INVESTIGATION OF PLASTIC FILTER CLOTHS

By

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INVESTIGATION OF PLASTIC FILTER CLOTHS

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PREFACE

The study in this thesis is part of an overall investigation to develop acceptance specifications and design criteria for plastic filter cloths for the U. S. Army Corps of Engineers. The study was conducted at the U. S. Army Engineer Waterways Experiment Station and was sponsored by the U. S. Army Corps of Engineers Lower Mississippi Valley Division and the Office, Chief of Engineers. The author is grateful to officials of these three Corps of Engineers' offices for allowing him to use this study for thesis research.

The author extends his appreciation to all the members of the staff of the Waterways Experiment Station who participated in the study. A special thanks is given to Messrs. A. R. Gann, B. J. Houston, R. R. Johnson, J. L. Grace, and G. A. Pickering who were involved in the laboratory testing phase of the study. The suggestions and review provided by the author's supervisors, Messrs. W. E. Strohm, Jr., and J. R. Compton, are greatly appreciated.

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CHAPTER I

INTRODUCTION

Statement of Problem

Since 1962 some U. S. Army Corps of Engineers' offices have been using plastic filter cloths as a substitute for sand and gravel filters and riprap bedding in various projects. Filter cloths are relatively thin pervious sheets made of plastic yarns that will retain soil particles while allowing water to pass. Filter cloths had been used prior to 1962 in the United States (although not by the Corps of Engineers) and foreign countries and had been found effective in some types of coastal structures (Reference 1). Prior to 1967 only two filter cloths were known to be on the market. Since that time, at least seven additional cloths have been known to be placed on the market, and the use of filter cloths has become more widespread. As an initial phase of this study, a questionnaire was circulated in 1969 to Corps of Engineers' offices to determine the extent and diversification of uses of filter cloths. Information was obtained on 46 projects where filter cloths had been used and on 10 projects where cloths were planned to be used (Reference 2). There have been other uses of filter cloths by the Corps of Engineers, but information on these installations was not readily available. Since the survey, filter cloths have been used at numerous other Corps of Engineers' projects.

Filter cloths have been used as bedding beneath riprap and rubble, in subsurface drainage systems, as well screens, around piezometer tips, as grout stops, and for erosion control. Despite these widespread and diversified uses of the cloths, the Corps of Engineers had no standard specifications or design criteria for their procurement and use. Prior to the initiation of this study in 1967, published literature on filter cloths was limited to one paper (Reference 1). That publication was written by a filter cloth distributor and pertained only to the use of cloths in coastal structures. Since then, two other papers have been published on the performance of filter cloths in test sections (References 3 and 4). Visits were made by the author to these test sites, as will be discussed in Chapter V.

Purpose and Scope of This Thesis

The purpose of this investigation was to obtain information for use in developing standard acceptance specifications and design criteria for plastic filter cloths. The scope of the project included determination of the physical, chemical, and engineering properties of available filter cloths in order to develop specifications and design criteria. Field and laboratory studies were made to determine the chemical composition and resistance to chemical attack and deterioration; the determination of physical properties such as strength, abrasion resistance, etc.; and the filtering capabilities of the cloths. Field visits and contacts with offices of the Corps of Engineers and other agencies were made to obtain information on the use and performance of existing filter cloths.

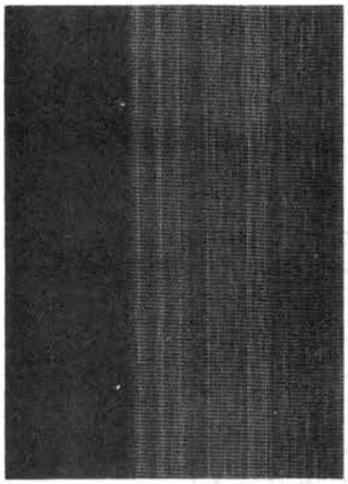
CHAPTER II

CHEMICAL AND PHYSICAL PROPERTIES TESTS

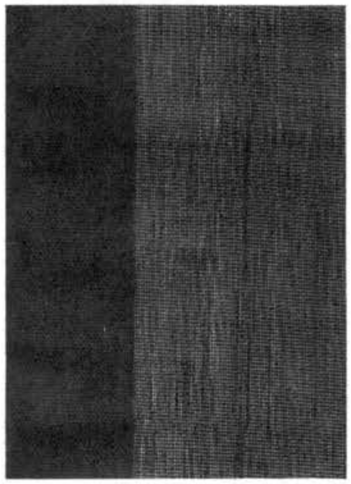
Cloths Evaluated

Seven filter cloths designated A through G were investigated during this study. Photographs of the cloths are shown in Figure 1. All of the cloths except cloth F are woven. Cloth F is produced by entangling fibers by needle punching and then bonding them by heat fusion. It is gray in color and has the appearance of a felt having no distinct openings. There were yarns embedded longitudinally in the cloth. Cloth E is white and is woven of monofilament yarns; the yarns in the warp direction are much smaller than those in the fill and are very closely spaced, resulting in the cloth not having distinctly visible openings. The other cloths are woven from monofilament yarns of approximately equal size in the warp and fill directions, producing a distinct grid. The openings in cloths A, B, D, and G are rectangular, while the openings in cloth C are approximately square. Cloth A is green, and cloths B, C. D, and G are black. All of the cloths were made of polypropylene yarns, except cloth A which was made of polyvinylidene chloride. All of these cloths were subjected to extensive chemical and physical property testing as described in the following sections.

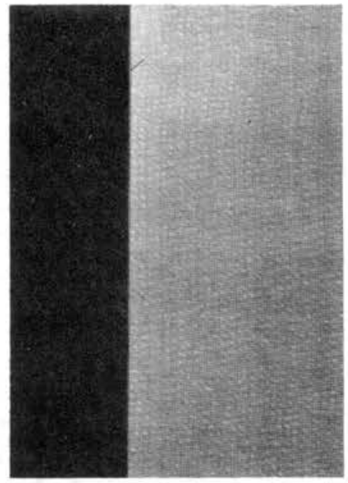
Information was obtained on two other cloths which were not evaluated in the laboratory and field tests. One, designated as cloth Z,



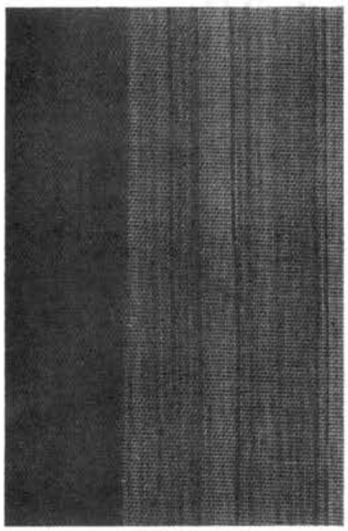
Cloth A



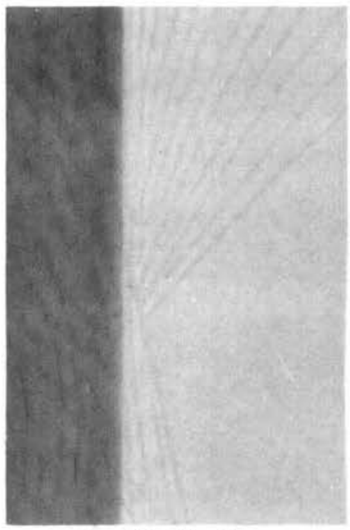
Cloth B



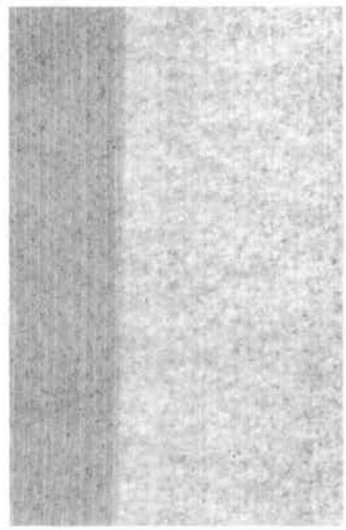
Cloth C



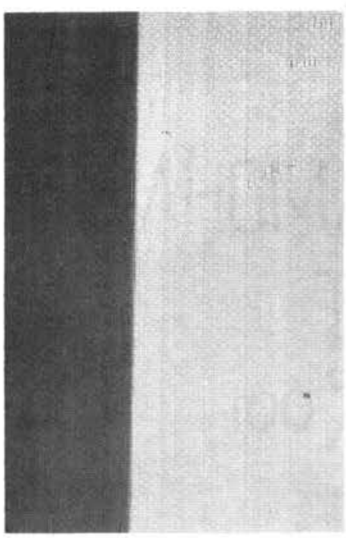
Cloth D



Cloth E



Cloth F



Cloth G

Note: Cloths are front-lighted on left, back-lighted on right.

Figure 1. Filter Cloths A Through G

was used by the Louisiana Department of Highways in the New Orleans District of the Corps of Engineers. The cloth was made by the same manufacturer as cloth G and was made of polyethylene yarns; cloths G and Z were manufactured in Holland. The other cloth, designated as cloth Y, was used by the Soil Conservation Service and was nonwoven. Cloth Y was much thinner than any cloth evaluated in the laboratory investigation and could be easily torn by hand. The cloth was made of fiberglass. Information on cloths Z and Y is inclosed in Chapter V, Field Performance Studies.

Test Procedures

Chemical Analysis

The chemical compositions of cloths A through G were analyzed. The materials could not be dissolved in xylene, chloroform, or acetone. The materials could be dissolved for testing in tetrachloroethane and orthodichlorobenzene ($O\text{-}Cl_2\text{-}\emptyset$). Prolonged heating and refluxing of the materials with $O\text{-}Cl_2\text{-}\emptyset$ were used in dissolving the filter cloths in this study. Films were cast of the dissolved materials on sodium chloride crystals, and potassium bromide pellets were made of the small amount of insoluble residue. Infrared spectra were obtained on these films and residues, and identification and differences among the materials were noted from these and other tests.

Physical Properties

The physical properties and the effects of some chemical action on the cloths were studied. Test procedures used were American Society for

Testing and Materials (ASTM), CRD-C designations given in "Handbook for Concrete and Cement," or special test procedures described subsequently. The following paragraphs describe the tests that were conducted.

Dimensions of Fibers and Openings. With the exception of cloths E and F, the number of fibers per inch, the fiber size, the type and variation of the dimensions of the openings, and the open area of the cloths were determined on five samples of each cloth. The number of fibers per inch was determined by counting the number of fibers in square inch samples. Fiber thickness was determined with a micrometer. The other properties were determined by the use of a micrometer scale microscope by projecting an image of the cloth on a screen and measuring the dimensions of the openings by use of a cross hair with a micrometer adjustment being moved horizontally and vertically over the cloth. This method could not be used on cloths E and F which did not have distinct openings. An alternate method was developed to determine the percent open area using equipment commonly available. The procedure was as follows: The image of a representative specimen of the cloth, placed in a 2 by 2 in. glass slide holder, was projected with a slide projector on a screen so that the dimensions of open and closed areas could be measured with a scale. A block of 100 openings near the center of the image was selected. Of the 100 openings in the block, 20 openings were selected for measurement, using a table of random numbers. The length and width of each opening (L_O and W_O) and the length and width of each opening plus the width of a fiber (L_T and W_T) were measured as shown in Figure 2. The individual open area (A_O) was computed by multiplying its length by width ($L_O \times W_O$). The individual total area (A_T) was computed by multiplying the width of the opening plus the width of one adjacent fiber by the length of the opening plus the width of one adjacent fiber ($L_T \times W_T$). The percent open area of the specimen is the ratio of the sum of the 20 or more individual open areas (times 100) to the sum of the 20 or more individual total areas. Since the ratio of the two areas is used, this procedure is applicable to opening shapes other than exactly square or rectangular.

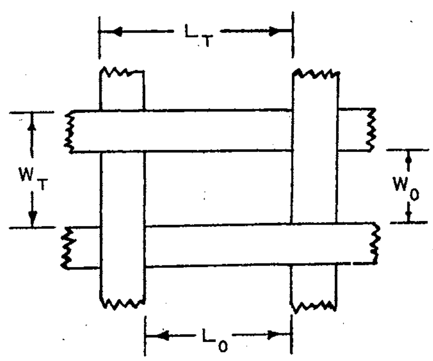


Figure 2. Cloth Opening

Equivalent Opening Size. Since the dimensions of the openings varied somewhat and they were not square, the average area of the openings was not an indicator of what size particles would pass through the cloth. Consequently, a special procedure was developed to determine the soil particle retention ability of the varous cloths. The cloth was placed between a sieve with a much greater opening than the cloth and a pan and the combination placed in a sieve nest. About 150 gm. of each of the following fractions of rounded to subrounded sand was obtained:

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

Starting with a fraction which would permit more than five percent of the sand to pass through the cloth, each successively coarser fraction was dry-sieved for 20 min. with an automatic shaker to determine that fraction of which five percent or less by weight passed the cloth. The equivalent opening size was the "retained on" size of that fraction expressed as a U. S. Bureau of Standard Sieve Number.

Tensile Strength and Elongation. Tensile strength and elongation of at least five samples each in the warp and fill directions were determined in accordance with ASTM D-1682, "Breaking Load and Elongation of Textile Fabrics - Grab Test Method," at temperatures of 0°, 73°, 110°, 150°, and 180°F. One-square-inch jaws were used, and the constant rate of traverse was 12 in./min. The strengths determined by this method at 73°F were used as a basis of comparison for determining the effects that the conditions described subsequently had on the strengths of the cloths.

Burst Strength. Burst strengths of at least five samples of each cloth were determined in accordance with ASTM D-751-68, "Testing Coated Fabrics - Bursting Strength, Diaphragm Test Method."

Puncture Resistance. Puncture strength was determined in accordance with ASTM D-751-68, "Testing Coated Fabrics - Bursting Strength - Tension Testing Machine with Ring Clamp," except that the polished steel ball was replaced with a 5/16 in. OD solid steel cylinder centered within the ring clamp. The modification to the standard ASTM test was made so that the results would be comparable to the test results given in the technical data sheet supplied by the manufacturer of cloths A, B, and C. This test was performed on ten samples of each cloth.

Abrasion Resistance. Abrasion resistance of the cloths was determined in accordance with ASTM D-1175-64T, "Abrasion Resistance of Textile Fabrics, Rotary Platform, Double Head Method." The abrasive wheels used were rubber-base CS-17 "Calibrase" manufactured by Taber Instrument Company. The load on each wheel was 1000 gm., and except for cloth F the test was continued for 1000 revolutions. Cloth F had obviously failed at less than 1000 revolutions. The unabraded tensile strengths of five specimens each in the warp and fill directions of cloths C, E, F, and G and ten specimens each in the warp and fill directions of cloths A, B, and D were determined in accordance with ASTM D-1682, "Breaking Load and Elongation of Textile Fabrics, One-Inch Ravelled Strip Test Method." One-inch-square jaws were used, and the constant rate of traverse was 12 in./min. The abraded strengths for the same number of samples were then determined. Additional tests were performed on cloths A, B, and D because samples were supplied from two separate sources.

Low-Temperature Brittleness. Five samples each in the warp and fill directions were subjected to testing in accordance with CRD-C 570, "Brittleness, Low Temperature, Motor Driven Apparatus," using alcohol heat transfer medium. The test was continued to (-)60°F.

Freeze-Thaw. Five samples in the warp and fill directions were subjected to 300 two hour freeze-thaw cycles as given in CRD-C 20-69, "Resistance of Concrete Specimens to Rapid Freezing and Thawing in

Water." The samples were of 4 in. by 6 in. size, and the temperature was varied from 0° to 40°F. The tensile strength and corresponding elongation were determined at the conclusion of the conditioning.

Weatherometer. Five samples each in the warp and fill directions were subjected to 250 cycles in a type D weatherometer described in ASTM E-42-69, "Operating Light- and Water-Exposure Apparatus (Carbon Arc Type) for Exposure of Nonmetallic Materials." In this test, a cycle consisted of exposing the cloth for 102 min. to ultraviolet rays (carbon arc) at 63° ±5°C. and 18 min. to a cold water spray and ultraviolet rays.

Oxidation. The effects of oxidation were determined on each of five samples in the warp and fill directions for each cloth in accordance with CRD-C 577, "Oxygen Pressure Test." The dimensions of the specimens were 4 in. by 6 in.

Effects of Alkalis and Acids (Accelerated Test). Five specimens, 4 in. wide and 6 in. long, were cut in each of the warp and fill directions. The specimens were placed in a one liter tall form beaker with spout that was filled to within two inches of the top with a solution made by dissolving equal amounts of chemically pure sodium hydroxide and chemically pure potassium hydroxide in 1.0 liter of distilled water to obtain a pH of 13 ±0.1. The specimens were immersed, and the top of the beaker was covered with a watch glass. The beaker was placed in a constant temperature bath, and the temperature of the solution was maintained between 140° and 150°F. A 1/4 in. OD glass tube was inserted to within 1/2 in. of the bottom of the beaker. Throughout the test air was gently bubbled through the solution at the rate of about one bubble per second. The solution was changed every 24 hr., the new solution being warmed to 150°F. before replacing the old. The test was continued until a constant sample weight was obtained. After this period, the specimens were tested for tensile strength and elongation at failure in accordance with ASTM D-1682 (Grab Method).

The effects of acids were determined by a test run exactly as described above except the solution was made from hydrochloric acid and distilled water to give a pH of 2 $\pm$0.1, and the test was discontinued after 14 days.

Absorption. Each of five samples in the warp and fill directions of each cloth was subjected to CRD-C 575, "Change in Weight, Water Immersion," to determine the absorption of the cloths. The samples were 4 in. by 6 in., and the percent absorption was determined from:

$$\frac{\text{Change in weight of specimen after immersion}}{\text{Weight of specimen before immersion}} \times 100$$

Effects of JP-4 Fuel. The effects of fuel spillage or prolonged exposure on the cloths were studied by immersing ten samples in each of the warp and fill directions in JP-4 fuel at room temperature. Strength tests were performed on the samples after 24 hr. and one week periods immersion.

Long-Term Immersion Tests. Each of five samples in the warp and fill directions was immersed for either 6 or 12 months at room temperature in pH = 10, pH = 3, and toluene solutions. The pH = 10 solution was made of equal parts of chemically pure sodium hydroxide and potassium hydroxide in distilled water. The pH = 3 solution was made by adding hydrochloric acid to distilled water.

Test Results and Discussion

Chemical Analyses

The type of chemical analysis conducted did not give quantitative results, but did indicate the cloths were made predominantly of polypropylene, or in the case of cloth A, polyvinylidene chloride. Affidavits from the manufacturers indicated that each cloth contained at least 85 percent polypropylene or polyvinylidene chloride by weight.

Physical Properties

Table I summarizes the results of tests (described in previous sections) to determine the physical properties of the cloths. Since cloth F is nonwoven, it has no warp or fill directions. In this case, warp direction refers to the longitudinal direction, while fill direction refers to the width of the cloth. The results of the various tests are discussed in detail in the following paragraphs.

Fiber and Opening Dimensions. The fibers used in the weaving of cloths A, B, and D were flat, while those in cloths C, E, and G were rounded. The opening dimensions produced by the entangled fibers in cloth F could not be determined. Results of tests to determine the geometry of the weave of the cloths are discussed below. In the following discussion, warp opening width refers to the measurement taken of the opening between two adjacent fill fibers and vice versa for fill opening width. The average area of openings is the average of the areas of the individual openings and may not be equal to the product of the average opening widths in the warp and fill directions.

TABLE I

SUMMARY OF PHYSICAL PROPERTIES

	Cloth A		Cloth B		Cloth C		Cloth D		Cloth E		Cloth F		Cloth G	
	Warp	Fill	Warp	Fill	Warp	Fill	Warp	Fill	Warp	Fill	Warp	Fill	Warp	Fill
Average number of fibers/in.	29.8	19.8	29.2	19.4	43.4	40.4	29.0	19.0	--	32.8	Could not test		42.0	24.4
Fiber width, average, in.	0.031	0.030	0.031	0.029	0.013*	0.014*	0.030	0.028	0.003*	0.010*	Could not test		0.015*	0.013*
Variation, in.	0.025 to 0.035	0.025 to 0.035	0.025 to 0.040	0.025 to 0.040	0.008 to 0.017	0.008 to 0.017	0.017 to 0.035	0.026 to 0.034	--	--	Could not test		0.010 to 0.023	0.010 to 0.023
Fiber thickness, average, in.	0.0085	0.0070	0.0085	0.0070	0.013*	0.014*	0.0085	0.0070	0.003*	0.010*	Could not test		0.015*	0.013*
Width of opening, average, in.	0.024	0.004	0.022	0.004	0.010	0.011	0.026	0.003	Could not test		Could not test		0.016	0.017
Variation, in.	0.017 to 0.035	0.002 to 0.007	0.014 to 0.030	0.001 to 0.009	0.009 to 0.017	0.009 to 0.017	0.020 to 0.041	0.001 to 0.008	Could not test		Could not test		0.004 to 0.019	0.010 to 0.018
Area of opening, average, in.^{2} × 10^{-6}	85		96		139		79		Could not test		Could not test		222	
Variation, in.^{2} × 10^{-6}	26 to 182		20 to 120		117 to 176		26 to 226		Could not test		Could not test		60 to 288	
Percent open area	4.6		5.2		24.4		4.3		Could not test		Could not test		36	
Equivalent opening size (U. S. standard sieve number)	100		70		40		100		Could not test		Could not test		30	
Tensile test (ASTM D-1682-64, Grab Method) at														
0 F strength, lb	200	150	380	252	201	195	420	263	106	247	39	102	176	126
Strength, % of 73 F strength	97	132	98	98	97	97	105	107	83	107	126	98	95	84
Elongation, %	16.8	26.2	23.0	23.0	18.0	15.8	16.8	24.0	9.0	24.6	10.0	31.4	16.8	8.0
73 F strength, lb (initial strength)	206	113	388	257	208	202	399	244	127	231	31	104	186	150
Elongation, %	22.2	27.4	22.4	26.8	23.6	16.6	17.0	24.6	10.6	26.3	11.3	40.3	23.0	10.6
110 F strength, lb	186	114	348	239	216	209	416	223	139	242	33	104	172	157
Strength, % of 73 F strength	90	101	90	93	104	103	104	91	109	105	106	100	92	105
Elongation, %	23.4	33.0	25.4	25.4	23.6	17.5	21.0	26.4	16.0	25.8	8.0	41.6	22.8	12.2
150 F strength, lb	204	109	341	249	221	205	433	222	149	241	25	98	183	150
Strength, % of 73 F strength	99	97	88	97	106	101	109	91	117	104	81	94	98	100
Elongation, %	25.4	31.8	25.4	29.0	19.4	24.2	23.0	27.6	20.6	28.5	7.4	38.4	25.0	11.0
180 F strength, lb	206	112	395	266	223	203	422	206	151	244	23	91	196	138
Strength, % of 73 F strength	100	99	102	104	107	100	106	85	119	106	74	88	105	92
Elongation, %	28.0	32.2	26.6	35.6	21.6	23.4	28.0	32.6	23.8	30.6	8.0	41.0	28.4	12.0
Burst, psi (ASTM D-751-68)	268		542		625		528		316		180		437	
Puncture, lb (special)	72		148		128		138		89		46		86	
Abrasion resistance (ASTM D-1175-64T)														
Strength loss, %	61.5	65.7	61.3	61.9	7.0	19.0	48.6	65.4	4	87	**	**	79.3	4.2
Abraded strength, lb (ASTM D-1682-64, One-Inch Ravelled Strip Test)	57	19	115	80	162	161	167	60	88	24	**	**	38	145
Low-temperature brittleness (CRD-C 570-64)	No failure		No failure		No failure		No failure		No failure		No failure		No failure	

* Diameter of round thread.
** Obvious failure after 400 to 600 revolutions.

TABLE I (Continued)

	Cloth A		Cloth B		Cloth C		Cloth D		Cloth E		Cloth F		Cloth G	
	Warp	Fill	Warp	Fill	Warp	Fill	Warp	Fill	Warp	Fill	Warp	Fill	Warp	Fill
Freeze-thaw (300 cycles)(CRD-C 20-69)														
Strength, lb	199	108	360	251	214	176	410	220	145	247	33	95	184	156
Strength, % of 73 F strength	97	96	93	98	103	87	103	90	114	107	106	91	99	104
Elongation, %	25.0	37.0	25.5	29.5	20.6	17.8	21.8	28.0	15.7	26	11	43.3	23.6	11.7
Weatherometer, 250 cycles (ASTM E-42-69)														
Strength, lb	172	115	385	207	269	249	450	245	74	171	26	5	170	162
Strength, % of 73 F strength	83	102	99	81	129	123	92	82	58	74	84	5	91	108
Elongation, %	15.0	21.2	20.4	21.6	23.3	19.2	18.3	19.0	7.8	20.4	7.6	2.5	16.6	14.9
Oxygen pressure test (CRD-C 577-60)														
Strength, lb	230	113	409	235	285	281	439	223	182	240	32	101	180	140
Strength, % of 73 F strength	112	100	106	91	137	139	110	91	143	104	103	97	97	93
Elongation, %	21.8	19.3	26.0	24.6	19.4	25.4	19.3	25.0	24.2	15.8	13.0	38.0	23.0	10.8
Effects of alkalies (special)														
Number of cycles	33†		14		16		17		19		19		14	
Weight loss, %	9.5†		0.82		1.1		0.64		5.8		7.8		1.72	
Strength, lb	190	108	410	245	289	248	415	234	141	226	28	104	184	149
Strength, % of 73 F strength	92	96	106	95	139	123	104	96	111	98	90	100	99	99
Elongation, %	16.2	33.0	33.0	27.2	24.6	19.0	17.8	29.5	16.2	23.3	13.8	40.0	24.2	10.8
Effects of acids (special)														
Number of cycles	14		14		14		14		14		14		14	
Strength, lb	211	113	375	262	223	216	444	229	158	270	64.2	131	180	165
Strength, % of 73 F strength	102	100	97	105	107	107	111	94	124	117	207	126	97	110
Elongation, %	18	26	24	22	20.6	22.2	19.8	24.3	17.7	21.5	72	50	29	16
Absorption, % (CRD-C 575-60)	0.91		0.13		0.87		0.38		0.08		0.31		0.29	
JP-4 fuel immersion (special)														
Before immersion (initial)														
Strength, lb	172	101	349	247	208	202	397	189	127	231	30.7	104	186	150
24-hr immersion														
Strength, lb	179	94	327	210	212	207	393	190	130	240	21.7	88.3	148	127
Strength, % of initial strength	104	93	94	85	102	103	99	101	102	104	71	85	80	85
1-week immersion														
Strength, lb	185	107	344	212	208	226	385	181	123	227	20.7	75	174	143
Strength, % of initial strength	108	106	99	86	100	112	97	96	97	98	67	72	94	95
Long-term immersion tests (special)														
Immersion time, months	12		12		6		12		6		6		6	
pH = 10 solution														
Strength, lb	214	118	408	266	205	204	416	242	141	248	36	102	185	158
Strength, % of 73 F strength	104	104	105	104	99	101	104	99	111	107	117	98	99	105
pH = 3 solution														
Strength, lb	206	113	374	254	207	184	403	238	141	250	34	117	199	156
Strength, % of 73 F strength	100	100	97	99	100	91	101	98	111	108	111	112	107	104
Toluene solution														
Strength, lb	177	99	394	264	174	172	397	230	124	243	13.4	73.2	186	161
Strength, % of 73 F strength	86	88	101	107	84	85	99	95	97	105	43	70	100	108

† Samples continued to lose weight until termination of test.

