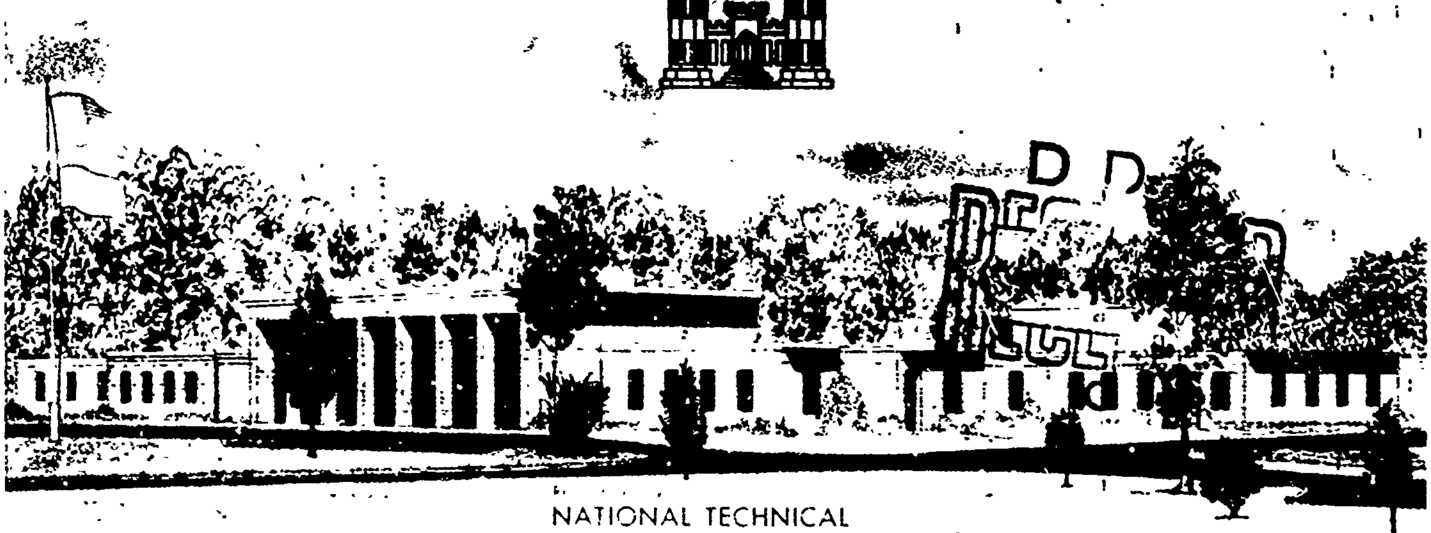
TECHNICAL REPORT S-72-7

DEVELOPMENT OF DESIGN CRITERIA AND ACCEPTANCE SPECIFICATIONS FOR PLASTIC FILTER CLOTHS

by

C. C. Calhoun, Jr.



June 1972

Sponsored by Office, Chief of Engineers, U. S. Army and
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13. ABSTRACT

Laboratory and field investigations were conducted to obtain data for the development of design criteria and acceptance specifications for plastic filter cloths used as a replacement for granular filter material. The investigations included a survey of CE Districts and Divisions to determine current uses and experiences with filter cloths. Information was also obtained from various other agencies on the performance of filter cloths. Based on the results of the survey, seven filter cloths were subjected to laboratory and field tests. Performance information was obtained on two other cloths not tested during this study. The chemical compositions of the cloths were determined. Tests were conducted to determine such physical properties of the cloths as size of opening, percent open area, strength, abrasion resistance, and resistance to deterioration from the elements. In addition, field exposure tests were conducted. Filtration tests were conducted using various soil types. The tendency of the cloths to clog due to the migration of fines was studied using special filtration tests. Head losses through the cloths were determined from flume tests. Field tests were conducted where stones were dropped on the cloths from various heights. Field performance data were obtained from visits to several sites where filter cloths had been used. Results of the study indicated that cloths made of 85 percent or more by weight propylene, vinylidene chloride, or ethylene and that meet various tests given in the report do not tend to deteriorate under most conditions. Recommendations are made for strength and abrasion resistance requirements for cloths used for various purposes. Laboratory tests indicated that cloths should be woven and have distinct, visible openings to prevent clogging. The filtering properties of the cloths are related to the opening sizes (termed "equivalent opening size" or "EOS") and percent open area. Filter criteria in terms of EOS and percent open area are presented for various soil types. Field performance data indicate that in instances where the revetment is relatively light and where relatively high seepage velocities or rapid fluctuations in the differential hydrostatic pressures can occur, the open area of the cloth should be as large as possible within the limits set forth in the report. Information from questionnaires on uses of filter cloths in the Corps of Engineers is summarized in Appendix A.

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FOREWORD

The study reported herein was conducted at the U. S. Army Engineer Waterways Experiment Station (WES) to develop acceptance specifications and design criteria for plastic filter cloths. The initial phases of the study were sponsored by the U. S. Army Engineer Division, Lower Mississippi Valley (LMVD), as authorized in LMVD 3d Ind dated 14 September 1967 to WES letter dated 14 July 1967, subject: Proposal for Investigating the Permeability and Filtering Characteristics of Plastic Filter Cloths. In FY 1970, continuation of the overall study was funded jointly by LMVD and the Office, Chief of Engineers (OCE), as authorized in OCE 2d Ind dated 21 October 1968 to LMVD letter dated 17 June 1968, subject: Development of Performance Specifications for Plastic Filter Cloth. The project was funded in FY 1971 and 1972 by LMVD.

The study was under the general direction of Messrs. J. P. Sale, R. G. Ahlvin, J. R. Compton, and W. E. Strohm, Jr., Soils and Pavements Laboratory. Mr. C. C. Calhoun, Jr., Embankment and Foundation Branch, was project engineer. Mr. B. J. Houston, formerly of the Engineering Mechanics Branch, Concrete Laboratory, was responsible for conducting most of the tests to determine the physical and chemical properties of the filter cloths. Strength tests were conducted by Mr. R. R. Johnson, Flexible Pavement Branch, Soils and Pavements Laboratory. Flume tests were conducted under the supervision of Messrs. J. L. Grace, Jr., and G. A. Pickering, Structures Branch, Hydraulics Laboratory. The report was written by Mr. Calhoun.

Directors of WES during the conduct of the study and preparation of the report were COL Levi A. Brown, CE, and COL Ernest D. Peixotto. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
miles (U. S. statute)	1.609344	kilometers
square inches	6.4516	square centimeters
square feet	0.092903	square meters
gallons (U. S. liquid)	3.785412	cubic decimeters
pounds	0.45359237	kilograms
pounds per square inch	0.00689476	megapascals (= meganewtons per square meter)
pounds per square foot	47.8803	newtons per square meter
pounds per cubic foot	16.0185	kilograms per cubic meter
feet per minute	5.080	meters per second
Fahrenheit degrees	5/9	Celsius or Kelvin degrees*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

DEVELOPMENT OF DESIGN CRITERIA AND ACCEPTANCE SPECIFICATIONS FOR PLASTIC FILTER CLOTHS

PART I: INTRODUCTION

Background

1. Since 1962 some Corps of Engineers (CE) offices have been using plastic filter cloths as a substitute for sand and gravel filters and riprap bedding in various projects. Filter cloths had been used prior to 1962 in the United States (although not by the CE) and foreign countries and had been found to be effective in some types of coastal structures.[1] Prior to 1967 only two filter cloths were known to be on the market. Since that time, at least seven additional cloths have become available commercially, and the use of filter cloths is more widespread. As an initial phase of the study reported herein, a questionnaire was circulated to CE offices to determine the extent and diversification of uses of filter cloths. Information from replies to the questionnaires was summarized and published by the U. S. Army Engineer Waterways Experiment Station (WES).[2] An edited version of this summary is included herein as Appendix A. Information was obtained on 46 projects where filter cloths had been used and on 10 projects where cloths were planned to be used. There have been other uses of filter cloths by the CE, but information on these installations was not readily available. Since the survey, filter cloths have been used at numerous other CE projects. The 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. Because of these widespread and diversified uses of the cloths, the CE has need for standard specifications or design criteria for their procurement and use.

Purpose and Scope

2. 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 commercially available filter cloths in order to develop specifications and design criteria. Field and laboratory studies of the cloths were made to determine their chemical composition and resistance to chemical attack and deterioration; physical properties such as strength, abrasion resistance, etc.; and filtering capabilities. Field visits and contacts with other agencies were made to obtain information on the use and performance of filter cloths.

Cloths Evaluated

3. Seven filter cloths designated A through G were investigated. Photographs of the cloths are shown in fig. 1. Cloth A is green; cloths B, C, D, and G are black; cloth E is white; and cloth F is gray. Cloths A, B, C, D, and G are woven from monofilament yarns of approximately equal size in the warp* and fill* directions. The yarn used in cloth A is predominantly vinylidene chloride and the yarns used in cloths B, C, D, E, F, and G are predominantly propylene. The openings in cloths A, B, D, and G are rectangular, while the openings in cloth C are approximately square. Cloth E is woven of monofilament yarns in the warp direction and multifilament yarns in the fill direction. The yarns in the warp direction of cloth E are much smaller and more closely spaced than those in the fill direction; this results in a cloth with no distinctly visible openings. Cloth F is produced by entangling fibers by needle punching and then bonding them by heat fusion; yarns are also embedded lengthwise in the cloth. This cloth has the appearance of felt and has no distinct openings.

4. Information was obtained on two other cloths which were not evaluated in the laboratory studies reported herein. One, designated

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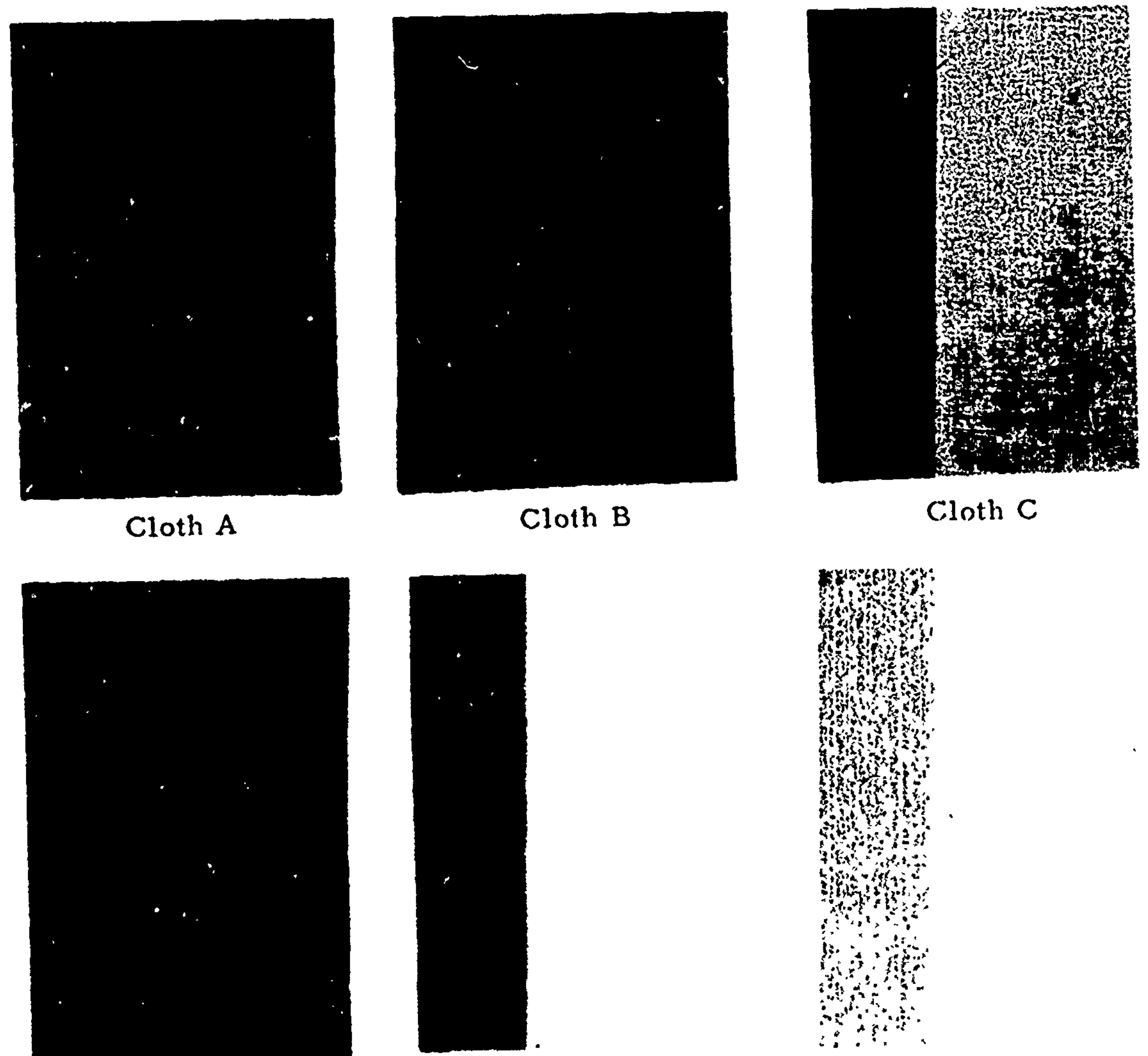
* "Warp" refers to the yarns placed lengthwise in the cloth; "fill" refers to the yarns interlaced at right angles with the warp.



Cloth A

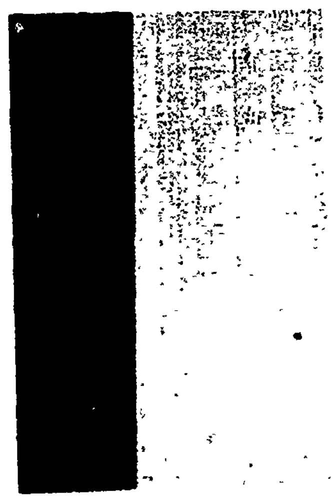
Cloth B

Cloth C

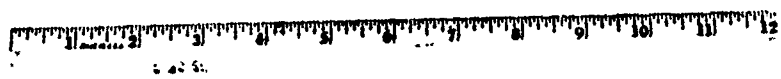
Cloth D

Cloth E

Cloth F



Cloth G



Note: A table of factors for converting British units of measurement to metric units is presented on page ix.

Fig. 1. Filter cloths A through G (front-lighted on left, back-lighted on right)

cloth Z, was used by the Louisiana Department of Highways in the New Orleans District. Cloth Z is made of polyethylene yarns; cloths G and Z are manufactured in Holland by the same company. The other cloth, designated cloth Y, was used by the Soil Conservation Service. The cloth is made of nonwoven fiberglass and is much thinner than any cloth evaluated in the investigation; it can be easily torn by hand. Information on cloths Z and Y is included in Part V.

PART II: CHEMICAL AND PHYSICAL PROPERTIES TESTS

Test Procedures

Chemical properties

5. The chemical properties of the materials in cloths A through G were analyzed. The materials could not be dissolved in xylene, chloroform, or acetone; they could be dissolved for testing in tetrachloroethane and orthodichlorobenzene ($O-Cl_2-\phi$). Prolonged heating and refluxing with $O-Cl_2-\phi$ dissolved the filter cloths. 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

6. The physical properties and the effects of some chemical action on the cloths were determined by American Society for Testing and Materials (ASTM) procedures, methods given in Handbook for Concrete and Cement,[3] or special test procedures described subsequently. The following tests were conducted:

a. 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 1-sq-in. samples. Fiber thickness was determined with a micrometer. Other properties were determined by the use of a micrometer scale microscope. An image of the cloth was projected on a screen and the dimensions of the openings were determined by moving a cross hair with a micrometer adjustment 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 by a slide projector on a screen so that the dimensions of the 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, respectively) and the length and width of each opening plus the width of a fiber (L_T and W_T, respectively) were measured as shown in fig. 2:

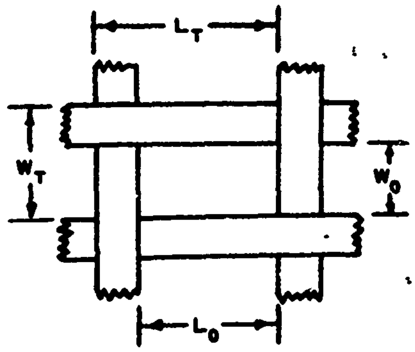


Fig. 2. Method of determining L_O and W_O and L_T and W_T.

The individual open area (A_O) was computed by multiplying the length of the open area by its 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 ($W_T \times L_T$). 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.

b. Equivalent opening size (EOS). Since the dimensions of the openings varied somewhat and the openings were not square, the average area of the openings was not an indicator of what size particles would pass through the cloth. Consequently, the following test procedure was developed to determine the soil particle retention ability of the various cloths. The cloth was placed between a sieve having much greater openings than those of the cloth and a pan in a sieve nest. About 150 g of each of the following fractions of a rounded to subrounded river sand was obtained:

U. S. Standard Sieve No.	
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 5 percent of the sand by weight 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 5 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. Standard Sieve Number.

c. Tensile strength and elongation. Tensile strength and elongation were determined on 10 samples of each cloth, 5 in the warp direction and 5 in the fill. These determinations were made in accordance with ASTM D-1682-64, "Breaking Load and Elongation of Textile Fabrics - Grab Test Method," at temperatures of 0, 73, 110, 150, and 180 F. Jaws 1 in. square were used, and the constant rate of traverse was 12 in. per min. The strengths 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.

d. 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."

e. 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.-diam 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 10 samples of each cloth.

f. 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." Rubber-base CS-17 "Calibrase" abrasive wheels, manufactured by Taber Instrument Company, were used in the tests. The load on each wheel was 1000 g, and except for cloth F the test was continued for 1000 revolutions. Unabraded tensile strength was determined on 10 samples each of cloths C, E, F, and G, 5 samples in the warp direction and 5 in the fill, and on 20 samples each of cloths A, B, and D, 10 samples in the warp direction and 10 in the fill. The determinations were made in accordance with ASTM D-1682-64, "Breaking Load and Elongation of Textile Fabric, One-Inch Ravelled Strip Test Method." Jaws 1 in. square were used, and the constant rate of traverse was 12 in. per 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.

g. Low-temperature brittleness. Ten samples of each cloth were subjected to testing in accordance with CRD-C 570-64, "Brittleness, Low Temperature, Motor Driven Apparatus," using alcohol heat transfer medium to determine low-temperature brittleness. Five samples each were tested in the warp direction and five each in the fill. The test was continued to minus 60 F.

h. Freeze-thaw. Ten samples of each cloth were subjected to 300 2-hr freeze-thaw cycles as prescribed in CRD-C 20-69, "Resistance of Concrete Specimens to Rapid Freezing and Thawing in Water." Each sample was 4 by 6 in., and the temperature in the test was varied from 0 to 40 F. The tensile strength and elongation of the warp and fill at failure were determined at the conclusion of the conditioning.

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

j. Oxidation. The effects of oxidation were determined on 10 samples of each cloth in accordance with CRD-C 577-60, "Oxygen Pressure Test." Five samples each were tested in the warp direction and five each in the fill. Each sample measured 4 by 6 in.

k. Effects of alkalies and acids (accelerated test).

(1) Ten samples of each cloth were tested for the effects of alkalies. Five samples each were tested in the

warp direction and five each in the fill. Each sample measured 4 by 6 in. The samples were placed in a 1-liter tall form beaker with spout that was filled to within 2 in. of the top with a solution made by dissolving equal amounts of chemically pure sodium hydroxide and chemically pure potassium hydroxide in 1 liter of distilled water to obtain a pH of 13 $\pm$ 0.1. The samples of cloth were completely 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.-diam glass tube was inserted into the spout of the beaker to within 1/2 in. of the bottom of the beaker. Air was gently bubbled through the solution throughout the test 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 carried out continuously until a constant sample weight was obtained. After this period, the samples were tested for tensile strength and elongation at failure in accordance with ASTM D-1682-64 (Grab Method).

(2) The effects of acids were determined by a test run exactly as that for alkalies except the solution was of hydrochloric acid in 1 liter of distilled water to give a pH of 2 $\pm$ 0.1, and the test was discontinued after 14 days.

l. Absorption. To determine the absorbency of the cloths, 10 samples of each cloth were tested according to CRD-C 575-60, "Change in Weight, Water Immersion." Five samples each were tested in the warp direction, and five each in the fill. Each sample measured 4 by 6 in. The percent absorption was determined as follows:

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

m. Effects of JP-4 fuel. The effects of jet fuel spillage or prolonged exposure on the cloths were studied by immersing 20 samples of each cloth in JP-4 fuel at room temperature. Ten samples were warp samples, and ten were fill. Strength tests were performed on the samples after 24-hr and 1-week periods of immersion.

n. Effects of long-term immersion. Ten samples of each cloth (five warp samples and five fill samples) were immersed for 6 or 12 months at room temperature in pH 10, pH3, and toluene solutions. The pH 10 solution was of equal parts of chemically pure sodium hydroxide and potassium hydroxide in distilled water. The pH 3 solution was of hydrochloric acid in distilled water.

Test Results and Discussion

Chemical analyses

7. Chemical analyses of the cloths indicated that with the exception of cloth A all were predominantly propylene. Cloth A was predominantly vinylidene chloride. The type of analysis conducted did not give quantitative results. Affidavits from the manufacturers indicated that each cloth contained at least 85 percent propylene or vinylidene chloride by weight.

Physical properties

8. Table 1 summarizes the results of tests described in previous paragraphs to determine the physical properties of the cloths in the warp and fill directions. Since cloth F is nonwoven, it has no warp or fill directions; in this case, warp refers to the length of the cloth and fill refers to the width (6 ft). The results of the various tests are discussed in detail in the following paragraphs.

