. Department of Agriculture (4) installed subdrains near Orlando, Florida, to lower the water table in an agricultural test field. Although not a CE installation, this project is discussed because of the significant difference in the performance of 2 filter cloths subjected to conditions of high iron concentration. The 2 filter cloths used were cloth A and a cloth not included in the WES tests but similar in appearance to the nonwoven cloth F. Figure 1 shows the flexible, slotted, corrugated, plastic collector pipe and cloth A being installed in a trench. The trench was backfilled with the excavated soil, which was a fine sand (90 percent passing the No. 50 sieve). The flow and water table drawdown produced by the 2 systems were observed. The cloth similar to cloth F became clogged in a matter of weeks with an iron sludge. The sludge on the cloth was formed by "iron bacteria" that are common to the area and that oxidize and precipitate iron into the water. There was no sludge buildup on cloth A, although there was some buildup within the pipe as was the case at Sam Rayburn Dam. With periodic flushing, the system with cloth A has functioned properly since 1968.

At 4 CE projects cloth B was used to line trenches for subdrain systems that are now performing satisfactorily. The subgrade material varied from a silty gravel to a clayey silt. With the filter cloth between the subgrade material and the granular filter, the granular filter layer did not have to meet the filter criteria with respect to the subgrade material but had only to be coarse enough to prevent its entrance into the collector pipes.

Miscellaneous Uses

In 1964 filter cloth B was used in one instance in the Memphis District as a grout stop beneath grouted riprap. The cloth was placed on a gravel bedding, and riprap weighing up to 800 lb was placed on the cloth. The riprap was then grouted with a low-alkali Portland cement grout. The district was satisfied with the use of the cloth for this purpose.

In the Galveston District, cloth B was used in 1966 behind a retaining wall constructed from prestressed concrete sheet piles to prevent sand backfill from escaping from between the piles. The work was done in connection with a hurricane flood protection project, and the cloth has performed satisfactorily.

Cloth B was used in 7 projects in the fabrication of several hundred piezometer tips. At 3 projects, the tips were made by placing 1 wrap of filter cloth around the perforated end of a pipe; that perforated end was placed in sand contained in a bag made of the same cloth. At other projects, 2 layers of cloth were simply wrapped around the perforated ends of steel pipe. The piezometers were installed in MH, ML, and SM soils, and service records indicated good response and no clogging of the tips.

Beneath Riprap and Other Revetment Materials

Table 2 gives the use of filter cloths at 28 projects beneath riprap and rubble. The most common use was beneath riprap on the bottom or bank slopes of rivers, creeks, or other channels. Filter cloth was placed under articulated concrete mattresses and riprap along the Mississippi River (projects 3 and 4) and as protection for a highway fill paralleling the shore line of the Gulf of Mexico (project 5). Other uses of filter cloths have been in connection with breakwaters, protection at drop inlet structures, bridge pier protection, and groins. Cloth F was used only in a temporary diversion channel and was expected to be in service for only about 2 years (project 28).

At 19 of the 28 projects, filter cloths were placed directly on subgrade materials varying from fine sands to fat clays. In 3 cases (projects 4, 16, and 17), granular bedding was placed between the cloth and subgrade materials varying from medium to fine sands to silty clays. At 6 projects, granular bedding material was used above the filter cloth. Installation of the cloths was usually in accordance with the manufacturers' recommendations. When cloths were used on slopes, the slopes were shaped to grade, and the cloths were generally laid parallel to the centerline of the channel. The cloths were, in most cases, overlapped 8 to 12 in. and secured at 3-ft intervals with 15- to 18-in. long steel pins. Use of pins was unsatisfactory at 2 sites where the subgrade consisted of loose sands and stones or where other means were used to weight down the cloths prior to placing the revetment material. Problems were encountered when cloths had to be placed underwater, and various methods were used, such as putting the cloth on a frame and weighting the frame and cloth with stone or, in one instance, rolling the cloth on steel pipe and then letting the cloth unroll into the channel. At Island 40 (project 4) the cloth was bonded to the articulated concrete mats when they were cast, and the cloth and mat were successfully placed as a unit. At Big Bay Harbor, Michigan (project 19), the cloth was placed under 8 ft of water by divers. The cloth was overlapped 3 ft and secured with specially made $^3/_8$-in. diameter, 2-ft long steel pins. The procedure was reported to be inefficient.