Filter Cloth A. The areas of individual openings varied from 26-182 x 10^{-6} in.^{2}, with the average area being 85 x 10^{-6} in.^{2}. Some of this variation in areas of individual openings is attributed to the fact that the width of the opening in the fill direction was determined to only one significant figure. This was true in the case of the other cloths also. Although visual inspection of the cloth showed some variation in opening sizes (Figure 1), the cloth's appearance indicated good weaving quality control by the manufacturer.

Filter Cloth B. Openings varied in area from 20-120 x 10^{-6} in.^{2} (average 96 x 10^{-6} in.^{2}); however, this large variation was not obvious from visual inspection (Figure 1), and the quality control in weaving appeared to be good.

Filter Cloth C. The computed areas of the individual openings varied only from 117-176 x 10^{-6} in.^{2}, the average being 139 x 10^{-6} in.^{2}. The areas of approximately 40 percent of the openings were between 130-132 x 10^{-6} in.^{2}. From the appearance of the cloth (Figure 1), the quality control of weaving was excellent.

Filter Cloth D. Areas of individual openings varied from 26-226 x 10^{-6} in.^{2}, with the average being 79 x 10^{-6} in.^{2}. The variations in opening widths and areas were apparent from visual inspection as indicated by the very dark lines in Figure 1. This indicates that the quality control in weaving for cloth D is not as good as for cloths A, B, and C.

Filter Cloth E. The number of fibers in the warp direction could not be determined since the fibers appeared to almost be multifilament. There were 32.8 fibers per inch in the fill direction. Because of the tight weave, the opening dimensions of the cloth could not be determined.

The diameter of the fill fibers averaged 0.010 in., and for the warp fibers, 0.003 in., or about 1/3 that of the warp fibers.

Filter Cloth G. The area of the openings varied from 60-288 x 10^{-6} in.^{2}, the average being 222 x 10^{-6} in.^{2}. The variations were apparent in visual inspection of the cloth, particularly when compared to filter cloth C. Small flaws were also noted in cloth G (Figure 1). Therefore, the quality control for weaving of filter cloth C appears superior to that of filter cloth G.

Equivalent Opening Size. The following tabulation summarizes the equivalent opening size determinations for the respective cloths:

Cloth	Equivalent Opening Size (U. S. Standard Sieve Size)
A	100
B	70
C	40
D	100
E	Could not test
F	Could not test
G	30

Strength Parameters. Table I includes the results of tests to determine the effects of various conditions on the strength of the cloths. In most cases the values shown are the averages of five tests. The results of tests shown in Table I are discussed in the following paragraphs. Tensile strengths of the cloths under various conditions are plotted in Figure 3. A strength loss of 10 percent or more was usually interpreted to mean that a sample had been adversely affected by the conditioning.

Initial Strengths. The tensile strength of each cloth was determined at 73°F. It was found that strength variations of about ±10 percent could be expected from samples of the same cloth. The tensile

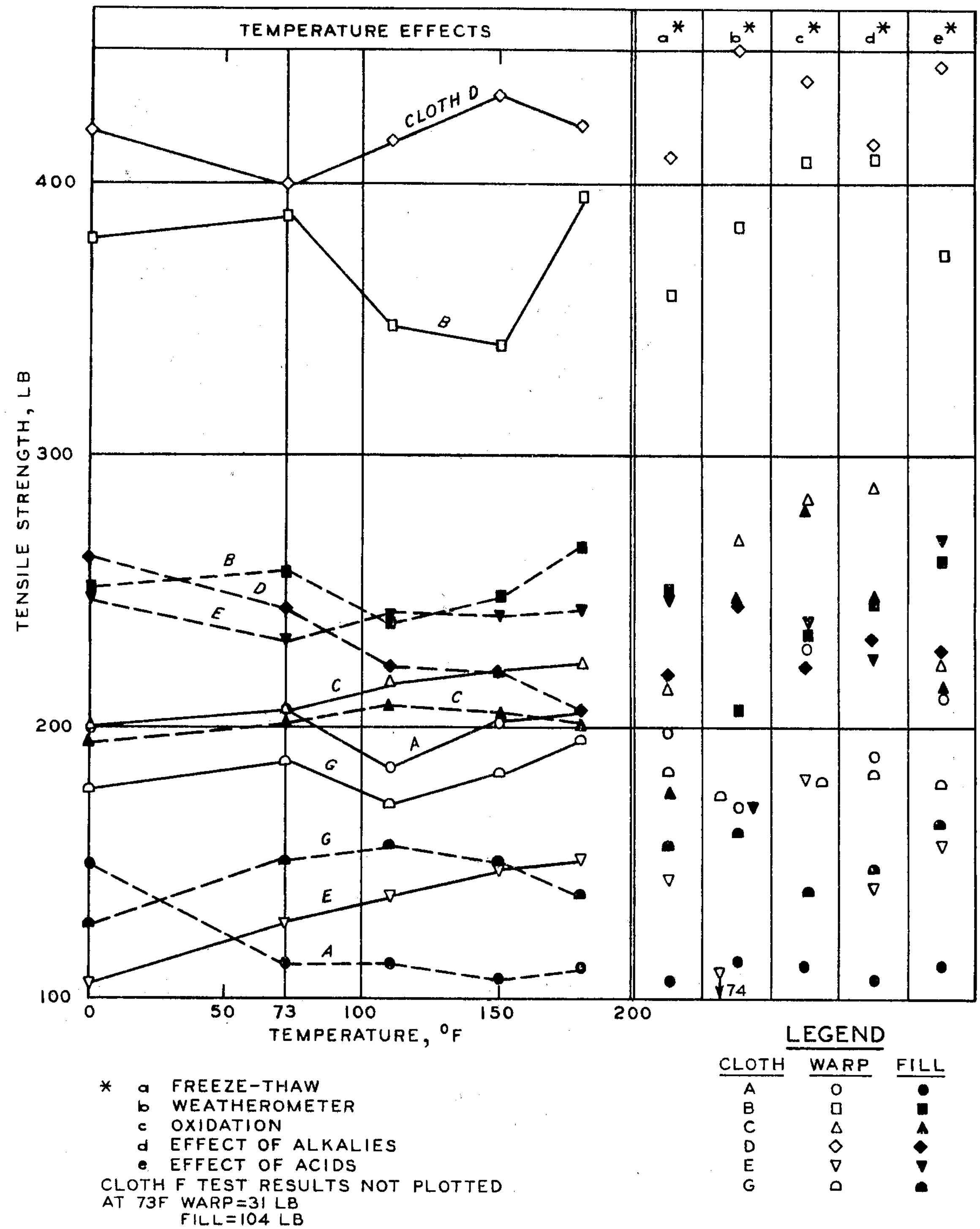


Figure 3. Tensile Strengths of Cloths Under Various Conditions

strengths of filter cloths B and D were approximately equal. The strengths of filter cloth E are roughly comparable to those of filter cloth A, and filter cloth G had lower strengths than filter cloth C in the warp and fill directions, respectively. This might be expected in the fill direction since there are fewer fill fibers per inch in cloth G than in cloth C. The strength of cloth F was 31 lb. in the warp direction and 104 lb. in the fill direction. Filter cloth C had the highest burst strength (625 lb./in.^{2}), while cloth B had the highest puncture strength (148 lb.). The burst and puncture strengths of cloth F were well below the strengths of any of the other cloths tested.

Temperature Effects. The effects of temperatures from 0° to 180°F. on the tensile strengths of the cloth did not appear to be significant. The strength at 73°F. was used as a basis for comparison. As would be expected, there was a tendency for the ultimate elongation of the cloths to increase as the temperature was increased, indicating the elasticity of the materials was affected somewhat. There were no failures when the cloths were subjected to the Low Temperature Brittleness test, indicating the fibers were not excessively brittle at (-)60°F. Cloth C showed a 13 percent strength loss in the fill direction at the conclusion of the freeze-thaw tests. Strength losses for the other cloths did not exceed 10 percent.

Abrasion Resistance. Tests indicated that cloth C had the highest resistance to abrasion. The cloth lost only 7 and 19 percent of its strength in the warp and fill directions, respectively. Holes were worn through cloth F after only 400 to 600 revolutions. In the weaving processes of cloths E and G, fibers in one direction are curved over and under the relatively straight fibers in the other direction.

Consequently, the abrasion wheel rode primarily on the fibers in one of the principal directions, while the fibers in the other direction were protected. The fibers of the other cloths appeared to be abraded about the same in both directions.

Weatherometer. The weatherometer test primarily indicates the effects of sunlight (carbon arc light) with wetting and drying. Cloth F was the most severely affected by this test, losing 95 percent of its initial strength in the fill direction. Only cloths C and G showed no significant effects from the test. Fibers in one or both directions of the other cloths were affected to some degree. It should be noted that cycles in this test cannot be correlated to number of actual field exposure days, but the results can be used for qualitative comparisons.

Oxidation Effects. The test results indicated that no significant deterioration would occur due to oxidation.

Effects of Alkalis. The tensile strengths of the cloths were not significantly affected by the accelerated test or the long-term immersion tests. Cloth A showed a weight loss of 9.5 percent after 33 days, and the weight loss continued until the test was terminated. (However, samples of cloth A immersed for one year in a pH = 10 solution showed no strength loss.) None of the cloths lost over 10 percent strength in the accelerated tests or two percent in the long-term immersion tests.

Effects of Acids. Accelerated acid tests indicated that no cloths were significantly affected by this test.

Effects of Petroleum Spillage. Cloth F was significantly affected by immersion in both JP-4 and toluene. Cloth B had a 14 percent strength loss in the fill direction after being immersed in JP-4 fuel, but showed no detrimental effects after 12 months' immersion in the toluene solution. Cloths A and C also lost more than 10 percent of their initial strength when immersed for 12 and 6 months, respectively, in toluene. There was no significant deterioration of the other cloths.

Absorption. No cloth absorbed more than 1.0 percent by weight of water. Cloth A had the highest absorption rate (0.91 percent), while cloth E had the lowest (0.08 percent).

Summary and Discussion

All of the fibers in the various cloths were predominantly polypropylene except for cloth A, which was predominantly polyvinylidene chloride.

The number of fibers and fiber widths and thicknesses of cloths A, B, and D were approximately equal. The fiber diameters of cloths C and G were approximately the same. Because of the wide variations in opening areas in the cloths, the quantitative significance of the average individual open area values shown in Table I is questionable. These values do show, however, that cloths C and G have openings considerably larger than the other cloths, with cloth G having the largest. The percent open areas shown is considered significant. Although the quality control for all the cloths is considered acceptable, the weaves of cloths A, B, and C are more nearly uniform than the weaves of cloths D and G.

The initial tensile strengths of cloths B and D are considered equivalent. The tensile strengths of cloths A and E are comparable. While the tensile strengths of cloths C and G are somewhat comparable in the warp direction, cloth C is the stronger in the fill direction.

The strength of cloth F was considerably lower than that of any other cloth tested. The puncture and burst tests also indicated the strengths of cloths B and D could be considered equivalent, while the strength of cloth A was considerably lower. Tests indicated that cloth C had very high abrasive resistance, while cloth F was completely worn through after 400 to 600 revolutions.

The effects of temperature and oxidation appeared to be negligible for the cloths tested. Absorption is considered nil. Accelerated alkali tests indicated that cloth A would be affected somewhat by alkalis; however, long-term immersion tests appear to contradict these data. None of the cloths appeared to be affected by acidic solutions. Weatherometer tests indicated that cloths A, B, D, E, and F were affected by ultraviolet rays to some extent. A possible explanation, given by one manufacturer's representative, as to why cloths A, B, and D lost strength primarily in only one direction is that all the fill fibers in a sample are from one spool, while each fiber in the warp direction is from a separate spool. Therefore, the performance of the cloth in the fill direction reflects the properties of material from one source, while the performance of the cloth in the warp direction is an average of the properties of materials from 19 to 20 different sources.

Cloth F was affected by both the JP-4 and toluene immersion tests, while cloths A and C were affected only by the toluene solution.

These data when correlated with other tests to be described subsequently, field data, and experience will form the basis for establishing recommendations of desired properties for filter cloths.

CHAPTER III

FILTRATION AND CLOGGING TESTS

Filtration tests were performed to determine the applicability to filter cloths of Corps of Engineers filter criteria for granular material adjacent to holes in drainage pipes or well screens. The criteria stated in terms of equivalent opening size are:

$$\frac{D_{85} \text{ of material}}{\text{Equivalent Opening Size}} \geqq 1.0$$

Tests were also conducted to determine the ability of the cloths to retain silty materials. It was also desired to measure the head losses through the filter cloths and to determine, by applying surcharge loads to simulate pressures of riprap stone or other type structures on the filter cloth, if stretching, tearing, or puncturing of the cloth would occur which would cause excessive movement of soil through the cloth. Special "clogging" tests were also conducted to determine any tendency of the cloths to clog from migration of fines through the soil.

Test Apparatus

Two pieces of apparatus were used during the investigation; one was 12 in. in diameter and one was 5 in. in diameter. Figures 4 and 5 show the 12 in. OD filtration test apparatus. The bottom of the cylinder was molded in wax so that any material passing the filter cloth would be washed into a trap, as shown in Figure 4. A standpipe was

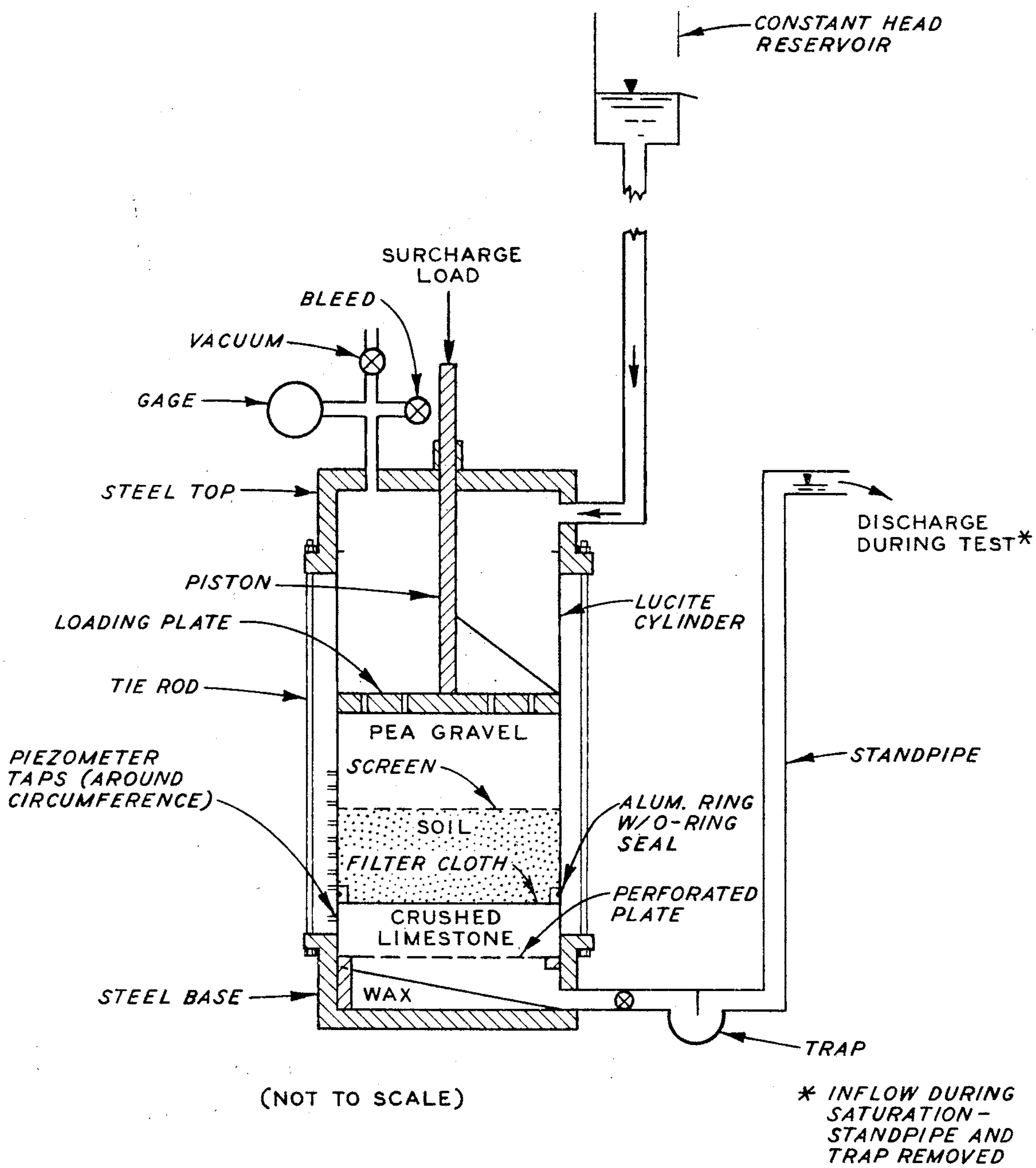


Figure 4. Twelve Inch Diameter Filtration Test Apparatus (Schematic)

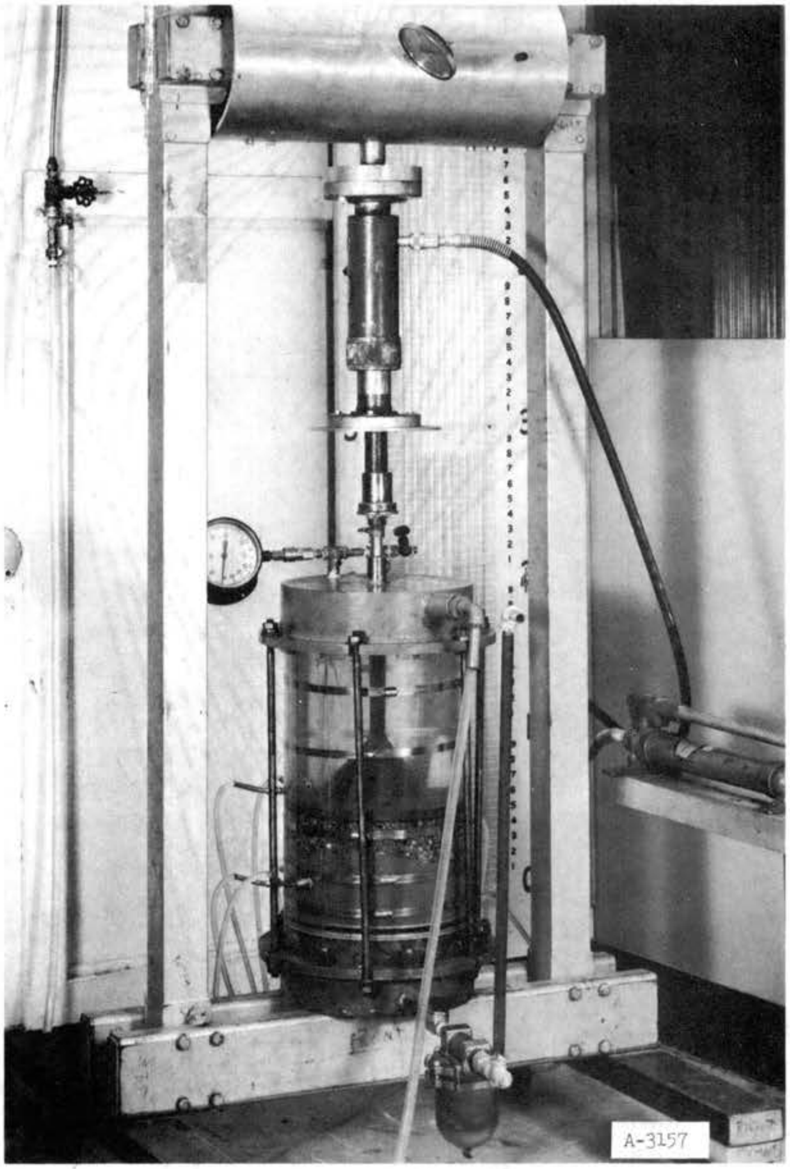


Figure 5. Twelve Inch Diameter Filtration Test Apparatus

attached to the trap outlet to provide a tailwater elevation above the top of the soil. The 1/4 in. thick, 11.5 in. ID Lucite cylinder was seated on a rubber gasket extending around the rim of the steel baseplate. A line of 3/8 in. OD piezometer taps was spaced 1.0 in. vertically and 1.0 in. horizontally up the side. Piezometer taps were brass tubes covered with No. 200 screen that fitted flush with the inside of the cylinder. The cylinder was secured to the base with L clamps bearing on spacer blocks secured to the cylinder. The steel top was seated on a rubber gasket around the rim of the cylinder and was secured with six steel tie rods extending to the baseplate. A 3/8 in. ID hole tapped into the top was fitted with a pressure gage, bleed valve, and vacuum line attachment. A discharge outlet was also provided in the top. A 3/4 in. ID hole in the center of the top provided with a grease fitting accommodated the loading piston. A perforated steel loading plate, 3/4 in. thick with a diameter of 11-5/16 in., was used to transmit surcharge loads. Surcharge loads were applied by a hydraulic jack and measured by observing deflections of a Warlam loading frame with a dial gage. A constant head reservoir was used to apply hydrostatic pressures on the soil. Deaired water was used, obtained by spraying distilled water into a 20 gal. tank under a high vacuum (about 20 in. of mercury).