9. 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 entangled fibers in cloth F were not considered. Results of tests to determine the geometry of the cloths are discussed below. In the following discussion, warp opening width refers to the measurement of the opening between two 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.

a. Filter cloth A. The areas of individual openings varied from 26 to 182 $\times 10^{-6}$ sq in., with the average area being 85 $\times 10^{-6}$ sq in. 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 (fig. 1),

Table 1

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.$^2 \times 10^{-6}$	85		96		139		79		Could not test		Could not test		222	
Variation, in.$^2 \times 10^{-6}$	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	

(Continued)

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

Table 1 (Concluded)

	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	97	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.

the cloth's appearance indicated good quality control of weaving by the manufacturer.

b. Filter cloth B. Openings varied in area from 20 to 120 $\times 10^{-6}$ sq in. (average 96 $\times 10^{-6}$ sq in.); however, this large variation was not obvious from visual inspection (fig. 1), and the quality control of weaving appeared to be good.

c. Filter cloth C. The computed areas of the individual openings varied only from 117 to 176 $\times 10^{-6}$ sq in., the average being 139 $\times 10^{-6}$ sq in. The areas of approximately 40 percent of the openings were between 130 and 132 $\times 10^{-6}$ sq in. From the appearance of the cloth (fig. 1), the quality control of weaving was excellent.

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

e. Filter cloth E. The number of fibers in the warp direction could not be determined since they appeared to be almost multifilament. There were 32.8 fibers per inch in the fill direction. Because of the tight weave, only the diameters of the fibers could be determined. The diameter of the fill fibers averaged 0.010 in., and of the warp fibers, 0.003 in. or about one-third that of the warp fibers.

f. Filter cloth G. The area of the openings varied from 60 to 288 $\times 10^{-6}$ sq in., the average being 222 $\times 10^{-6}$ sq in. The variations were apparent in visible inspection of the cloth, particularly when compared with filter cloth C. Small flaws were also noted in cloth G (fig. 1). Therefore, the quality control of weaving for filter cloth C appears to be superior to that of filter cloth G.

10. Equivalent opening size. The following tabulation summarizes the EOS determinations for the respective cloths:

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

11. Strength parameters. Table 1 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 1 are discussed in the following paragraphs. Tensile strengths of the cloths under various conditions are plotted in fig. 3. A strength loss of 10 percent or more was usually used to indicate a sample had been affected by the conditioning.

a. 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 strengths of filter cloths B and D were approximately equal. The strengths of filter cloth E were 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 in the warp direction was only 31 lb, and only 104 lb in the fill direction. Filter cloth C had the highest burst strength (625 psi), while cloth B had the highest puncture strength (148 psi). The burst and puncture strengths of cloth F were well below the strengths of any of the other cloths tested.

b. 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 that 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.

c. 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

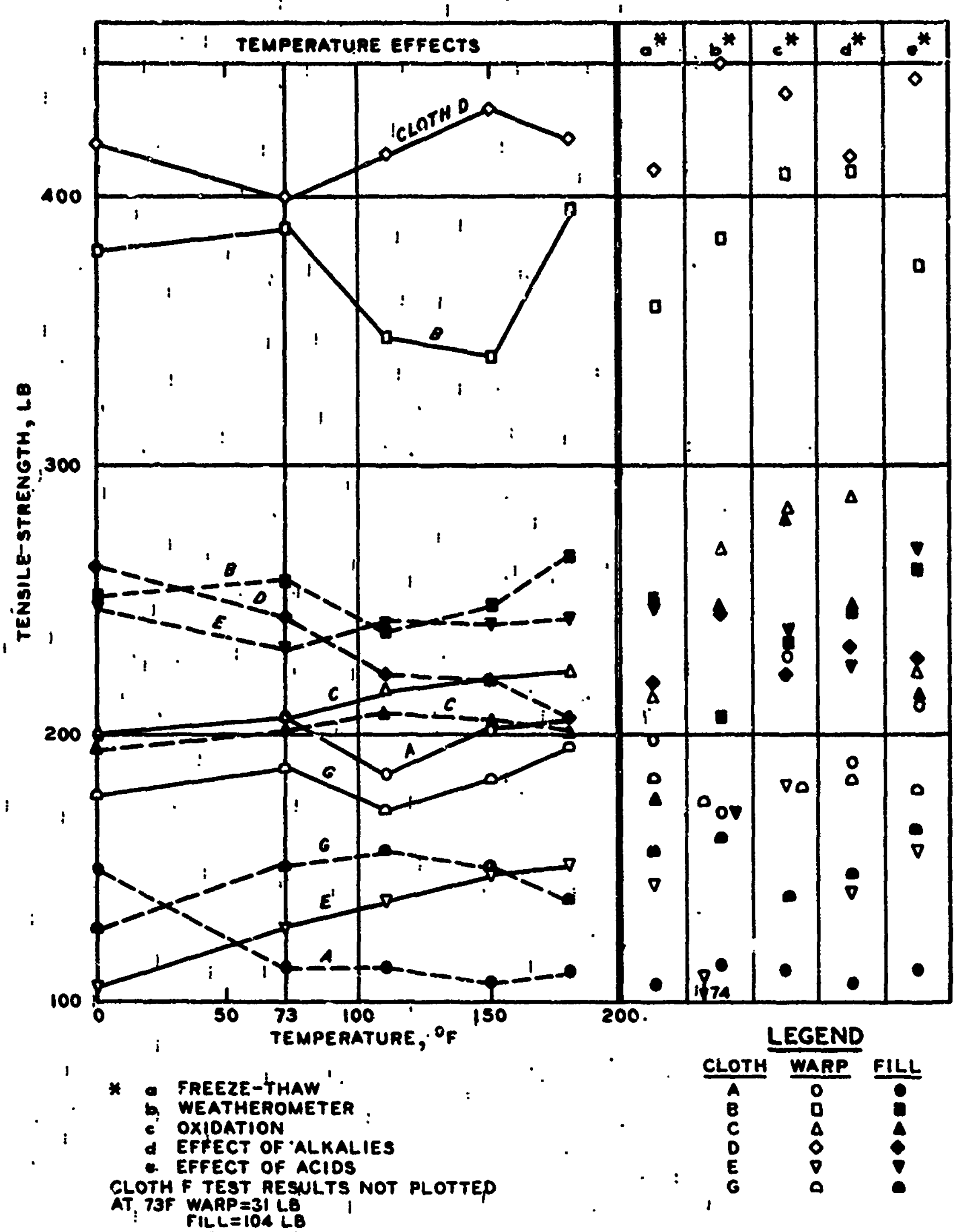


Fig. 3. Tensile strengths of cloths under various conditions

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.

d. 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.

e. Oxidation effects. The test results indicated no significant deterioration would occur due to oxidation.

f. Effects of alkalies. The tensile strengths of the cloths were not significantly affected by the accelerated 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, the 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 2 percent in the long-term immersion tests.

g. Effects of acids. Accelerated acid tests indicated no significant decrease in strength for any of the cloths.

h. Absorption. No cloth absorbed more than 1 percent by weight of water. Cloth A had the highest absorption rate (0.91 percent), while cloth E had the lowest (0.08 percent).

i. Effects of fuel 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 strengths when immersed for 12 and 6 months, respectively, in toluene. There was no significant deterioration of the other cloths.

Summary and discussion

12. All of the fibers in the various cloths were predominantly propylene except those in cloth A were predominantly vinylidene chloride.

13. 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 areas of the openings in the cloths, the quantitative significance of the average individual open area shown in table 1 is questionable. These values do show, however, that cloths C and G have openings considerably larger than those of the other cloths, with cloth G having the largest. The percentages of open areas shown are considered to be significant. Cloths C and G were found to have open areas considerably larger than those of the other cloths. Although the quality control for all the cloths is considered to be acceptable, the weaves of cloths A, B, and C appear to be more uniform than the weaves of cloths D and G.

14. The initial tensile strengths of cloths B and D are considered to be 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.

15. The effects of temperature and oxidation appeared to be negligible for the cloths tested. Absorption is considered to be nil. Accelerated alkali tests indicated that cloth A would be affected somewhat by alkalies; however, long-term immersion tests appear to contradict this. None of the cloths appeared to be adversely 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.

16. 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.

PART III: FILTRATION AND CLOGGING TESTS

Purpose

17. Filtration tests were performed to determine the applicability to filter cloths of CE filter criterion for granular material adjacent to holes in drainage pipe or well screens. The criterion stated in terms of EOS is:

$$\frac{D_{85}\text{* of material}}{\text{EOS}} \geqq 1$$

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 due to the migration of fines through the soil.

Test Apparatus

18. Two pieces of apparatus were used during the investigation; one was 12 in. in diameter and one was 5 in. in diameter. They are described in the following paragraphs.

12-in.-diam apparatus

19. Figs. 4 and 5 show the 12-in.-diam filtration test apparatus. The bottom of the cylinder was molded in wax so that any material passing the filter cloth would be washed into the trap, as shown in fig. 4. A standpipe was attached to the trap outlet to provide a tailwater elevation above the top of the soil. The

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* D_{85} is the effective grain size in millimeters for which 85 percent of the sample by weight has smaller grains.

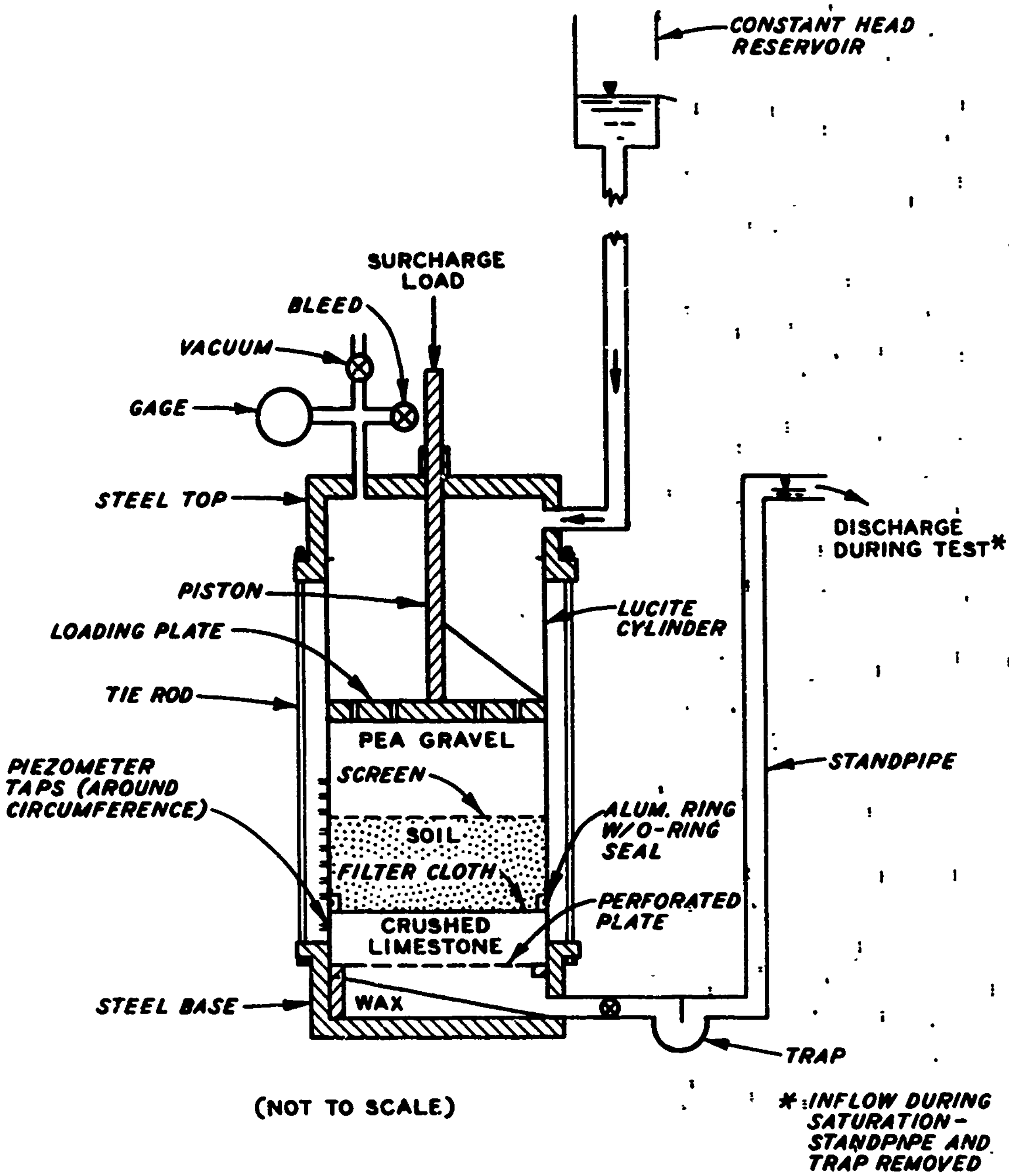


Fig. 4. 12-in.-diam filtration test apparatus (schematic)

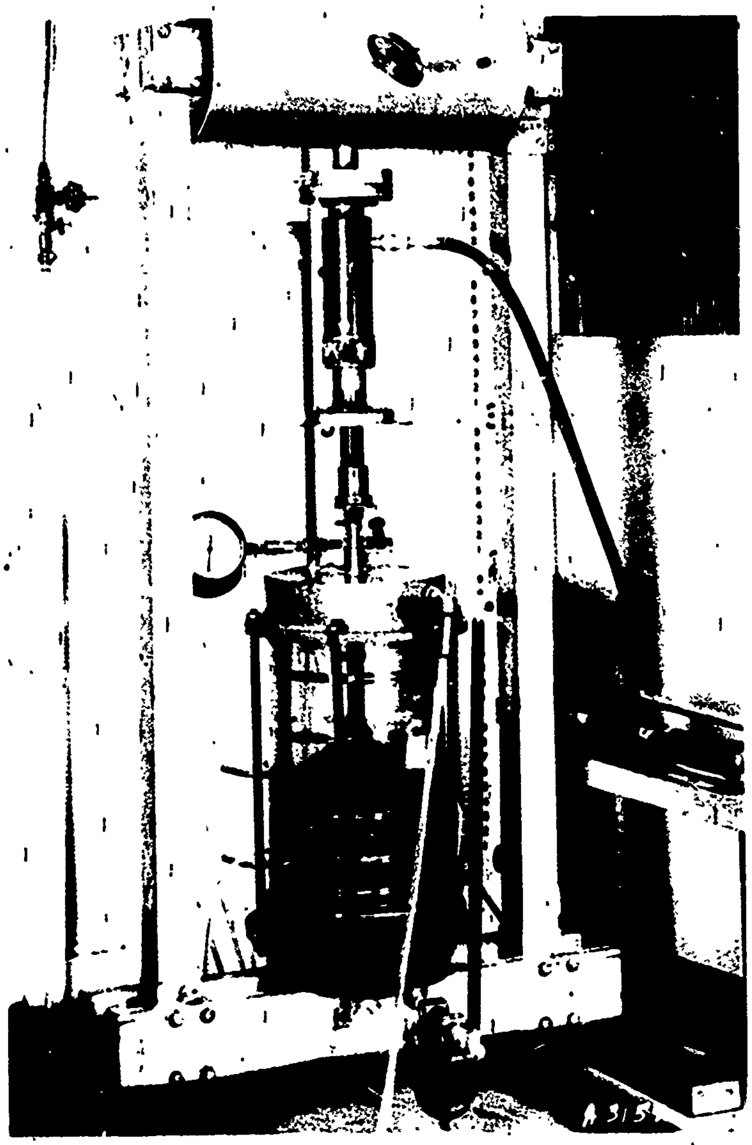


Fig. 5. 12-in.-diam filtration test apparatus

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 were spaced 1 in. vertically and 1 in. horizontally up the side of the cylinder. Piezometer tips 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.-diam 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 grease fitting in a 3/4-in. opening in the center of the top 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 were measured by observing deflections of a Warlam loading frame using a dial gage. A constant head reservoir was used to apply the 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).

5-in.-diam apparatus

20. Fig. 6 shows the 5-in.-diam apparatus used for one filtration test and for all clogging tests. The apparatus is shown schematically in fig. 7. The apparatus was constructed of two 5-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 fig. 7. The connection was made watertight with silicone grease. This resulted in a continuous cylinder in contrast to the disruption caused by the aluminum ring in the 12-in.-diam apparatus. Lines of 3/8-in.-OD piezometer taps were located as shown in fig. 7. Piezometer 1 measured the tailwater elevation. Piezometers 2, 4, and 6 were spaced on 1-in. vertical centers above the cloth, and piezometers 3, 5, and 7 were located 180 deg around the cylinder. Piezometers 6, 8, and 9 were spaced on 2-in. vertical centers, and 9, 10, and 11 on 3-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 saturation was at the base of the standpipe. The constant head reservoir and the source of distilled deaired water were the same as those for the larger apparatus.

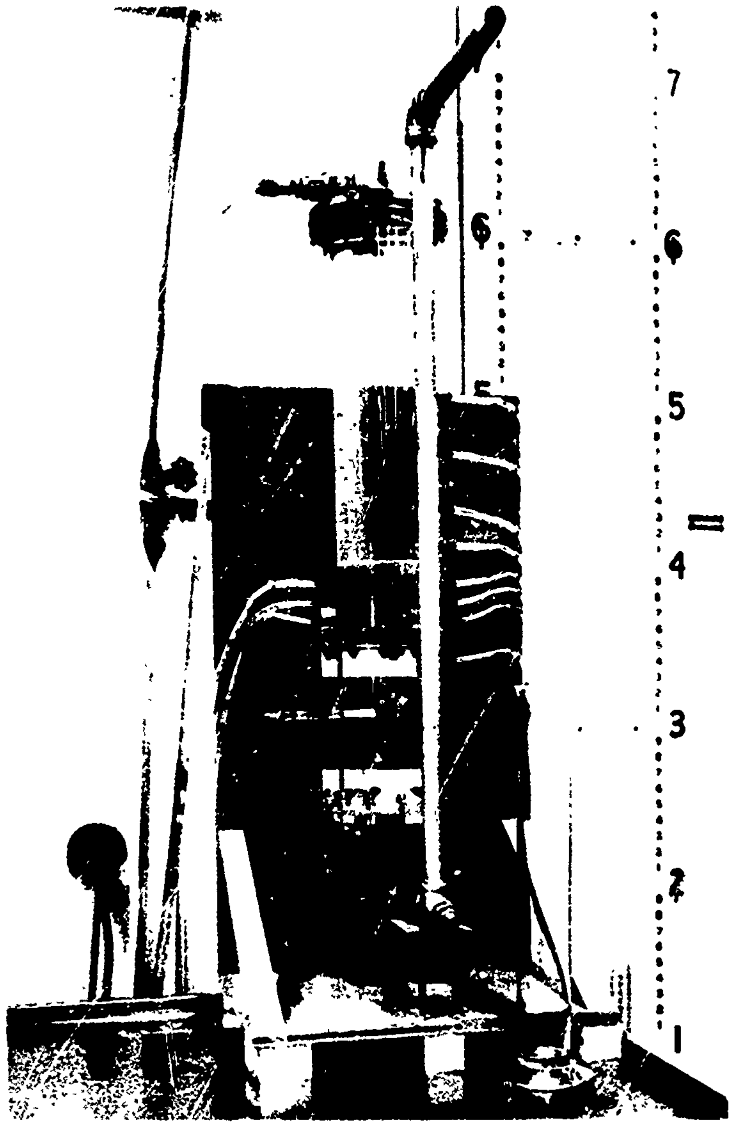


Fig. 6. 5-in.-diam filtration and clogging test apparatus

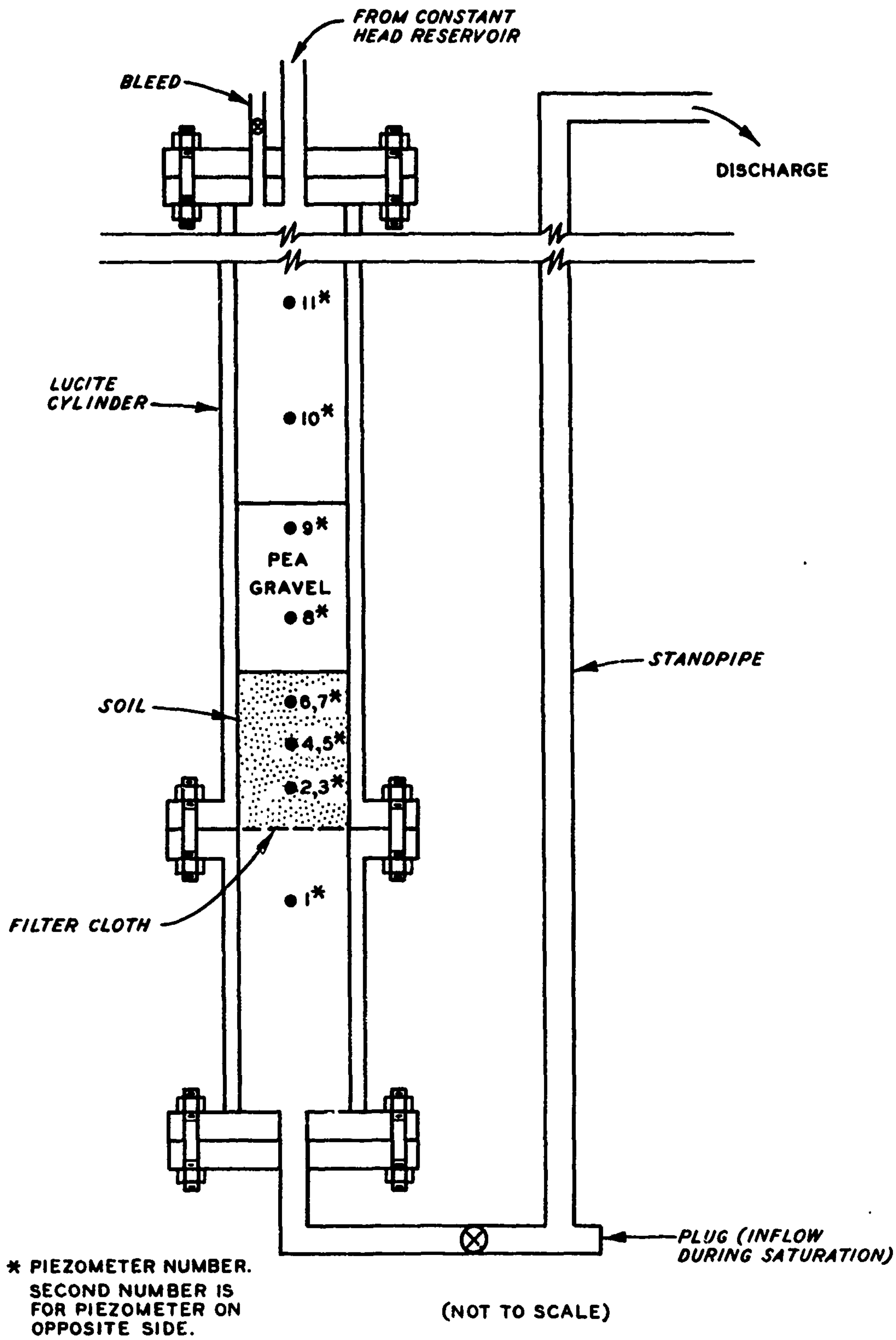


Fig. 7. 5-in.-diam filtration and clogging test apparatus (schematic)

