1970

Penetration in a graded filter

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PENETRATION IN A GRADED FILTER

BY

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THESIS

submitted to the faculty of

UNIVERSITY OF MISSOURI - ROLLA

in partial fulfillment of the requirements for the

Degree of

MASTER OF SCIENCE IN CIVIL ENGINEERING

Rolla, Missouri

1970

Approved by

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PUBLICATION THESIS OPTION

This thesis has been prepared in the style utilized by the Journal of American Society of Civil Engineers. Pages 1-26 will be presented for publication in that journal. Appendix III has been added for purposes normal to thesis writing.

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ABSTRACT (1)

An experimental laboratory study conducted to examine clogging within and penetration of fines into a single layer graded filter. Hydraulic gradient, filter gradation and flow direction were varied. Forty one tests gave over six hundred individual penetration depths. The magnitude of penetration in filters with considerable variation in gradation patterns correlated with an average hydraulic radius based on the volume of voids and an approximated total surface area. It has been shown than an increased thickness of poorly graded filter will stop penetration such as that caused by seepage erosion. A relationship between hydraulic radius, penetration depth and probability of penetration has been presented.

KEY WORDS : filter ; hydraulic ; drainage ; deposition ; clogging ; seepage ; porous media ; slope protection

ABSTRACT (2)

An experimental study to examine the clogging within and penetration of fines into a single layer graded filter has been made and a relationship between hydraulic radius, penetration depth and probability of penetration developed.

KEY WORDS : filter ; hydraulic ; drainage ; deposition ; clogging ; seepage ; porous media ; slope protection

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INTRODUCTION

A problem frequently encountered by the engineer is the protection of earth embankment slopes from erosion due to seepage. Examples of the occurrence of such embankments are highway cut sections, drainage ditches, and dam faces subject to a fluctuating water level. The required protection against erosion caused by seepage can be provided by a protective filter composed of particles coarser than the majority of those present in the embankment.

The normal design of a protective filter consists of several layers each graded to specifications such as those given by the U. S. Department of Interior, Bureau of Reclamation (7)* in which the d_{15} size of the filter divided by the d_{85} size of the base must be equal to 5 or less and the ratio of the d_{15} sizes must be between 5 and 40. Subscripts refer to the size at which that percent of the particles in a gradation are smaller. However, the construction of such layered

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* Numerals in parentheses refer to corresponding items in Appendix 1.- References.

filters are often too costly for limited budget construction. In many cases, the cost of providing a protective filter could be reduced by the use of a machine-placed single layer filter utilizing available materials. Kjellman (2) on the basis of tests with dry sand argues that the clogging of a randomly graded filter layer is a statistical function. Therefore, if the randomly graded filter is thick enough it will perform its function. Further support for the use of a single layer randomly graded filter as protection against erosion has been given by Hedar (1). In addition, Sakthivadivel and Einstein (4) have studied the accumulation of sediment and pointed out that in a porous column composed of spheres the probability of penetration varies with the depth of the porous column. A purely theoretical approach to the transport and deposition of sediment particles needed to clog a graded filter seems almost impossible at present because of the complex interactions between the fluid flowing in the filter and the sediment as well as the complicated boundary conditions. Therefore, the writers have studied the problem experimentally in the laboratory. The specific objectives of this investigation were as follow:

1. To study the feasibility of using a graded single layer protective filter by correlating the probability of clogging in such a filter with the gradation and thickness of the filter.

2. To provide needed insight and criteria for the design of such a filter.

EXPERIMENTAL APPARATUS AND MATERIALS

The experiments for this investigation were conducted in a rectangular chamber 23 inches long, 6 inches wide and 60 inches high as shown in Fig. 1. To facilitate the examination and placement of test material, the chamber was divided into five sections each having a height of 12 inches. To allow visual observation, these sections were made of 1/2 inch thick plexiglass. Steel angles around the top and bottom perimeter of each section provided reinforcement. In addition, the horizontal angle legs provided a means of bolting the sections together. Manometer or gage taps were placed in the center of a side of each section. Valved inlets in the top and bottom section provided the means of introducing water into the test chamber. Enclosure of the chamber was completed by the addition of a plexiglass plate on the top and bottom. Standard pressure gages were used to measure pressure.

Filter aggregates in this study were Meramec River sand and gravel having a specific gravity (S.G.) of 2.58. The fine particles introduced into the filter were white silica sand with a specific gravity (S.G.) of 2.64 and coefficient of permeability (k) of 0.495 cm/sec. The average diameter or d_{50} size was 0.0185 in. All fine particles were less than 0.0234 in. in diameter with 80 percent being between 0.0234 and 0.0165 in. in diameter.