Figure 6 shows the 5.0 in. ID apparatus used for one filtration test and all clogging tests. The apparatus is shown schematically in Figure 7. The apparatus was constructed of two 5.0 in. ID, 1/4 in. thick Lucite cylinders. Filter cloth was placed between flanges on the ends of the cylinders and bolted into place as shown in Figure 7. The connection was made watertight with silicone grease. This resulted in a continuous cylinder as opposed to the disruption caused by the ring in

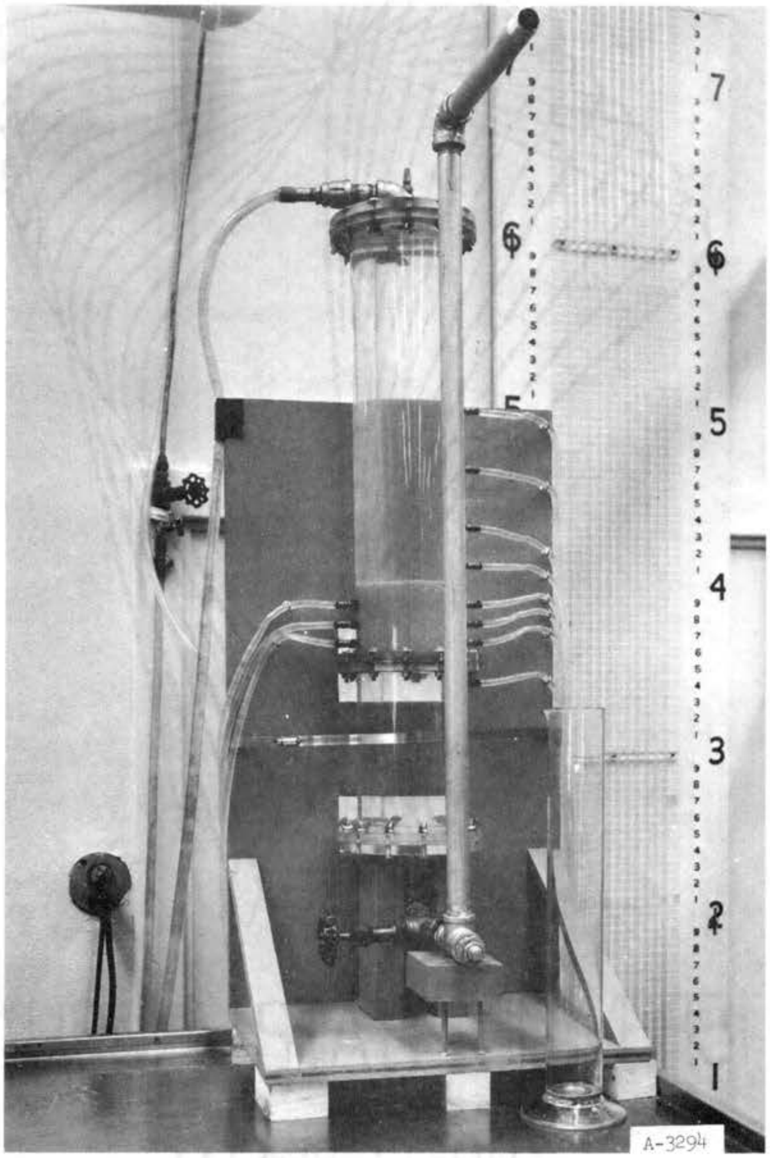


Figure 6. Five Inch Diameter Filtration and Clogging Test Apparatus

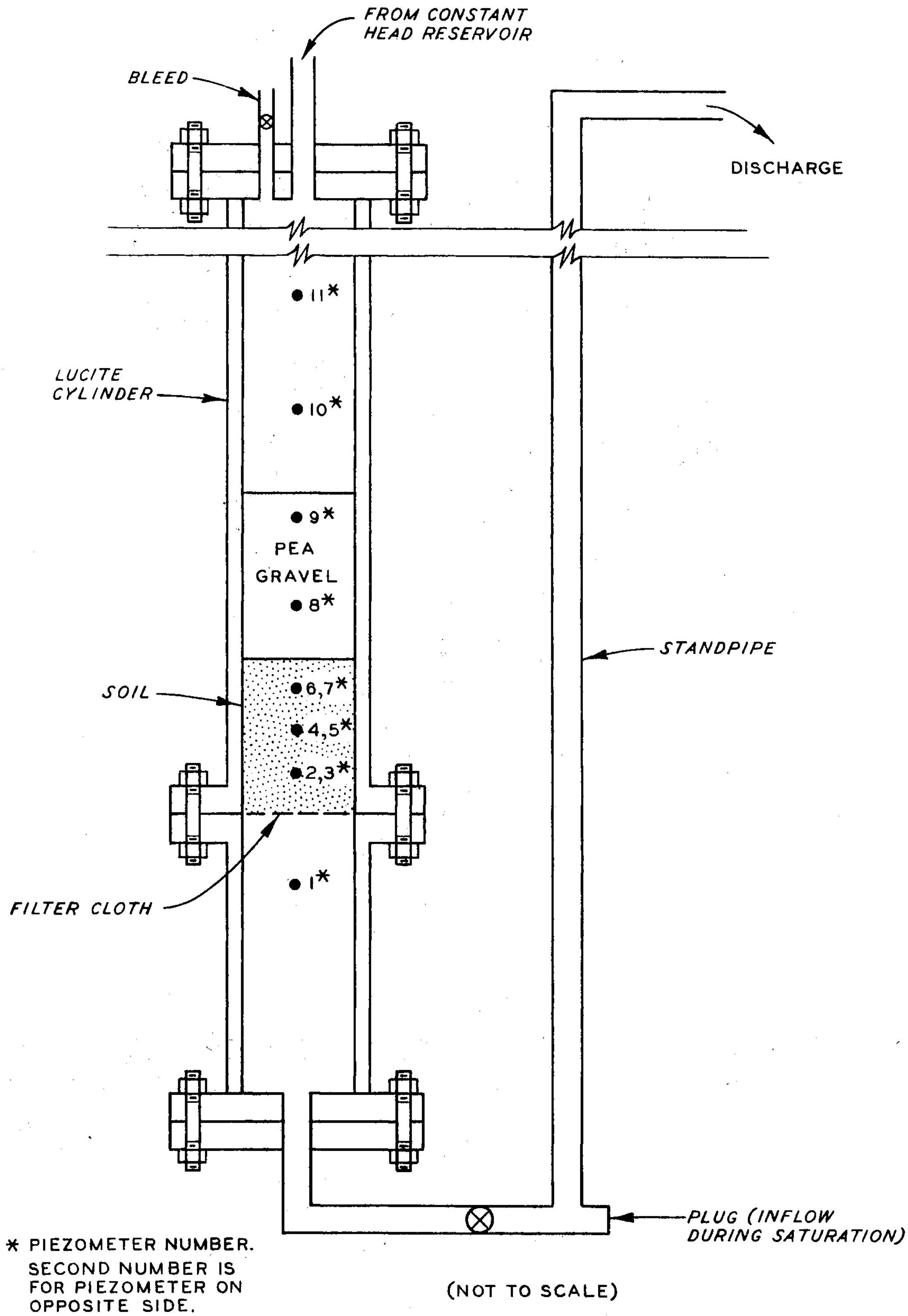


Figure 7. Five Inch Diameter Filtration and Clogging Test Apparatus (Schematic)

the 12 in. ID apparatus. Lines of 3/8 in. OD piezometer taps were located as shown in Figure 7. Piezometer No. 1 measured the tailwater elevation. Piezometer Nos. 2, 4, and 6 were spaced on 1.0 in. vertical centers above the cloth, with piezometer Nos. 3, 5, and 7 located 180 degrees around the cylinder. Piezometer Nos. 6, 8, and 9 were spaced on 2.0 in. vertical centers, and Nos. 10 and 11 on 3.0 in. centers. The Lucite top plate was fitted with a 3/4 in. opening to allow water from the constant head reservoir to enter the apparatus. A bleed valve was also provided. The Lucite baseplate was fitted with a 3/4 in. opening to which the standpipe was connected. A valve was placed between the base and standpipe, and a plug for draining the apparatus and for inflow during saturating was at the base of the standpipe. The constant head reservoir and the source of distilled deaired water were the same as for the larger apparatus.

Soils Used in Testing

It was desired to determine if the filter cloths would provide an adequate filter for two types of soil. One was a clean sand. Clean sands are used for backfill material in drainage systems and relatively clean sands often compose channel banks. The other desired soil type was a fine-grained, practically cohesionless material. This type of soil is particularly susceptible to piping. Cohesive soils were not considered since generally they present no problem with piping.

In four of the seven filtration tests performed, two gradations of uniform, rounded to subrounded river sands, graded as shown in Figure 8, were used. In the other three tests, a silty sand (classified SM by the Unified Soil Classification System) was used, consisting of 50 percent

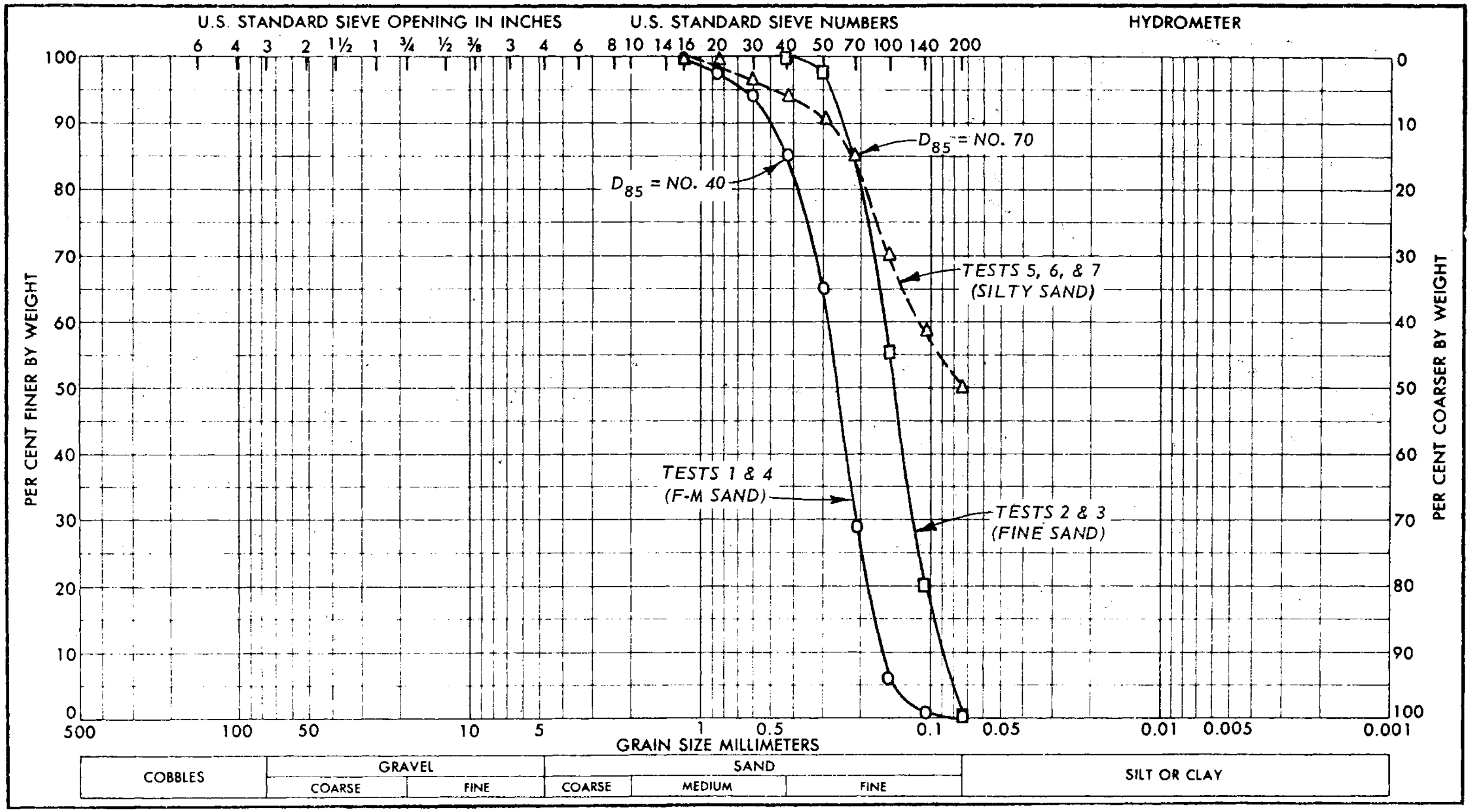


Figure 8. Gradation of Soils Used in Filtration Tests

sand sizes and of 50 percent loess that had been sieved over a No. 200 screen. The coarser gradation of sand was used in test 1 before the method described subsequently for determining the equivalent opening size was established, and the equivalent opening size of cloth B was thought to be equal to the No. 40 sieve. The silty sand was selected after a preliminary test indicated that no meaningful data could be obtained using a loess because of its low permeability. It is thought that the silty sand imposes a more severe condition on the cloths than silt alone as the water velocities through the silty sand would be higher and piping of fines could still occur. Ottawa sand (graded between the Nos. 20 and 40 sieve sizes) mixtures with 0, 5, 10, and 20 percent loess fines were used in the clogging tests. (In future sections, tests with these materials will be referred to as the "5 percent silt tests," etc.) The rather coarse-graded Ottawa sand was selected to provide a skip-graded mixture having a size distribution shown in Figure 9 that would allow easy migration of the loess fines.

Preparation of Test Specimens

Tests With 12 in. OD Apparatus

Tests 1-6 were performed with the 12 in. OD apparatus. To prepare the apparatus for testing, a perforated brass plate was fitted above the base and the Lucite cylinder was then attached to the base. Uniform size 2.0 in. angular limestone fragments were placed on the perforated plate to a height of three to four inches. Angular limestone was used to see if it would cause tearing, puncturing, or severe stretching of the filter cloth when the surcharge loads were applied. In the first

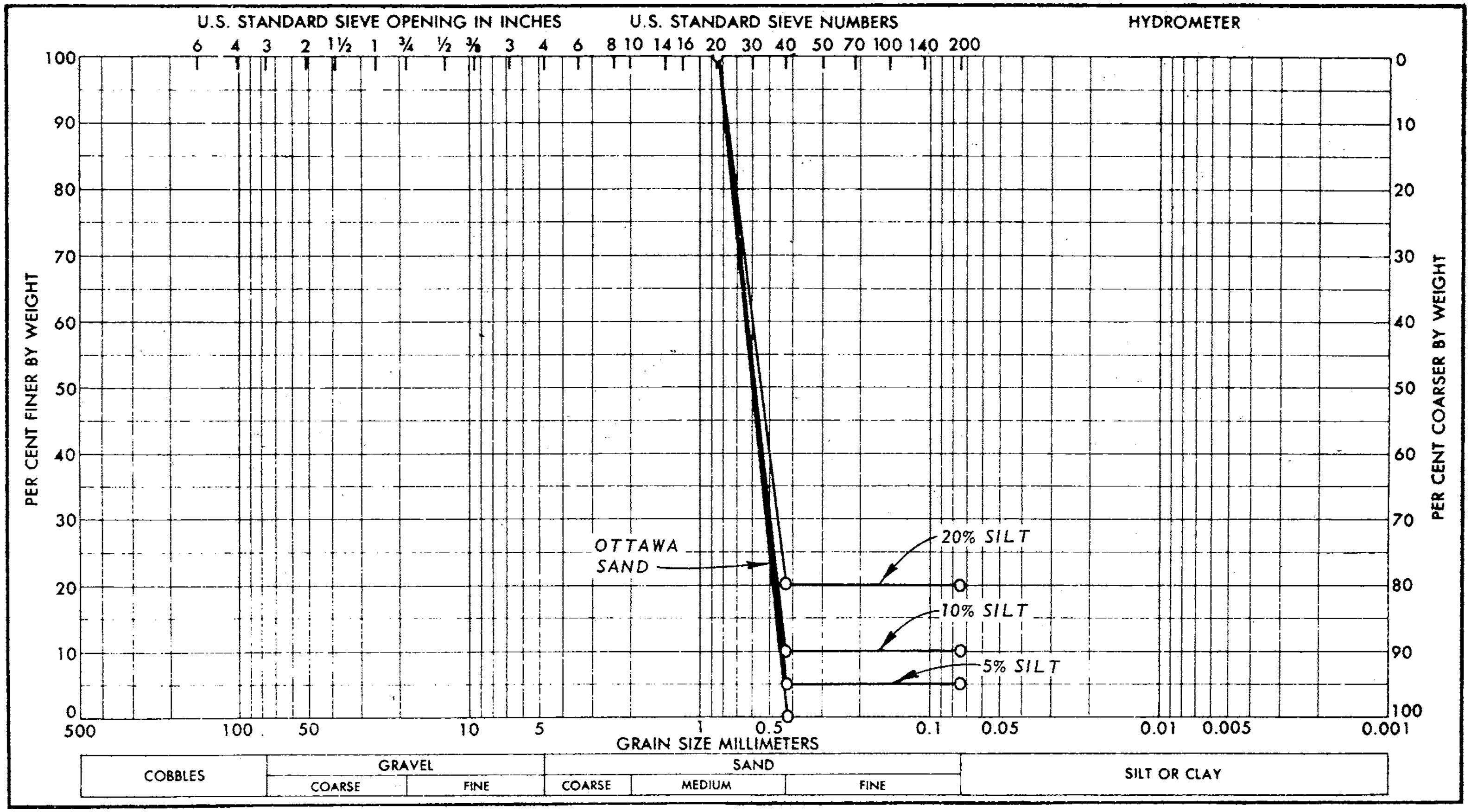


Figure 9. Gradation of Soils Used in Clogging Tests

two tests, the filter cloth was secured to the ring with epoxy cement. This method proved to be unsatisfactory. In the remaining tests, a smaller ring was bolted over the cloth to the larger ring. An O-ring fitted into a groove around the aluminum ring assured a tight fit with the cylinder wall. The filter cloth and ring were then placed into the cylinder, with the cloth in direct contact with the limestone. The ring was leveled in the cylinder. The base was filled with deaired water and brought to an elevation of about one inch below the filter cloth. The deaired water was introduced through the valve and discharge pipe in the base (shown in Figure 4). The soil was placed in a uniformly loose condition on top of the cloth. The top of the soil was leveled, and a wire screen was placed on its surface. Pea gravel (+ U. S. 1/4 in. sieve) was placed on top of the screen to evenly distribute the flow of water during the test. The loading piston was then set on the pea gravel and the chamber top was secured.

The soil was saturated in the following manner. After the apparatus had been assembled and the piezometers and top discharge opening closed, deaired water was brought just above the level of the filter cloth. The valve was then shut and a vacuum of about 20 in. of mercury was applied for approximately 15 min. (in tests using silty sand, the vacuum was applied for a longer period, as will be discussed later). Water was allowed to rise in one inch increments within the sample with the vacuum applied until the soil was saturated. The overlying pea gravel was then saturated by simply raising the water level within it, and when the water level was just above the plate, the vacuum was again applied for about 15 min. Deaired water was then allowed to fill the cylinder to the level of the top discharge pipe. Piezometers were attached to the manometer board, and the water was allowed to flow into the top until it began to exit from the bleed valve. The trap and standpipe were then attached. The heights of the filter cloth, top of soil, and top of pea gravel above the base were carefully measured at four points around the cylinder and recorded.

Tests With 5.0 in. ID Apparatus

Filtration test 7 and all clogging tests were performed with the 5.0 in. ID apparatus. In the filtration test, the soil was placed dry on the cloth and was saturated by allowing deaired water to flow slowly from the bottom of the sample. No vacuum was applied within the cylinder. This procedure could not be followed for the clogging tests since the upward flow would cause the fines to migrate upward and out of the sample prior to the test. Therefore, prior to placing the soil for the clogging test, deaired water was placed in the apparatus to an elevation above that to which the soil would be placed. The soil was then placed underwater using a tremie-type device. By using this procedure, segregation of the material was held to a minimum although the water did become muddy during placement, causing (in some instances) a thin film on the top of the soil from the fines settling out of the water. In the filtration test, a wire screen was placed on top of the soil and pea gravel was placed on top of the screen to evenly distribute the flow of water during the tests. The filtration test indicated the pea gravel and wire screen were not needed with the smaller apparatus, and therefore they were not used in the clogging tests. The remainder of the apparatus was then filled from the top with deaired water and the test begun. The flow was recorded and the piezometers read periodically.

Due to the limited capacity (20 gal.) of the deairing tank, some of the tests had to be interrupted to replenish the supply of deaired water. The height of the soil was carefully measured prior to initiating the tests.

Test Procedures

Filtration Tests, 12 in. OD Apparatus

The filtration tests were performed with downward flow. For the initial test in a series, no surcharge load was applied. A differential head (usually about 0.25 ft.) was applied, and the bottom of the filter cloth and the trap were carefully observed to detect any infiltration. Any discoloration of the discharge water was noted. After it had stabilized, the discharge was measured over a given period of time, and the piezometers were read. The flow was recorded, and for all tests the piezometers were read a minimum of three times at 15 min. intervals for each applied head. The head was increased and the procedure was repeated. The head was increased until the maximum flow obtainable was reached or until the maximum height of the constant head reservoir was reached. The head was then reduced to approximately half of the maximum head (subsequently denoted as intermediate head) and then reduced to the initial head. Temperature measurements were made of water entering and exiting the apparatus.

After completion of the initial tests, a surcharge of 500 lb./ft.^{2} was applied. The heights of cloth, top of soil, and top of pea gravel above the base were again measured. The initial, intermediate, and maximum heads were applied and then lowered, as in the initial tests.

A 1000 lb./ft.^{2} surcharge was then applied, height measurements were again recorded, and the procedure was repeated in the same manner as the 500 lb./ft.^{2} surcharge test. The intensity of the maximum surcharge load was limited to 1000 lb./ft.^{2} by the equipment used.

The surcharge was removed and the soil was "surged." The surging was accomplished by opening and closing the discharge valve ten times at the initial, intermediate, and maximum heads. This procedure quickly varied the differential head from that produced by the position of the constant head reservoir to zero. After surging, the base was struck continuously with a rubber mallet for about five minutes at the initial, intermediate, and maximum heads, first with no surcharge and then with 500 lb./ft.^{2} surcharge, but not with the 1000 lb./ft.^{2} surcharge (as a safety precaution).

The apparatus was then disassembled, the trap was inspected to detect infiltrated material, and in-place densities were made at the top and bottom of the soil column using a 1.0 in. ID Hvorslev piston sampler. Samples of soil from the top and bottom were obtained for sieve analysis. A sieve analysis was also run on any material passing the cloth during the test. The cloth was visually inspected and photographed to note any clogging or any tears, punctures, or other alterations resulting from stretching of the cloth by the angular limestone. Soil used in the test was then washed over the cloth, and sieve analyses were run on the fractions passing and retained to determine any change in the equivalent opening size and the percent of the total mixture that could be washed through the cloth.

Filtration and Clogging Tests,

5.0 in. ID Apparatus

All the filtration and clogging tests were downward flow tests. The procedures for applying the heads and recording flows and temperature using the smaller apparatus were similar to those used with the larger apparatus. The test was concluded after the maximum head obtainable with the equipment had been applied and the flows measured. The head was not reduced as was done in the previous tests. The flow was recorded, and piezometers were read a minimum of three times at 15 min. intervals for each head applied.

The clogging tests were conducted for periods up to 320 min. with the reservoir at a constant head. All piezometers were read and flows were measured periodically. Actual time periods and hydraulic gradients (head loss per unit length of sample) used are given in subsequent discussions of the individual test results. There was a slight buildup in the net head as the tests continued; however, as discussed later, corrections were made to the test results to account for the variation.

Infiltration occurring during the tests was carefully noted. After the tests were completed, the soil was removed from the apparatus and any clogging of the cloth was noted. The percent fines in various zones of the soil specimen was determined. These determinations were made on soil in the first 1/4 in. above the cloth, and on soil between that level to the elevation of the first piezometers above the cloth. Above that level, determinations of fines were made of the material between the remaining piezometers (1.0 in. intervals). The fines content was computed by determining the dry weight of soil, washing the fines through a No. 200 sieve, and then determining the dry weight of the retained sand, the difference in the two weights being the weight of the fines.

Test Results and Discussion

Filtration Tests

Information on the soil specimens is given in Table II. In all of the tests using the 12 in. OD apparatus (tests 1-6), there was some difficulty in determining the exact length of the soil specimen after the apparatus had been set up ready for the tests. This was particularly true after the surcharge loads had been applied. Sometimes it appeared visually that the filter cloth had moved downward a greater distance than the top of the specimen had moved. It was thought that this problem was probably due to the sand having been pushed through the top screen into the pea gravel, and also due to deformation of the bottom of the soil specimen by the pressure of the rocks on the filter cloth. Since water temperature did not vary over 1° or 2°C. during a test, no corrections were made in the analyses of the data. As will be discussed subsequently, variations in hydraulic gradients throughout the samples did not allow head loss determinations through the cloths to be made during the filtration tests.

Cloth B

Results Using F-M Sand (Test No. 1). Net heads up to one foot of water were applied, first under conditions of no surcharge and then

TABLE II

DATA ON SOILS USED IN FILTRATION TESTS

Cloth Tested			Soil Specimen				
			Material*		After Saturation		
Key	EOS** (Sieve No.)	Test No.	Classification	D_{85} (Sieve No.)	Height in.	Dry Density γ_d, pcf	Relative Density %
B	70	1	F-M sand	40	3.5	95.4	35
		2	Fine sand	70	3.5	82.9	<0
		5	Silty sand	70	2.5	79.6	-
		6	Silty sand	70	1.6		-
C	40	4	F-M sand	40	4.1	91.4	12
D	100	3	Fine sand	70	4.7	85.9	<0
G	30	7	Silty sand	70	1.4	111.0	-

* F-M sand (SP), nonplastic, maximum vibrated γ_d = 108.2 pcf, minimum γ_d = 89.9 pcf.
Fine sand (SP), nonplastic, maximum vibrated γ_d = 104.9 pcf, minimum γ_d = 90.2 pcf.
Silty sand (SM), D_{50} = No. 200 sieve, LL = 15, PL = 14, PI = 1.

** EOS = equivalent opening size.

under a 500 lb./ft.^{2} surcharge. Because of high head losses through the base valve, trap, and standpipe, the maximum head differential was only about one foot even though the elevation of the constant head reservoir was several feet about tailwater elevation. The Lucite cylinder cracked upon application of 1000 lb./ft.^{2} surcharge, and the test was discontinued. Sand density after testing was 97.5 lb./ft.^{3} in the top 1.0 in. and 95.7 lb./ft.^{3} in the lower 1.0 in., compared with the initial density after saturation of 95.4 lb./ft.^{3}. Plots of head losses through the soil specimen and filter cloth under 0 and 500 lb./ft.^{2} surcharge conditions are shown in Figure 10. Because of the variation in density of the specimen, it is noted that the head loss throughout the specimen, even with no surcharge applied, was not uniform. Peizometer No. 2, only 0.2 in. above the filter cloth but adjacent to the aluminum ring on which the filter cloth was affixed, read the same as tailwater. (This was also found to be true in tests 2 and 3 for the piezometer nearest the filter cloth). There was no indication of sand infiltration through the cloth or piping within the sand specimen during any period of the test (maximum water velocity = 0.16 ft./min.). Sieve analyses of the material taken from the top and bottom of the soil specimen showed practically identical gradations. Figure 11 shows the condition of the upper and lower surfaces of the cloth at the end of the test. There were no indications of clogging. Indentations caused by the pressure of the limestone fragments are clearly visible in the photographs; however, there were no tears or punctures in the cloth.