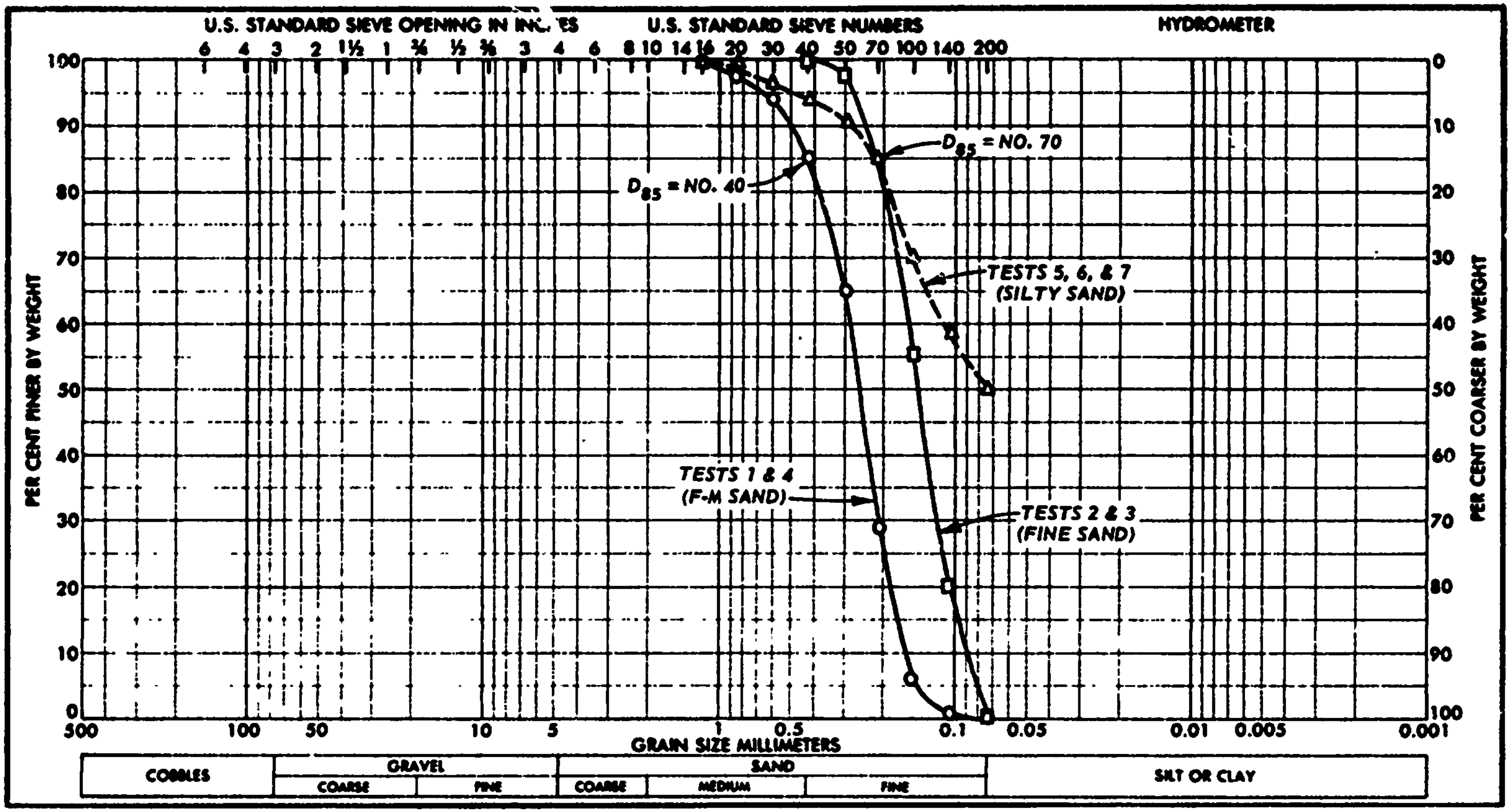
Soils Used

21. In four of the seven filtration tests performed, two gradations of uniform, rounded to subrounded river sands, graded as shown in fig. 8, were used. In the other three tests, a silty sand (SM) was used, consisting of 50 percent sand sizes and 50 percent loess sieved over a No. 200 screen. The coarser gradation of sand was used in test 1 before the method, described in paragraph 6b, for determining the EOS was established, and the EOS 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 than silt since the water velocities through the silty sand would be higher and piping of fines could still occur. Ottawa sand (between the Nos. 20 and 40 sieve sizes) with 0, 5, 10, and 20 percent loess fines was used in the clogging tests; in future references, tests with these materials will be referred to as the "5 percent silt tests," etc. The rather coarse gradation of Ottawa sand was selected to provide a skip graded mixture (fig. 9) that would allow easy migration of the loess fines.

Preparation of Test Specimens and Apparatus

Tests with 12-in.-diam apparatus

22. Tests 1-6 were performed with the larger apparatus. The apparatus was readied for testing in the following manner. A perforated brass plate was fitted above the base, and the Lucite cylinder was then attached to the base. Uniform size 2-in. angular limestone fragments were placed on the perforated plate to a height of 3 to 4 in. Angular limestone was used to see if it would cause tearing, puncturing, or a severe stretching condition of the filter cloth when the surcharge loads were applied. In the first two tests, the filter cloth was secured to an aluminum ring with epoxy cement. This method proved to be unsatisfactory. In the remaining tests, a smaller ring was bolted over the



	LL	PL	PI
F-M SAND (SP)	--	NP	--
FINE SAND (SP)	--	NP	--
SILTY SAND (SM)	15	14	1

Fig. 8. Gradation of soils used in filtration tests

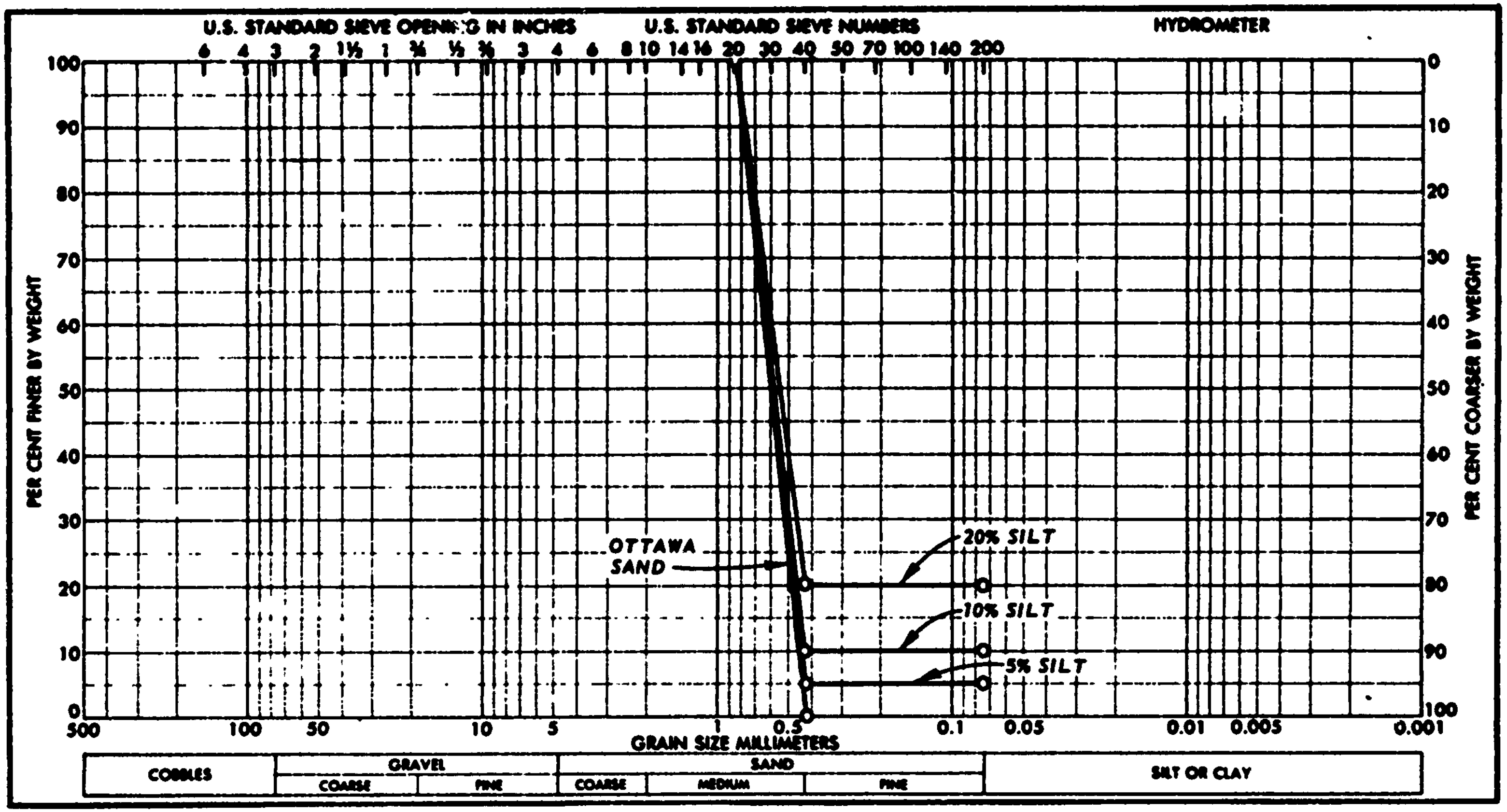


Fig. 9. Gradation of soils used in clogging tests

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 in 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 the water was brought to an elevation about 1 in. below the filter cloth. The deaired water was introduced through the valve and discharge pipe in the base (shown in fig. 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 (plus 1/4 in.) 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.

23. The soil was saturated in the following manner. After the apparatus had been assembled and the piezometers and top discharge opening closed off, deaired water was brought just above the level of the filter cloth. The valve was then shut off 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 at 1-in. increments within the sample with the vacuum applied after the valve was closed. This was continued 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 a 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-in.-diam apparatus

24. Filtration test 7 and all clogging tests were performed with the 5-in.-diam apparatus. In the filtration test, the soil was placed

dry on the cloth and was saturated by allowing deaired water to flow slowly up 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 minimized although the water did become muddy during placement. This resulted, in some instances, in the formation of a 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 (plus 1/4 in.) 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 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.-diam apparatus

25. The filtration tests were performed with downward flow. For the initial test in a series, no surcharge load was applied. A differential head was applied (usually about 0.25 ft) 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. The discharge was measured over a given period of time after it had stabilized, and the piezometers were read. The flow was recorded, and the piezometers were read a minimum of three times at 15-min intervals for

each applied head for all tests. 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 (intermediate head) and then reduced to the initial head. Temperature measurements were made of the water entering and exiting the apparatus.

26. After completion of the initial tests, a surcharge of 500 psf 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-psf surcharge was then applied, height measurements were again recorded, and the procedure was repeated in the same manner as that for the 500-psf surcharge test.

27. The surcharge was removed and the soil was "surged" by opening and closing the discharge valve 10 times each 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 with a rubber mallet for about 5 min at the initial, intermediate, and maximum heads, first with no surcharge and then with 500-psf surcharge. This was not done at the 1000-psf surcharge as a safety precaution.

28. The apparatus was then disassembled, the trap inspected to detect infiltrated material, and in-place densities were determined at the top and bottom of the soil column using a 1-in.-diam Hvorslev sampler. Samples of soil from the top and bottom were obtained for sieve analysis. A sieve analysis was also run on any material that passed the cloth during the test. The cloth was visually inspected and photographed to note any clogging or any tears, punctures, or other alterations due to 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-in.-diam apparatus

29. Filtration test 7 and all clogging tests were downward flow tests. The procedures for applying the heads and recording flows and temperatures using the smaller apparatus were about the same as 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.

30. The clogging tests were conducted with the reservoir at a constant head for periods up to 320 min. All piezometers were read and flows were measured periodically. Actual time periods and hydraulic gradients 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.

31. 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 the soil in the first 1/4 in. above the cloth, and on soil between that level and the elevation of the first piezometers above the cloth (see sketch in table 3, page 53). Above the first piezometers, determinations of fines were made on the material between the elevations of the remaining piezometers (1-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

32. General. Information on the soil specimens is given in

table 2. In all of the tests using the 12-in.-diam apparatus (tests 1-6), there was some difficulty in determining the exact length of the soil specimen after the apparatus had been set up for the tests. This was particularly true after the surcharge loads had been applied. Sometimes it appeared that the filter cloth had moved downward a greater distance than the top of the specimen had moved. It was thought that this 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 F during the tests, 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.

33. Cloth B.

a. Using F-M sand (test 1). Net heads up to 1-ft water were applied, first under conditions of no surcharge and then under a 500-psf surcharge. Due to high head losses through the base valve, trap, and standpipe, the maximum head differential was only about 1 ft even though the elevation of the constant head reservoir was several feet above tailwater elevation. The Lucite cylinder cracked upon application of 1000-psf surcharge, and the test was discontinued. Sand density after testing was 97.5 pcf in the top 1 in. and 95.7 pcf in the lower 1 in., compared with the initial density after saturation of 95.4 pcf. Plots of head losses through the soil specimen and filter cloth under 0- and 500-psf surcharge are shown in fig. 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. Piezometer 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.* There was no indication of sand infiltration through the cloth or piping within the sand specimen during any period of the test (maximum velocity, 0.16 fpm). Sieve analyses of the material taken from the top and bottom of the soil

* This was also found to be true in tests 2 and 3 for the piezometer nearest the filter cloth.

Table 2

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.

** Reduction from placement density probably caused by upward flow of water during saturation.

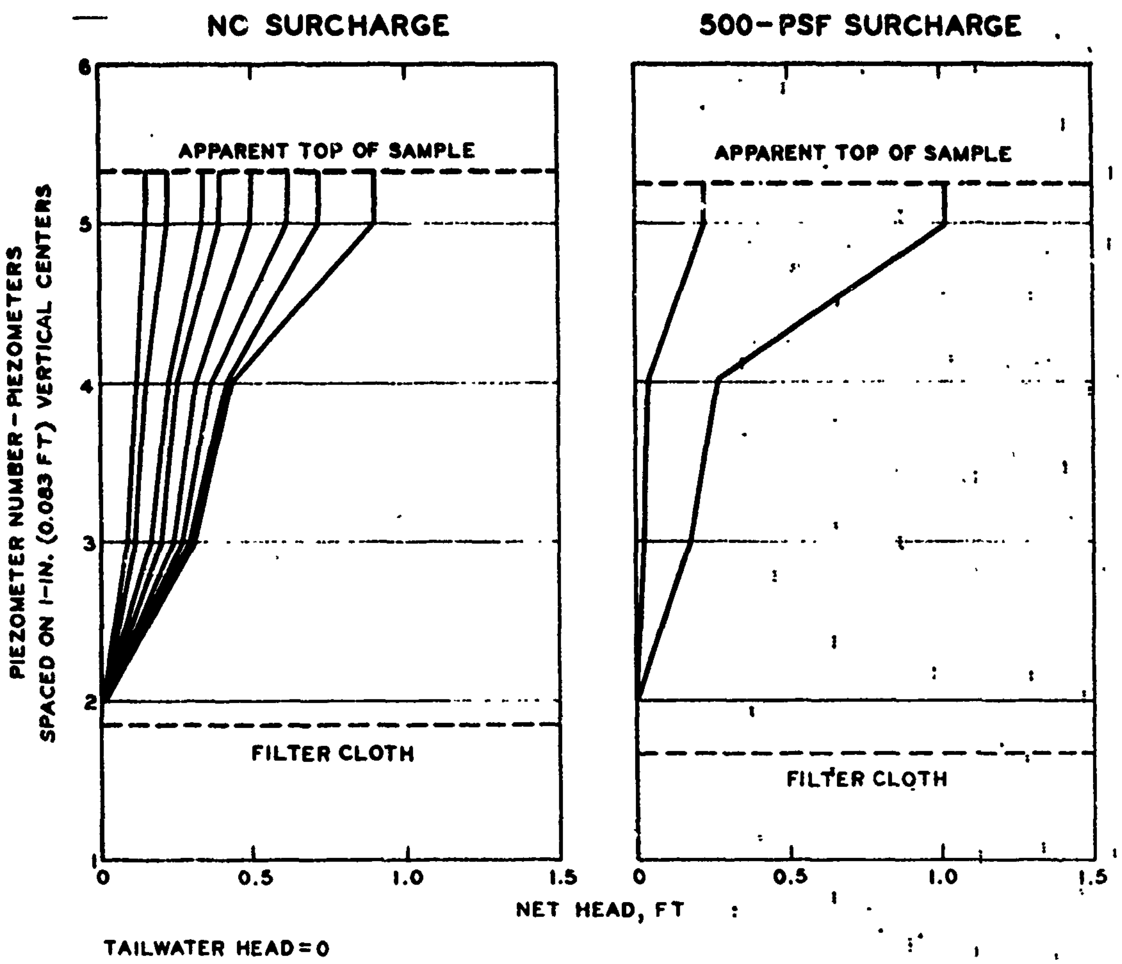
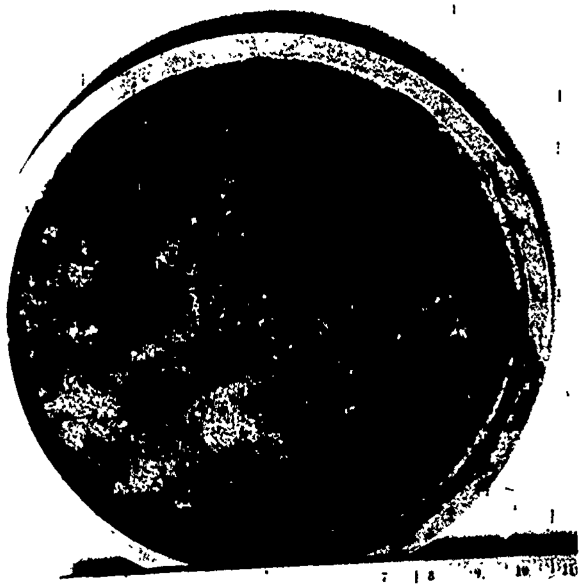


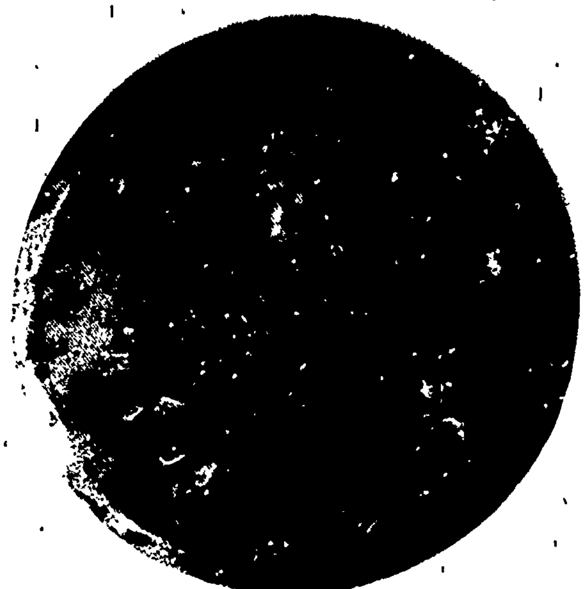
Fig. 10. Head losses through sample and cloth B, test 1

specimen showed practically identical gradations. Fig. 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.

b. Using fine sand (test 2). In this test, application of a 1000-psf surcharge was also attempted, the Lucite cylinder 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



a. Top of cloth



b. Underside of cloth

Fig. 11. Cloth B after completion of test 1

the filtration test (maximum velocity, 0.15 fpm); the gradation of the material taken from the top of the sample at the end of the test was practically identical with that of the bottom. The condition of the cloth after testing was similar to that shown in fig. 11. There were no tears or punctures. Head losses through the sand and filter cloth under 0- and 500-psf surcharge are plotted in fig. 12.