The Memphis District reported that extreme care was necessary when placing 125-lb riprap on cloth A (project 2). Dropping stones from a height of 2 ft damaged cloth A, but dropping stones from 4 ft did not damage cloth B under almost identical conditions (project 1). The Pittsburgh District also reported tears in cloth A when 500-lb stones were dropped from a height of 2 ft. The manufacturer of cloth A does not recommend its use where high strength and abrasion resistance are required. The Tulsa District reported extreme care was also necessary when placing stones on cloth F.

No damage to the cloths from stone placement was reported at any of the projects where cloth B was used or at the one project where cloth D was used. Stones weighing 3,000 lb were placed on cloth B in the Kansas City District (project 12), and areas later uncovered showed no damage. It was reported that some tears occurred at the securing pins because of the stones creeping down 1-on-2 slopes. This did not occur on slopes 1 on 3 or flatter. The Pittsburgh District reported the same experience (project 23). At 8 projects, stones of various sizes were dropped directly on cloth B from heights of 2 to 5 ft, and no apparent damage occurred. Unsatisfactory factory-sewed seams were noted in 2 instances (projects 10 and 12) with cloths B and D. This situation has since been corrected, and factory-sewed seams for both cloths were considered satisfactory.

At only 2 of the 28 sites where filter cloths were used beneath riprap or other types of revetment was their performance as a filter material considered questionable. Performance of the cloths at all other sites was satisfactory, and their continued use was recommended by the various districts. In the 2 questionable cases (projects 3 and 5), the cloth used appeared not to have sufficient open area to allow for free drainage. At Holly Beach, Louisiana (project 5), a section of cloth B was lifted or "floated" out of position because of pumping action caused by high waves during a storm, but an immediately adjacent section of cloth G was practically undamaged. The cloths at these 2 sections were overlaid by revetment blocks. At Island 63 (project 3) there was apparently a buildup of hydrostatic pressures beneath cloth B in the sand slope, and bulges in the slope resulted. These 2 sites were full-scale test sections, and the performance of the filter cloths will be discussed in more detail in a later section.