Results Using Fine Sand (Test No. 2). In this test, application of a 1000 lb./ft. surcharge was also attempted, the Lucite cylinder

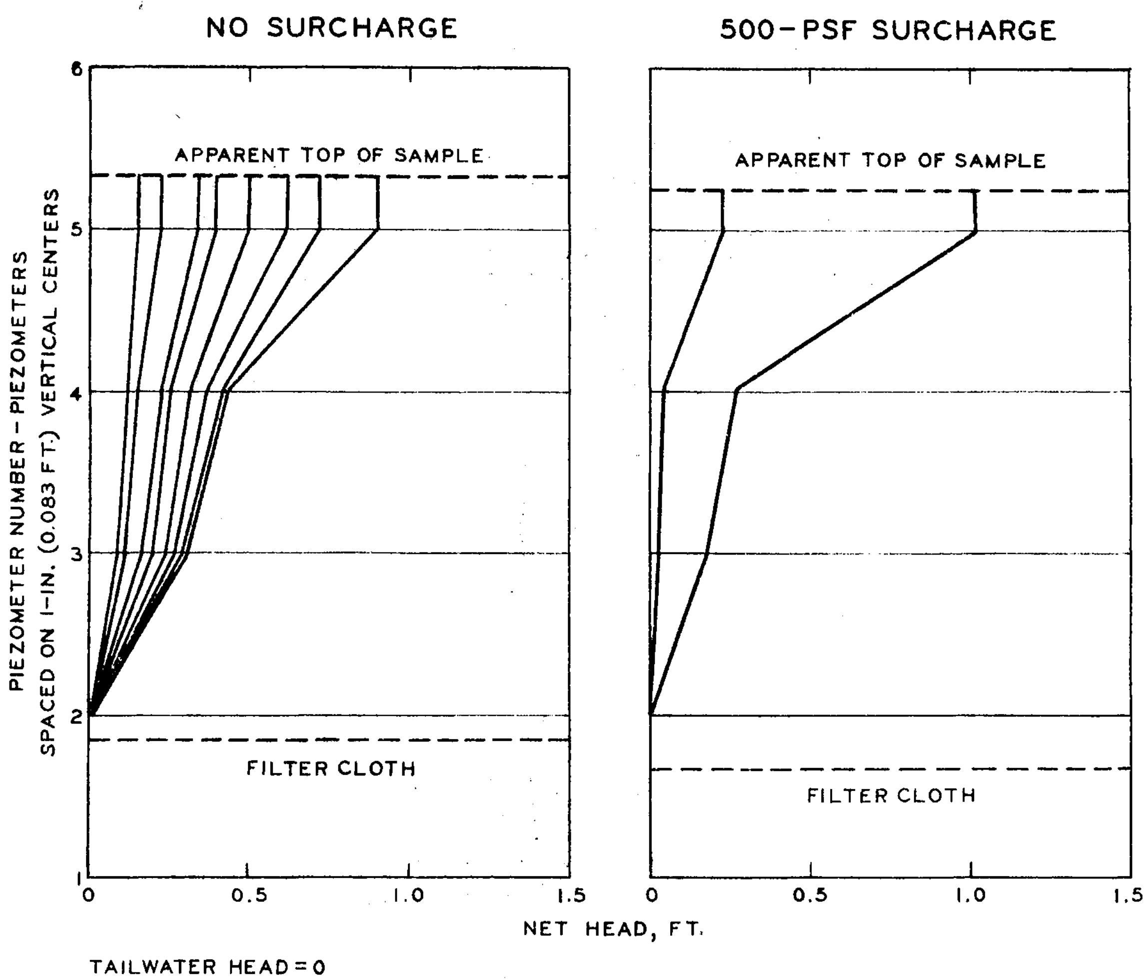
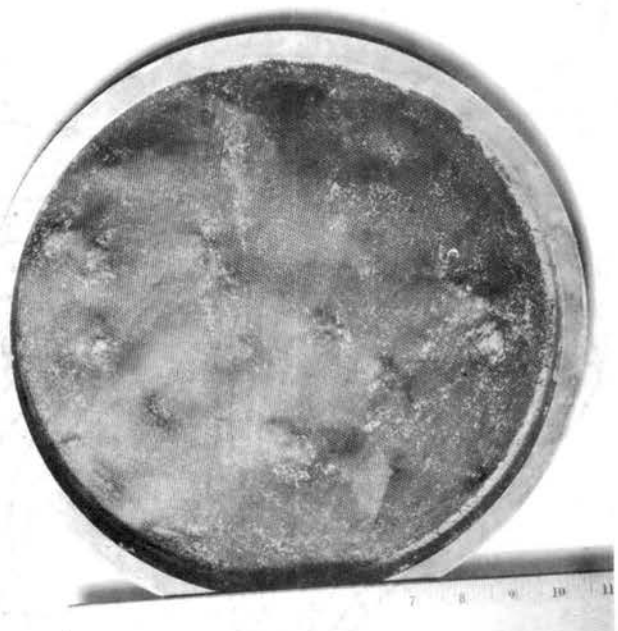
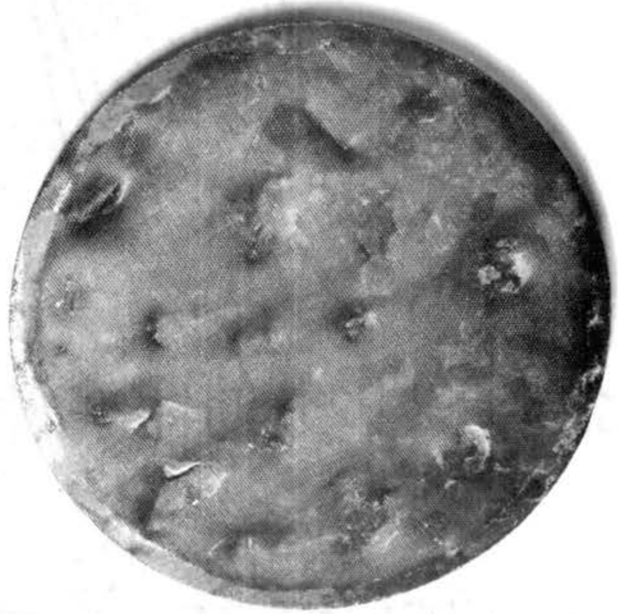


Figure 10. Head Losses Through Sample and Cloth B, Test 1



a.) Top of Cloth



b.) Underside of Cloth

Figure 11. Cloth B After Completion of Test 1

having been reinforced with steel bands, but the filter cloth separated from the aluminum ring to which it had been bonded and the test had to be terminated. In spite of the fact that 67 percent of the test sand could be washed through the filter cloth, there was no indication of infiltration of sand at any time during the filtration test (maximum water velocity = 0.15 ft./min.); the gradation of the material taken from the top of the sample at the end of the test was practically identical to that of the bottom. The condition of the cloth after testing was similar to that shown in Figure 11. There were no tears or punctures. Head losses through the sand and filter cloth under 0 and 500 lb./ft.^{2} surcharge were plotted in Figure 12.

Results Using Silty Sand (Test Nos. 5 and 6). The purpose of these tests was to see if the presence of silt sizes would cause the cloth to clog or would cause more movement of soil through the cloth. There were some difficulties experienced saturating the samples prior to the filtration tests. The presence of air undoubtedly affected the results and perhaps affected the response of the piezometers. In some instances, the vacuum was applied for two to three hours without effecting complete air removal. In test 5, upon application of the initial head (hydraulic gradient through the entire soil sample and cloth of about 1.5), the water discharge was discolored, but cleared within five minutes. The discharge remained clear throughout the application of higher heads to the maximum applied (hydraulic gradient = 29). When the flow was initiated after the 500 lb./ft.^{2} surcharge was applied (hydraulic gradient = approximately 0.5), the water was considerably discolored for about 15 min. before clearing. It was also noted that the pea gravel was being pushed into the soil when the surcharge was

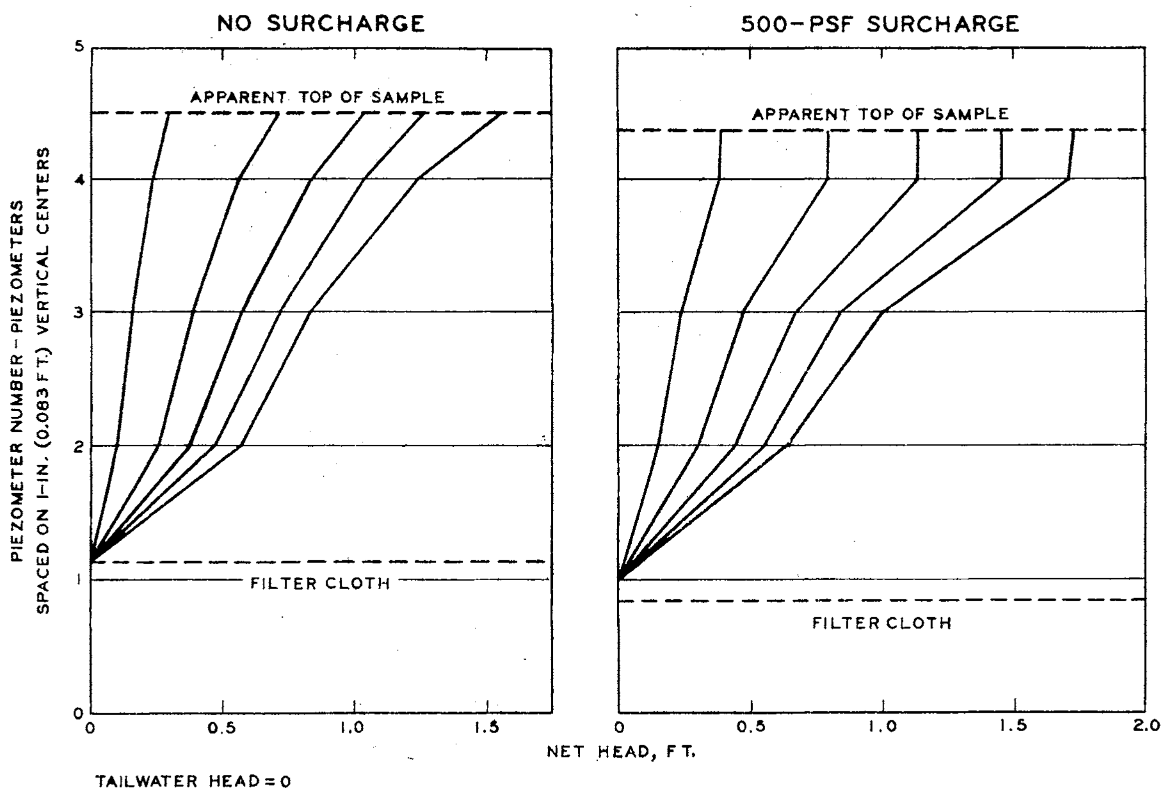


Figure 12. Head Losses Through Sample and Cloth B, Test 2

applied. The discharge also was discolored when the permeameter was first struck with a rubber mallet; under continued striking, the water cleared. The shape of the plots of velocity versus hydraulic gradient shown in Figure 13 indicates no significant clogging of the cloth as the test was continued. Following the test, grain-size analysis on material from the lower 1/2 in. of the sample indicated that a considerable amount of fines had passed through the cloth, as only 39 percent of the remaining material was smaller than the No. 200 sieve, compared to 50 percent in the soil as placed. Figure 14 shows the underside of the cloth after the test was completed; silt adhering to the cloth can be noted. It should be noted that 71 percent of the test soil could be washed through the cloth. The second test on cloth B (test 6) using the same silty sand was performed to determine if material passing the cloth in test 5 was largely from seepage forces or was squeezed through the cloth by the pressure of the surcharge. In this test no limestone fragments were used below the filter cloth. The holding ring for the filter cloth was supported above the base of the permeameter to permit the underside of the filter cloth to be viewed during the test. The soil was loosely placed to a height after saturation of 1.6 in. No satisfactory determination of density could be made since some material was lost into the overlying pea gravel during saturation. An overall maximum hydraulic gradient of 53 was applied in increments. On the application of the initial hydraulic gradient of 0.3, the discharge was slightly discolored but cleared within 5 min. and remained clear throughout the application of increasing hydraulic gradients. The shape of the plot of velocity versus hydraulic gradient in Figure 15 indicates no significant clogging of the cloth as the test was

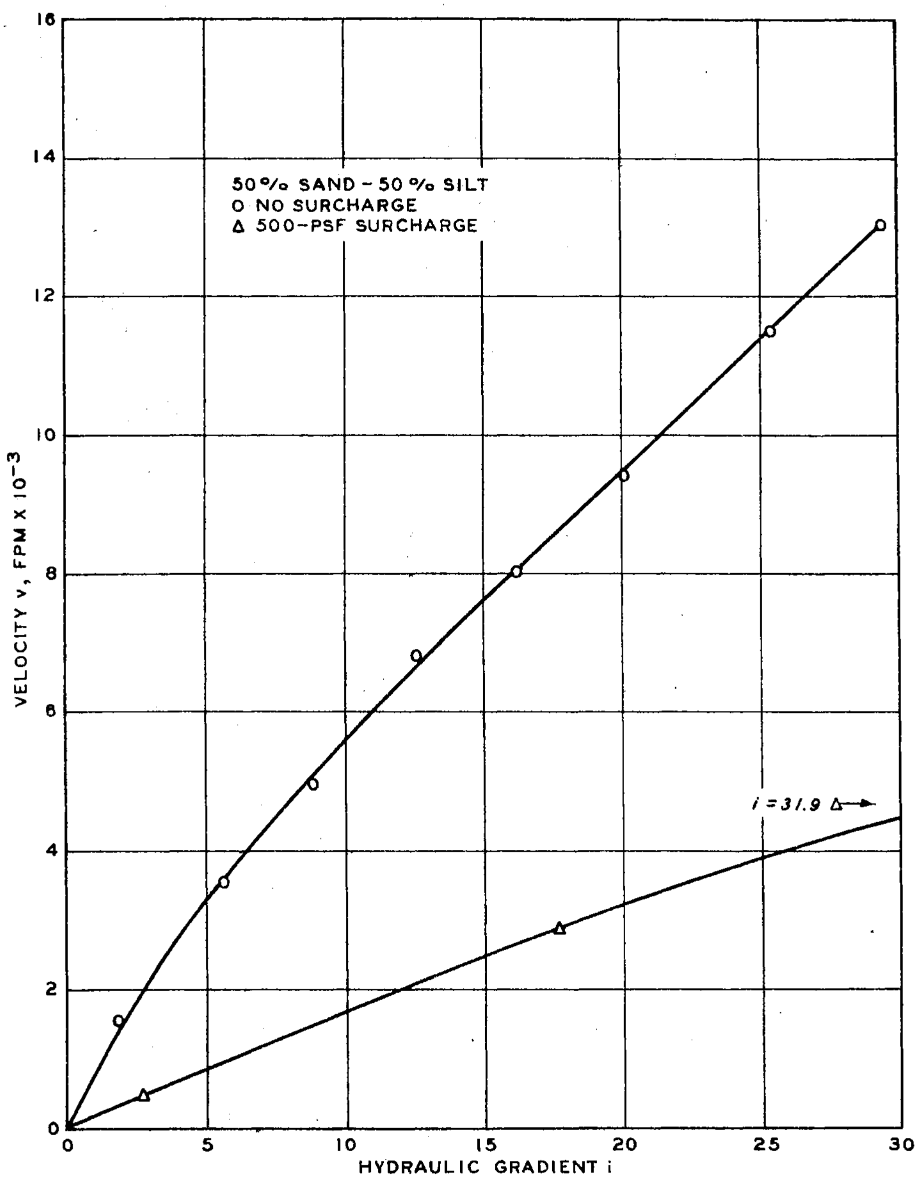


Figure 13. Velocity Versus Hydraulic Gradient; Cloth B, Test 5

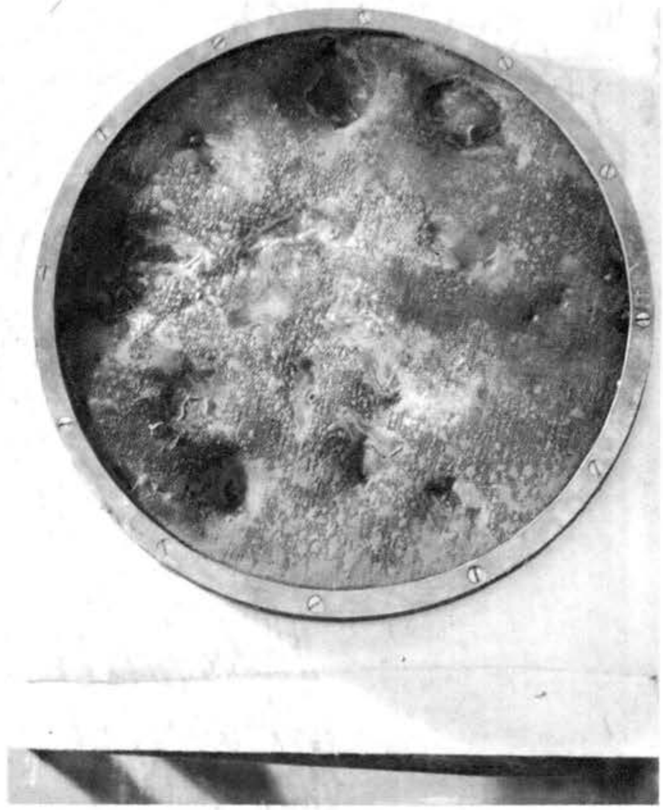


Figure 14. Cloth B After Completion of Test 5 (Underside of Cloth)

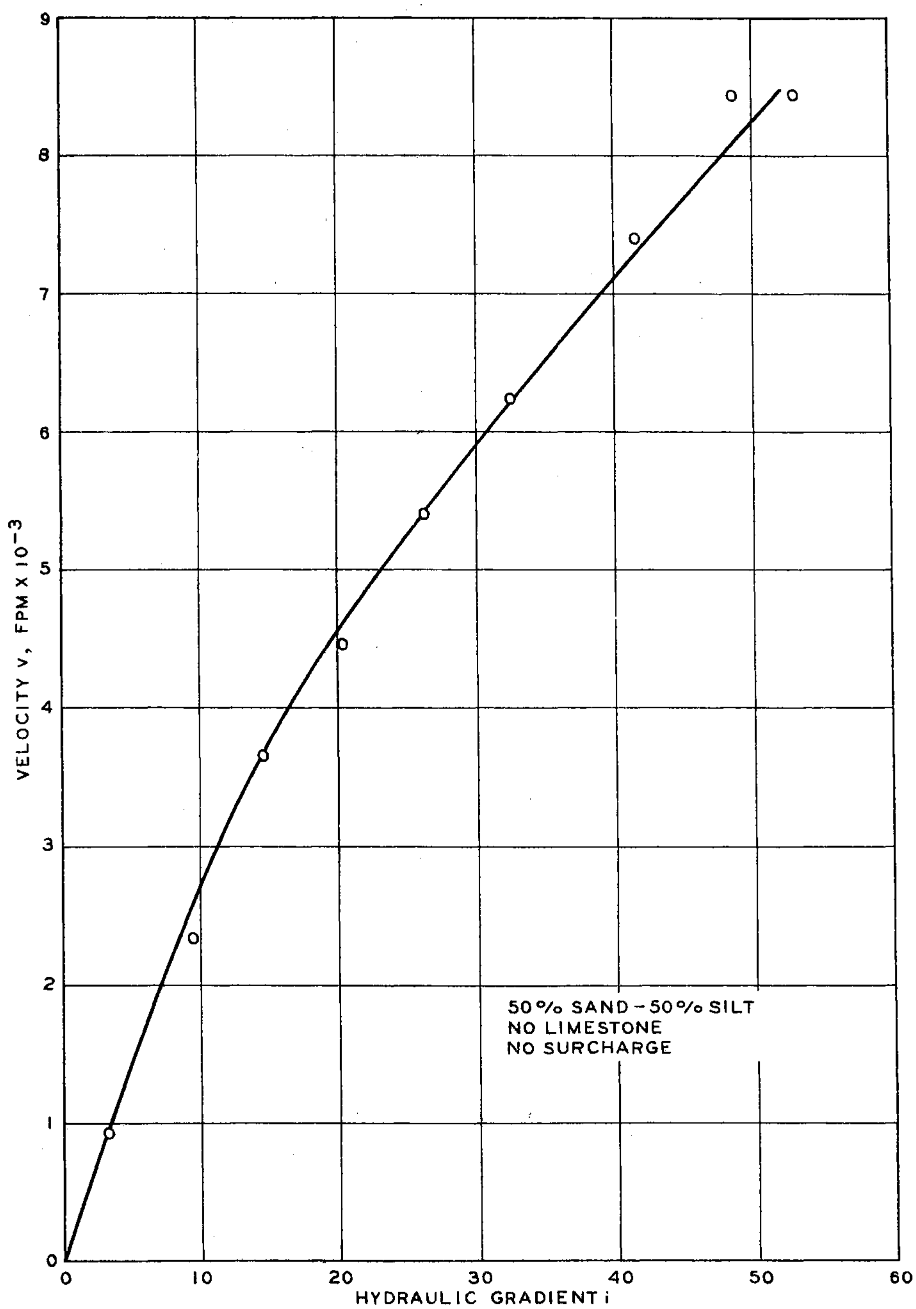


Figure 15. Velocity Versus Hydraulic Gradient; Cloth B, Test 6

continued. When the apparatus was struck with a rubber mallet, the discharge became cloudy. It appeared, however, that this material was coming from between the rim of the cylinder and the aluminum ring where some soil had been trapped above the O-ring during placement. Striking the apparatus allowed the material to pass the O-ring. After the material passed, the water was clear under continued striking. The underside of the cloth remained clean. Sieve analyses on two samples taken from the top of the sand indicated no change in the gradation of the material from the as-placed condition. Sieve analyses from the lower 1/2 in. of the sample indicated only a slight reduction in the percent passing the No. 200 sieve, indicating that very few fines passed through the cloth.

Cloth C, Using F-M Sand (Test No. 4). There were no evidences of any material passing through the cloth at velocities up to 0.15 ft./min. Gradations of the material taken from the top and bottom of the sand specimen after test were practically identical. Figure 16 shows the underside of the cloth after it was removed from the apparatus and washed. There was no indication of any clogging. There were no tears or punctures in the cloth. Head losses through the sand and filter cloth under 0, 500, and 1000 lb./ft.^{2} surcharges are shown in Figure 17.

Cloth D, Using Fine Sand (Test No. 3). The sand density in this test was also less than the minimum dry density determined in the laboratory, because of loosening during upward saturation. Although 71 percent of the test sand could be washed through the cloth, there was no infiltration of sand through the cloth during any phase of the filtration test (maximum water velocity = 0.14 ft./min.). Gradations of the sand taken from the top and bottom of the sample specimen after

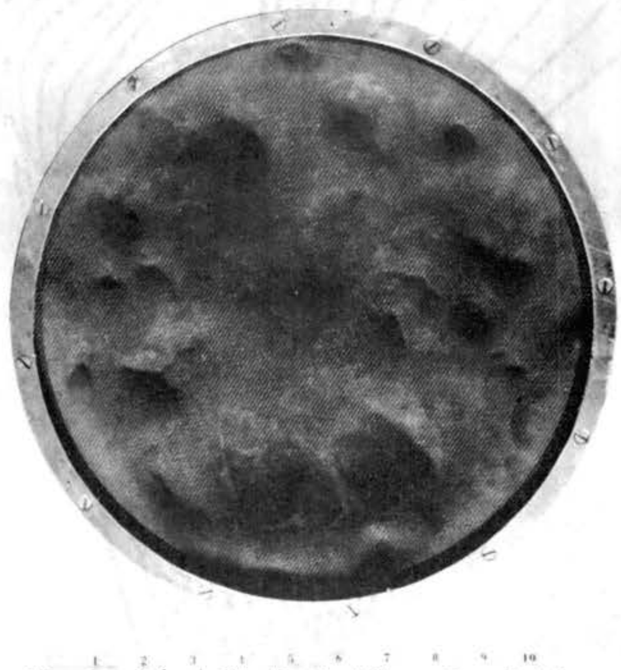


Figure 16. Cloth C After Completion of Test 4 (Underside of Cloth After Washing)

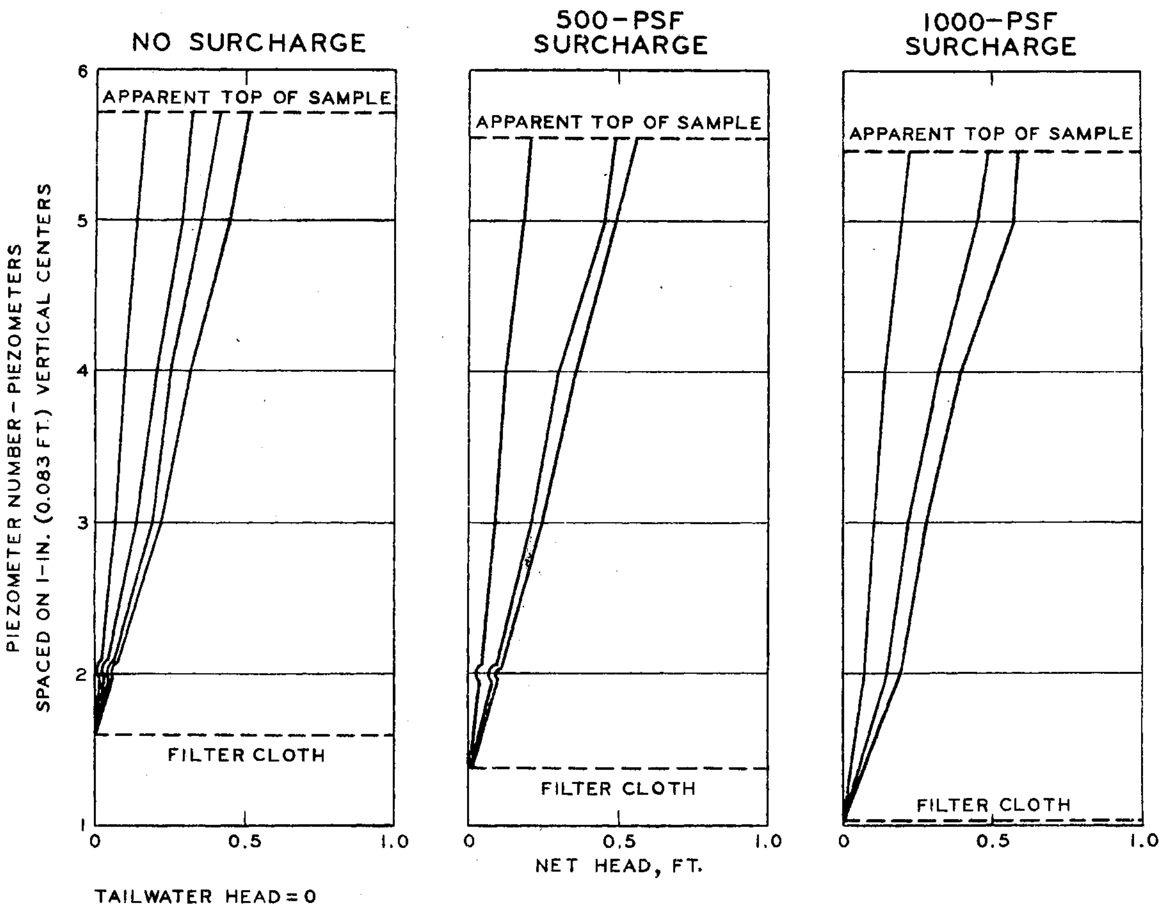
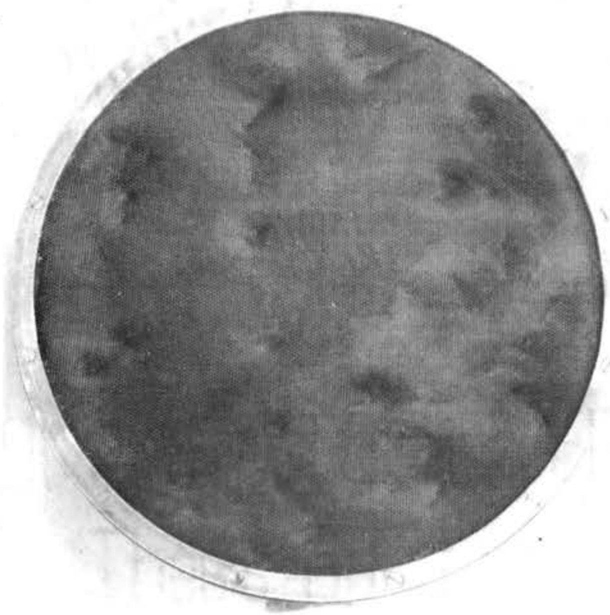


Figure 17. Head Losses Through Sample and Cloth C, Test 4

test were essentially unchanged from the initial gradation. Figure 18 shows the under surface of the cloth immediately after testing. The lighter areas are powder from the limestone fragments; some chipped edges of the limestone are also visible. Indentations from the limestone are shown more clearly in a photograph made after washing the cloth. There was no indication of any sand particles embedded in the openings. Head losses through the sand and filter cloth under 0, 500, and 1000 $lb./ft.^2$ surcharges are shown in Figure 19.