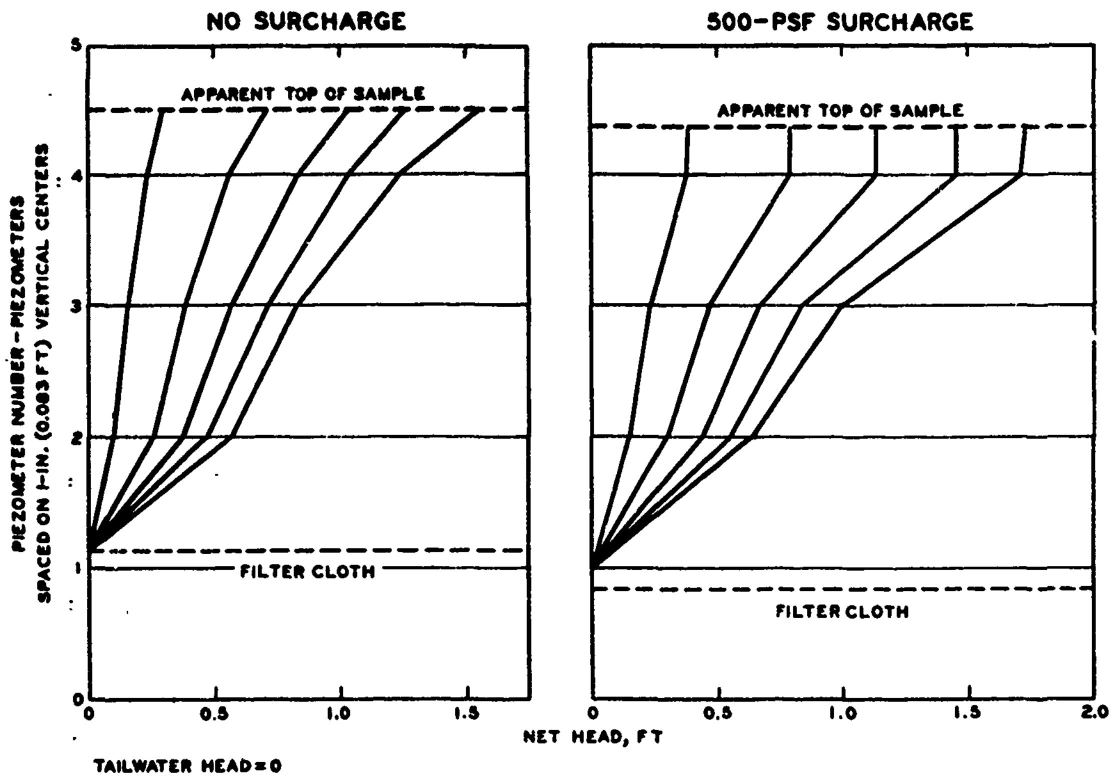


Fig. 12. Head losses through sample and cloth B, test 2

c. Using silty sand (tests 5 and 6). The purpose of these tests was to determine if the presence of silt sizes would cause the cloth to clog or would cause more movement of soil through the cloth. Some difficulties were experienced in saturating the samples prior to the filtration tests, and the presence of air undoubtedly affected the results and perhaps affected the response of the piezometers. In some instances, the vacuum was applied for 2 to 3 hr to no avail. In test 5, upon application of the initial head (hydraulic gradient through the entire soil sample and cloth of about 1.5), the water discharging was discolored, but cleared within 5 min. The discharge remained clear throughout the application of higher heads to the maximum head applied (i = 29). When the flow was initiated after the 500-psf surcharge was applied (i = approximately 0.5), the water was considerably discolored for about 15 min before clearing. It was also noted that pea gravel was being pushed into the soil when the surcharge was applied. The discharge also was discolored when the base of the permeameter was first struck with a rubber mallet; after continued striking, the water cleared. The shapes of the curves of velocity versus hydraulic gradient shown in fig. 13 indicate no significant clogging of the cloth as the test was continued. Following

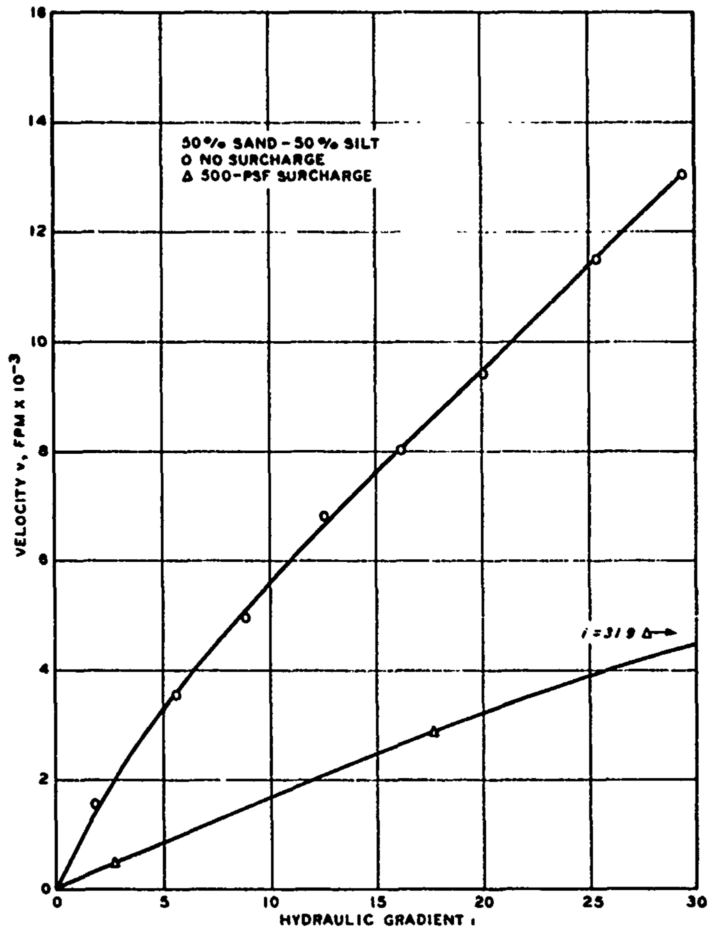


Fig. 13. Velocity versus hydraulic gradient; cloth B, test 5

the test, grain-size analysis of 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 with 50 percent in the soil as placed. Fig. 14 shows the underside of the cloth

Fig. 14. Cloth B after completion of test 5 (underside of cloth)

after the test was completed; silt adhering to the cloth can be seen. It is to be noted that 71 percent of the test soil could be washed through the cloth. The second test on cloth B using the same silty sand (test 6) was performed to determine if material passing the cloth in test 5 was largely due to 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 up to 53 was applied in increments. On the application of the initial hydraulic gradient of 0.3, the discharge was slightly discolored, but cleared up within 5 min and remained clear throughout the application of increasing hydraulic gradients. The shape of the curve of velocity versus hydraulic gradient in fig. 15 indicates no significant clogging of the cloth as the test was 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

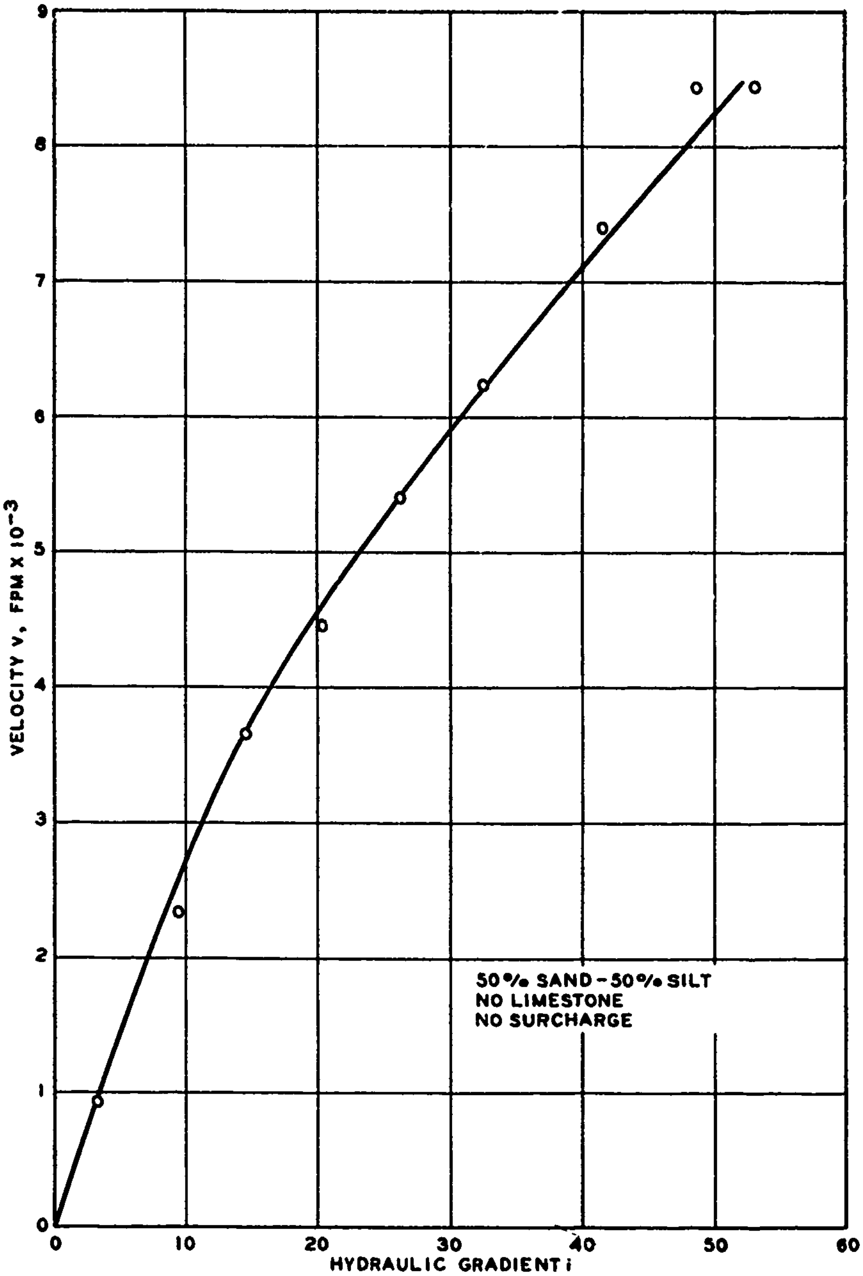


Fig. 15. Velocity versus hydraulic gradient; cloth B, test 6

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 after 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. Sie e analyses from the lower 1/2 in. of the sample showed only a slight reduction in the percent passing the No. 200 sieve, indicating that very few fines passed through the cloth.

34. Cloth C, using F-M sand (test 4). There were no evidences of any material passing through the cloth at velocities up to 0.15 fpm. Gradations of the material taken from the top and bottom of the sand specimen after test were practically identical. Fig. 16 shows the

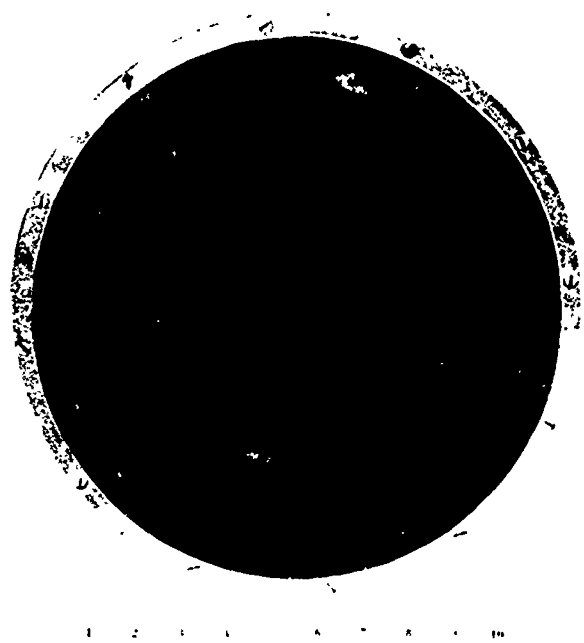


Fig. 16. Cloth C after completion of test 4 (underside of cloth after washing)

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-psf surcharges are shown in fig. 17.

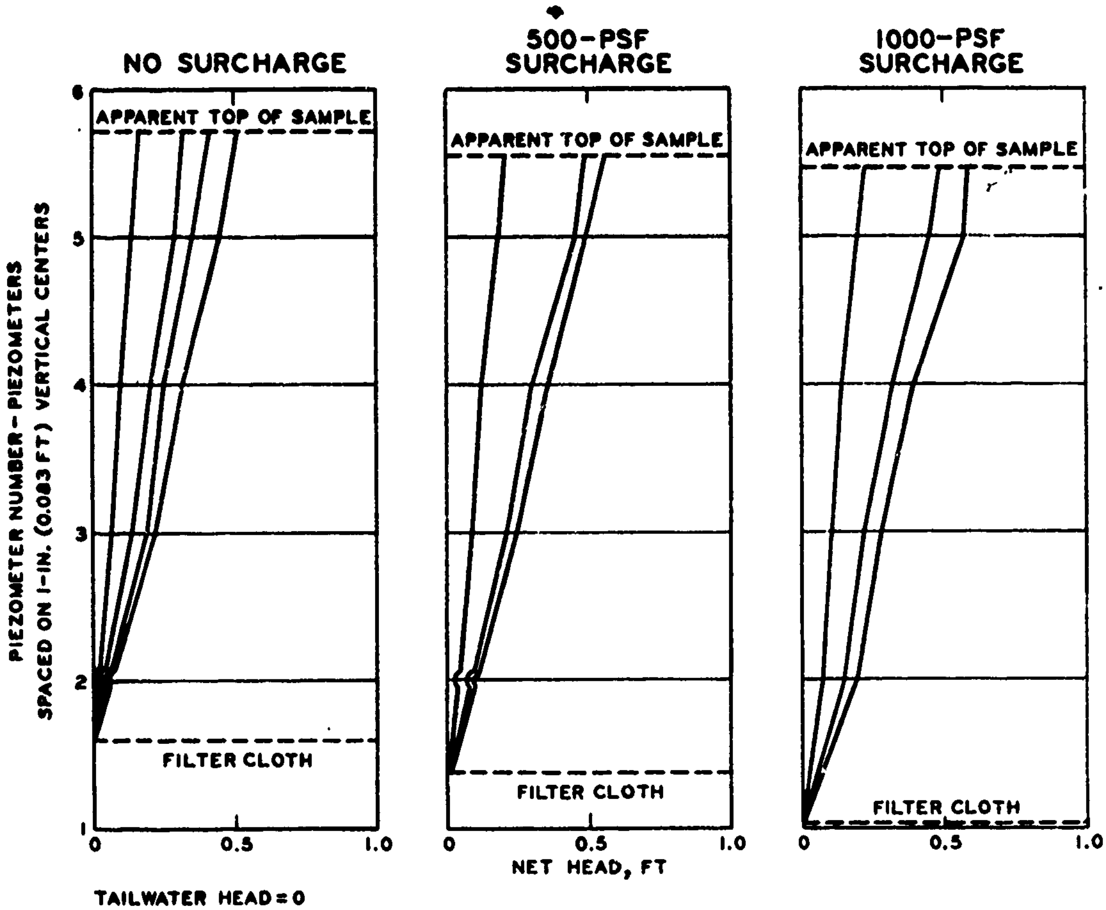
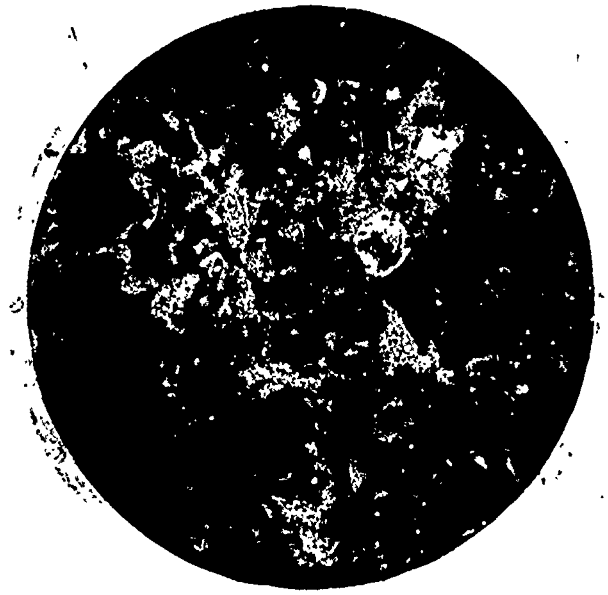
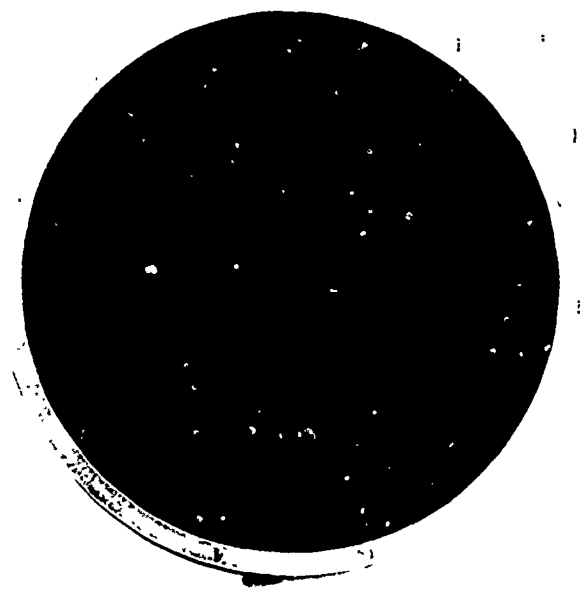


Fig. 17. Head losses through sample and cloth C, test 4

35. Cloth D, using fine sand (test 3). The sand density in this test was also less than the minimum dry density determined in the laboratory because of loosening during upward flow of 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, which included also the imposition of 1000-psf surcharge (maximum velocity, 0.14 fpm). Gradations of the sand taken from the top and bottom of the sample after test were essentially unchanged from the initial gradation. Fig. 18a shows the underside of the cloth immediately after testing. The lighter areas are powder from the limestone fragments; some chipped edges of the limestone also are visible. Indentations from the limestone are shown more clearly in fig. 18b, which was made after washing the cloth. There was no indication of any sand particles



a. Underside of cloth before washing



b. Underside of cloth after washing

Fig. 18. Cloth D after completion of test 3

embedded in the openings. Head losses through the sand and filter cloth under 0-, 500-, and 1000-psf surcharges are shown in fig. 19.

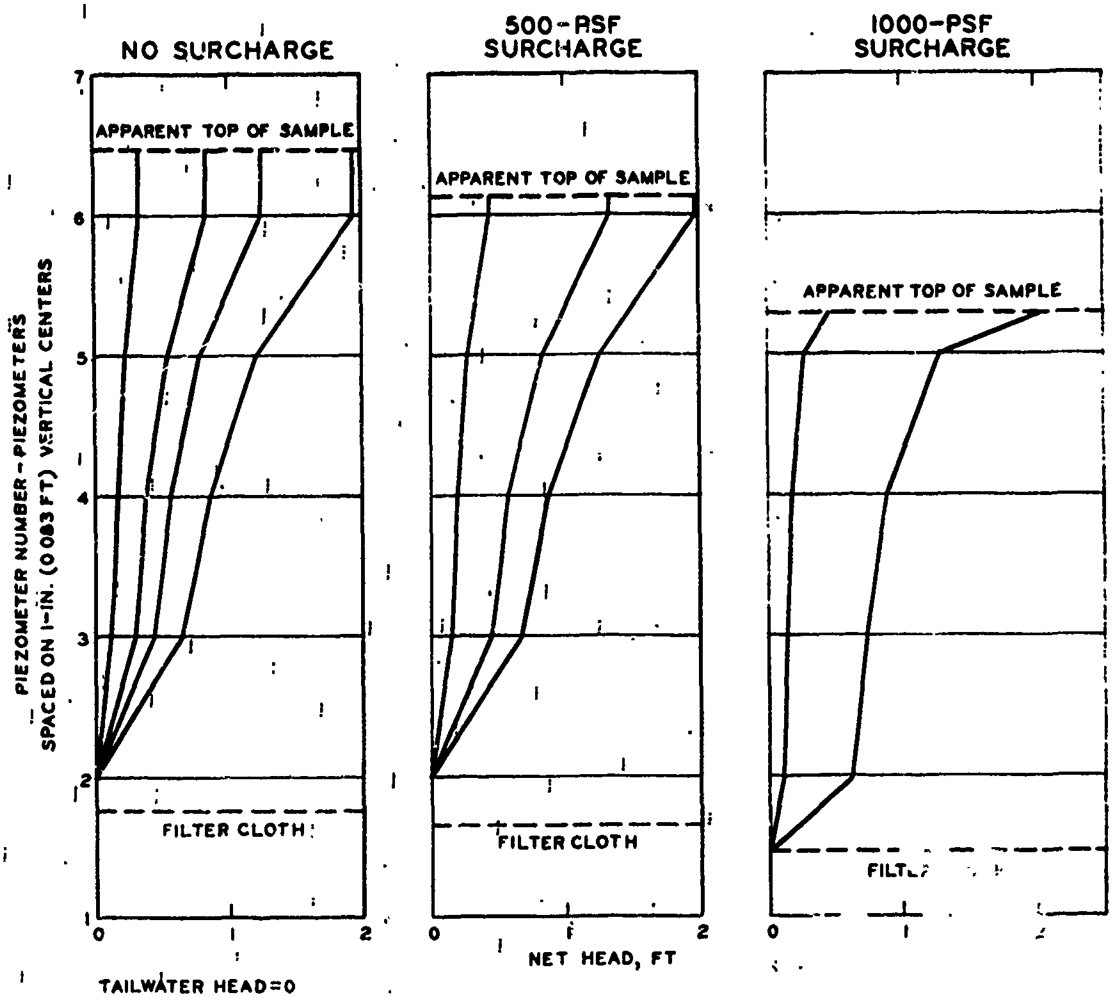


Fig. 19. Head losses through sample and cloth D, test 3

36. Cloth G, using silty sand (test 7). This was the only filtration test performed in the 5-in.-diam apparatus. Cloth G was tested since it had the most open weave of any of the cloths. The height of soil above the cloth was 1.36 in. with a dry density of 111.0 pcf. As in the previous two tests, the water became cloudy upon application of the initial head (i = 4.16), but cleared up in a matter of minutes. The discharge remained clear throughout the application of the higher heads to the maximum applied (i = 35). A plot of velocity versus

hydraulic gradient for this test is shown in fig. 20. The abrupt change in velocity at i = 13 , shown on the plot, was probably due to

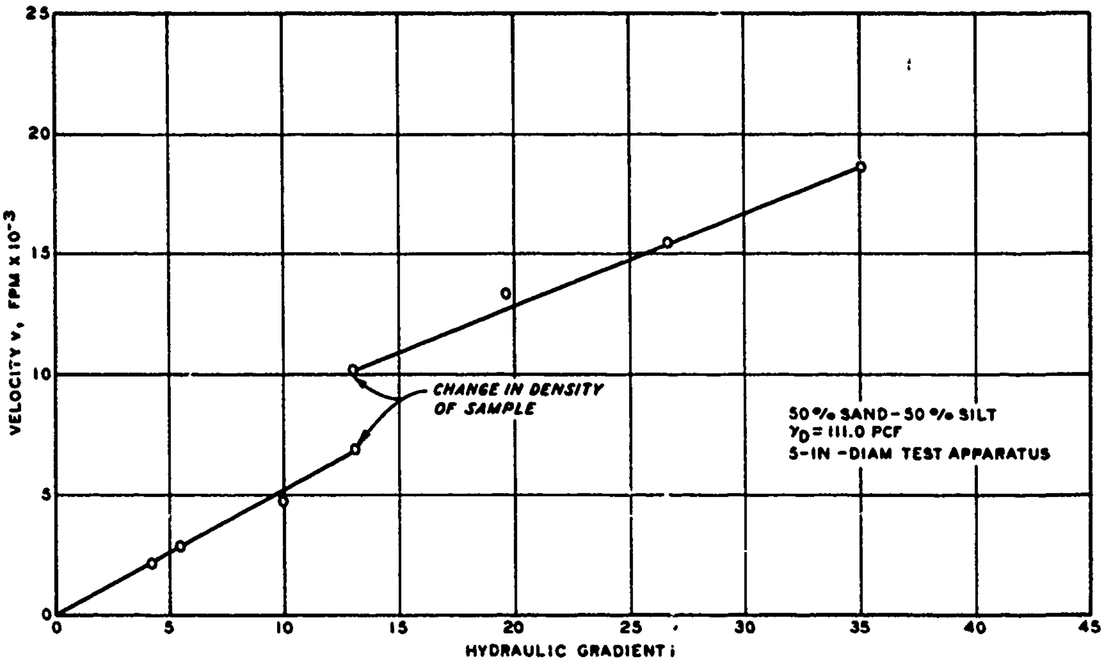


Fig. 20. Velocity versus hydraulic gradient; cloth G, test 7

a change in density of the soil sample. The lower velocity reading was taken at the conclusion of the workday and the test was shut down overnight. The next morning it was found that the constant head reservoir had emptied, thereby reducing the hydrostatic pressure on top of the soil creating a pressure differential between the top and bottom of the sample. It is thought that the upward flow through the sample loosened the soil somewhat, thereby increasing its permeability. The discharge became cloudy when the apparatus was struck with a rubber mallet under the highest gradient applied. The water cleared in less than 5 min 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.