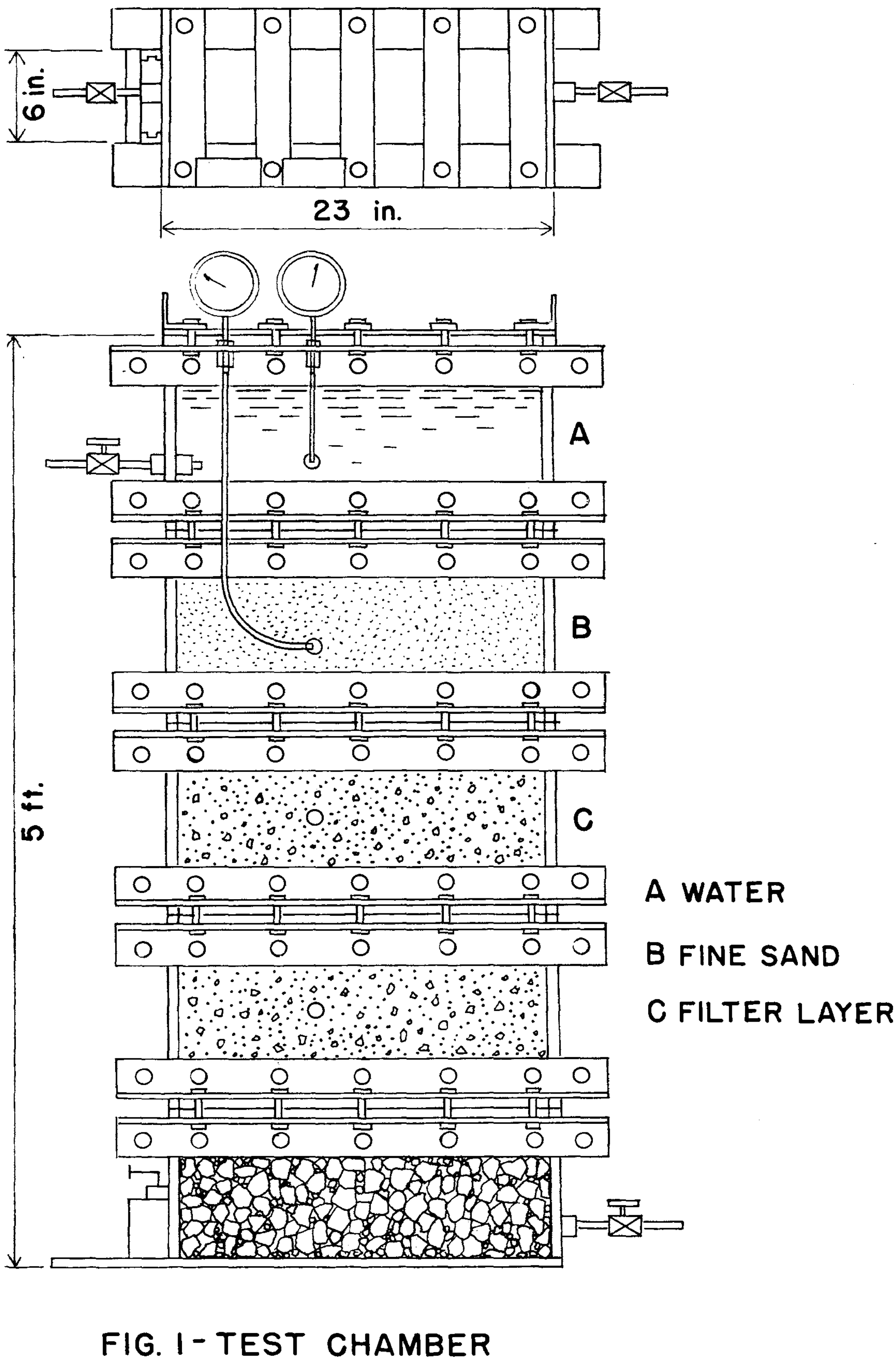

FIG. 1 - TEST CHAMBER

EXPERIMENTAL PROCEDURE

The test filter gradations for this investigation shown in Table 1 were obtained by combining aggregates sieved into various sizes and mixing in a concrete mixer. The gradations represent d_{15}/d_{85} ratios in excess of 6.4. Material was placed in the test chamber to give a 24 inch high filter test section supported by larger aggregates. Fine silica sand with a depth of 12 inches was placed between the filter and 12 inches of water. The majority of tests were conducted with the fine particle penetration downward into an unsaturated filter. For these tests the water flow into the water zone was adjusted to give pressures at the top of the water surface of 0, 2, and 4 pounds per square inch. These pressures correspond to hydraulic gradients of 2.33 6.95 and 11.57 respectively. In addition to the tests with downward flow, several comparative tests with upward penetration into a saturated filter were conducted with base pressures of 3, 4, 5, and 6 pounds per squard inch corresponding to hydraulic gradients at 3.93, 6.24, 8.55 and 10.86 respectively were used. During all the tests the pressure was kept constant until movement in the filter reached equilibrium under visual observation. The total time for each test depended on the test but the average was about 20 hours. The fine sediment particles were forced to enter the filter through a 4 x 6 inch slot. This araangement aided in observing the horizontal movement of the sediment. Data recorded at various time during each test included pressure and penetration depth in the filter based on visual observation through the