Cloth G, Using Silty Sand (Test No. 7). This was the only filtration test performed in the 5.0 in. ID apparatus. Cloth G was tested since it had the most open weave of any cloth. The height of soil above the cloth was 1.36 in., and the soil had a dry density of 111.0 $lb./ft.^3$. As in the previous two tests, the water became cloudy upon application of the initial head (hydraulic gradient = 4.2), but cleared in a matter of minutes. The discharge remained clear throughout application of the higher heads up to the maximum applied (hydraulic gradient = 35). A plot of velocity versus hydraulic gradient for this test is shown in Figure 20. The abrupt change in velocity at a hydraulic gradient of 13, shown on the plot, probably resulted from a change in density of the soil sample. The lower velocity reading was taken at the conclusion of the workday and the test discontinued overnight. The next morning it was found that the constant head reservoir had emptied, thereby reducing the hydrostatic pressure on top of the soil and creating a pressure differential between the top and bottom of the soil. It is thought that the upward flow through the soil loosened it, thereby increasing its permeability. The discharge became cloudy when the apparatus was struck with a rubber mallet under the highest gradient

a.) Underside of Cloth Before Washing



b.) Underside of Cloth After Washing

Figure 18. Cloth D After Completion of Test 3

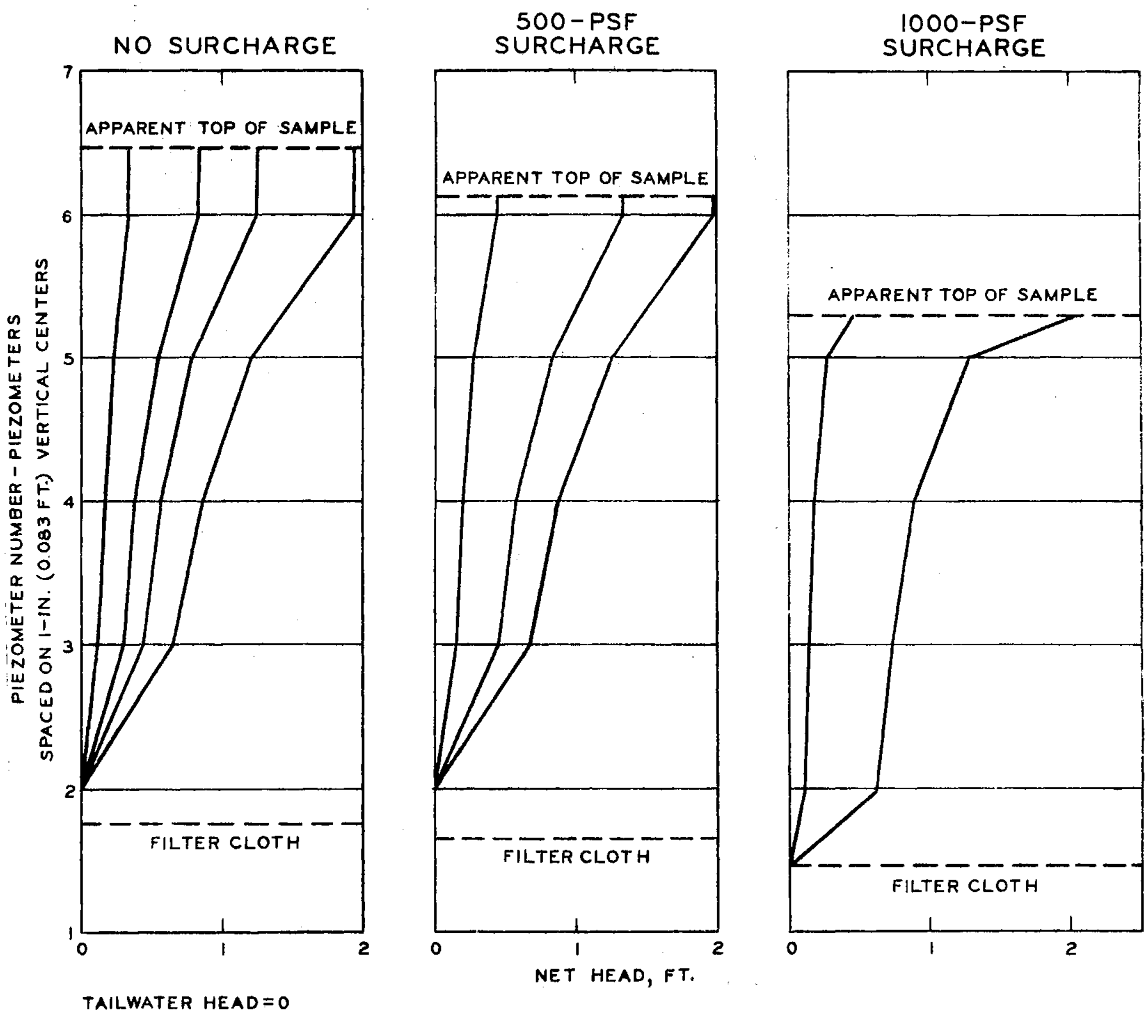


Figure 19. Head Losses Through Sample and Cloth D, Test 3

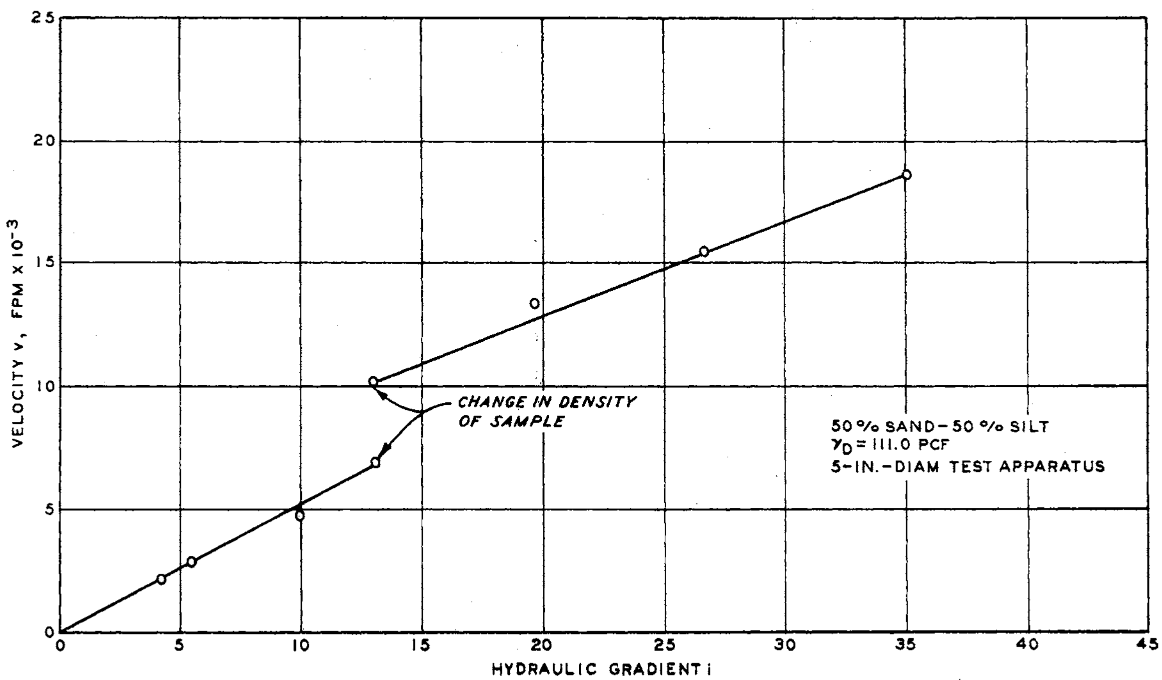


Figure 20. Velocity Versus Hydraulic Gradient; Cloth G, Test 7

applied. The water cleared in less than five minutes and remained clear when the apparatus continued to be struck. During removal of the soil from the apparatus, the cloth slipped from between the flanges and the soil dropped into the bottom of the apparatus, disturbing it to the extent that no further analysis could be made.

Summary of Filtration Tests. Tests 2 through 4 indicated that woven filter cloths will effectively retain loose uniform sands when the D_{85} size of the sand was equal to or greater than the equivalent opening size of the cloth. Maximum velocity of flow during the tests was 0.16 ft./min. Because of density variations within the soil specimens and the influence of the aluminum securing ring on the piezometer readings, no accurate indication of head losses through the cloths was obtained. As will be discussed later, some insight into these head losses was obtained during the clogging tests.

Tests 5, 6, and 7 indicated that cloths B and G would effectively retain and prevent piping of the silty sand at hydraulic gradients up to about 50 (maximum tested). Since cloth G had the most open weave of any of the cloths tested (equivalent opening size = No. 30, open area = 36 percent), it was not considered necessary to test the remaining cloths.

No filtration tests were run on cloths E and F since it was obvious from their tight weaves that sand could not pass through them. They were subjected to clogging tests later in the test program. In none of the tests with surcharge loads of 500 lb./ft.^{2} and in some cases 1000 lb./ft.^{2}, did any punctures, tears, or other significant alterations occur in any of the cloths tested.

Clogging Tests

General. Clogging tests were performed on cloths A, E, and F. Cloth A was selected because it had been widely used in the field and had a low equivalent opening size (U. S. No. 100 sieve size). No tests were performed on cloths B, C, D, and G because their equivalent opening sizes were equal to or larger than that of cloth A and their percent open areas was about the same or greater. Cloths E and F were also tested since they had no distinct openings and were thought to be susceptible to clogging. As there was some variation in the net head applied during the tests, all flows and hydraulic gradients measured throughout the samples were related to the hydraulic gradient measured from the tailwater piezometer (piezometer No. 1) to the first peizometer below the top of the specimen (piezometer No. 6). This hydraulic gradient was designated as i'. By dividing the hydraulic gradients measured through various 1.0 in. vertical increments of the soil by i', an indication of variation in silt content (clogging in the case of the lowest 1.0 in. soil increment plus the cloth) could be obtained. The ratio of the hydraulic gradient through the lowest 1.0 in. of soil plus filter cloth to i' at the conclusion of the test was termed the "clogging ratio." A ratio greater than 1.0 would indicate clogging while a ratio less than 1.0 would indicate a loss of fines. Of course, density variations in the sample would affect the results of the test. However, in tests on sand alone, the variation in hydraulic gradients of the 1.0 in. layers was found to be in the range of 10 to 30 percent. In all tests there was initial infiltration of silt through the cloth when the test was initiated or restarted after shutdown for a new supply of water. The water always cleared in from 3 to 10 min. The water temperature during a test varied only by 1° to 3°C. and was not considered in the analysis. Results of these tests are summarized in Table III and in the figures discussed in subsequent paragraphs.

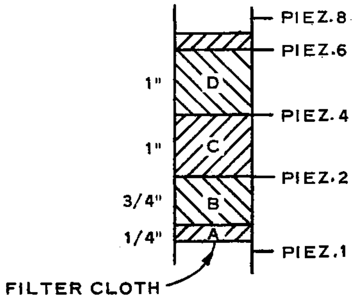
Cloth A. The results of clogging tests on cloth A are shown in Figures 21 through 24. The flow measurements are not considered particularly significant other than the fact that they indicated no consistent decrease in flow during the tests. The clogging ratio at 20 percent silt was 1.06, which was slightly lower than that measured on the sand alone. At 5 and 10 percent silt, the clogging ratios were less than 1.0. The relatively high head loss between piezometer Nos. 4 and 6 in the test on the 10 percent silt mixture was attributed to fines segregated during placement settling on and in the top 1.0 in. of the sample. This was verified by the relatively large percentage of silt found in the section (see Table III). Visual inspection of the top of the cloth after the test revealed an obvious increase in fines on and just above the cloth for the 5 and 10 percent silt tests. This was also shown by the silt contents measured throughout the sample. Although a silt content of only 10.5 percent was measured in the soil adjacent to the cloth at the conclusion of the 10 percent test, the silt content was higher at that location than any other within the sample. There was a cake of fines on top of the soil which would reduce the overall silt content. Because of the high percentage of fines initially in the soil, it was not possible to detect a cake at the conclusion of the 20 percent test. However, the measured silt content was higher adjacent to the cloth than throughout the sample. Although

TABLE III

SUMMARY OF CLOGGING TEST RESULTS

Filter Cloth	Soil Sample: Initial Percent Silt	Soil Sample: Dry Density pcf	Maximum Hydraulic Gradient i'	q/i' cc/min.	Clogging Ratio	Silt Content (%) After Test at Location: A*	B*	C*	D*
A	0	105.7	0.56	2214	1.07	0	0	0	0
	5	114.7	0.82	1055	0.95	9.6	3.9	3.6	4.0
	10	114.0	0.88	875	0.82	10.5	5.6	6.9	8.5
	20	118.9	1.24	129	1.06	19.5	13.2	17.5	17.9
E	0	-	0.60	1933	1.10	0	0	0	0
	5	107.5	0.72	1319	1.00	10.4	2.8	4.2	3.3
	10	-	0.74	1216	1.33	19.5	7.2	17.8	12.5
	20	129.7	1.12	277	1.61	18.2	12.9	10.9	19.6
F	0	105.7	0.56	1732	0.96	0	0	0	0
	5	104.1	0.72	1069	1.67	9.5	3.8	3.5	4.0
	10	101.4	0.88	489	1.98	14.4	-	6.5	9.7
	20	115.1	1.18	83	1.60	18.9	18.1	18.6	13.0

* Piezometers were located in the test apparatus as shown in the sketch below.



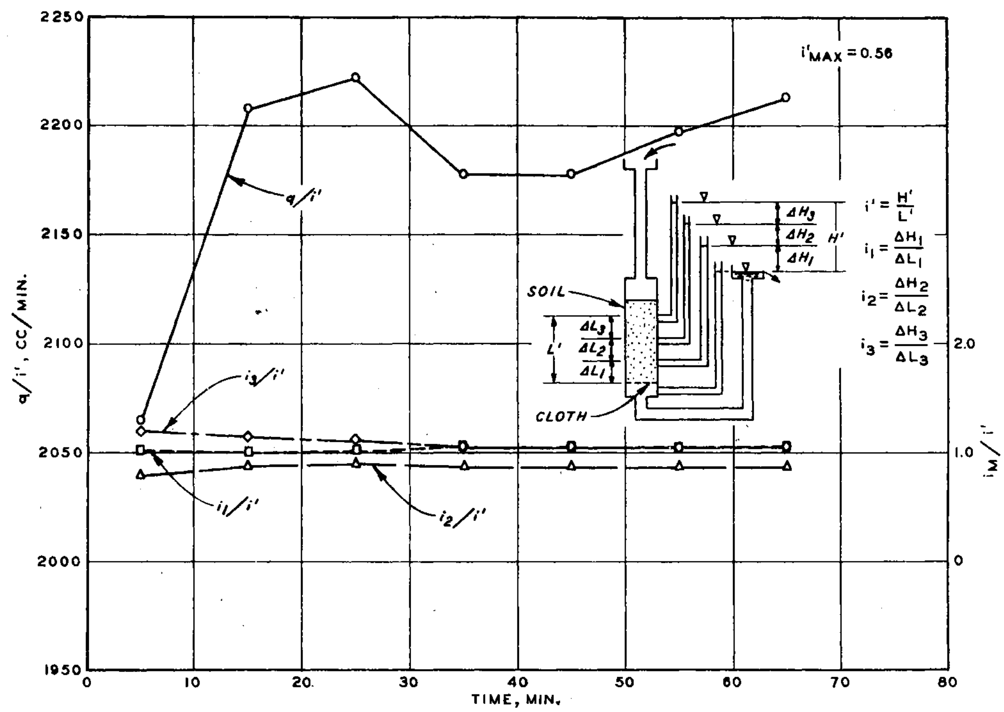


Figure 21. Clogging Test, Cloth A, No Silt

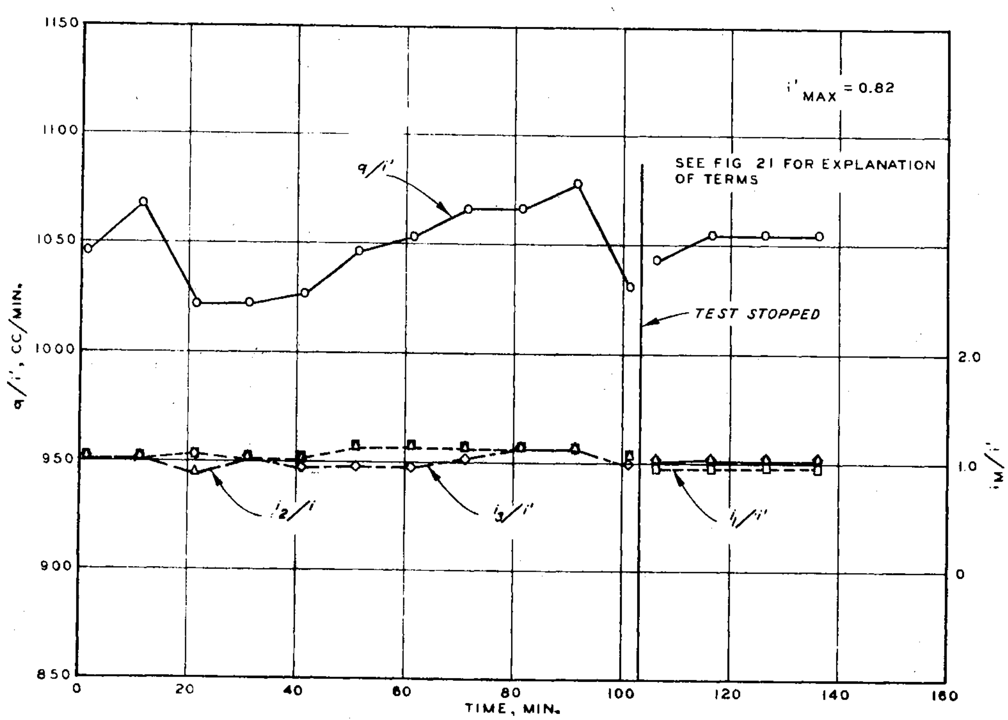


Figure 22. Clogging Test, Cloth A, Five Percent Silt

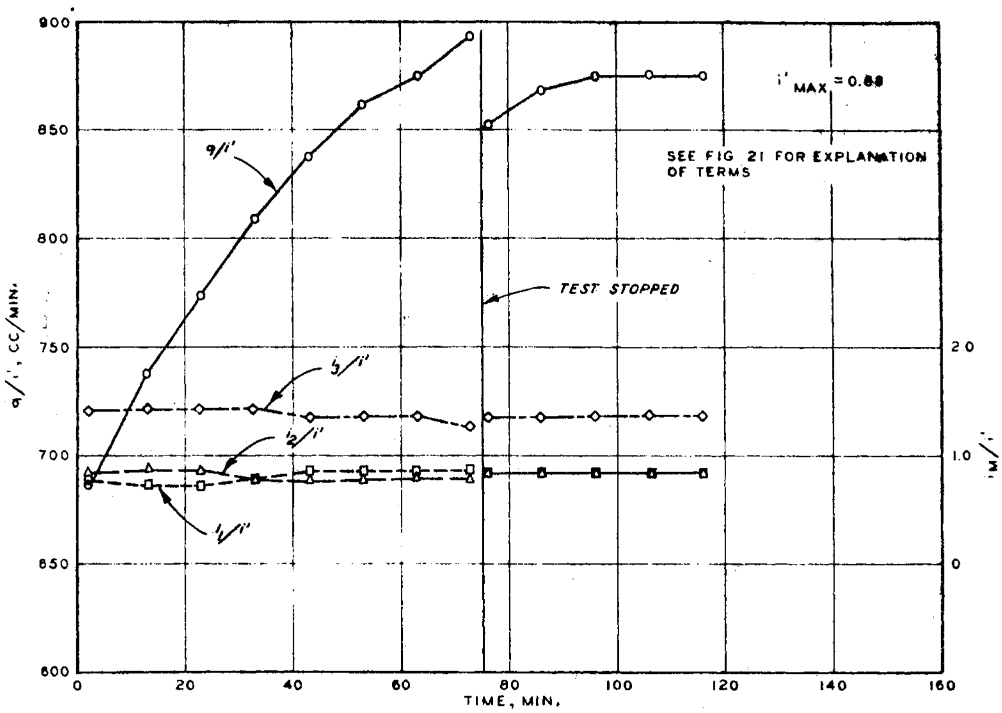


Figure 23. Clogging Test, Cloth A, 10 Percent Silt

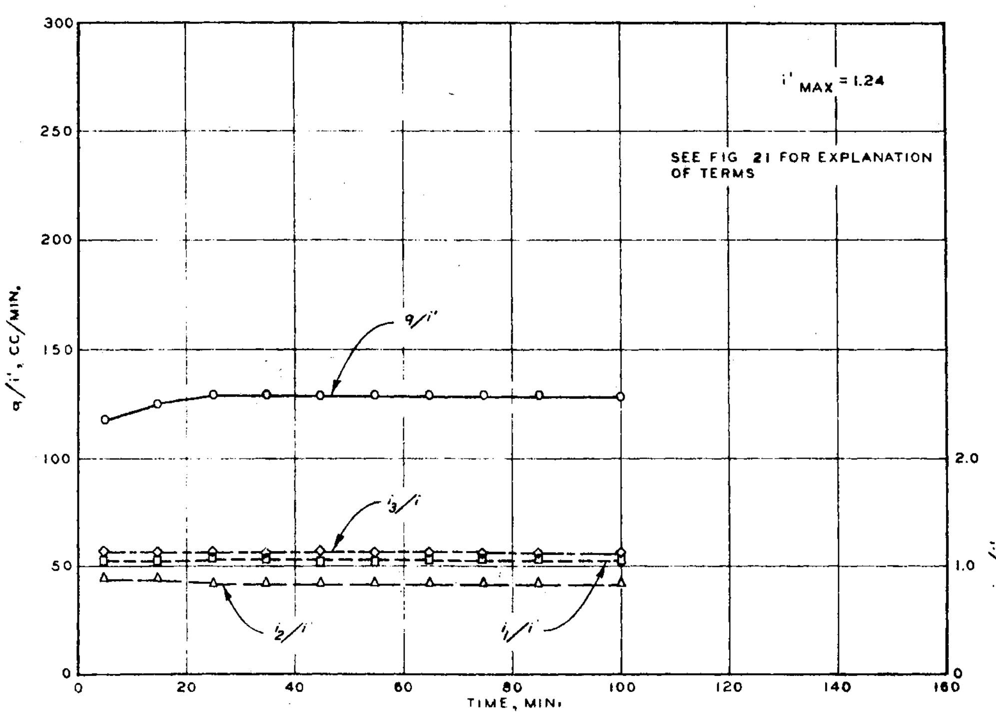


Figure 24. Clogging Test, Cloth A, 20 Percent Silt

cakes of fines developed in the 5 and 10 percent silt tests and probably in the 20 percent silt test, there appeared to be no significant head loss through the cloth as shown in the figures and by the low clogging ratios obtained.