37. Summary of filtration tests. Tests 2 through 4 indicated that woven filter cloths effectively retained loose uniform sands when the D_{85} size of the sand was equal to or greater than the EOS of the cloth. Maximum velocity of flow during the tests was 0.16 fpm. 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.

38. 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 (EOS = No. 30 , open area = 36 percent), it was not considered necessary to test the remaining cloths.

39. No filtration tests were run on cloths E and F since it was obvious 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 psf and in some tests with 1000 psf, and with the filter cloth in direct contact with angular stones, did any punctures, tears, or other significant alterations of any of the cloths tested occur.

Clogging tests

40. 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 EOS (No. 100 sieve size). No tests were performed on cloths B, C, D, and G because their EOS's were equal to or larger than the EOS of cloth A and their percent open areas were 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 measurements plotted in figs. 21 through 32 were related to the hydraulic gradient measured from the tailwater piezometer (piezometer 1) to the first piezometer below the top of the specimen (piezometer 6). This value was designated i' .

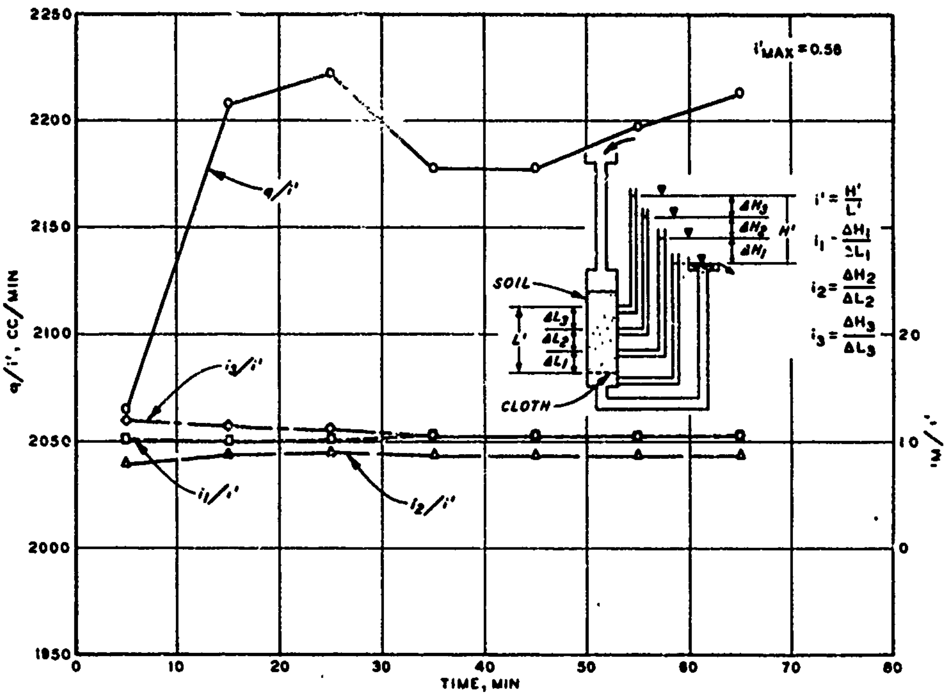


Fig. 21. Clogging test, cloth A, no silt

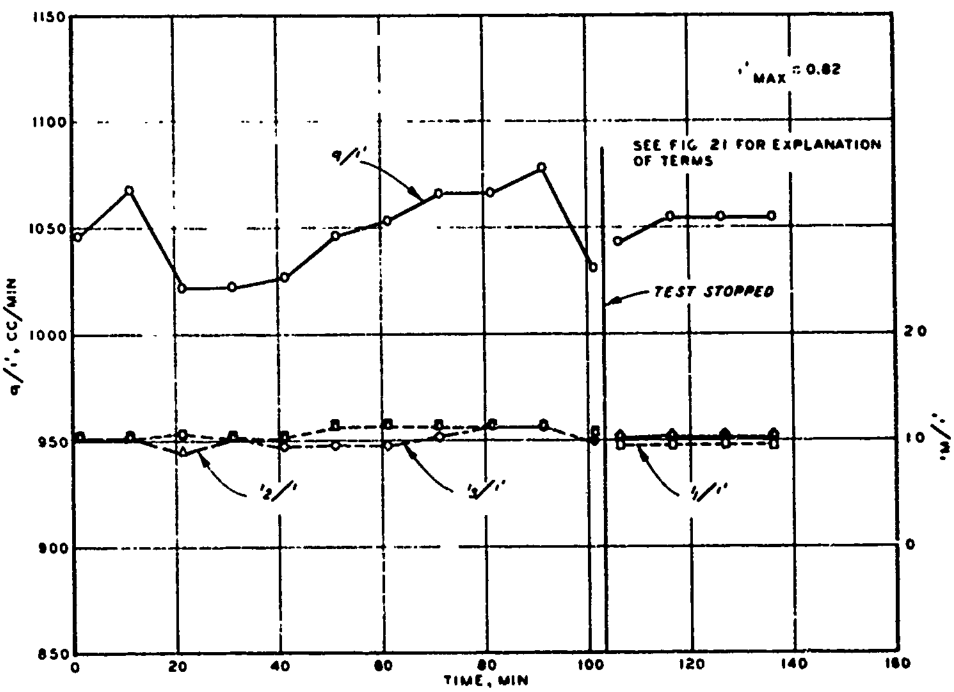


Fig. 22. Clogging test, cloth A, 5% silt

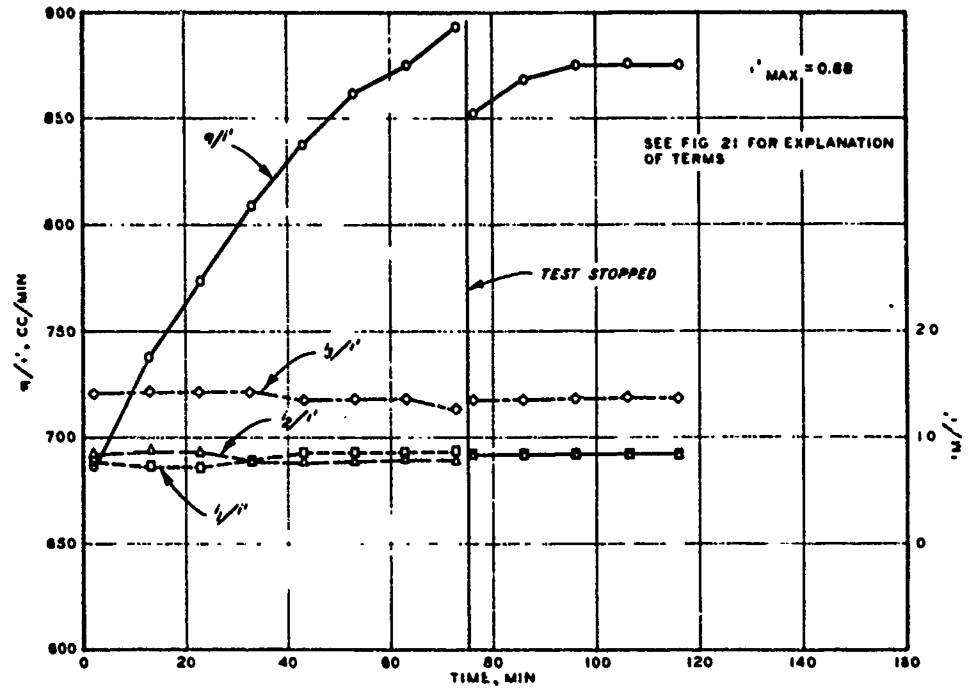


Fig. 23. Clogging test, cloth A, 10% silt

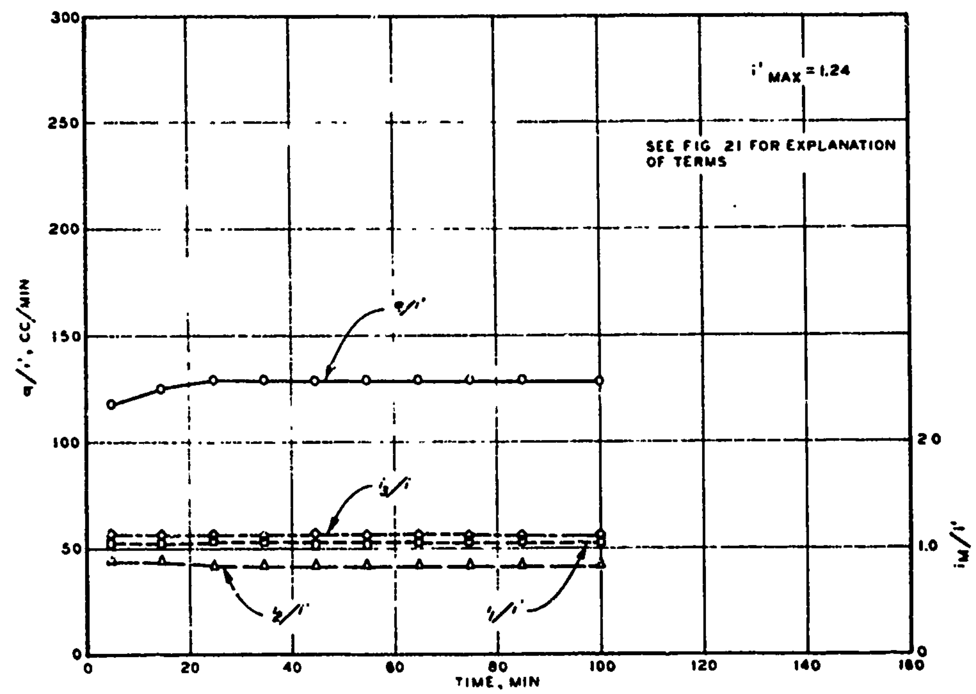


Fig. 24. Clogging test, cloth A, 20% silt

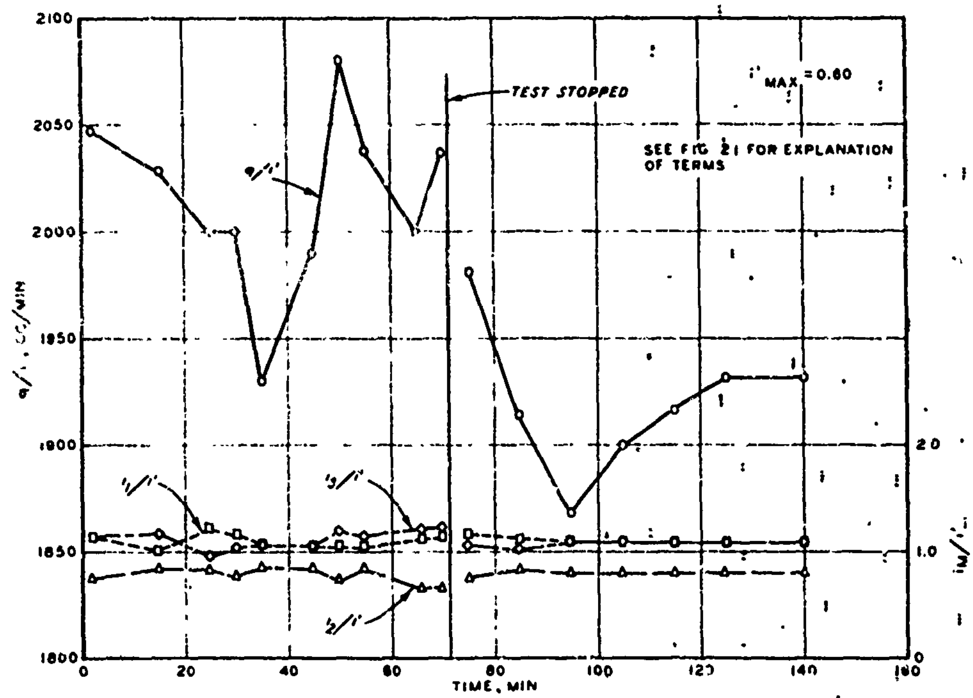


Fig. 25. Clogging test, cloth E, no silt

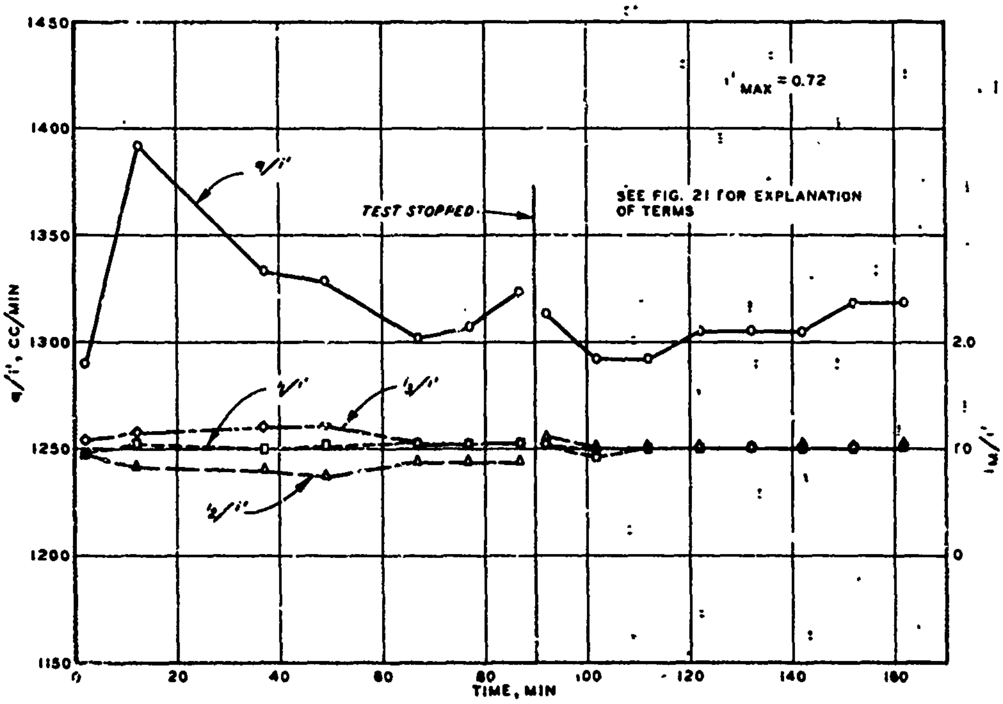


Fig. 26. Clogging test, cloth E, 5% silt

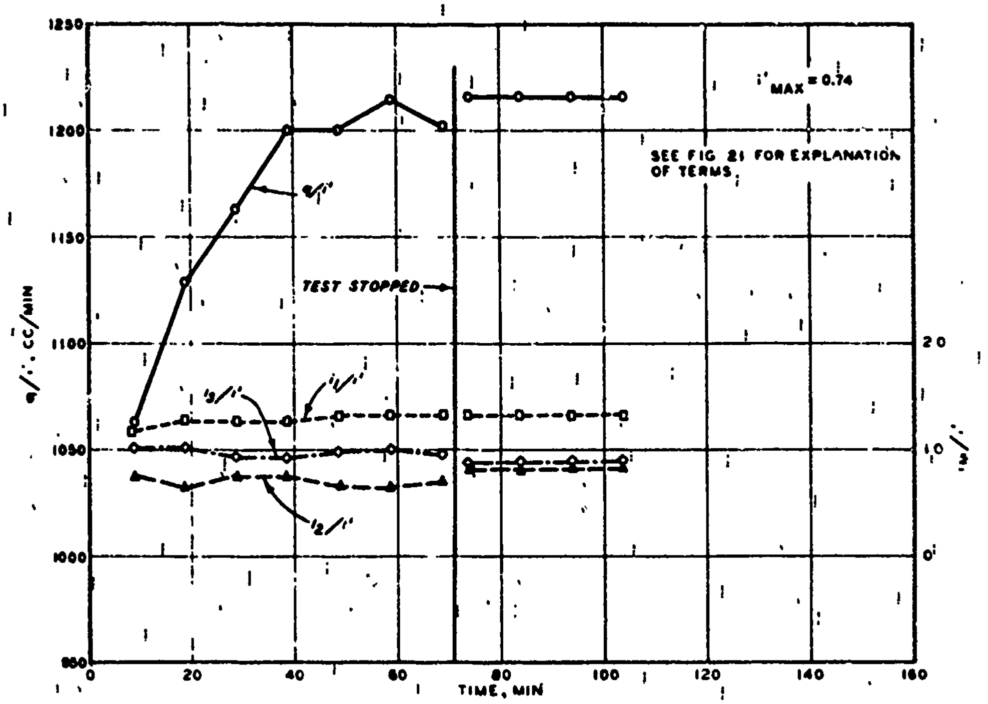


Fig. 27. Clogging test, cloth E, 10% silt

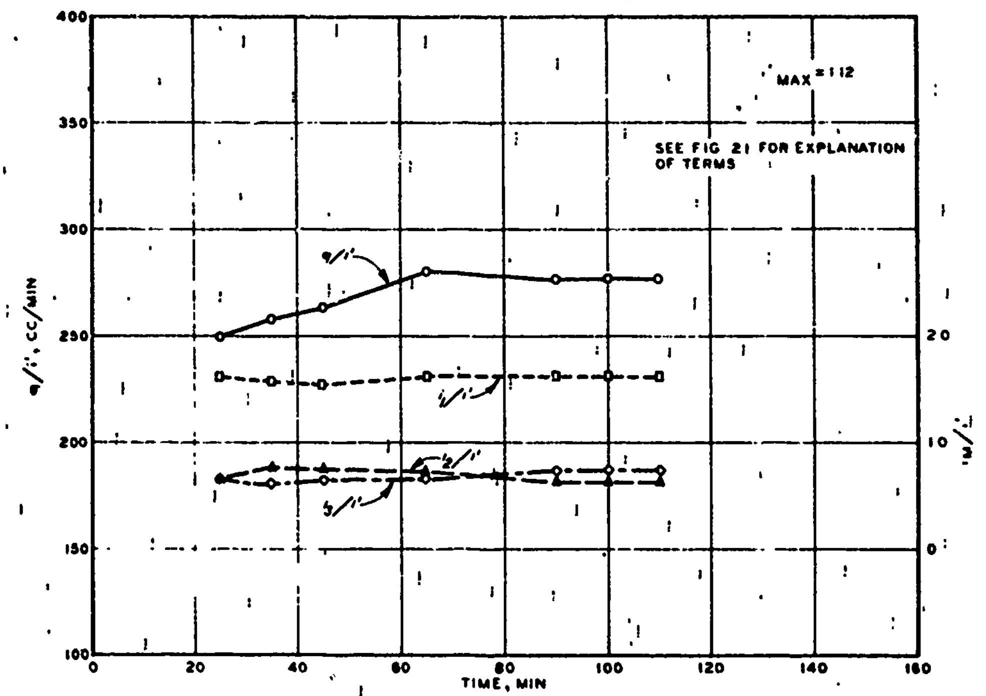


Fig. 28. Clogging test, cloth E, 20% silt

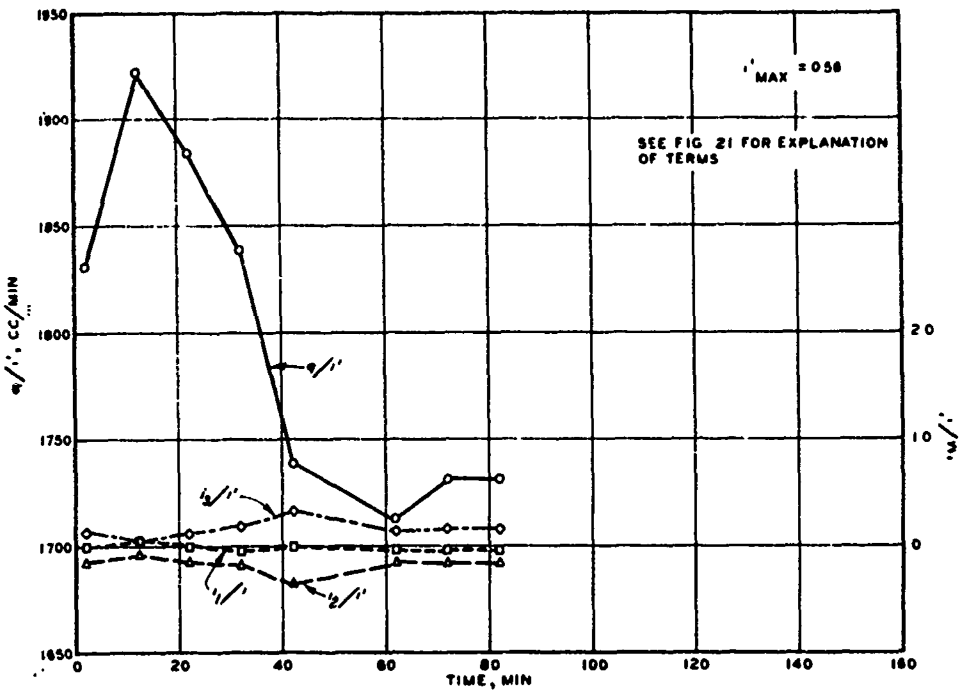


Fig. 29. Clogging test, cloth F, no silt

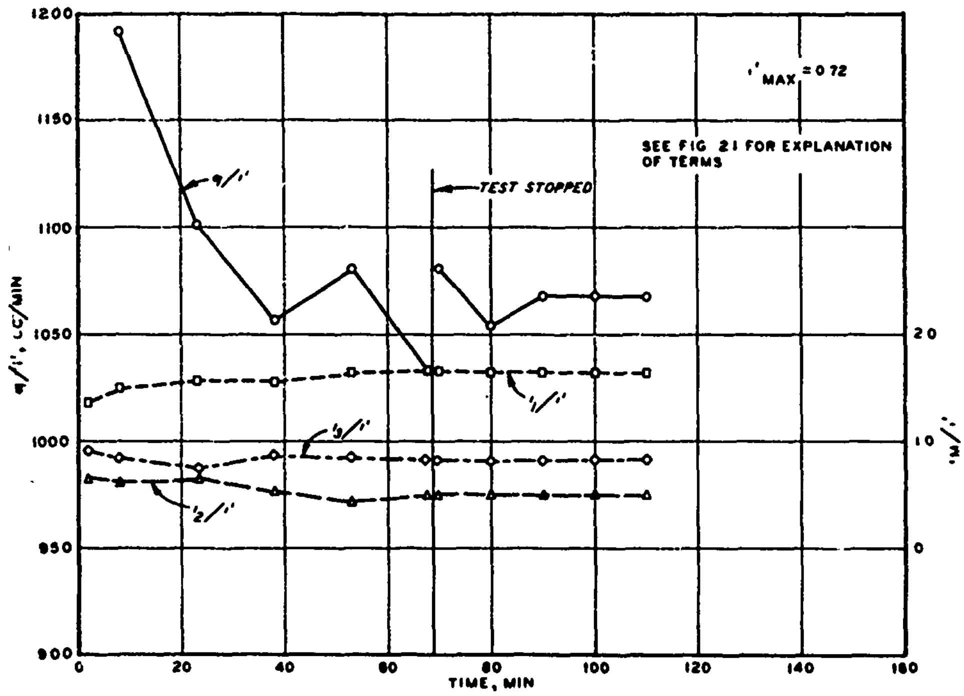


Fig. 30. Clogging test, cloth F, 5% silt

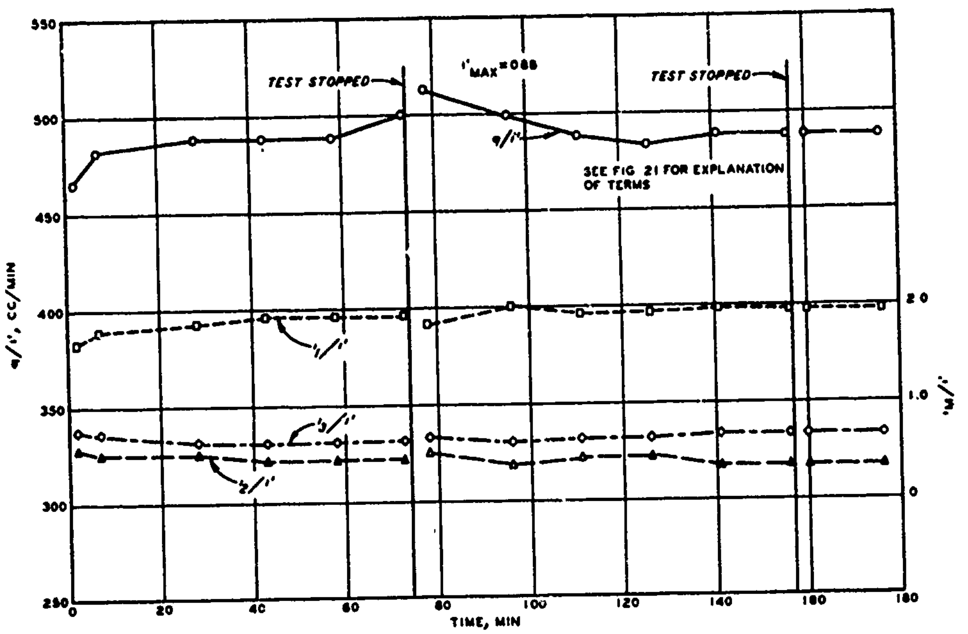


Fig. 31. Clogging test, cloth F, 10% silt

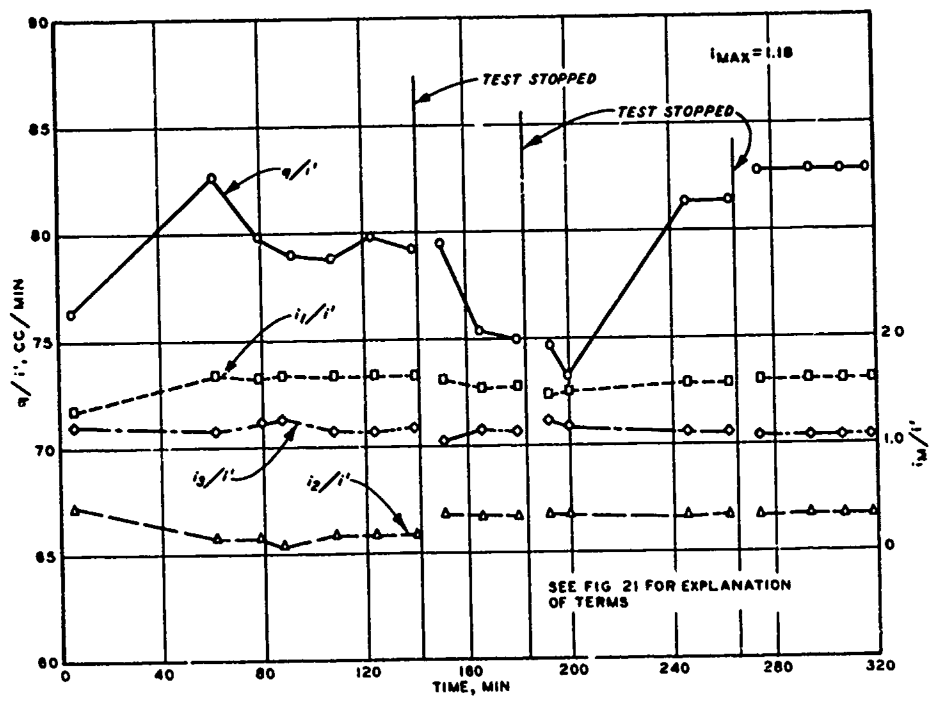


Fig. 32. Clogging test, cloth F, 20% silt

By dividing the hydraulic gradients measured through various 1-in. vertical increments of the soil by i' , an indication of variation in silt content (clogging in the case of the lowest 1-in. soil increment plus the cloth) could be obtained. The ratio of the hydraulic gradient through the lowest 1 in. of soil plus filter cloth to i' at the conclusion of the test was termed the "clogging ratio." A ratio greater than 1 would indicate clogging. Of course, variation in densities of the sample would affect the results as well as other factors inherent in this type of test. However, in tests on sand alone, the variation in hydraulic gradients of the 1-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 within 3 to 10 min. The water temperature varied only by 1 to 3 deg and was not considered in the analysis. Results of these tests are summarized in table 3 and in the figures discussed in subsequent paragraphs.

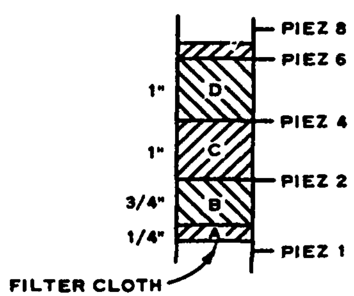
41. Cloth A. The results of clogging tests on cloth A are shown in figs. 21 through 24. The flow measurements are not considered particularly significant other than the fact that they indicated no consistent decrease in flow during the tests. The clogging ratio at 20 percent silt was 1.06, which was slightly lower than that measured on the sand alone. At 5 and 10 percent silt, the clogging ratios were less than 1. The relatively high head loss between piezometers 4 and 6 in the test on the 10 percent silt mixture was attributed to fines, segregated during placement, settling to the top and in the top 1 in. of the sample. This was verified by the relatively large percentage of silt found in the section (see table 3). 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 at any other within the sample. There was a cake of fines on top of the soil which would reduce the

Table 3

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.



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 cakes of fines developed, there appeared to be no significant head loss through the cloth as shown in the figures and by the low clogging ratios.

42. Cloth E. The results of the clogging tests on cloth E are shown in figs. 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 5 percent silt. However, with soils having 10 and 20 percent silt content, clogging ratios of 1.33 and 1.61, 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.

43. Cloth F. Results of tests on cloth F are given in figs. 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 zero and 5 percent silt. Since the reduction occurred with no silt present in one test, the flow reduction in the 5 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 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.

44. Summary of clogging tests. Flow measurements taken during the clogging test were not conclusive. However, it is considered 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 in testing with soil containing 10 percent silt, since the hydraulic gradient through the lower inch of sample and cloth was almost twice as great as the gradient through the entire sample. Cloth E, without distinct openings, showed a tendency to clog from soil having 10 and 20 percent silt content, while cloth A, with distinct openings, had clogging ratios near 1 for all gradations tested, indicating no significant clogging. Tests with soils containing no silt showed no significant head loss through the filter cloth when compared with head losses through the entire soil column.

PART IV: FIELD AND HYDRAULIC TESTS

Stone Drop Tests

Purpose

45. Field performance data collected throughout the study indicated that cloth B had performed satisfactorily under every loading it had been subjected to, while in some instances cloth A had torn during placement of riprap, and holes attributed to abrasion were found several years after placement. Therefore, the strength and abrasion resistance of cloth B appeared to be satisfactory, while these properties 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

46. Fig. 33 shows the test site--a loess bank graded to a 1V-on-3H 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 mixing the material to a uniform depth. Also, the resulting surface was thought to provide much too soft a bed. Consequently, it was decided to simply hand rake the slope before placing the cloths. This provided a smooth uniform bed.