TABLE 2

USES OF FILTER CLOTH BENEATH RIPRAP, RUBBLE AND ARTICULATED MAT

Division	District	Project No.	Project Description	Cloth	Material Used Beneath[a]	Installation Date	Max. Stone Weight (lb)	Max. Drop (ft)	Subgrade Material	Bedding Max. Size (in.)	Bedding Thickness (in.)
LMVD	Memphis	1	Clark's Corner Cutoff Bridge, Ark.	B	Riprap slope repair	Nov. 1964	125	4	SP fine		None
		2	Madison-Marriana Bridge 4, Ark.	A	Riprap slope repair	Nov. 1962	125	<1	SP fine		None
		3	Island 63	B	Revetment (ACM and riprap)	Sept. 1965	125	4	SP fine		None
		4	Island 40	B	ACM Revetment	Aug. 1968	N.A.	N.A.	SP m to f	1½[b]	4[b]
	New Orleans	5	Test sections, Holly Beach, La.	B and Z[c]	Shore protection	Jan. 1969	14	0	SP fine		None
		6	Calcasieu saltwater barrier	B	Riprap bedding	1966-67	1,400	5	SP	1½	6
	St. Louis	7	Wood River Drive and Levee, Ill.	B	Riprap on riverbank	Aug. 1968	300	3	SP-SM, SP		None
		8	Prairie du Pont Creek, Ill.	B	Riprap on creek bank	Nov. 1965	150	3	SP-SM, SP		None
	Vicksburg	9	Levee from Wasp Lake to Marksville, Miss.	B	Riprap bedding	Oct. 1965, 67	250	5	SP to CH	2½	6
		10	Columbia Lock and Dam, La.	D	Riprap bedding at outlet structure		2,000 riprap 6,000 derrick	0 0	SP to CH	4	9
MRD	Omaha	11	Channel stab., Gerring Valley, Nebr.	A and B	Riprap along channel slopes	1963-64, 66	900	3	ML		None
	Kansas City	12	Flood protection project, Topeka, Kansas	B	Riprap on channel slopes and bottom	Sept. 1968	3,000	<1	CL, ML SP fine		None
NCD	Buffalo	13	Presque Isle Pen., Pa.	B	Bedding of rubble groins	May-Nov. 1965	3,000	0	SP	2½	6
	Detroit	14	Kawkawlin River flood control project, Mich.	B	Riprap around bridge piers	June 1969	150	0	Clayey sand W/G		None
	St. Paul	15	Red Lake Cont. Dam, Clearwater, Minn.	B	Riprap slope protection	Oct. 1968	100	0	SM, SP		None
		16	Channel improvement, Polk and Clearwater Counties, Minn.	A	Riprap slope protection	Oct. 1963	250	3	ML, CL, SM	1½[b]	6[b]
		17	Channel improvement, Russ River, Cass County, N.D.	B	Riprap slope protection	Sept. 1967	150	3	SC	1½[b]	6[b]
		18	Remedial work, Sand Hill River, Polk County, Minn.	B	Fieldstone riprap in drop structure	Oct. 1967	250	2	CL, ML, SM		None
		19	Big Bay Harbor, Marquette County, Mich.	B	Rubble mound breakwater	1968	Core 1,000 Cover 6,000	0	SP		None
		20	Breakwater extension, Houghton County, Mich.	B	Rock berm	July 1968	500	<1	SP		None
NPD	Seattle	21	Libby Dam, Mont.	B	Riprap bedding	1967	10 in.	3	CL	-No. 4	24
ORD	Louisville	22	Temp. Lock and Dam 52, Ohio River, Ill.	B	Riprap slope protection	Dec. 1968	150	3	SP		None
	Pittsburgh	23	Hannibal Lock and Dam, Ohio River, Ill.	A	Riprap slope protection	1966-67	500	2	ML, CL, SM		None
SAD	Charleston	24	Morris Island Spoil Dike, Charleston Harbor, S.C.	B	Riprap bedding	March 1969	300	4	SM-OL w/shell	4	9
	Mobile	25	Lake Douglas, Bainbridge, Ga.	B	Riprap	July 1968	12 in.	0	SC		None
SPD	Sacramento	26	Pit River channel improvement, Modoc County, Calif.	B	Sack concrete	July 1969	1.25 ft^3	0	Unknown		None
SWD	Galveston	27	White Oak Bayou, Houston, Tex.	B	Riprap	1964	15 in.	2	SM, CL		None
	Tulsa	28	Kaw Dam, Ponca City, Okla.	F	Riprap slopes and bottom of diversion channel	1969	2,000	N.D.	SM, SP		None

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[a] ACM = articulated concrete mat.

[b] Bedding beneath the filter cloth.

[c] Cloth Z made by the manufacturer of cloth G.

In one district, cloth A was used to temporarily protect excavated sand slopes from erosion. Surface water ran beneath the cloth and erosion occurred. In this case the cloth did not serve as a filter and is included here only as a matter of record and interest.

Figure 2. Conditions at bridge prior to repair work in 1962 by the Memphis District.

FULL-SCALE FIELD TESTS

Memphis District Tests

The Memphis District (5) has conducted full-scale field tests on cloths A and B in repair work (projects 1 and 2, Table 2) for 2 bridge abutments on the St. Francis River in Arkansas and as a replacement for gravel bedding beneath articulated concrete mattresses and riprap along the Mississippi River (project 3). During the first 3 years after the projects were completed, large scour pockets occurred immediately downstream of the bridges. These pockets extended some 50 ft landward and were 200 to 300 ft long. The scouring extended to the centerline of the approach roads, endangering the bridges. The condition at one bridge, shown in Figure 2, is typical of conditions at the other bridge. The areas had been protected by riprap on a gravel blanket. Repairs were made in 1962 and 1964 in the manner shown in Figure 3. The cloth in 6- and 12-ft widths was placed on the sand fill (medium to fine sand) and graded bank parallel to the water's edge, overlapped 8 in., and secured with 18-in. long pins at 3-ft intervals. As previously stated, 125-lb riprap dropped from 2 ft damaged cloth A, but drops of the