Cloth E. The results of the clogging tests on cloth E are shown in Figures 25 through 28. The erratic behavior of the flow measurements in the test on sand was probably due to a steadily increasing i' (from an initial 0.32 to 0.66 at conclusion) during the test. Since the piezometers were read after flow measurements were made, the particular flow measurement may not have corresponded to the head differentials recorded some minutes later. Cloth E showed no tendency to clog at five percent silt. However, with soils having 10 and 20 percent silt contents, clogging ratios of 1.33 and 1.67, respectively, were indicated. As in the case of the previous tests, the flow measurements indicated no reduction due to clogging. Cakes of silt were found on the cloths at the conclusion of the 5 and 10 percent tests. A relative silt increase was measured when the 20 percent silt test was completed, but a cake could not be visually detected because of the large silt content of the soil.

Cloth F. Results of tests on cloth F are given in Figures 29 through 32. Clogging ratios of 1.67, 1.98, and 1.60 were determined in the 5, 10, and 20 percent tests, respectively. There were considerable decreases in flow with time in tests using sand with no and five percent silt. Since the reduction occurred with no silt present in one test, the flow reduction in the five percent test cannot be attributed entirely to clogging. Probably there was some densification of the soil under the downward gradient. Inspection of the cloths after the 5 and

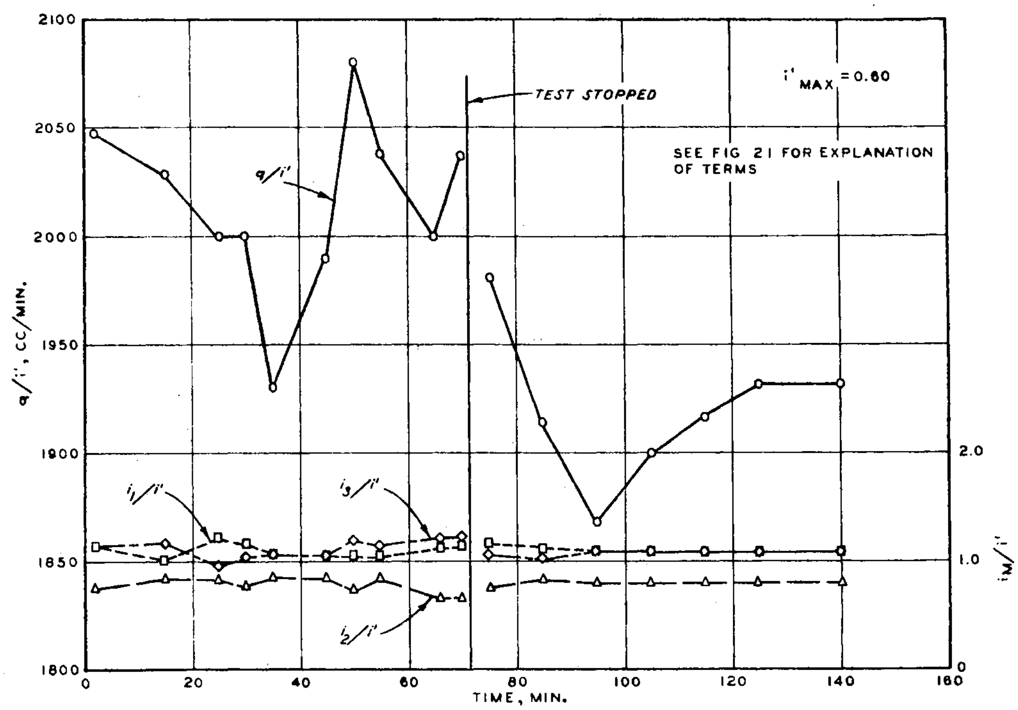


Figure 25. Clogging Test, Cloth E, No Silt

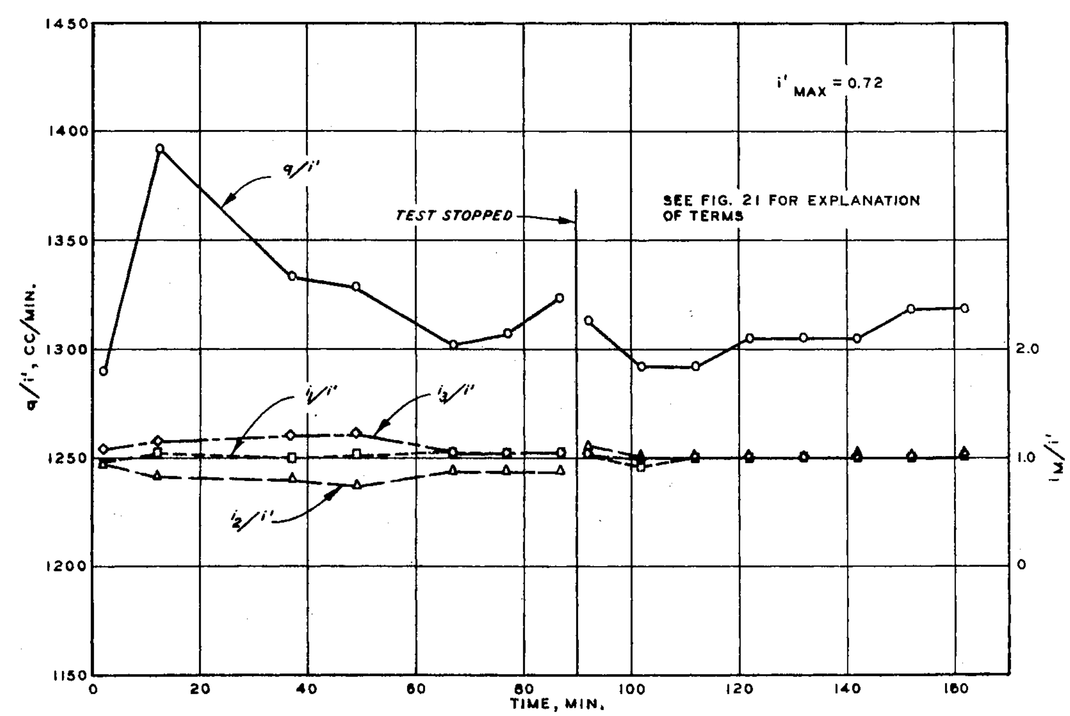


Figure 26. Clogging Test, Cloth E, Five Percent Silt

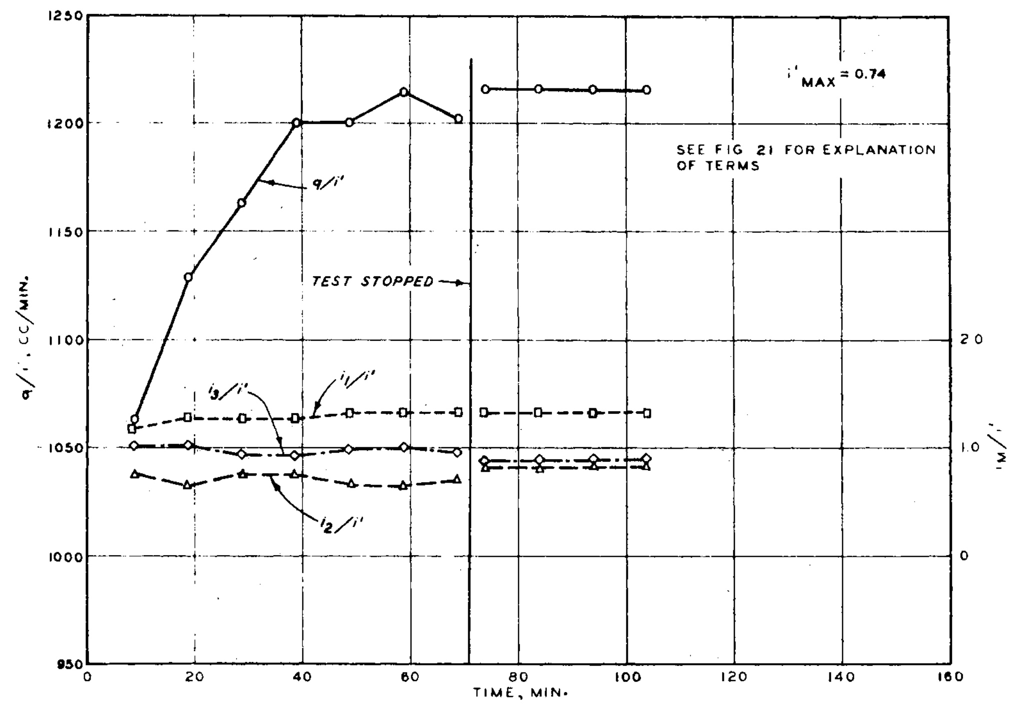


Figure 27. Clogging Test, Cloth E, 10 Percent Silt

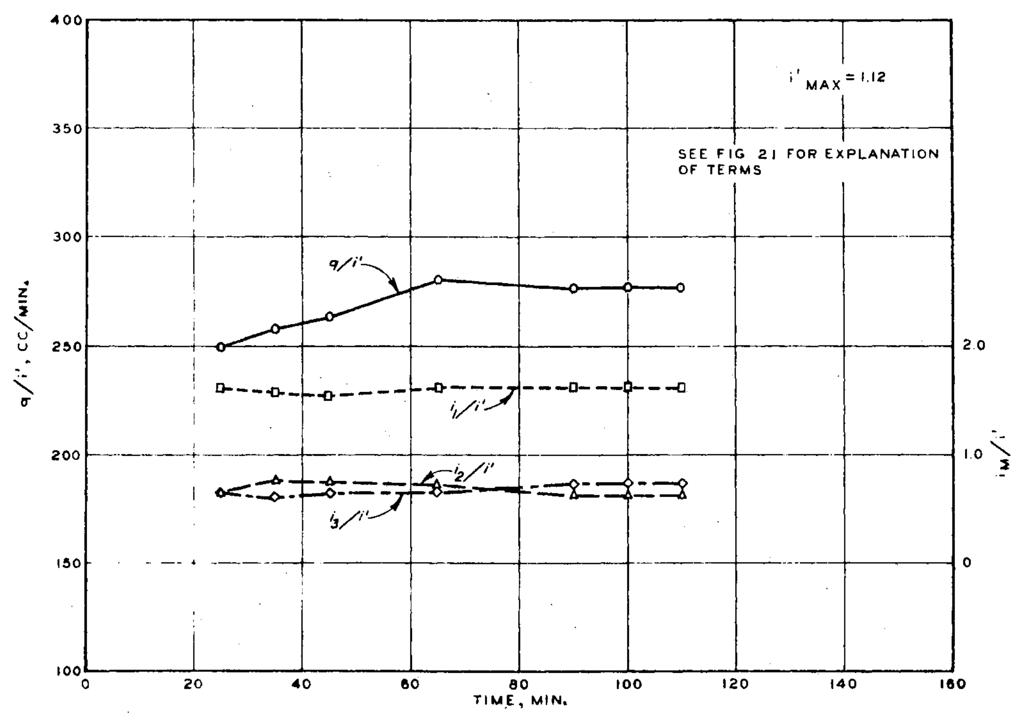


Figure 28. Clogging Test, Cloth E, 20 Percent Silt

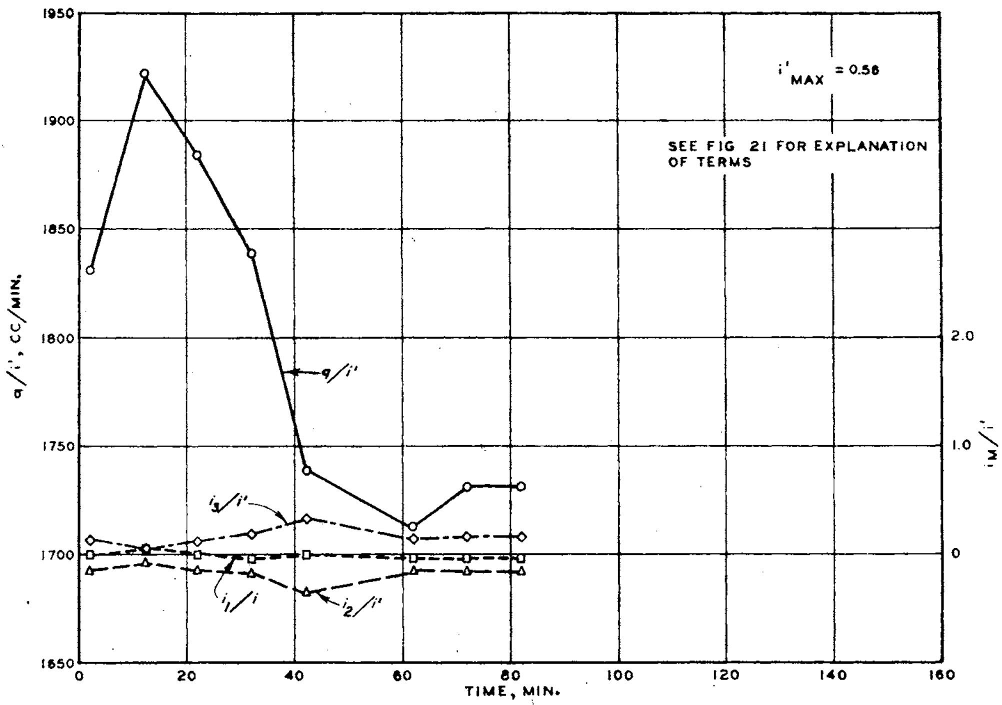


Figure 29. Clogging Test, Cloth F, No Silt

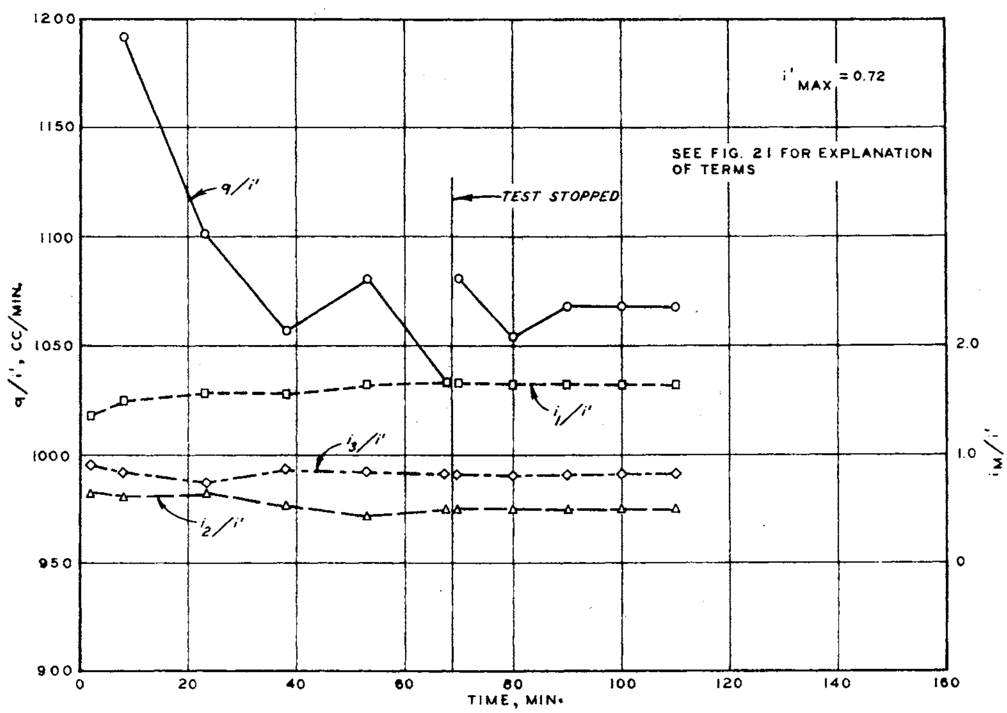


Figure 30. Clogging Test, Cloth F, Five Percent Silt

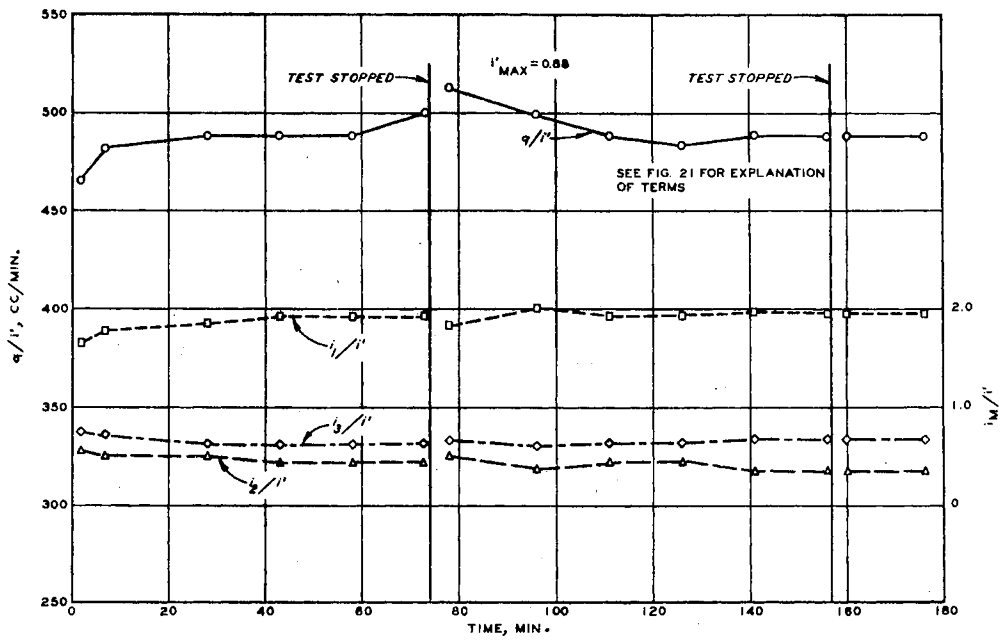


Figure 31. Clogging Test, Cloth F, 10 Percent Silt

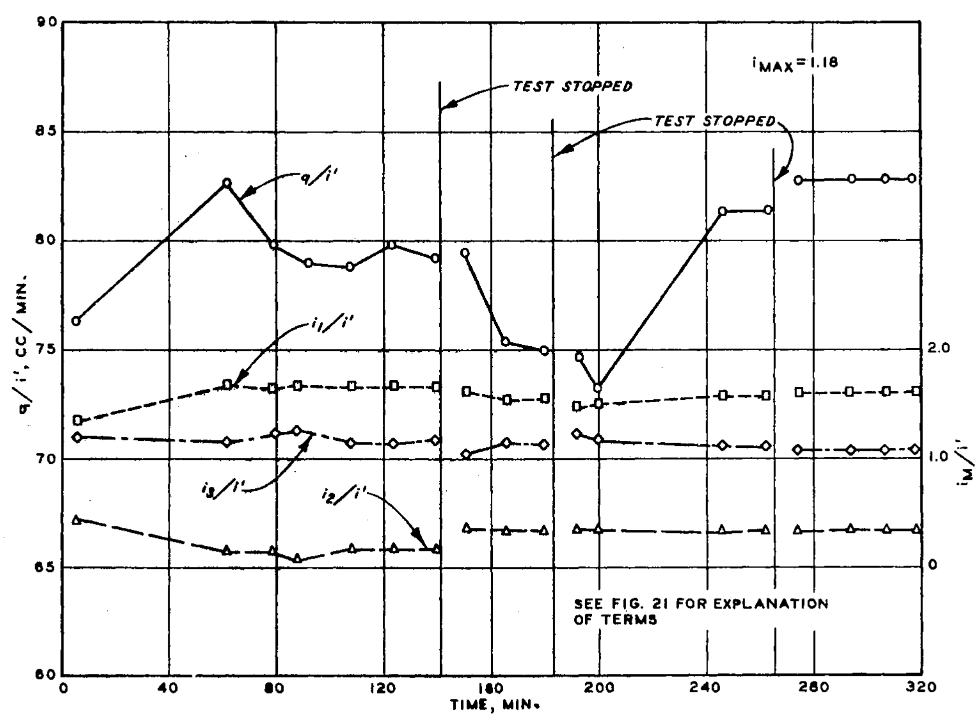


Figure 32. Clogging Test, Cloth F, 20 Percent Silt

10 percent tests revealed obvious caking of fines on and within the entangled fibers of the cloth. Fines within the cloth were noted after the 20 percent test also. Visual inspection indicated that caking was more severe on this cloth than the other two cloths studied. The cloth remained impregnated with fines even after it had been washed. Any fines on cloths A and E were easily removed by washing.

Summary of Clogging Tests. Flow measurements taken during the clogging test were not conclusive. However, it is thought that the clogging ratios are valid indications of the degree of clogging of the cloths. The nonwoven cloth F was particularly susceptible to clogging with a maximum clogging ratio of 1.98 obtained in the test with soil containing 10 percent silt. Cloth E, without distinct openings, showed a tendency to clog from soil having 10 to 20 percent silt content, while cloth A, with distinct openings, had clogging ratios near 1.0 for all gradations tested, indicating no significant clogging. The tests with sand containing no silt showed no significant head loss through the filter cloth when compared to head losses through the entire soil column.

CHAPTER IV

FIELD AND HYDRAULIC TESTS

Field tests were conducted to supplement field performance and laboratory data. Tests were conducted by dropping large angular stones on the cloths to evaluate their resistance to tearing and puncture under field placement conditions. Prior to the initiation of this study, field exposure tests on cloths A and B had been in progress in connection with another study at the Waterways Experiment Station. These tests were continued as a part of this study. As has been previously discussed, the filtration tests yielded no information on head losses through the cloths. Therefore tests were conducted in a Waterways Experiment Station hydraulics laboratory to determine the head losses through the cloths with no adjacent soil.

Stone Drop Tests

The strength of a filter cloth must be such that it will not tear or puncture when stones, riprap, rubble, etc., are placed on it. These holes will destroy the continuity of the filter system and will provide areas susceptible to piping. Field performance data collected throughout the study had indicated that cloth B had performed satisfactorily under every loading it has been subjected to, while in some instances cloth A had torn during placement of riprap. Therefore, the strength of cloth B appeared satisfactory, while the strength of cloth A did not appear to be satisfactory. No field data were available on cloths with strengths between the strengths of cloths A and B, and consequently controlled field drop tests were conducted primarily to evaluate the performance of those cloths with intermediate strengths.

Procedure for Testing

Figure 33 is a photograph of the test site. A loess bank was graded to a 1 on 3 slope for placement of the cloths. Initially, it was planned to loosen the upper 2 to 4 in. of the slope with a pulvimixer. However, it was found to be difficult for the pulvimixer to operate up and down the slope and to mix the material to a uniform depth. Also, the resulting surface was thought to provide too soft a bed. Consequently it was decided to simply hand rake the slope before placing the cloths, which provided a smooth uniform bed.

Test strips of the cloths were 15 ft. long and 6 ft. wide, with the exception of cloth G which was only 5 ft. wide. As in most field installations, long dimensions were placed parallel with the toe of the slope. Except for cloths E and F, this orientation resulted in the weaker principal direction being perpendicular to the toe of the slope. For comparative purposes, cloth E was also tested with its weakest principal direction being perpendicular to the toe of the slope. The cloths were loosely placed on the slope and pinned along their edges on three foot centers with 3/16 in. OD, 15 in. long pins. The pins had 1-1/2 in. washers.

In the principal tests, six stones were dropped simultaneously from the bucket of a front-end loader. The weights of the chunky, rather angular stones were as follows:

Figure 33. Overall View of Drop Test Site

Stone No.	Weight lb.	Stone No.	Weight lb.
1	256	4	164
2	192	5	270
3	186	6	141

The stones were hand placed along the lower edge of the bucket for each test. The stones were oriented the same way in each test so that the same pointed portion of each stone would strike the cloth (Figure 34).

Drops were made from 2.5 ft. and then 4.5 ft. on each cloth. Drops of three and five feet had been planned. However, it was discovered that the actual drop was 0.5 ft. less than indicated by the measuring device on the bucket. Each cloth was marked into two sections, seven to eight feet long, and drops from the same height were made on each section. The order of testing was cloths B, A, D, F, C, G, and E. Stone 4 broke after testing cloth A at 4.5 ft., and for the remaining tests, only five stones were used. Stone 4 had not caused any damage to the cloths prior to its breaking. With the exception of Stone 6, the pointed portions of the stones contacting the cloths did not chip or otherwise become altered. On the next to last drop, Stone 6 chipped but the resulting sharp edge was removed before the final drop was made. Any damage to the cloths was recorded, identifying the stone that produced the damage, if detectable.

In less controlled drop tests than the above, dump trucks hauling stones to the test site discharged the stones from approximately a three foot height on other strips of cloths B, C, D, and G placed on the slope. Full bucket loads of stones were dropped by the front-end loader from 2.5 ft. on cloths A, E, and F.

Figure 34. Stones Being Dropped From Bucket

Results of Tests

Results of the stone drop tests on the seven cloths are given in Table IV and in the subsequent subparagraphs.

Cloth A. There was no major damage to cloth A from the 2.5 ft. drop or from the bucket load of stones dumped on the cloth. There was significant damage to the cloth due to the 4.5 ft. drop. A six inch tear caused by the 186 lb. stone (No. 3) is shown in Figure 35. The 256 lb. stone (No. 1) caused a five inch rupture in the cloth and three other smaller tears were also noted.

Cloth B. Cloth B was not significantly damaged by the 2.5 ft. drop (one, one inch tear) or by the stones unloaded from the truck. There were four punctures (about 1/4 in. diameter or smaller) and a two inch long tear (Figure 36) resulting from the 4.5 ft. drop. The particular stone or stones causing this damage could not be determined.

Cloth C. Cloth C was not damaged from the 2.5 ft. drop or the drop from the truck. There was a five inch long tear (Figure 37) in the cloth from the 186 lb. stone (No. 3) dropped 4.5 ft.