47. 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. Cloth E was also tested with its weaker principal direction perpendicular to the toe of the slope. The cloths were loosely placed on the slope and pinned along their edges on 3-ft centers with 3/16-in.-diam, 15-in.-long pins. The pins had 1-1/2-in. washers.

Fig. 33. Overall view of drop test site

48. 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:

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 (fig. 34).

49. Drops were made from 2.5 ft and then 4.5 ft on each cloth. Drops of 3 and 5 ft had been planned. However, it was discovered that the actual drop was 0.5 ft less than indicated by the measuring device

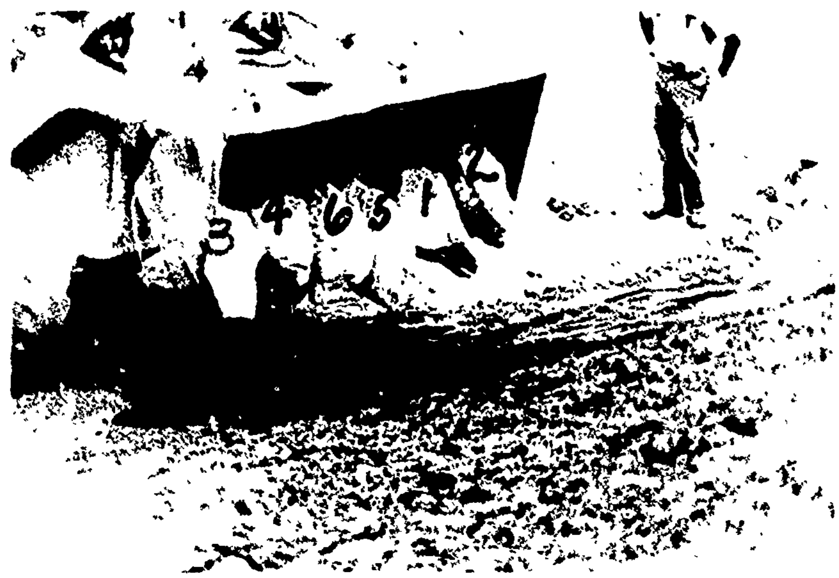


Fig. 34. Stones being dropped from bucket

on the bucket. Each cloth was marked off into two sections, 7 to 8 ft 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.

50. In other drop tests less controlled than those described above, dump trucks hauling stones to the test site discharged the stones from approximately a 3-ft 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 3 ft on cloths A, E, and F.

Results

51. Results of the stone drop tests on the seven cloths are given in table 4 and in the subsequent subparagraphs.

Table 4

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 2d drop - 2 tears: 5-in. tear from stone 1; 1-in. tear from stone 5	No damage
B	2d drop - 1 tear, 1 in. long from stone 3	1st drop - 4 puncture holes about 1/4-in. diam 2d drop - 1 tear, 2 in. long from stone 1	No damage
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 2d drop - 2 tears, 1 and 2 in. long from stone 3	No damage
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.

a. 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 from the 4.5-ft drop. A 6-in. tear caused by the 186-lb stone is shown in fig. 35. The 256-lb stone caused a 5-in. rupture in the cloth, and there were three other small tears.

Fig. 35. Cloth A, 6-in. tear after 4.5-ft drop

b. Cloth B. Cloth B was not significantly damaged by the 2.5-ft drop (one 1-in. tear) or by the stones unloaded from the truck. There were four small punctures (about the diameter of a pencil or smaller) and a 2-in. long tear (fig. 36) resulting from the 4.5-ft drop. Generally the particular stone or stones causing the damage could not be determined.

c. Cloth C. Cloth C was not damaged from the 2.5-ft drop or the drop from the truck. There was a 5-in.-long tear (fig. 37) in the cloth from the 186-lb stone dropped 4.5 ft.

d. Cloth D. There was one small tear in the cloth resulting from the 164-lb stone being dropped 2.5 ft, but no damage from the stones dumped from the truck. There were two 1-in. tears and one 2-in. tear in the cloth, all caused by the 186-lb stone being dropped from 4.5 ft (fig. 38).

e. Cloth E. Cloth E oriented in either direction was not damaged from the 2.5-ft drops; however, there were two 1-in. tears resulting from dropping the full bucket load

Fig. 36. Cloth B, 2-in. tear after 4.5-ft drop

Fig. 37. Cloth C, 5-in. tear after 4.5-ft drop

Fig. 38. Cloth D, 1- and 2-in. tears after 4.5-ft drop

of stone on the cloth. In the latter case, the cloth was oriented with its weaker principal direction up and down the slope. It should be noted that the full bucket drop was conducted approximately one week after the regular 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 regular 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 approximately 3 in. long and was caused by the 186-lb stone. In addition to these tears, one stone hit directly on top of a securing-pin washer, and the washer cut the cloth around approximately one-half the circumference of the washer (fig. 39).

f. 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 7 ft. There was no damage due to the 7-ft drop. However, it should be noted that when dropped 7 ft, the stones tended to flip over during fall and the sharpest edges did not directly contact the cloth. A 3-in. 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 compact than in earlier tests.

Fig. 39. Cloth E, tear caused by direct hit of stone on securing-pin washer

g. Cloth G. Cloth G was not damaged by the 2.5-ft drop or the stones dumped from the truck. There was one 1-in. tear due to the 4.5-ft drop. It could not be determined which stone or stones caused the damage.

Summary of stone drop tests

52. None of the cloths were significantly damaged by the 2.5-ft drops, while all cloths except cloths F and G were significantly damaged by the 4.5-ft drops. Most of the damage was caused by stones 1 and 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 stone dropped from 3 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

53. Filter cloths A and B were exposed for 72 months at Treat Island, Maine, with companion control samples aged in the old WES Concrete Division Laboratory near Jackson, Mississippi. The samples at Jackson were kept in the laboratory building and not subjected to field exposure. At Treat Island, one set of samples was exposed in an open-sided shed, while the other was covered by about 1 ft of sand (neither set was exposed to sunlight). Both sets of samples at Treat Island were under salt water part-time due to 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 minus 15 F in the winter months. A sample from each set was tested at 6-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 with the average strengths 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 1.

54. Fig. 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, 6 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 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 4 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 relation between the samples exposed at Treat Island or aged at Jackson. From these tests, it is concluded

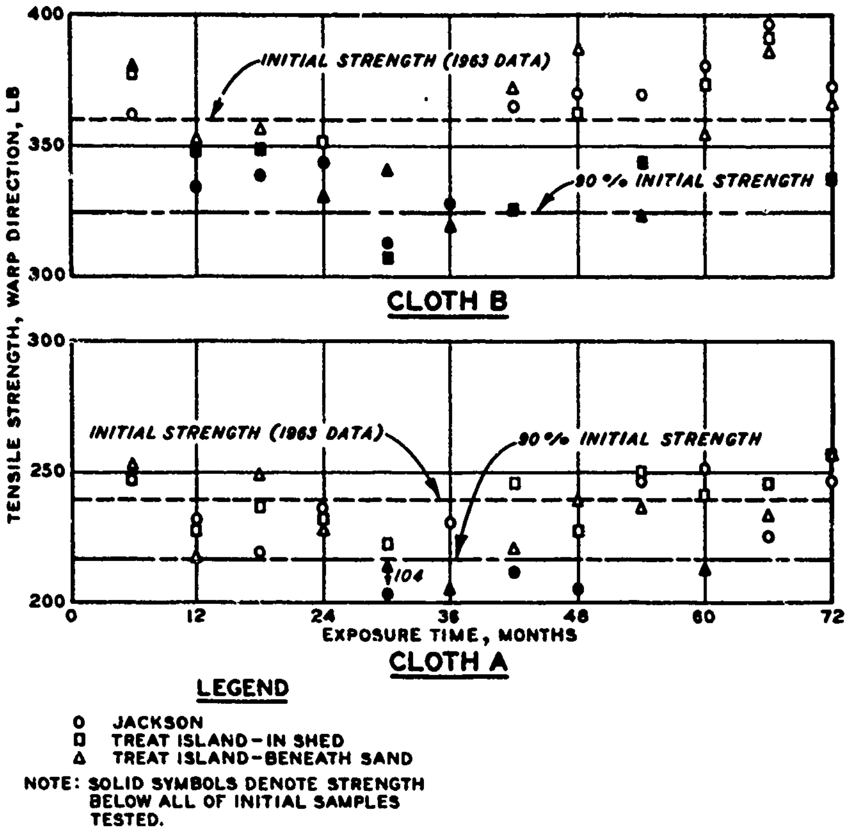


Fig. 40. Effects of field exposure

that both cloths A and B are performing satisfactorily.

Flume Tests

55. 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- by 1-ft orifice, 0.25 ft above the floor in the center of the flume. The orifice 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-sq-ft 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.

56. Results of the flume tests are shown in fig. 41. Equations for head loss through 1 sq ft for the cloths (no air) obtained from this figure are given below:

Cloth	Head Loss, h , ft in terms of Velocity, v fps
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	$0.1\ v^{1.78}$

57. It is recognized that head losses through the cloths would be influenced to a great extent by the adjacent soil. However, these tests do clearly show the relative differences in the cloths' abilities to allow water to freely pass. 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 will provide the most resistance to flow at 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, had an effect on the 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 could be significant.