TABLE 1. -FILTER GRADATION DATA

Test No.	Percent retained on sieve 3/4"	1/2"	3/8"	#4	#8	#16
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	2.35	21.05	20.60	47.00	6.75	2.25
2	2.30	20.65	20.20	46.00	7.50	3.25
3	2.25	20.25	19.75	45.25	8.25	4.25
4	2.24	19.75	19.40	44.30	9.00	5.11
5	2.20	19.45	19.00	43.55	9.70	6.00
6	2.15	19.10	18.70	42.80	10.35	6.85
7	2.05	18.40	17.95	41.00	11.85	8.70
8	2.00	18.00	17.60	40.35	12.55	9.50
9	2.20	19.45	19.00	43.50	9.70	6.15
10	2.15	19.20	18.70	42.75	10.35	6.85
11	2.10	18.75	18.35	42.00	11.15	7.65
12	2.00	18.20	17.80	40.85	12.15	9.00
13	7.15	17.10	16.45	38.45	11.75	9.10
14	11.35	16.20	15.85	36.45	11.15	9.00
15	16.50	15.40	15.00	34.55	10.60	7.95
16	20.95	14.55	14.20	32.80	10.00	7.50
17	23.35	13.60	13.40	31.00	9.50	7.15
18	2.40	20.76	20.31	46.60	0.93	9.00
19	10.15	16.55	16.25	37.15	11.35	8.55
20	2.22	19.05	19.66	44.03	5.43	9.50
21	10.15	16.55	16.25	37.15	11.35	8.55
22	2.24	19.78	19.43	45.35	3.60	9.60
23	23.25	14.10	13.85	31.85	9.85	7.15
24	2.30	20.35	19.90	45.10	4.25	8.45
25	12.90	16.05	15.70	36.00	11.05	8.30
26	2.35	20.75	20.29	46.35	5.13	5.13
27	2.35	20.75	20.29	46.35	5.13	5.13
28	2.30	20.45	20.00	45.65	5.05	6.55
29	2.30	20.45	20.00	45.65	5.05	6.55
30	2.15	19.25	18.80	42.95	4.60	12.15
31	2.15	19.23	18.80	42.95	4.60	12.15
32	2.40	20.76	20.31	46.60	0.93	9.00
33	2.25	19.80	19.35	44.35	9.00	5.25
34	2.22	19.35	18.98	43.35	9.85	6.25
35	2.15	19.00	18.60	42.55	10.60	7.10
36	2.03	18.22	17.80	40.90	12.10	8.95
37	2.03	18.22	17.80	40.90	12.10	8.95
38	2.30	20.40	20.00	45.63	5.04	6.53
39	2.25	20.00	19.60	44.75	4.95	8.45
40	2.20	19.63	19.22	43.93	4.90	10.12
41	2.25	20.00	19.60	44.75	4.95	8.45

plexiglass wall of the test chamber. Intermittently pressure checks were made to verify gravity flow in the filter. In addition, gradation samples were taken at various points each time the test chamber was disassembled. It should be noted at this point that since visual data was to be obtained, it was necessary to place fiberglass in the corners of the test chamber and strips of rubber horizontally around inside of the chamber walls to eliminate wall effect. Comparisons of gradation samples indicated that these efforts to eliminate the wall effect were successful.

The test gradations use in this investigation fall in to the following four categories:

1. Category 1 (Tests No. 1-12) represents the combination of two graded materials.
2. Category 2 (Tests No. 13-17, 19, 21, 23, 25) represents the addition of coarse material to graded filter.
3. Category 3 (Tests No. 18, 20, 22, 24) represents minimizing the amount of one size material in a graded mixture.
4. Category 4 (Tests No. 26-31) represent the addition of one size fine aggregate to the filter.

Unit weights and void ratios used in this study were obtained in accordance with ASTM Designations: C 30-37, and C 29-39.