Cloth D. There was one small tear in the cloth resulting from the 164 lb. stone (No. 4) being dropped 2.5 ft., but no damage from the stones dumped from the truck. There were two, one inch tears and one, two inch tear in the cloth, all caused by the 186 lb. stone (No. 3) being dropped from 4.5 ft. (Figure 38).

Cloth E. Cloth E oriented in either direction was not damaged from the 2.5 ft. drops. There were two, one inch tears resulting from dropping the full bucket load of stone on the cloth. In the latter case, the cloth was oriented with its weaker principal direction up and

TABLE IV

SUMMARY OF DROP TEST RESULTS

Cloth	Six-Stone Drop* 2.5-ft Drop	Six-Stone Drop* 4.5-ft Drop	Full Truck Load or Bucket Drop
A	2d drop - 1 tear, 1 in. long from stone 3	1st drop - 3 tears: 6-in. tear from stone 3; 1-in. tears from stones 1 and 4	No damage
		2d drop - 2 tears: 5-in. tear from stone 1; 1-in. tear from stone 5	
B	2d drop - 1 tear, 1 in. long from stone 3	1st drop - 4 puncture holes about 1/4-in. diam	No damage
		2d drop - 1 tear, 2 in. long from stone 1	
C	No damage	2d drop - 1 tear, 5 in. long from stone 3	No damage
D	2d drop - 1 tear, <1 in. long from stone 4	1st drop - 1 tear, 1 in. long from stone 3	No damage
		2d drop - 2 tears, 1 and 2 in. long from stone 3	
E (warp direction parallel w/slope	No damage	2d drop - 3 tears, two 1-1/2 in. long from stone 1; one 3 in. long from stone 3	Not tested
E (fill direction parallel w/slope	No damage	1st drop - 2 tears, 1 in. long from stone 3	2 tears** 1 in. long
F	No damage	No damage †	1 tear** 3 in. long
G	No damage	2d drop - 1 tear, 1 in. long	No damage

* Stone 4 (164 lb) broke after testing cloth A at 4.5-ft drop. For the remaining tests only five stones were dropped.

** Test conducted one week after other tests.

† No damage from 7-ft drop.

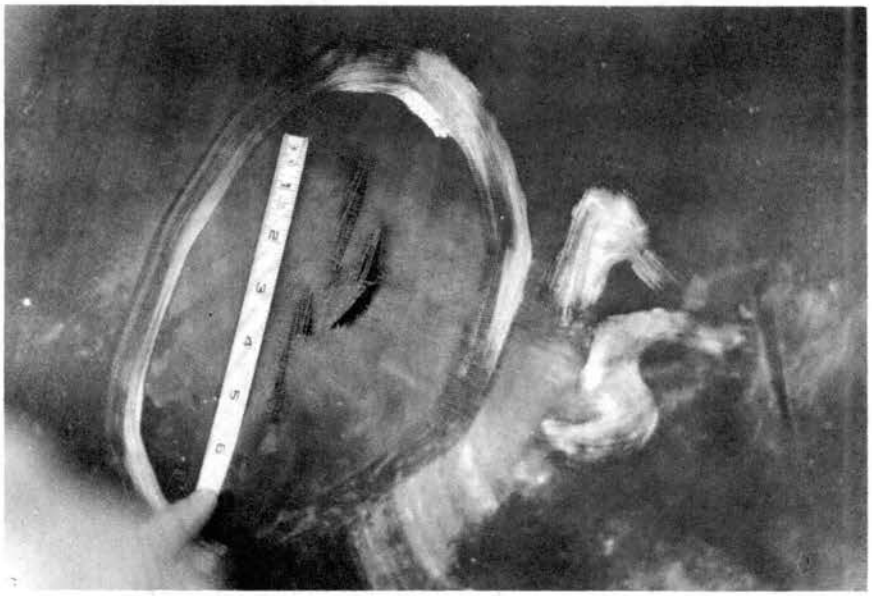


Figure 35. Cloth A, Six Inch Tear After 4.5 ft. Drop

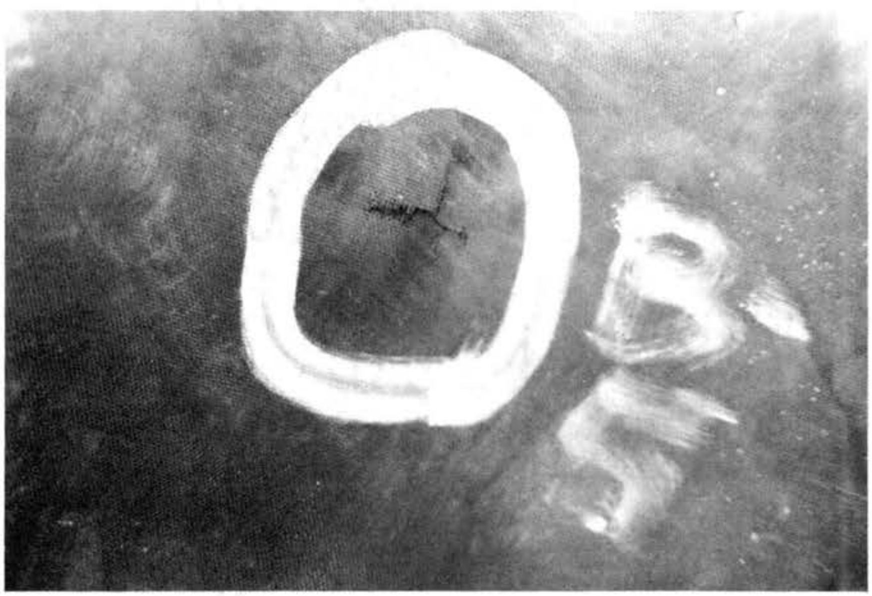


Figure 36. Cloth B, Two Inch Tear After 4.5 ft. Drop

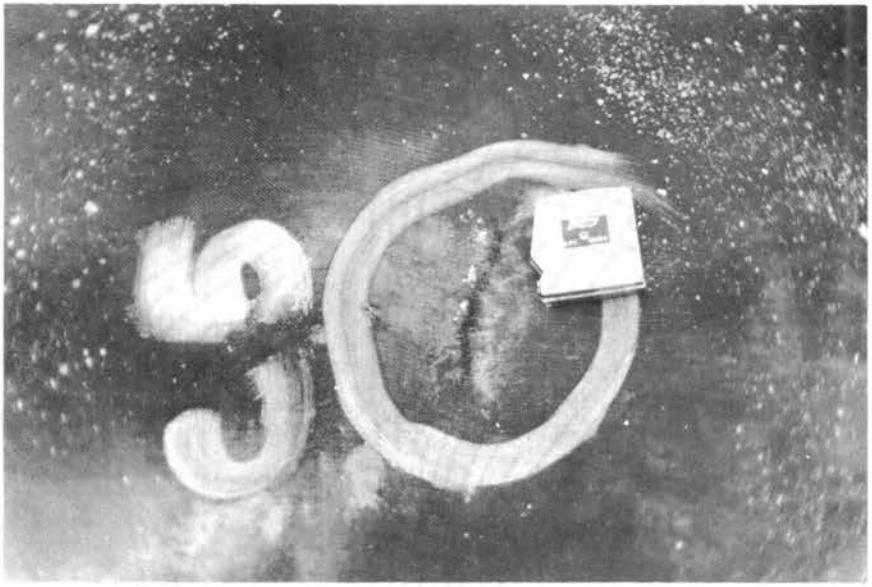


Figure 37. Cloth C, Five Inch Tear After 4.5 ft. Drop

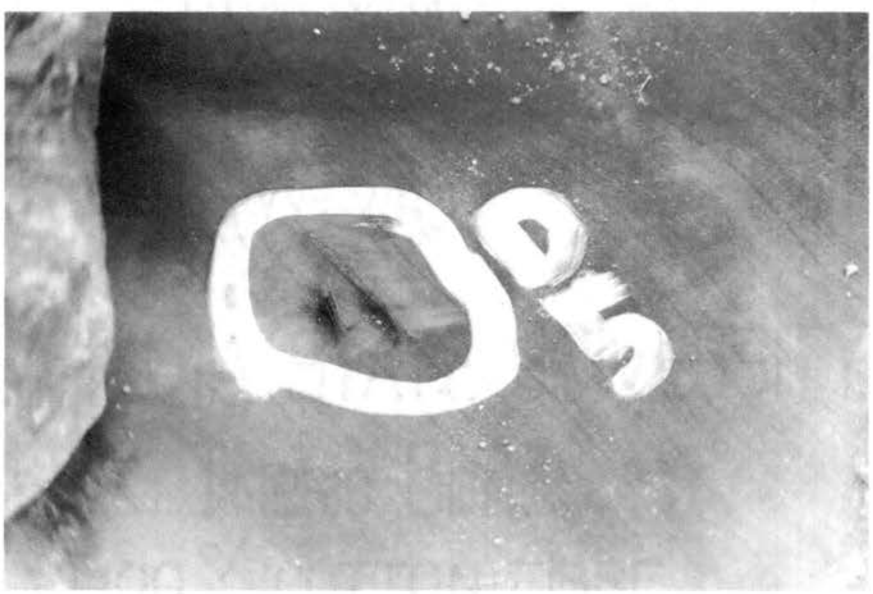


Figure 38. Cloth D, One and Two Inch Tears After 4.5 ft. Drop

down the slope. It should be noted that the full bucket drop was conducted approximately one week after the other tests had been completed. Heavy rains had occurred during the interim period, and the soil on the slope was noticeably harder (even after raking) than during the previous tests. There were five tears in the cloth, resulting from the 4.5 ft. drop. Four of the tears were 1 to 1-1/2 in. long; however, the other tear was about three inches long and was cuased by the 186 lb. stone (No. 3). In addition to these tears, one stone hit directly on top of a securing pin washer, and the washer cut the cloth around approximately 1/2 the circumference of the washer (Figure 39).

Cloth F. Cloth F was not damaged by the 2.5 and 4.5 ft. drops. This was the only cloth not damaged by the 4.5 ft. drop, and therefore the drop height was raised to seven feet. There was no damage due to the seven foot drop. However, it should be noted that when dropped seven feet, the stones tended to flip over during the fall and the sharpest edges did not directly contact the cloth. A three inch tear resulted from dropping the full bucket load on the cloth. As noted in the discussion of cloth E, the full bucket drops were conducted approximately one week after the other tests, at which time the soil on the slope appeared to be more dense than in earlier tests.

Cloth G. Cloth G was not damaged by the 2.5 ft. drop or the stones dumped from the truck. There was a one inch tear from the 4.5 ft. drop. It could not be determined which stone or stones caused the damage.

Summary of Stone Drop Tests

None of the cloths were significantly damaged by the 2.5 ft. drops, while all cloths except cloths F and G were significantly

Figure 39. Cloth E, Tear Caused by Direct Hit of Stone on Securing Pin Washer

damaged by the 4.5 ft. drops. Most of the damage was caused by Stones 1 or 3, weighing 256 and 186 lb., respectively. Those portions of these two stones impacting the cloths were very angular. Most of the stones made 3 to 5 in. indentations into the soil beneath the cloths. Cloths E and F were damaged somewhat by the full bucket load of stones dropped from 2.5 ft.; however, the bedding for these tests appeared to be harder than that in the other tests. While this implies that the harder bedding may be a more severe case than the other test conditions, it is thought that the softer bedding is more representative of field conditions where cloths are placed on sandy soils. Damage to cloth E caused by the washer cutting the fibers points out a problem that could occur to any cloth during placement of the riprap and is a reason the number of laps should be kept to a minimum.

Field Exposure Tests

Filter cloths A and B were exposed for 72 months at Treat Island, Maine, with companion control samples aged in the old Waterways Experiment Station Concrete Division Laboratory near Jackson, Mississippi. The samples at Jackson were kept in the laboratory building and not subjected to outdoor exposure. At Treat Island, one set of samples was exposed in an open-sided shed, while the other was covered by about one foot of sand (neither set was exposed to sunlight). Both sets of samples at Treat Island were under salt water part time from tide fluctuations, resulting in daily freeze-thaw cycles during the winter. Air temperatures in the area varied from a high of about 80°F. during the summer months to a low of about (-)15°F. in the winter months. A sample from each set was tested at six month intervals to determine the effects of exposure. This was done by determining the tensile strength of the cloth in the warp direction and comparing it to the average strength of 10 samples that had been tested in 1963 prior to the exposure. It should be noted that the average initial strengths determined in 1963 are somewhat different from the initial strengths given in Table I.

Figure 40 is a summary of data collected for 72 months on the performance of cloths A and B at Treat Island and Jackson. The data appear to follow no particular trend. Of the 35 samples of cloth B tested, 15 had strengths below those of any of the 10 samples tested initially and 16 were above the initial average strength. Of the 35 samples of cloth A tested, six had strengths below any of the 10 initially tested, while 10 were above the average initial strength. The variation in initial strengths of cloth A was about 10 percent of the average strength shown. However, the variation in results of the 10 initial tests on cloth B was less than 10 percent of the average. When considering the number of exposed samples with strengths less than 90 percent of the initial average strength, only four of the 35 cloth B samples tested failed to be within 10 percent of the initial average. It should also be noted that there is no apparent relationship between the samples exposed at Treat Island or aged at Jackson. From these tests, it is concluded that both cloths A and B are performing satisfactorily.

Hydraulic Tests

Tests to determine the head loss through the filter cloth alone were conducted in a 2.5 ft. wide flume with an orifice located in a vertical barrier. The cloth was placed over a 1.0 by 1.0 ft. orifice, 0.25 ft. above the bottom and in the center of the flume. The orifice

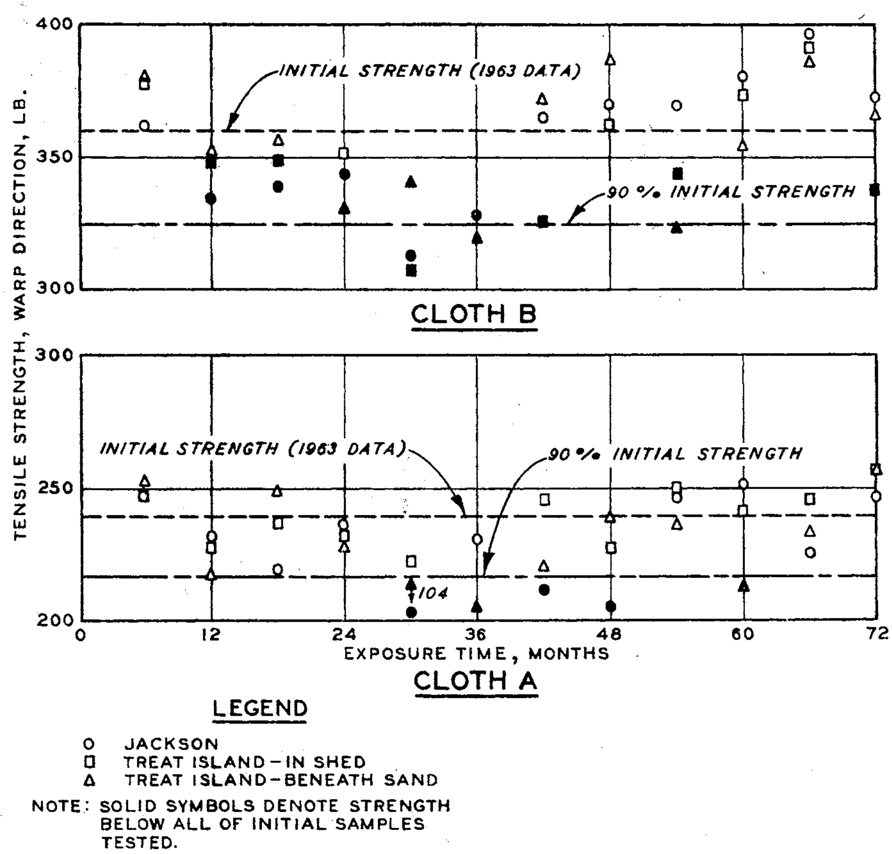


Figure 40. Effects of Field Exposure

was calibrated by introducing constant discharges into the model and recording the water surface elevations upstream and downstream from the orifice after sufficient time for settling was allowed. The orifice was submerged at all times. The filter cloth was then placed over the orifice and the procedure repeated. A settling time of 30 min. was used for each discharge with air bubbles allowed to collect on the cloth. The elevations were recorded and the air bubbles raked off the cloth and kept off until the water surfaces stabilized. The water elevations were again recorded. The head loss for the 1.0 ft.^{2} area of cloth was obtained by subtracting the head differences for a given discharge on the calibration curve from the head difference obtained for the same discharge with a particular cloth.

Results of the flume tests are shown in Figure 41. Equations for head loss through 1.0 ft.^{2} for the cloths (no air) obtained from this figure are given below:

Cloth	Head Loss, h (ft.) in terms of Velocity, v (ft./sec.)
A	$6.5\ v^{1.20}$
B	$10.1\ v^{1.70}$
C	$0.2\ v^{1.65}$
D	$5.8\ v^{1.36}$
E	$2.1\ v^{1.01}$
F	$1.8\ v^{0.90}$
G	$0.1\ v^{1.78}$

It is recognized that head losses through the cloths would be influenced to a great extent by the adjacent soil. However, these tests

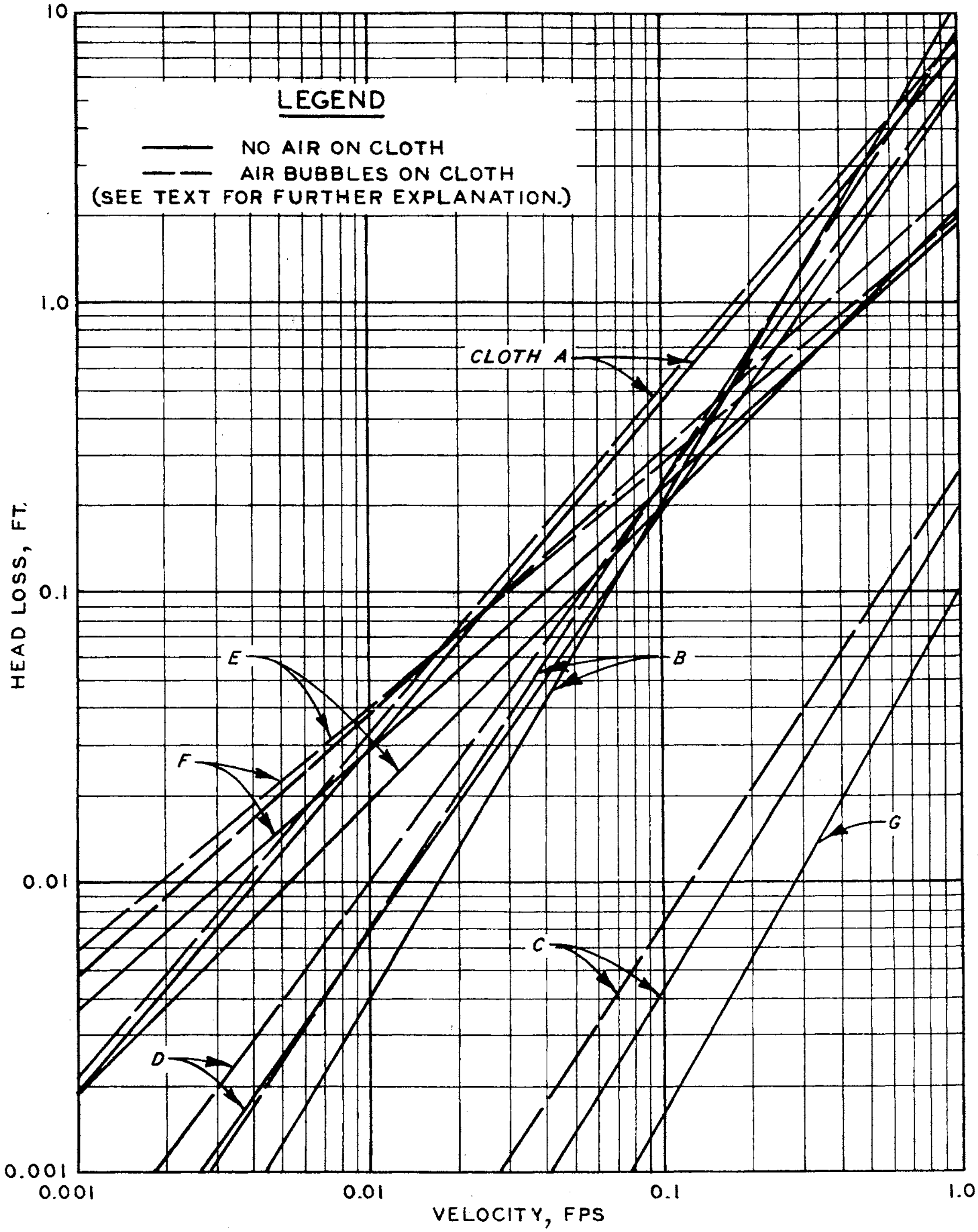


Figure 41. Flume Test Results

do show clearly the relative differences in the cloths' abilities to pass water freely. As would be expected, cloths C and G with relatively large open areas provide less resistance to flow than the tighter woven or nonwoven cloths. Cloth F has the most resistance to flow at the very low velocities which would be expected from seepage conditions. A buildup of air on the downstream side of the cloths, with the exception of cloth G, affected head losses through the cloths. Generally, the head loss was decreased by the removal of the air. Air bubbles could possibly develop on cloths used as well screens, and therefore this effect could be significant.

CHAPTER V

FIELD PERFORMANCE STUDIES

Visits were made by the author to several sites where filter cloths had been used to obtain field performance data. These data coupled with information obtained from field tests, other agencies, and results of the survey reported in Reference 2, provided the field data needed for correlation with the laboratory data. Visits were made to the following locations to observe the performance of filter cloths:

Corps of Engineers' District	Type of Installation	Cloth Used
Memphis	Beneath riprap bank proteetion	A and B
Memphis	Beneath riprap and articulated concrete mattresses on Mississippi River	B
New Orleans	Beneath concrete paving block protection for highway fill along Gulf Coast	B and Z
Kansas City	Beneath riprap channel bank protection	B
Fort Worth	Wrap subdrain collector pipes	A

Contacts were made with other agencies using filter cloths. Of particular interest were tests conducted by the U. S. Department of Agriculture, Soil Conservation Service, in Florida on cloths used to wrap subdrain collector pipes. Reports were prepared containing details of the installations visited and are on file at the Waterways Experiment

Station. The following discussions will cite the principal observations made and conclusions drawn from the inspections or correspondence.

Memphis District

Cloths A and B were used in connection with repair work at four bridges on the St. Francis River in the Memphis District (Reference 3). Severe scouring of the bank had occurred immediately downstream from the bridges and had progressed to the point where pilings for the abutments were exposed. Banks adjacent to abutments of two bridges were repaired in 1962 using cloth A, and the remaining two were repaired in 1964 using cloth B. The scoured areas were backfilled with sand and the cloth placed on the sand slopes which were graded to approximately 1 on 3. Riprap (125 lb. maximum) was dropped from approximately four feet on both cloths. When tears were noted in cloth A, the drop height was reduced to less than one foot. Cloth B was not damaged.

The author made an inspection of the repaired bank slopes in the summer of 1969, and the cloths were uncovered at two sites. The repaired areas as a whole were in good condition. However, in cloth A there were numerous tears and holes attributed to abrasion by movement of riprap. Cloth B was in excellent condition. Tensile strengths of samples obtained from the areas and compared to strengths shown in Table I indicated there had been no apparent deterioration of the cloths since they were installed.

Cloth B was used in a test area on Island 63 located in the Mississippi River south of Helena, Arkansas. Figure 42 is a layout of the test installation as constructed in 1965. The cloth was placed beneath both riprap and articulated concrete mattresses; for comparative

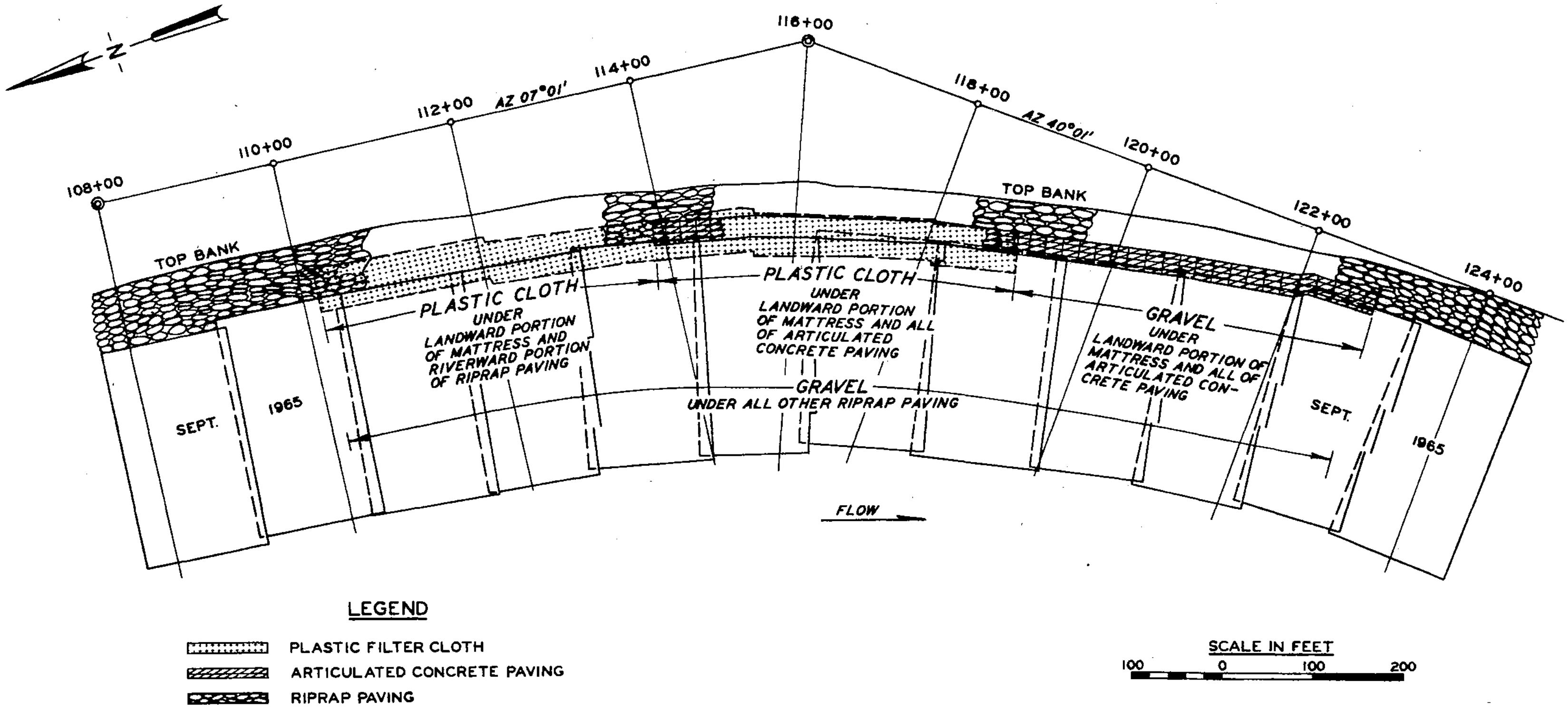


Figure 42. Layout of Island 63 Test Site

purposes gravel bedding was used in adjacent areas. The revetment was placed on 1 on 3 fine sand slopes. Memphis District personnel reported that no damage to the cloth had occurred during construction of the revetment. The 125 lb. stones were dropped from about four feet.