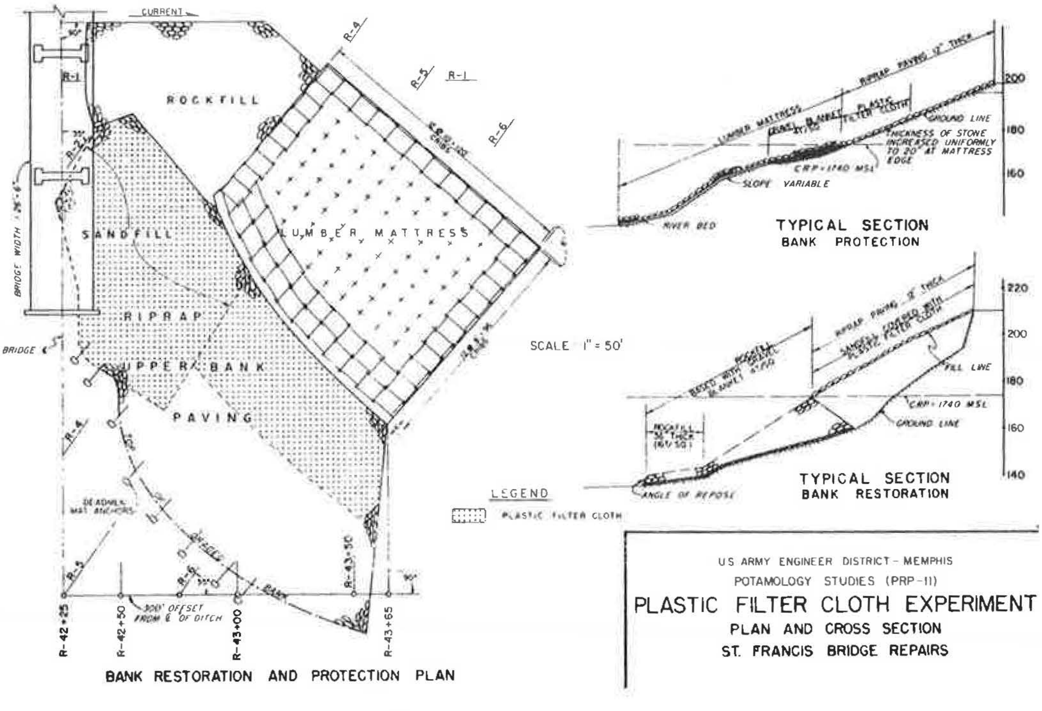

Figure 3. Bridge repair plan.

same weight material from 4 ft did not damage cloth B. The sites were inspected after each high water, and no change occurred in the repaired area. Figure 4 shows the condition of one of the repaired areas during an author's visit in 1969. The area was in excellent condition, as were the other repaired areas. The severity of the attack continuing in unprotected adjacent areas was evident from large scour holes noted in the banks immediately downstream of each repaired area.

Figure 4. Condition of repaired area in 1969.

During an author's visit, riprap was removed from sections of cloths A and B. Although the repaired area as a whole was in good condition, the condition of cloth A was poor. Tears, probably from riprap placement, and holes attributed to abrasion were noted in the cloth. Cloth B was in excellent condition. Samples of both cloths were obtained from the areas and tested at WES. Strength tests indicated there was no apparent deterioration of the fibers since the cloths were installed.

Figure 5 shows a layout of the test site at Island 63 in the Mississippi River near Greenville, Mississippi, where in 1965 filter cloth was placed under riprap and concrete mats in some areas and a 4-in. gravel blanket was used in other areas. The subgrade material was a fine sand. Figure 6 shows cloth B being placed. After the bank had been graded to a 1-on-3 slope, it was covered with two 18-ft wide sections (three 6-ft widths sewed together in the factory) and one 12-ft wide section (two 6-ft widths sewed together in the factory). The field seams perpendicular to the river edge were overlapped 8 in. and secured with 15-in. long pins at 3-ft intervals. The horizontal seams were sewed with nylon twine after it was found that the securing pins did not properly hold in the sand. The lower edge of the cloth was placed 4 ft underwater.