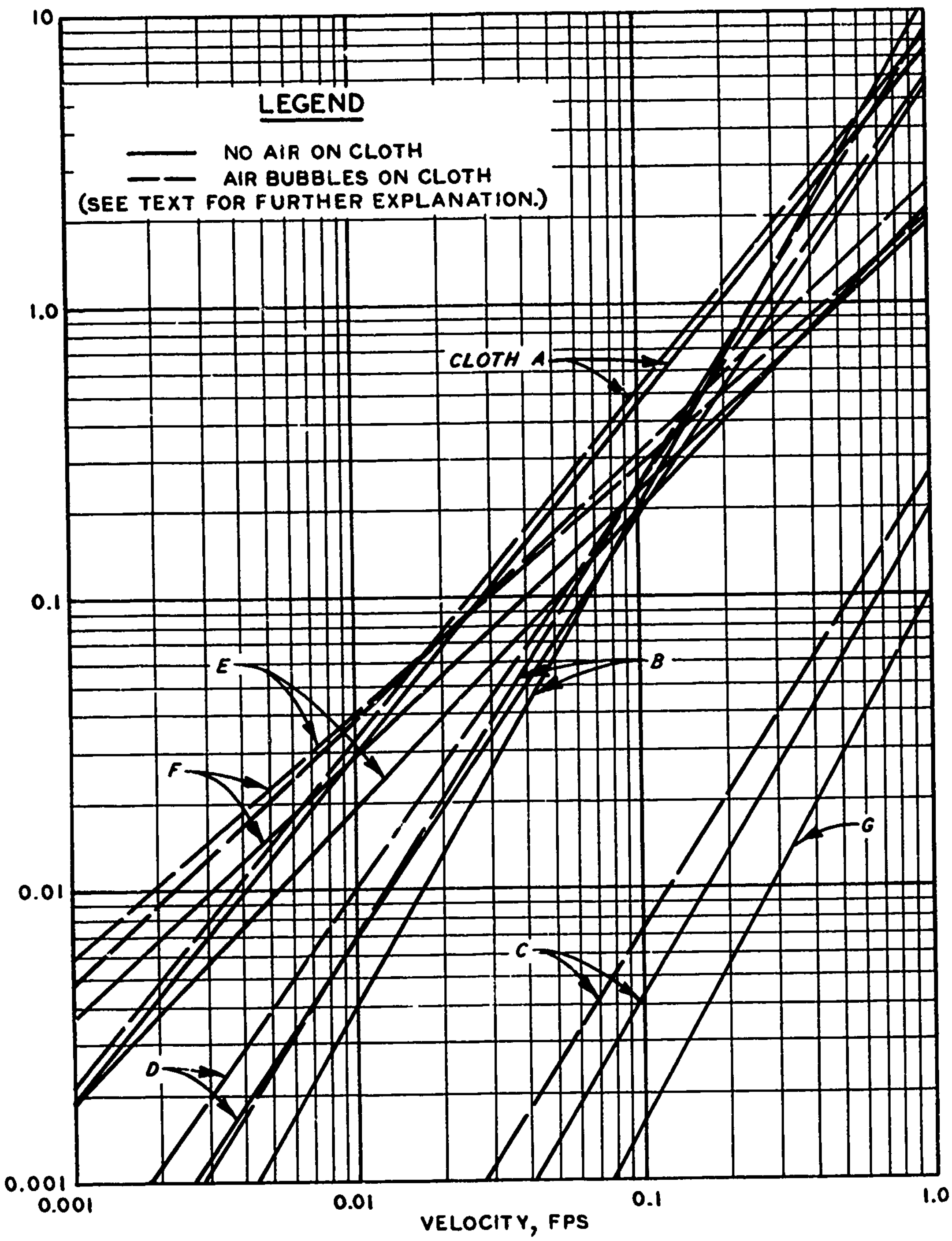


Fig. 41. Flume test results

PART V: SURVEY OF FIELD INSTALLATIONS

General

58. Visits were made by WES representatives to the following locations to observe the performance of filter cloths:

CE District	Type of Installation	Cloth Used
Memphis	Beneath riprap bank protection	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. Memorandum reports were prepared containing details of the installations visited by WES personnel and are on file at WES. Discussions in this report will cite the principal observations made and conclusions drawn from the inspections or correspondence.

Memphis District[4]

59. Cloths A and B were used in connection with repair work at four bridges on the St. Francis River in the Memphis District. Severe scouring of the bank had occurred immediately downstream of 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 1V on 3H. Riprap (125 lb maximum) was dropped from approximately 4 ft on both

cloths. When tears were noted in cloth A, the drop height was reduced to less than 1 ft. Cloth B was not damaged.

60. An inspection was made 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 with strengths shown in table 1 indicated there had been no apparent deterioration of the cloths since they were installed.

61. Cloth B was used in a test area on Island 63 located in the Mississippi River south of Helena, Ark. Fig. 42 is a layout of the test installation as constructed in 1965. The cloth was placed beneath both riprap and articulated concrete mattresses (ACM); for comparative purposes gravel bedding was used beneath riprap on ACM in adjacent areas. The revetment was placed on 1V-on-3H 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 4 ft.

62. The site was inspected in 1969. Fig. 43 shows the condition of the ACM revetted area underlain with filter cloth, and fig. 44 shows the condition of the ACM 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.

63. Fig. 45 shows bulging of the cloth beneath the riprap at its intersection with ACM (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

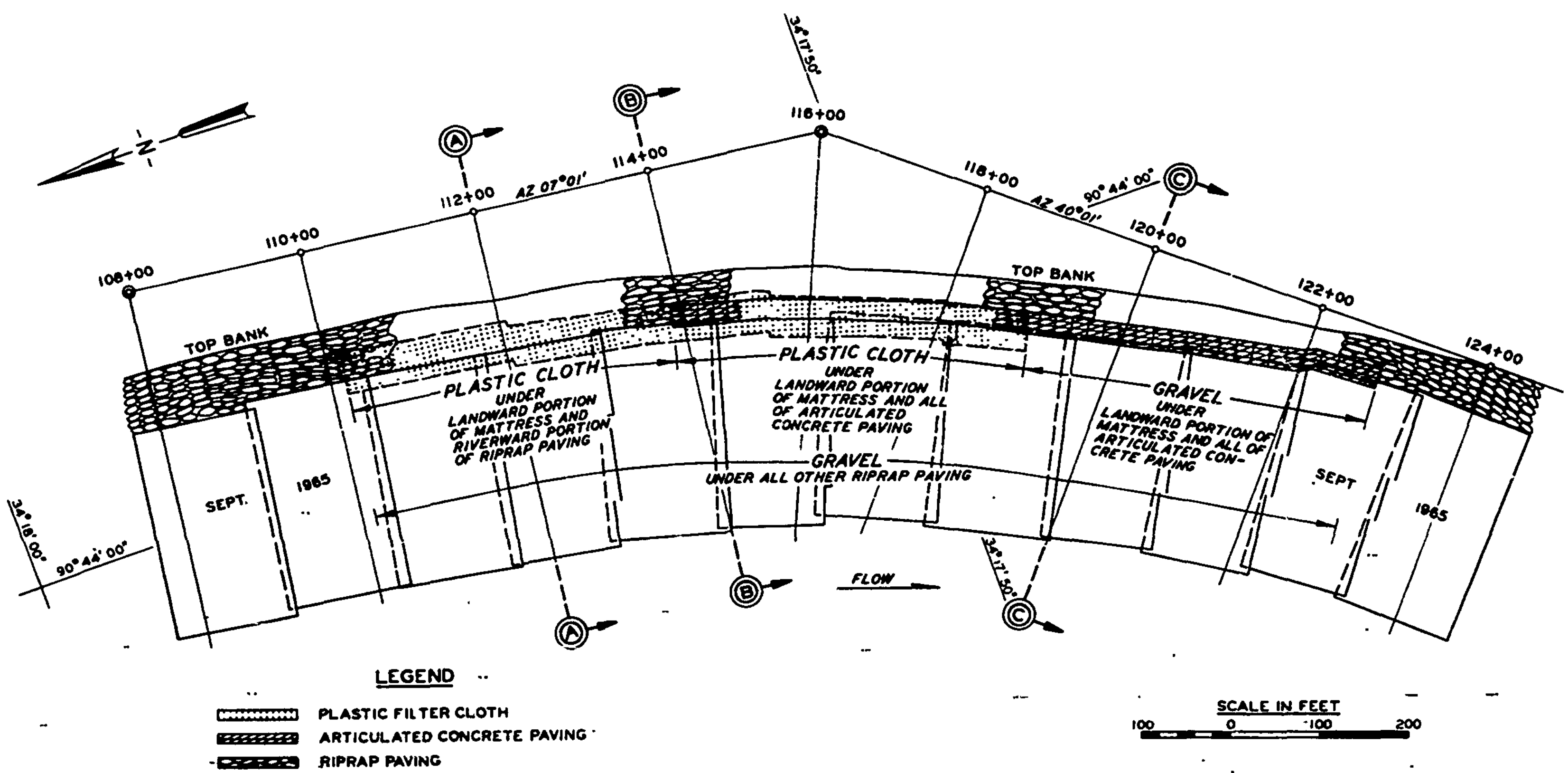


Fig. 42. Layout of Island 63 test site

Fig. 1[illegible]. Island [illegible] revetted area underlain with filter cloth

Fig. 14. Island of revetted area underlain with gravel bedding

Fig. 45. Bulged areas at Island 63

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 is pointed out that this reach has been predicted susceptible to flow failures,[5] a common phenomenon along the Mississippi River where sections of sand banks liquefy and "flow" into the river. It is possible that small flow failures occurred in the area and the cloth prevented the material from going into the river, possibly preventing a more general failure.

64. 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 failures.

New Orleans District[6]

65. The Louisiana Department of Highways (LDH) (with some assistance from the New Orleans District) conducted full-scale tests using cloth B and cloth Z beneath slope protection for a highway fill along the Gulf Coast. Although not tested during the study, cloth Z appeared to have an open area somewhat smaller than cloth G but greater than cloth C. 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 by 8 by 4 in. (when in place, the revetment had an open area of about 30 percent). The cloths were placed directly on a graded 1V-on-3H slope and the blocks were placed 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 water from the area flowed seaward through the embankment when flooded. Cloth B was used in constructing the westward 100 ft and cloth Z was used for the other 100 ft.

66. 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 readily pass through the more open weave of cloth Z. Approximately one year later a similar storm hit the area, with the only damage being to the unprotected ends of the revetment.

67. Samples of both cloths were obtained during an inspection approximately one week after the second storm. Results of strength tests on cloth B from beneath the revetment indicated no significant deterioration when compared with the initial strength given in table [illegible]. However, there had been considerable deterioration of cloth B which had been exposed since the 1969 storm (one year of exposure), and cloth B could be torn by hand. According to the distributor of cloth Z, the initial tensile strength is approximately 300 lb in the warp and fill directions. Strength tests on cloth Z from beneath the revetment showed no significant deterioration when compared with 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.

68. In 1971 a 3-mile stretch of the beach was revetted using the cellular concrete blocks and cloth Z.

Kansas City District

69. 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 1V-on-2H slope and the other a 1V-on-3H. The banks were composed of a silty sand. Stones weighing up to 300 lb were placed (free fall less than 1 ft) directly on cloth which had been placed directly on the slope. Some tearing at the securing pins was attributed to stones slipping down the 1V-on-2H slope; this did not occur on the 1V-on-3H slope. A 12-in.

bedding of gravel was used between the cloth and the sills. Areas of the cloth 10 ft square on the slopes were uncovered to check the gradation of the riprap, and the cloth was found to be undamaged. During an inspection 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 with the initial strength shown in table 1.

Fort Worth District

70. 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. The cloth was not clogged, but the perforations in the pipe were practically completely closed with 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 the initial strength shown in table 1.

Soil Conservation Service*

71. In 1968 the Soil Conservation Service installed slotted pipe subdrains wrapped with two different kinds of cloths near Orlando, Florida, to lower the water table in an agricultural test field. The two filter cloths used were cloth A and a cloth (designated cloth Y) not included in the WES tests but somewhat similar in appearance to the nonwoven cloth F. 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 No. 50 sieve). The system using cloth Y was

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* Information provided by Mr. B. C. Beville, U. S. Department of Agriculture, Soil Conservation Service, Orlando, Florida.

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. The sludge on the cloth was formed by iron bacteria that oxidized and precipitated iron into the water. There was no sludge buildup on cloth A, although there was some buildup within the pipe as was the case at Sam Rayburn Dam. With periodic flushing, the system with cloth A has functioned properly since 1968.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

General

72. The following conclusions and recommendations are based on laboratory and field data developed from this study; information summarized in reference 2, and field observations made by WES personnel. Most field performance data available during this study were for cloths A and B. Cloths D, F, and G had been used at only one CE installation each, and cloths C and E had not been used by CE. Cloths Y and Z have not been used by the CE although they were used by other agencies. The field performance data on cloths A and B provided valuable information which could be related to laboratory studies, and consequently many of the commendations in the following paragraphs are based on the performance of the two cloth

Chemical Properties

73. The chemical composition of a plastic is complex, and minute changes in its formulation can significantly change the character of the material. For example, cloths B through G are all predominantly propylene, but, as indicated in table 1, their physical properties varied considerably. Consequently, specifying a plastic by name without accompanying physical requirements is not sufficient. Based on this test program, it appears that cloths made of 85 percent by weight or more of propylene or vinylidene chloride will provide satisfactory service when other physical requirements to be discussed later are met. Field performance data on cloth Z, made by the manufacturer of cloth G, indicate that cloths made of ethylene may be acceptable. However, cloths of this material have not yet been evaluated in the laboratory.

Physical Properties

Requirements applicable to all cloths

74. The requirements given in table 5 are recommended for all

Table 5

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
ASTM D-1175-64T	Abrasion resistance of textile fabrics, rotary platform, double head method	5 warp 5 fill	Maximum strength† loss in either direction, 70% Minimum strength† after abrading: Stronger direction, 100 lb Weaker direction, 55 lb

* 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 cloths. The test procedures have been described previously. All cloths evaluated during this study meet the requirements given in table 5 except cloths A, E, F, and G which did not meet the abrasion resistance requirements

Strength requirements

75. The strength requirements for filter cloths depend upon the specific use made of the cloth. Current uses of filter cloth can be divided into two main categories:

a. Filter cloth subjected to severe dynamic loadings. Included in this category would be installations where stones are dropped on the cloth and 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.

b. Filter cloth subjected to static loadings. This category 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.

76. 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 1 ft on cloth B laid on a 1V-on-3H sand slope without any damage to the cloth. Information gathered on cloth A has shown that it was punctured and torn by 125-lb stones dropped from 4 ft, while cloth B was not damaged under practically the same conditions. Tears in cloth A had also been noted in other installations, as discussed in Appendix A. Inspections by WES personnel 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 occur and where high abrasive resistance is required. 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. This cloth 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.

77. Based on field data and drop tests, filter cloths are divided into three categories for strength requirements. Minimum strengths for each category are given in the following tabulation:

	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

78. Cloths meeting category A strength requirements are generally suitable for use under severe dynamic loadings (paragraph 75a). Cloths meeting category B strength requirements are also probably suitable for use under severe dynamic loading, although no field performance data are available. Drop tests indicated riprap should not be dropped from a height greater than 3 ft and placement of the stones should be carefully observed to detect any damage to the cloth. Possibly lower drop heights are necessary when stones weigh more than about 300 lb. Cloths in any of the three strength requirement categories are suitable for use under static loadings (paragraph 75b). As indicated in the tabulation above, cloths B and D meet category A requirements, cloth C meets category B requirements, and cloths A, E, and G meet category C requirements. (Cloths A, E, and G do not meet abrasion resistance criteria, however.) Cloth F did not meet any of the strength requirements.

79. Sewn seam strengths of 195 lb have been found sufficient for cloths in strength category A. For cloths in categories B and C, sewn seam strengths equal to or greater than 90 percent of the strength of the weaker principal direction are recommended.

Filtering Characteristics

General

80. Filtering characteristics of cloths are related to the EOS and percent open area of the cloth. The two requirements assure a sieve-like material and therefore both must be specified. Procedures have been given previously for determining these two properties of the cloth. Only woven filter cloths with distinct openings are recommended based on the clogging of cloths E and F during the clogging tests. In any application the EOS should not be finer than the No. 100 sieve and the open area no less than 4 percent. The performance of cloth B at Holly Beach, La., indicates that in instances where the revetment is relatively light and where relatively high seepage velocities or rapid fluctuations in the differential hydrostatic pressures can occur, open areas exceeding 4 percent may be required. Therefore, when possible the maximum open area allowed by the criteria should be used.

Filter criteria

81. The following filter criteria are recommended:

a. Adjacent to granular materials containing 50 percent or less by weight of silt (material of little or no plasticity, passing the No. 200 sieve):

   (1) $\frac{\text{85 percent size of the material (mm)}}{\text{EOS (mm)}}$ greater than 1.

   (2) Open area not to exceed 40 percent.

b. Adjacent to soils having little or no cohesion containing more than 50 percent silt by weight:

   (1) EOS no larger than the opening in the U. S. Standard Sieve No. 70.

   (2) Open area not to exceed 10 percent.

Cloths used to wrap collector pipes should be surrounded by at least 6 in. of clean granular material. If the cloth is used to line a trench, the collector pipe should be separated from the cloth by a minimum of 6 in. of clean granular material.

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APPENDIX A: SUMMARY OF INFORMATION FROM QUESTIONNAIRES ON USES OF FILTER CLOTHS IN THE CORPS OF ENGINEERS*

Introduction

1. Questionnaires concerning the uses of plastic filter cloths were circulated to 38 District and Division offices. All addressees responded except the New York District. Twenty-six Districts and Divisions have used or are planning to use plastic filter cloths.

2. Seven filter cloths designated cloths A through G and one cloth designated Z have been or are planned to be used by the 26 Districts and Divisions. With the exception of cloth A, which is made of vinylidene chloride yarn, all the cloths are made of propylene. All cloths except cloths E and F are woven of monofilament yarns. Cloth E is woven of monofilament yarns in one direction and multifilament yarns in the other. Cloth F consists of fibers (some of rayon) entangled by needle punching and bonded by heat fusion. Cloth D is similar to cloth B, and cloth C is similar to cloth G.

3. Uses of filter cloths are categorized as follows:

   a. Beneath riprap, rubble, articulated revetment, etc.

   b. Around pipes, well screens, and piezometer tips.

   c. As substitute for granular layer in multilayered filter.

   d. Other.

The filter cloths used at various projects in these categories are as follows:

Cloth	No. of Projects Categorized as				Total
	a	b	c	d	
B	23	8	4	2	37
A	4	1	0	1	6
D	1	0	0	0	1
Z	1	0	0	0	1
F	1	0	0	0	1
Totals	30	9	4	3	46

* (This summary was prepared in 1969; since that time filter cloths have been used at numerous other projects.)

The proposed uses of filter cloths are as follows:

No. of Projects Where Filter Cloth will be Used, Categorized as				
a	b	c	d	Total
6	0	2	2	10

4. Cloths C, E, and G have been used to date. The use of cloth C is being considered by the Louisiana Department of Highways and possibly the New Orleans District in place of the foreign-made cloth Z. The Kansas City District plans to use cloth E.

5. In every case but one the filter cloths were specified by trade name or equal. In the Mobile District, the cloth was specified by requiring that it be made of "polypropylene monofilament yarns" which, at the time the specifications were written, limited the cloth to be used to cloth B. Ten Districts also specified some physical or chemical properties of the desired cloth in addition to trade name or equal. However, in each case the properties were simply those furnished by the manufacturer of the cloth specified by name. The initial use of a cloth was always based on limited data furnished by the manufacturer or distributor of the cloth.

Uses Beneath Riprap and Other Revetment Materials

6. Table A1 is a summary of the 28 projects where filter cloths have been used beneath riprap, rubble, etc. The number of projects shown in the table do not contradict the tabulation in paragraph 3 which shows 30 projects, since two different cloths were used at two projects. The following summarizes the answers to the questionnaires given by the Districts.

Filter cloths installed

7. The most common use of filter cloth was beneath riprap on the bottom or slopes of rivers, creeks, or other channels. In most of these cases, cloth B was used. However, cloth A has been used by the Memphis

Table A1

Uses of Filter Cloth Beneath Riprap, Rubble, Articulated Mat, Etc.

CE Division	CE District	Ref No.	Project	Filter Cloth	Use	Instal-lation Date	Max Stone Weight lb	Drop ft	Subgrade Material	Bedding Max Size in.	Bedding Thickness in.
LMVD	Memphis	1	Clark's Corner Cutoff Bridge, Ark.	B	Beneath riprap slope repair	Nov 1964	125	4	SP fine	None	
		2	Madison-Marianna Bridge #4, Ark.	A	Beneath riprap slope repair	Nov 1962	125	< 1	SP fine	None	
		3	Island 63	B	Beneath revetment (ACM[a] and riprap)	Sep 1965	125	4	SP fine	None	
		4	Island 40	B	Beneath ACM revetment	Aug 1968	NA	NA	SP m to f	1-1/2[b]	4[b]
	New Orleans	5	Test sections, Holly Beach, La.	B and Z	Beneath shore protection	Jan 1969	14	0	SP fine	None	
		6	Calcasieu salt water barrier	B	Beneath riprap bedding	1966-67	1400	5	SP	1-1/2	6
	St. Louis	7	Wood River Dr. & Levee, Ill.	B	Beneath riprap on riverbank	Aug 1968	300	3	SP-SM, SP	None	
		8	Prairie du Pont Creek, Ill.	B	Beneath riprap on creek bank	Nov 1965	150	3	SP-SM, SP	None	
	Vicksburg	9	Levee, Wasp Lake to Marksville, Miss.	B	Beneath riprap bedding	Oct 1965	250	5	SP to CH	2-1/2	6
		10	Columbia Lock & Dam, La.	D	Beneath riprap bedding at outlet structure	1967	2000 riprap 6000 derrick	0 0	SP to CH	4	9
MRD	Omaha	11	Channel Stab., Gering Valley, Nebr.	A and B	Beneath riprap along channel slopes	1963-64 1966	900	3	ML	None	
	Kansas City	12	Topeka, Kans., flood protection project	B	Beneath riprap, channel slopes and bottom	Sep 1968	3000	< 1	CL, ML SP fine	None	
NCD	Buffalo	13	Presque Isle Pen., Pa.	B	Beneath bedding of rubble groins	May-Nov 1965	3000	0	SP	2-1/2	6
	Detroit	14	Kawkawlin River flood control project, Mich.	B	Beneath riprap around bridge piers	Jun 1969	150	0	Clayey sand w/G	None	
	St. Paul	15	Red Lake Cont. Dam, Clearwater, Minn.	B	Beneath riprap slope protection	Oct 1968	100	0	SM, SP	None	
		16	Channel improvement, Polk and Clearwater Counties, Minn.	A	Beneath riprap slope protection	Oct 1963	250	3	ML, CL, SM	1-1/2[b]	6[b]
		17	C annel improvement, Russ River, Cass County, N. Dak.	B	Beneath riprap slope protection	Sep 1967	150	3	SC	1-1/2[b]	6[b]
		18	Remedial work, Sand Hill River, Polk County, Minn.	B	Beneath fieldstone riprap in drop structure	Oct 1967	250	2	CL, ML, SM	None	
		19	Big Bay Harbor, Marquette County, Mich.	B	Beneath rubble mound breakwater	1968	Core 1000 Cover 6000	0	SP	None	
		20	Breakwater extension, Houghton County, Mich.	B	Beneath rock berm	Jul 1968	500	< 1	SP	None	
NPD	Seattle	21	Libby Dam, Mont.	B	Beneath riprap bedding	1967	10 in.	3	CL	- No. 4	24
ORD	Louisville	22	Temp. Lock & Dam #52, Ohio River, Ill.	B	Beneath riprap slope protection	Dec 1968	150	3	SP	None	
	Pittsburgh	23	Hannibal Lock & Dam, Ohio River, Ill.	A	Beneath riprap slope protection	1966-67	500	2	ML, CL, SM	None	
SAD	Charleston	24	Morris Island Spoil Dike, Charleston Harbor, S. C.	B	Beneath riprap bedding	Mar 1969	300	4	SM-CL w/shell	4	9
	Mobile	25	Lake Douglas, Bainbridge, Ga.	B	Beneath riprap	Jul 1968	12 in.	0	SC	None	
SPD	Sacramento	26	Pit River channel improvement, Modoc County, Calif.	B	Beneath sack concrete	Jul 1969	1.25 cu ft	0	ND	None	
SWD	Galveston	27	White Oak Bayou, Houston, Tex.	B	Beneath riprap	1964	15 in.	2	SM, CL	None	
	Tulsa	28	Kaw Dam, Ponca City, Okla.	F	Beneath riprap slopes and bottom of diversion channel	1969	2000	ND	SM, SP	None	

a ACM = articulated concrete mat.

b Bedding beneath the filter cloth.