The site was inspected by the author in 1969. Figure 43 shows the condition of the revetted area underlain with filter cloth, and Figure 44 shows the condition of the revetted area constructed with a gravel bedding. The performance of the filter cloth was obviously superior to that of the gravel bedding. In the filter cloth area, the only noticeable subsidence was where field seams were faulty.

Figure 45 shows bulging of the cloth beneath the riprap at its intersection with articulated concrete mattresses (subsidence shown in the center of the photograph is from a faulty field seam). Such bulging was first noted in 1968. Reports from 1970 inspections made by the Memphis District indicate bulges have also appeared in the riprap upslope from the intersection. During the 1969 inspection, examination of cloth near the bulged areas showed what appeared to be a cake of fines immediately beneath the cloth. This cake may have prevented ready drainage through the cloth, resulting in excess pore pressures being developed in the fine sand, causing the sand to "flow" beneath the cloth. (However, in laboratory clogging tests, the cake of fines developing against cloth A did not cause any significant increase in head loss through the cloth.) It should be noted that this reach has been predicted susceptible to flow failures, a common phenomenon along the Mississippi River where sections of sand banks liquefy and "flow" into the river (Reference 5). It is possible that small flow failures

Figure 43. Island 63 Revetted Area Underlain With Filter Cloth

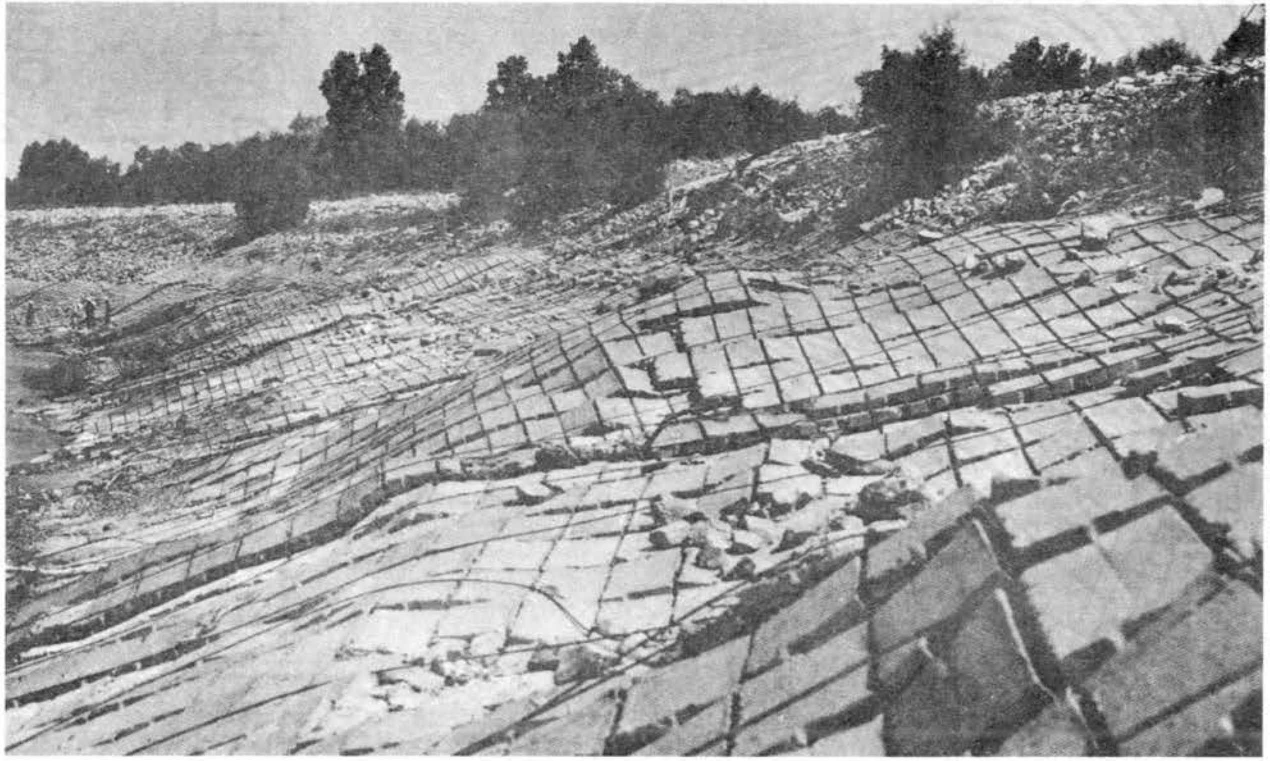


Figure 44. Island 63 Revetted Area Underlain With Gravel Bedding

Figure 45. Bulged Areas at Island 63

occurred in the area and the cloth prevented the material from going into the river, possibly preventing a more general failure.

The filter cloth was in good condition, with the exception of a few tears near the bulged area. 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 separations were noted at the factory-sewn seams. Strength tests on samples of cloth from near the bulged areas showed no apparent deterioration. No samples were taken from the bulged areas for fear of inducing further failure.

New Orleans District

The Louisiana Department of Highways (with some assistance from the New Orleans District of the Corps of Engineers) conducted full-scale tests using cloth B and cloth Z beneath slope protection for a highway fill along the Gulf Coast (Reference 4). Although not tested during the study, cloth Z appeared to have an open area somewhat smaller than cloth G (36 percent) but greater than cloth C (24.4 percent). The revetted area was constructed in January, 1969, using cellular concrete revetment blocks developed in Holland. Each block weighed approximately 14 lb. and was about 8 x 8 x 4 in. (when in place, the revetment had an open area of about 30 percent). The cloths were placed directly on a graded 1 on 3 slope and the blocks on the cloth. The soil was primarily a fine sand with some silt and shell fragments. The area landward of the fill was swampy, and when flooded water from the area flowed seaward through the embankment.

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, with wave heights well above the roadway elevation. The cloth B area failed, while the area in which cloth Z was used remained in place. Cloth B was apparently lifted or floated out of position due to wave action and water within the slope not being able to pass through the cloth fast enough to prevent hydrostatic pressure from developing beneath the cloth. Seepage water was apparently able to more readily pass through the more open weave cloth Z. Approximately one year later a similar storm hit the area, with the only damage being to the unprotected ends of the revetment.

Samples of both cloths were obtained during an inspection by the author approximately one week after the second storm. Results of strength tests on cloth B that had been beneath the revetment for about two years indicated no significant deterioration when compared to initial strength given in Table I. However, there had been considerable deterioration of cloth B exposed since the first storm (one year), and it could be torn by hand. According to the distributor of cloth Z, the initial tensile strength is approximately 300 lb. in both directions. Strength tests on cloth Z from beneath the revetment showed no significant deterioration when compared to the 300 lb. initial strength. However, the material exposed for one year had a strength of approximately 240 lb., a 20 percent decrease from the initial strength.

In 1971, a three mile stretch of the beach was revetted using the blocks and cloth Z.

Kansas City District

In 1968, cloth B was used to line the slopes of a channel in connection with a flood protection project in Topeka, Kansas. The cloth was also used beneath stone sills in the channel. One bank had a 1 on 2 slope and the other 1 on 3. The banks were composed of a silty sand. Stones weighing up to 3000 lb. were placed (free fall less than one foot) directly on cloth which had been placed directly on the slope. Some tearing at the securing pins was attributed to stones slipping down the 1 on 2 slope; this did not occur on the 1 on 3 slope. A 12 in. bedding of gravel was used between the cloth and the sills. Ten-foot-square areas of the cloth on the slopes were uncovered to check the gradation of the riprap and the cloth was found to be undamaged. During an inspection by the author in 1969, the area was found to be in excellent condition, and strength tests on samples of the cloth indicated no apparent deterioration when compared to the initial strength shown in Table I.

Fort Worth District

In 1966, cloth A was used to wrap the perforated collector pipe in a subdrain system at the downstream toe of Sam Rayburn Dam, Texas. Reports were received that the subdrains were not functioning properly and that the cloth may have become clogged with an iron sludge common to the area. In 1970, a section of the collector pipe was uncovered and inspected by the author. The cloth was not clogged, but the perforations in the pipe were almost completely closed by the iron sludge. It was concluded that the filter cloth did not contribute to the problem.

Strength tests on the cloth indicated no apparent deterioration when compared with initial strength shown in Table I.

Soil Conservation Service

In 1968, the Soil Conservation Service installed slotted pipe subdrains wrapped with two different cloths near Orlando, Florida, to lower the water table in an agricultural test field (Reference 6). The two filter cloths used were cloth A and a cloth not included in the Waterways Experiment Station tests but somewhat similar in appearance to the nonwoven cloth F (designated cloth Y). Four inch diameter flexible, slotted, corrugated, plastic collector pipe wrapped with cloth A was installed in a trench. The trench was backfilled with the excavated soil which was a fine sand (90 percent passing the U. S. No. 50 sieve). The system using cloth Y was installed in the same manner. The flow and water table drawdown produced by the two systems were observed. In a matter of weeks cloth Y became clogged with an iron sludge. 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.

Summary of Field Performance Studies

Based on the results of the field performance study, it appears that the strength and abrasion resistance of cloth B are sufficient for most field uses where stones will be dropped on the cloth and the cloth will be subjected to abrasive action. Cloth A apparently does not possess sufficient strength and abrasion resistance for such uses.

The open area of cloth B may not be sufficient to prevent excessive hydrostatic uplift resulting from water not being able to pass freely where the cloth is subjected to extremely heavy wave attack and is lightly loaded. Cloths with open areas in excess of about 25 percent appear satisfactory. The performance of the nonwoven cloth Y in the Soils Conservation Service tests is consistent with the results of the clogging tests on cloths E and F. The nonwoven cloth clogged while the woven cloths with distinct openings performed satisfactorily. Finally, the tests at Island 63 showed that filter cloths can be superior to granular bedding material in preventing undermining of revetments. However, these tests also indicated that open areas in excess of about four percent are desirable under severe drainage conditions.

CHAPTER VI

SUMMARY AND RECOMMENDATIONS

Summary

Chemical Composition

The chemical composition of all cloths subjected to chemical analysis was predominantly polypropylene, with the exception of cloth A. Cloth A was made predominantly of polyvinylidene chloride. Affidavits from the cloth manufacturers certified that each cloth contained at least 85 percent propylene or vinylidene chloride by weight.

Physical Properties

Although all the cloths evaluated were predominantly polypropylene (again with the exception of cloth A), their physical properties varied considerably (Table I). Consequently, specifying a plastic by name without accompanying physical requirements is not sufficient to assume the cloth will have the desired strength, abrasion and weathering resistance, etc.

Strength and Abrasion Resistance. Current uses of filter cloth can be divided into two main categories based upon the expected loading conditions: filter cloths subjected to severe dynamic loadings and filter cloths subjected to static loadings. Severe dynamic loadings would include installations where stones are dropped on the cloth and where there is continued abrasive movement of the stones from wave action or currents. It is obvious that cloth with high strength and abrasion resistance would be required in such applications. Static loadings would include such applications as where the cloth is used to wrap collector pipes or acts as a replacement for granular filter material beneath concrete structures. Also included in this category would be applications where revetment materials are carefully placed (not dropped) on the cloth. In the latter case, high abrasion strength may still be required.

Field performance data on cloth B have indicated that it performed satisfactorily with respect to strength and abrasion resistance at every installation where it has been installed. Stones weighing up to 3000 lb. have been dropped one foot on cloth B laid on a 1 on 3 sand slope without any damage to the cloth. Tests indicate that the strengths of cloth D are comparable to those of cloth B. The tensile strengths of cloth C were below those of cloth B, but the burst strength of cloth C was considerably greater than that of cloth B. Cloth C appeared to be affected less by abrasion than any other tested. Cloth C held up very well during the drop tests, but no field performance data are available. Information gathered on cloth A has shown that it was punctured and torn by 125 lb. stones dropped from four feet, while cloth B was not damaged under practically the same conditions. Tears in cloth A had also been noted in other installations. Inspections of revetted areas where cloths A and B were used showed holes attributed to abrasion in cloth A, while again under practically the same conditions, cloth B was in excellent shape. The manufacturer of cloth A no longer recommends its use where severe dynamic loadings requiring high strength and high abrasive resistance are required. Tensile strengths of cloths E, F, and G were below those of cloth A, and burst and pucture strengths were well below those of cloth B. Abrasion tests showed cloths E, F, and G had lower abrasion resistance than cloth A. It appears then that the performance of cloths E, F, and G would be inferior to that of cloth A in installations requiring high strength and abrasion resistance. Although cloth A did not perform satisfactorily where high strength and abrasion resistance were required, it has performed satisfactorily under static loading conditions.

Based on the strength tests, the cloths can be divided into three general catagories as shown in Table V. The strengths of cloth F were well below those shown for strength Category C.

TABLE V

STRENGTH CATEGORIES FOR FILTER CLOTHS

	Minimum Unaged Strength Requirement				
	Tensile, lb.				
Strength Category	Stronger Principal Direction	Weaker Principal Direction	Burst psi	Puncture lb.	Cloths Within Category
A	350	220	510	125	B and D
B	200	200	610	125	C
C	180	100	250	65	A, E, and G

Resistance to Weathering. Field data and weatherometer tests indicate that all cloths are affected to some degree by prolonged exposure to sunlight. Accelerated alkali tests indicate that alkalis may tend to deteriorate cloth A. Cloths A, C, and F showed tensile strength losses in excess of 10 percent when immersed in the toluene solution. Cloth F also lost strength when immersed in JP-4 fuel. With the previously mentioned exceptions, exposure to the weathering conditions given in Table I did not significantly affect the filter cloths.

Filtering Characteristics

Filtering characteristics are related to the equivalent opening size and percent open area of the cloth. Filtration tests showed all cloths would retain clean sands when the D_{85} size of the sand was equal to or coarser than the equivalent opening size of the cloth. Cloths B and G retained the silty sand mixture. The maximum open area of a cloth tested was 36 percent; therefore, the performance of cloths with open areas exceeding 36 percent is not known.

Clogging tests indicated that cloths without distinct openings tended to clog. This was attributed to fines that migrate during the initial phases of the test not being able to pass the cloth, thus forming a cake at the soil-cloth interface. Apparently, these fines pass through cloths with distinct openings. Field experience has shown that cloths with relatively small open areas (around five percent) may not be pervious enough to prevent excessive hydrostatic forces from building up beneath the cloth under severe seepage conditions. This problem has been experienced at only two sites. In both cases the overlying revetment material was relatively light.

Recommendations

Chemical Composition

It is recommended that filter cloths be made of 85 percent or more (by weight) propylene or vinylidene chloride. Although no laboratory data are available, field data indicate that cloths made of 85 percent or more ethylene may also be suitable. Since the structure of plastic is complex and minute changes in the formula may significantly affect its properties, it is recommended that all filter cloths meet the requirements given in Table VI. Cloths A through G meet all these requirements. If the cloth may be exposed to fuel spillage or solvents, its resistance to such solutions should be investigated.

Physical Properties

It is recommended that only cloths in strength Categories A and B (see Table V) be used where the cloth is to be subjected to the severe dynamic loading conditions described previously in this Chapter. It is further recommended that the abraded strength of the cloth be no less than 100 and 55 lb., respectively, in the stronger and weaker principal directions when tested by the procedure described in Chapter II. In no case should the abraded strength be less than 30 percent of the initial or unabraded strength of the cloth. Only cloths B, C, and D meet all these requirements. Cloths in any of the three strength categories given in Table V are suitable for use under the static loading conditions previously described. Cloth F does not meet any of the above requirements.

TABLE VI

PHYSICAL AND CHEMICAL REQUIREMENTS FOR PLASTIC FILTER CLOTH

Test Method	Type of Test	No. and Type of Specimens	Requirements (Average of All Test Specimens)
CRD-C 577-60 (modified)	Oxygen pressure test	5 warp 5 fill	Tensile strength* not less than 90 percent of tensile strength of unaged specimens. Ultimate elongation* no less than 10 percent or no greater than 40 percent
Special	Effects of alkalies**	5 warp 5 fill	Tensile strength* not less than 90 percent of tensile strength of unaged specimens. Ultimate elongation* no less than 10 percent or no greater than 40 percent
Special	Effects of acids**	5 warp 5 fill	Tensile strength* not less than 90 percent of tensile strength of unaged specimens. Ultimate elongation* no less than 10 percent or no greater than 40 percent
CRD-C 575-60 (modified)	Change in weight, water immersion	5 warp 5 fill	Weight increase shall not exceed 1 percent
CRD-C 570-64	Brittleness, low temperature, motor-driven apparatus	5 warp	No failure at -60 F
Special	Effects of temperature	10 warp 10 fill	At 180 F, tensile strength* no less than 80 percent of unaged specimen strength, ultimate elongation no greater than 40 percent; at 0 F, tensile strength* no less than 85 percent of unaged specimen strength, ultimate elongation* no less than 8 percent
CRD-C 20-69	Resistance of concrete specimens to rapid freezing-and-thawing in water	5 warp 5 fill	Tensile strength* no less than 85 percent of tensile strength of unaged specimens. Ultimate elongation* no less than 10 percent or no greater than 35 percent
ASTM E-42-69	Weatherometer test	5 warp 5 fill	Tensile strength* no less than 65 percent of tensile strength of unaged specimens. Ultimate elongation* no less than 10 percent or no greater than 35 percent

* Tensile strength and elongation determined by ASTM D-1682-64 for "Breaking Load and Elongation of Textile Fabrics - Grab Test."

** Continue test for 14 days.

† Strength before and after abrading determined in accordance with ASTM D-1682-64 for "Breaking Load and Elongation of Fabrics - One-Inch Ravelled Strip Test Method."

Filter Requirements

It is recommended that for filter cloths used adjacent to granular material containing 50 percent or less by weight silty material, the 85 percent size of the material (expressed in millimeters) be equal to or coarser than the equivalent opening size (also expressed in millimeters) of the cloth. Further, the open area of the cloth should not exceed 36 percent. For cloths used adjacent to granular soils containing more than 50 percent silt, it is recommended that the equivalent opening size of the cloth be no larger than the opening of the U. S. No. 70 Sieve and the open area not exceed 10 percent. The recommendations for cloths used adjacent to granular material containing less than 50 percent silt are based on filtration tests, while the requirements for silty soils are based primarily on field performance data.

Only woven filter cloths having distinct openings should be used in order to reduce the chance of clogging. Therefore, cloths E and F are not acceptable. It is also recommended that for any use, the equivalent opening size of the filter cloth should not be smaller than the size of the U. S. No. 100 Sieve and the open area no less than four percent. In instances where the revetment is relatively light and where relatively high seepage velocities or rapid fluctuations in differential hydrostatic pressures can occur in free draining soils, the maximum open area allowed by the above criteria should be used.

To illustrate the use of the recommended filter criteria in a design problem, consider the two soils shown in Figure 46. Soil No. 1 is a medium to fine sand containing about nine percent silt, while soil

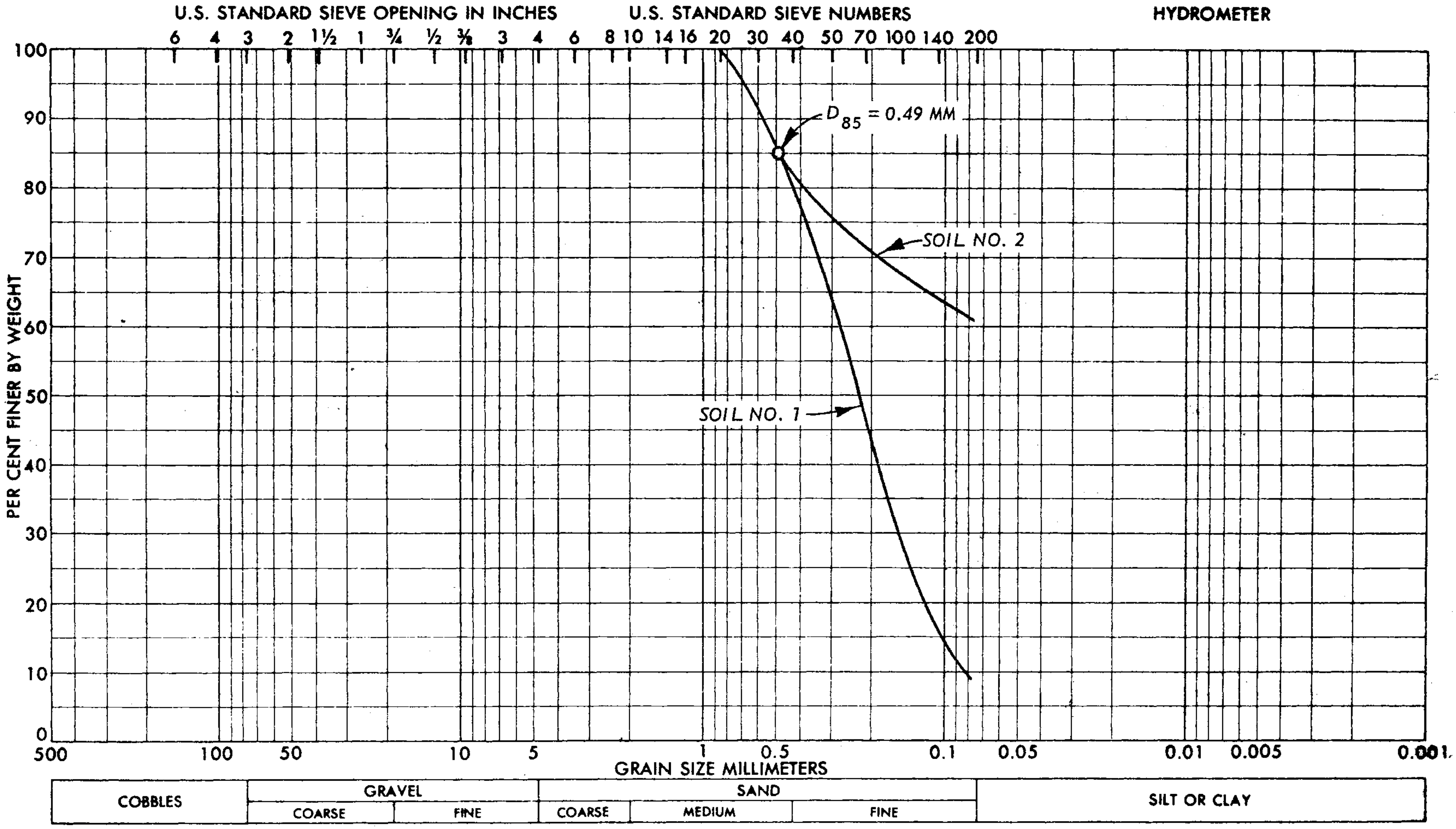


Figure 46. Gradation of Soils Used to Illustrate Filter Criteria

No. 2 is a silt containing some medium to fine sand. The D_{85} size of both cloths is 0.49 mm.

Since Soil No. 1 is a granular material containing less than 50 percent silt, the criteria that the D_{85} size of the soil must be equal to or coarser than the equivalent opening size (expressed in millimeters) of the cloth are applied. Therefore, the equivalent opening size of the cloth cannot be greater than 0.49 mm. The equivalent opening sizes of cloths A, B, C, and D are all less than 0.49 mm. (see Table I) and could be used to protect the sand. Since the sand is a free draining material, relatively high seepage velocities could be expected. Consequently, the cloth with the most open weave should be selected. Of the four cloths meeting the filter criteria, cloth C has the most open weave (equivalent opening size = U. S. No. 40 Sieve and 24.4 percent open area) and should be specified.

Soil No. 2 contains more than 50 percent silt and the criteria that the equivalent opening size be no larger than the openings in a U. S. No. 70 Sieve and the open area not exceed 10 percent are applicable. From Table I it can be determined that of the cloths found to be acceptable during this study, only cloths A, B, and D could be used to protect this soil. Since seepage velocities from the soil will be relatively small, all three cloths will probably be equally acceptable. The selection of the cloth to be specified now is based on the desired strength and/or cost.

Cloths E or F should not be used adjacent to either soil since neither cloth has distinct openings and the probability of the cloths becoming clogged with silt is great.

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