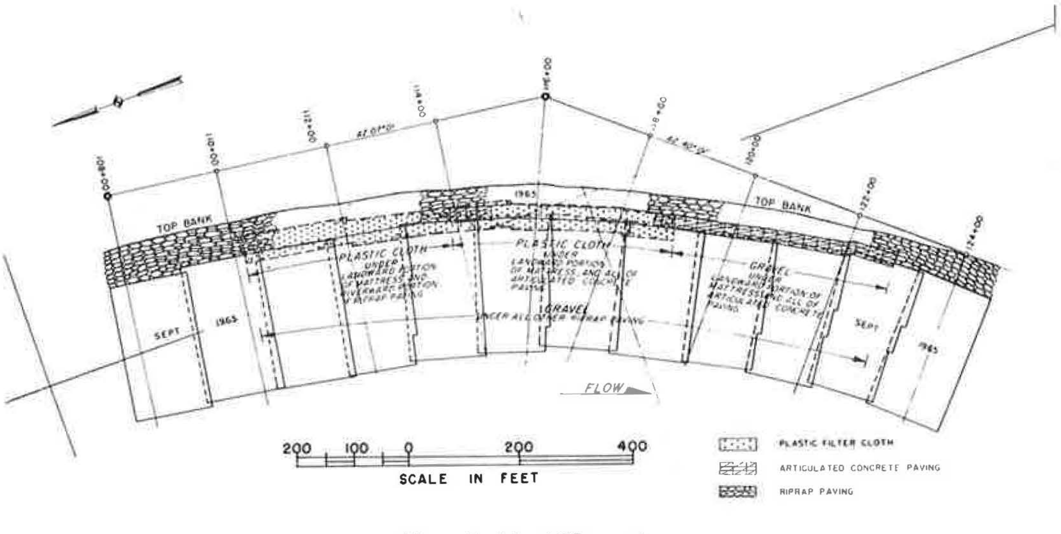

Figure 5. Island 63 test site.

Figure 6. Placement of cloth B at Island 63.

Figure 7. Island 63 revetted area underlaid with filter cloth (range 118+50).

This was accomplished by sewing $^3/_4$-in. reinforcement bars in a continuous line along the riverward edge of the cloth and by sewing additional bars (Fig. 6) perpendicular to the water's edge at 20-ft intervals. The cloth was then manually moved into the water. The weight of the rods was not sufficient to keep the cloth from billowing, and it had to be tamped into place. The revetment materials were placed directly on the cloth. The concrete mattresses extended past the filter cloth and granular bedding into the river.

Surveys and inspections were made by the Memphis District after each high-water season. During the first high-water period, scouring occurred in the lower part of the slope where no filter cloth had been placed. Inspections following each of the succeeding 2 high-water periods revealed that scour in the filter cloth area had apparently been stopped by the cloth. In the adjacent area where a gravel filter was used, the scour had progressed up the bank and into the riprap, requiring extensive repairs to the riprap sections. Figure 7 shows the condition of the concrete mattress revetment overlying the filter cloth, and Figure 8 shows the area where gravel filter material was used. It is obvious from a comparison of the 2 photographs that the filter cloth performed in a superior manner to the gravel filter. In the filter cloth area the only noticeable subsidence was at faulty field seams (center of Fig. 7).

Figure 9 shows a condition that existed in the riprap at its intersection with the mat (subsidence in the center of the photo resulted from a faulty field seam). The cloth had been bulging (first noticed in 1968) at the intersection and displacing the riprap. The bulges, 2 to 3 ft high all along the reach, may have resulted from excess pore water pressures being developed in the fine sand and causing the sand to "flow" beneath the cloth. Apparently, the continuous surcharge provided by the mats and their resistance to displacement stopped the migration of sand. If the mats had not been present, the bulging would probably have been more general.

Figure 8. Island 63 revetted area underlaid with gravel bedding (range 123+00).

Figure 9. Island 63 bulged areas.

A sample of cloth adjacent to one of the bulges was removed during an author's visit to the site in 1969. Examination of the underside of the cloth revealed a cake of fines that may have prevented ready drainage from the cloth during falling stages of the river. The inability of the water to drain freely from the cloth could have produced the excess pore pressures that led to the movement of the underlying sand. As data given in Table 1 show, the cloth used (cloth B) had only 5.2 percent open area. A cloth with a greater open area could possibly have prevented such bulging.

The filter cloth appeared to be in good condition with the exception of a few isolated tears near the bulged areas. These tears were probably caused by debris from the river during high-water stages. The cloth in the bulged areas was stretched very tightly, but no fiber ruptures or rips at the factory-sewed seams were noted. Strength tests on samples of the cloth indicated no significant deterioration of the cloth.