District (ref 2, table A1), Omaha District (ref 11), St. Paul District (ref 16), and Pittsburgh District (ref 23). Cloth F was used in the Tulsa District (ref 28) in a temporary diversion channel that will be in service for only about two years. Cloth B and cloth Z were used in field test sections along a highway fill paralleling the shoreline by the Louisiana Department of Highways (ref 5) in cooperation with the New Orleans District. This was at a test installation primarily to evaluate the effectiveness of a Dutch shore protection product (a cast concrete product, 8 in. by 8 in. by 4 in., weighing about 14 lb). The Memphis District has placed cloth B beneath articulated concrete mattresses (ACM) for revetment work (refs 3 and 4) along the Mississippi River. Other uses of cloth B, as indicated in table A1, have been in connection with breakwaters, protection at drop structures, bridge pier protection, and groins.

Earliest installations

8. The earliest installations of cloth A were in 1962 and 1963 in the Memphis District (ref 2), Omaha District (ref 11), and St. Paul District (ref 16). Cloth B was first installed in 1964 in the Memphis District (ref 1), Omaha District (ref 11), and Galveston District (ref 27). The only installations of cloths F and Z were in 1969 (refs 28 and 5, respectively). The only installation of cloth D was made in 1967 (ref 10).

Bedding material

9. At 19 of the 28 projects, filter cloths were placed directly on subgrade materials varying from fine sands to fat clays. In three cases, granular bedding was placed beneath the cloths (refs 4, 16, and 17) on subgrade materials varying from medium to fine sands to silty clays.

Installation procedures

10. Installations of cloths B, A, and D were generally in accordance with the manufacturers' recommendations. When used on slopes, the slopes were shaped to grade and the cloths laid parallel to the center line of the channel. The cloths were overlapped 8 to 12 in. and secured at 3-ft intervals with 15- to 18-in.-long, 3/16-in.-diam

steel pins. The pins were found to be ineffective in loose sands at two sites (refs 1 and 18) and stones were used to weight down the cloths. Problems were encountered when the cloths had to be installed underwater. At Island 63 (ref 3) and Presque Isle Peninsula (ref 13), the cloth was attached to frames made from rebars. At Island 63 the cloth still tended to float, but at Presque Isle a 6-in. gravel bedding was placed on the cloth before sinking; the latter procedure was reported to be satisfactory. At Island 40 (ref 4) the cloth had been bonded to the articulated concrete mats when they were cast, and the mats and cloth were successfully placed as one unit. In the St. Paul District (ref 15), the cloth was placed underwater perpendicular to the stream center line by wrapping the cloth around a steel pipe and letting the cloth unroll into the channel. The cloth was overlapped 2 ft and weighted with stones. At Big Bay Harbor, Michigan (ref 19), the cloth was placed under 8 ft of water by divers. The cloth was overlapped 3 ft and secured with specially made 3/8-in.-diam, 2-ft-long steel pins. This procedure was reported to be inefficient. No information was provided on the methods used to install cloths F and Z.

Effect of construction equipment

11. Construction equipment was allowed to operate on the exposed cloth at only four projects. At Columbia Lock and Dam (ref 10) a D-6 crawler tractor was allowed on exposed cloth D, with the only damage being some tears at the seams and securing pins. No damage was reported from rubber-tired front-end loaders operating on cloth B at two locations in the St. Louis District (refs 7 and 8). In the St. Paul District (ref 15) D-2 tractors with smooth rubber tracks did not damage cloth B.

Placement of riprap over filter

12. In six cases bedding material, 6 to 24 in. thick, was placed above the cloth to protect it from damage when placing riprap. The most severe loading conditions on the individual cloths are given below:

a. Cloth A. Stones weighing 900 lb were dropped 3 ft on the cloth placed on a silty subgrade material with no bedding material (ref 11). Stones weighing 250 lb were dropped 3 ft on the cloth placed over a 6-in.-thick bedding material (ref 16).

b. Cloth B. The heaviest stones to be placed on cloth B with no bedding materi . weighed 3000 lb (ref 12). The stones were placed by bucket, with less than 1-ft drop on the filter cloth which was laid on a subgrade material that varied from a fine sand to a lean clay. The most severe loading condition placed on the cloth when covered with a bedding material was in the New Orleans District (ref 6) where 140 -lb stones were dropped 5 ft on 6 in. of bedding.

c. Cloth D. At Columbia Lock and Dam (ref 10) the cloth was used over a 9-in. bedding. Riprap weighing 2000 lb was placed directly on the cloth, and 6000-lb derrick stones were placed on top of the riprap. This was the only installation of this product.

d. Cloth F. A 24-in. thickness of 1000-lb maximum size stones, overlaid with 30 in. of 2000-lb maximum size stones, was placed on cloth F (ref 28) which was laid directly on a sand or silty sand subgrade. No details were given on the placement of the stone.

e. Cloth Z. Cloth Z has been used only beneath hand-placed GOBIMAT, which does not impose any severe loading conditions.

Exposure to possible deteriorating factors

13. None of the cloths are completely uncovered and exposed to sunlight. The only possible exposure is from sunlight entering gaps in the riprap or between mats. Cloths A and B will be subjected in the various installations to temperatures ranging from -40 to about 110 F. The installations of cloths D and Z will be subjected to only moderate temperatures. No information was provided on cloth F. None of the Districts indicated the cloths would be subjected to severe chemical attack.

Performance of filter cloths

14. The Kansas City District (ref 12) and Louisville District (ref 22) uncovered areas after completion of the work and found cloth B to be undamaged. However, the Kansas City District reported that factory-sewn seams at Topeka (ref 12) could be easily pulled apart by hand and were unsatisfactory. The Vicksburg District reported that the factory-sewn seams of cloth D at Columbia Lock and Dam (ref 10) were unsatisfactory and could also be pulled apart by hand. At Hannibal

Lock and Dam (ref 23) tears in cloth A were noted due to dropping 500-lb riprap from 2 ft. Some tearing of cloth B at seams and securing pins was noted by the Kansas City District (ref 12) and St. Paul District (ref 18) due to stones creeping down 1V-on-2H slopes. At both sites, this did not occur where the slopes were 1V-on-3H or flatter. At Holly Beach, La. (ref 5), the cloth B section was lifted or "floated" out of position due to high waves, while the immediately adjacent cloth Z section was not damaged. This was attributed by the District to water beneath the cloth B not being able to escape fast enough and causing hydrostatic pressures to develop beneath the cloth. Cloth Z has a more open weave with less closed area, and allowed the water to escape. None of the Districts reported any deterioration, clogging, or loss of subgrade material through the cloth.

Use Around Collector Pipe

15. Filter cloths have been used around subsurface collector pipes at two projects, as follows:

CE Division	CE District	Project	Filter Cloth	Installation Date
SPD	Los Angeles	Los Angeles River Rehabilitation Project	B	1967
SWD	Fort Worth	Sam Rayburn Dam, Tex.	A	1966

16. At the Los Angeles project, cloth B was used as a replacement for burlap normally used to wrap open-joint subdrain pipe to prevent infiltration of backfill material. The pipes were 12 in. in diameter with 1-in. joint openings. The backfill material was graded such that 100 percent passed the 3/8-in. sieve, 90 to 100 percent passed the No. 4 sieve, and 0 to 4 percent passed the No. 200 sieve. The material was not compacted. Each joint was wrapped separately, with a 6-in. overlap permitted. The cloth was not secured to the pipe. The questionnaire indicated that the groundwater had a high concentration of iron and sulfides. The Los Angeles District reported that they

were satisfied with the performance of the cloth.

17. Cloth A was used to wrap the collector pipe for a 1600-ft-long subdrain system located at the toe of Sam Rayburn Dam, Jasper, Texas. The bituminous fiber pipe was 6 in. in diameter with 3/8-in.-diam perforations in two rows along the bottom of the pipe. The filter cloth was wrapped around the entire pipe and secured at the 2-in. overlap by staples. The maximum particle size of the backfill was 1/4 in.; 95 to 100 percent of the material passed the No. 4 sieve and 0 to 15 percent passed the No. 50 sieve. The backfill was compacted with a mechanical tamper. The groundwater has a high iron content. The Fort Worth District has no performance data on the installation; however, they do recommend it for future use.

Use Around Piezometer Tips

18. Cloth B has been used at seven projects in the fabrication of piezometers. The projects are listed below:

CE Division	CE District	Project	Installation Date
NED		Dickey-Lincoln Power Project, Me.	1967-1968
		Black Rock Dam, Conn.	1967-1968
		Sentinel ABM Site, Mass.	1967-1968
NPD	Portland	Reedsport Levee Test Fill	1966
		Gate Creek Reservoir	ND
		Elk Creek Reservoir	ND
		Lost Creek Reservoir	ND

19. In the New England Division (NED), piezometer tips fabricated as shown in fig. A1 have been used at three sites. Only one wrap of filter cloth is used in both the internal and external wraps. The cloths were overlapped 1/2 in. and glued. NED reported they are satisfied with the design, except for the glued seam. They have not yet found a satisfactory glue. The use of the cloth at the Sentinel site was the only military use of the cloths reported.

20. The Portland District uses two types of piezometers

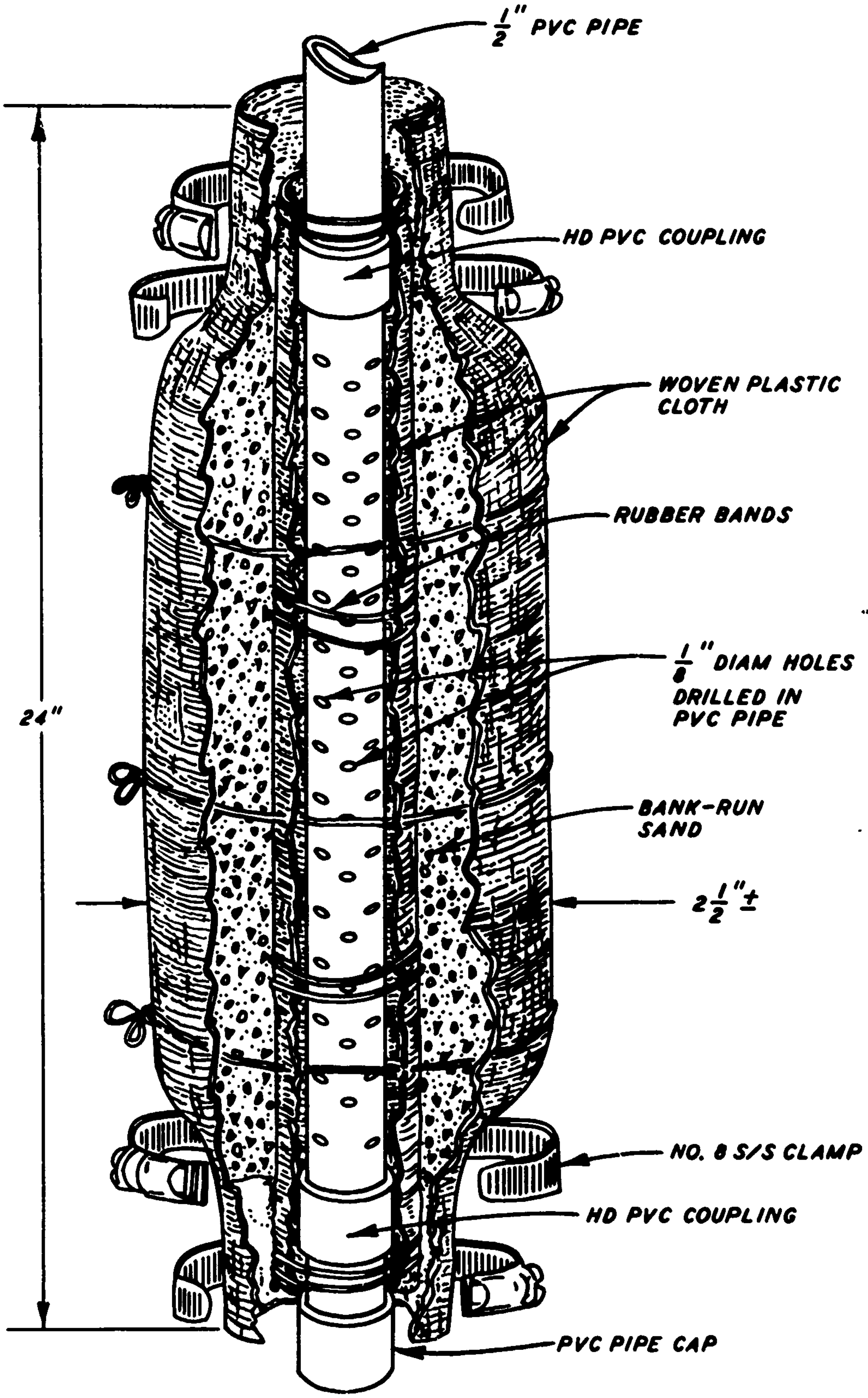

Fig. A1. Woven plastic cloth piezometer (NED) (designated types A and B) in which filter cloths are incorporated. For the type A piezometer, 5/16-in.-diam holes were drilled in a 1/2-in.-diam pipe. Two layers of filter cloth were wrapped around the pipe and secured at 6-in. intervals. Three men installed 49 of these piezometers in four days to depths of 14 to 33 ft in a soft organic silt at Reedsport. Before the piezometer was installed, a sheath made of 1-in.-diam thin-wall electrical conduit closed at one end was placed over the cloth. The piezometer was then pushed about 3 ft below the desired elevation and then pulled up to the desired elevation, withdrawing the piezometer tip from the sheath. This method was reported to be very efficient. Service records kept over a 2-year period indicated good response and no clogging of the tip. The cloth is exposed to decomposed organic materials, swamp gases, and salt water.

21. The type B piezometer was used at the other locations and was conventionally installed in borings. To fabricate these piezometers, 3/8-in.-diam holes were drilled in 1-in.-diam capped plastic pipes. Again two layers of filter cloth were wrapped around the pipe and secured by fiberglass tape. The piezometers were installed in MH, ML, and SM soils with a pea gravel backfill around the tips. Service records indicate that the piezometers are functioning properly. The Portland District concluded the piezometers are "very satisfactory," with considerable savings realized from using filter cloths rather than conventional wellpoints.

Use as Intermediate Filter

22. The questionnaires indicated that in only four instances were filter cloths used to prevent fine material from entering granular filter material in subdrain systems. Two projects were in the Baltimore District, located in Swoyersville-Forty Fort, Pa., and Unadilla, N. Y. Both were installed in late 1967 and early 1968, using cloth B. The cloth was placed on top of the filter material to prevent fines in the overlying random fill from migrating into the subdrain. No information was provided on the installation methods used at the projects or

the type of random fill used. At Unadilla the filter material was graded between the 3-in. and No. 40 size sieves; no information was given on the filter material at the Pennsylvania site except that it was coarse. No service behavior data were available from either location. It was noted that the Pennsylvania project was located in a coal mining area where acid wastes were common. The cloth installed at Unadilla is not subject to severe chemical attack.

23. A third project where filter cloth was used in connection with a subdrain was Fall Creek Reservoir, Oreg., constructed by the Portland District. Cloth B was used to line trenches for the subsurface drainage system. The subgrade material consisted of partially decomposed sand, gravel, and rock fragments in a matrix of plastic fines. The material was generally classified as GM. The filter material was graded as follows:

Sieve Size	Percent by Weight Passing
1-1/2-in.	100
3/8-in.	15-90
No. 4	0-10
No. 200	0-5

24. The cloth was laid loosely on the ground in 12-ft strips across the trench and extended 4 ft beyond the excavated slopes. The cloth strips were overlapped 8 in. and secured with 3/16-in.-diam by 15-in.-long steel pins at 3-ft intervals along the center of the overlap. The filter material was placed, and the cloth extending beyond the trench slope was folded back over the filter material 1.5 ft below the top of the trench, forming an envelope. Backfilling the trench was then completed. The District reported this installation was much faster and more economical than a graded filter, and recommended its future use. No problems were encountered during installation. The cloth will not be subjected to severe chemical attack.

25. At Shelbyville Dam in the St. Louis District, cloth B was placed in late 1968 in lieu of a filter sand in wall backfill

drainage systems and subsurface drainage systems beneath the paved section of the exit channel. The cloth was laid on subgrade material classified as SC to CL, and then the gravel filter (no data given) was placed. The cloth was placed with 8-in. overlaps and secured at 3-ft intervals with pins furnished by the manufacturer. Rubber-tired front-end loaders operated on the exposed cloth causing no damage. The District was satisfied with the cloth's performance during installation.

Miscellaneous Uses

26. In the Memphis District, cloth B was used as a grout stop between grouted riprap and a gravel filter blanket. In the Galveston District, cloth B was used to prevent sand from escaping between sheet piles. In the Little Rock District cloth A was used to prevent erosion of excavated slopes.

27. The cloth B used as a grout stop in the Memphis District was placed in 1964 at the Fletcher Creek Improvement Project. The cloth was placed on a gravel graded between the 1-1/2-in. and No. 4 sieves. The cloth was placed with 8-in. overlaps secured by steel pins, 14 in. long. Riprap weighing up to 800 lb was carefully placed on the cloth. The riprap was then grouted with a low-alkali portland cement grout. The Memphis District reported they had no problems placing the cloth and were satisfied with its performance.

28. The Galveston District used cloth B in 1966 behind a retaining wall constructed from prestressed concrete sheet piles in connection with the Texas City Hurricane Flood Protection Project. No information was given as to openings between piles or to the backfill material other than it was sand. The District was satisfied with the cloth's performance and recommended future uses.

29. In 1965 the Little Rock District used cloth A at Lock and Dam No. 6 on the Arkansas River to protect excavated slopes from erosion. The cloth was laid on 1V-on-1.5H slopes, overlapped 8 in., and secured at 3-ft intervals with 18-in.-long securing pins. The installation was temporary and the filter cloth was removed before

backfilling. The District was not satisfied with the performance of the cloth. The securing pins did not adequately hold in the sandy material during high winds and difficulty was experienced from water getting under the cloth. It was the Little Rock District's opinion that the cost of materials, installation, and maintenance exceeded the benefits.

Planned Uses of Filter Cloths

30. Table A7 is a summary of projects where filter cloths have been specified. In all the Districts except Baltimore, Nashville, and Savannah, cloth B or equal is specified. The Baltimore and Nashville Districts specify cloth A or equal, while the Savannah District does not specify the cloth by name.

Conclusions

31. The replies from the questionnaires confirm that there are wide and diversified uses of plastic filter cloths within the Corps of Engineers. It is obvious that a test program to develop acceptance criteria and to determine the engineering properties is justified since at present the only method used to specify cloths is by trade name or equal or by properties furnished by the manufacturer that describe his product. With the exception of some data provided by the manufacturers, few engineering properties of the cloths are known.

32. Filter cloths have been used successfully beneath riprap under severe loading conditions. The questionnaires did not cite any instances where the performance of a filter cloth for this purpose was completely unsatisfactory, which would have been useful in establishing minimum requirements. There was one report of cloth A being torn due to dropping stones (ref 23), but the District did not consider the problem serious enough for them not to consider its use in the future. The possibility that some cloths may not be permeable enough to prevent hydrostatic pressures from developing beneath them may present a definite problem. The questionnaires pointed out that requirements

Table A2

Planned Uses of Filter Cloths

CE				
Division	District	Project	Proposed Use	Estimated Installation Date
LMVD	St. Louis	Kaskaskia Lock and Dam, Ill.	Beneath riprap	1969
	Vicksburg	Jonesville Lock and Dam, La.	Replace component of graded filter beneath riprap	Unknown
		Big Sand Creek Diversion Channel	Grout stop between riprap and gravel	1971
NAD	Baltimore	Oxford, Talbot County, Md., Improvements	Beneath riprap	1971
NPD	Portland	Alsea Small Boat Basin, Oreg.	Beneath riprap	1970
		Floodwall, St. Woodland County, Wash.	Line drainage trench	1971
ORD	Nashville	Cordell Hull Power Plant, Carthage, Tenn.	Line drainage trench	1970
SAD	Savannah	Tide Gate Structure, Savannah Harbor	Beneath riprap	Unknown
		Water Supply Dam, Ft. Bragg, N. C.	Beneath riprap	1969
SWD	Galveston	Wallisville Reservoir, Tex.	Separate sand and concrete	Unknown

must be placed on factory-sewn seams. It should be noted that only cloths A and B have service records exceeding two years.

33. Although in most applications the filter cloths must serve as positive filters, only in their use beneath stone do they require high strengths and abrasion resistance. Little information is presently available on the long-term performance of the cloths in their various applications, and it would be valuable to have periodic examination made of their condition in actual installations.