Tests Made by Louisiana Department of Highways

The Louisiana Department of Highways, with some assistance from the New Orleans District, made full-scale field tests using cloth B and cloth Z beneath slope protection for a highway fill along the Gulf Coast (6). Figure 10 shows the test section at Holly Beach, Louisiana. The revetted area, 200 ft long, was constructed in January 1968 by using cellular concrete revetment blocks developed in Holland. Each block weighed approximately 14 lb and was about 8 by 8 by 4 in. The in-place revetment had about 30 percent open area obtained by 2-in. diameter holes in the blocks spaced on centers slightly less than 2 in. in both directions. Filter cloths were placed directly on a graded 1-on-3 slope, and the blocks were placed on the cloths. The soil along this stretch of beach is primarily fine sand with some silt and shell fragments. The elevation of the roadway was 7 to 8 ft above mean low water (called mean low gulf). Cloth B was used in constructing the westward 100 ft, and cloth Z was used for the other 100 ft.

In February 1969 a storm hit the area, and wave heights were well above the roadway elevation. The cloth B area failed, while the area in which cloth Z was used remained in place (Fig. 11). Cloth B was apparently lifted or floated out of position (dislodging the overlying block revetment) because water was not able to pass through fast enough to prevent hydrostatic pressures from developing beneath the cloth. Water apparently was able to pass readily through the more open weave of cloth Z. In February 1970 a similar storm hit the area, and the only damage was at the unprotected ends of the revetted area where cloth Z was used.

Samples of both cloths were obtained during an author's visit 1 week after the second storm. Strength tests indicated little if any deterioration of the cloths beneath the revetment. There had been considerable deterioration of both cloths exposed to sunlight since the first storm (1 year), and they could be torn by hand.

Figure 10. Louisiana Department of Highways test section (sand used as dry mortar).

Figure 11. Condition of Louisiana Department of Highways test section after storm (in-place revetment underlaid with cloth Z).

The highway department is satisfied with the performance of cloth Z and the block revetment. A 3-mile stretch of the beach has been revetted by using cloth Z and revetment blocks.

FIELD EXPOSURE TESTS

Cloths A and B have been subjected to field exposure tests at Treat Island, Maine, and at WES since 1964. Strength tests are performed on samples at 6-month intervals to determine the effects of exposure. The cloths at WES are enclosed in a laboratory building; at Treat Island one set of samples is protected from sunlight by an open-sided shed, and another set is covered with about 1 ft of sand. Both sets are under salt water part time because of tide fluctuations resulting in daily freeze-thaw cycles during the winter. There has been no apparent deterioration of either cloth since the tests were initiated.

CONCLUSIONS

The following conclusions were drawn from the results of this study.

1. In all but 2 cases, woven plastic filter cloths have satisfactorily replaced granular filter material. In the 2 cases where the performance of the cloths was not entirely satisfactory, the problem was attributed to the cloth not allowing free drainage. In both cases, it is believed that cloths C and G or similar cloths would have performed satisfactorily.
2. Nonwoven filter cloths or woven cloths with less than 4 percent open area should not be used where silt is present in sandy soils. Filtration tests on cloth G indicated that a cloth with an EOS equal to the No. 30 sieve and an open area of 36 percent would retain sands containing silt. Cloth G had the most open weave of any considered. Consequently, no laboratory or field data are available to provide guidance for the use of cloths having more open weaves.
3. When stones or rubble are to be dropped directly on the cloth, the minimum tensile strengths (ASTM Method D 1682) in the strongest and weakest directions should not be less than 350 and 200 lb respectively. Elongation at failure should not exceed 35 percent. The minimum burst strength (ASTM D 751-66T) should be 520 psi. When extreme care is used in placing stones or the cloth is used in applications not requiring high strengths or abrasion resistance, these strength requirements may be relaxed.
4. Cloths made of polypropylene, polyvinylidene chloride, and polyethylene fibers do not appear to deteriorate under most conditions. However, all of the cloths evaluated were affected to some degree by sunlight and consequently should be protected from direct sunlight in permanent installations.
5. When filter cloths are used to wrap collector pipes or in similar applications, backfill should consist of clean sands or gravels graded such that the 85 percent size of the backfill material is equal to or greater than the EOS of the cloth. When trenches are lined with filter cloth, the collector pipe should be separated from the cloth by at least 6 in. of granular filter material.
6. Cloths should be made of monofilament yarns, and the absorption of the cloth should not exceed 1 percent. These 2 requirements reduce the possibility of the fibers swelling and, thus, changing the EOS and percentage of open area.

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