RESULTS AND ANALYSIS

In order to compare the test results of filters with various gradations, a length parameter reflecting the differences in filter gradation was necessary. As one diameter size such as d_{10} did not provide adequate correlation, a value dependent on the sizes in the gradation was sought. The parameter adopted by the writers was the hydraulic radius (R) defined by Taylor (5)

$$R = e \frac{V_s}{A_s} \qquad (1)$$

Where R is the hydraulic radius, e is the void ratio, V_s is the volume of solids per cubic foot of aggregate and A_s is the total surface area of the particles per cubic foot of aggregate. The total surface areas used in Eq. 1 were obtained using mulitipliers and the weights of several fractions in a gradation. The mulitipliers used as shown in Table 2

TABLE 2. -SURFACE AREA MULTIPLIERS

Sieve No. Passing	Sand and Gravel Sq. Ft per 100 lb.
3/4	50.0
1/2	74.6
3/8	112.0
#4	185.0
#8	335.0
#16	700.0

were based on Young's (8) tabulation of the surface area per 100 pounds of sand.

PARTICLE MOVEMENT DUE TO DOWNWARD FLOW. -The experimental results for tests on the downward penetration of fine particles into a graded filter are summarized in Table 3. The average penetrations given in this table are the average of those values above 3 inches. The standard deviation has been shown to indicate the variation in penetration depths from the mean.

The movement of sediment into a graded filter with gravity flow is a problem complicated by the random nature number of penetration paths within the filter. Also, in this investigation the migrating particles had noticeable ability to seek a penetration. If the ideal case is considered and vertical movement with equal probability of penetrating a given pore opening or point in a column matrix is assumed the following expression is true

$$P = (P_0)^M \qquad (2)$$

where P is the probability of penetration to the point (M,1), M is the number of the rows in the matrix, P_0 is the probability of penetration at a given point.

However, if horizontal movement is allowed the penetration probability will become the sum of several exponential functions. The writer using a simplified random wald type approximation with assumed probabilities of movement, found that the restrictions placed on horizontal movement varied the shape of the probability of penetration versus depth curve. Since the relative probabilities of horizontal and vertical particle movements and their variations

TABLE 3. -TABULATION OF TEST RESULTS

(Flow Downward)

		Hydraulic Gradient						
		2.33	6.95			11.57		
Test No.	R in inches x 10^2	Penetration in inches Maximum	Penetration in inches Maximum	Penetration in inches Average[a]	Standard Deviation in inches	Penetration in inches Maximum	Penetration in inches Average	Standard Deviation in inches
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	3.00	12.00	***[b]	***		***	***	
2	2.83	6.50	***	***		***	***	
3	2.70	6.50	24.00	16.44		***	***	
4	2.57	*[c]	12.00	6.39	1.25	***	***	
5	2.45	4.00	10.00	4.34	1.63	20.50	12.15	4.25
6	2.34	5.00	10.00	3.22	1.34	18.00	13.36	1.36
7	2.17	*	4.50	1.28	0.18	9.00	5.59	0.74
8	2.08	*	*	*		6.20	1.68	0.69
9	2.45	4.20	16.00	3.68	2.26	***	18.49	1.71
10	2.34	*	11.00	4.40	1.72	20.00	9.78	2.65
11	2.24	*	8.00	2.10	1.12	16.50	7.45	0.79
12	2.15	*	8.00	2.08	1.51	12.00	4.57	1.62

[a] Average penetration depths based on those values above the 3 inch line.
[b] Penetration in the filter is more than 24 inches.
[c] Penetration in the filter is less than 3 inches.

TABLE 3.-CONTINUED

Test No.	R in inches x 10^2	Hydraulic Gradient 2.33 Penetration in inches Maximum	6.95 Penetration in inches Maximum	6.95 Penetration in inches Average	6.95 Standard Deviation in inches	11.57 Penetration in inches Maximum	11.57 Penetration in inches Average	11.57 Standard Deviation in inches
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
13	2.10	*	7.00	1.83	0.73	8.00	2.66	0.93
14	2.18	*	9.00	2.55	1.14	19.00	5.72	2.13
15	2.23	*	9.00	2.68	1.18	19.00	12.05	1.45
16	2.29	*	8.80	2.86	1.38	17.50	11.13	1.00
17	2.33	*	5.50	0.12	1.65	12.00	3.15	1.80
18	2.50	***	***	***		***	***	
19	2.15	*	7.70	0.33	2.61	11.00	1.30	1.83
20	2.29	*	6.00	0.60	0.67	9.50	2.84	1.69
21	2.15	*	6.00	0.38	1.02	11.00	4.76	1.28
22	2.40	10.00	11.00	4.26	2.35	24.00	10.30	4.97
23	2.32	*	9.00	2.43	1.70	15.50	4.39	2.02
24	2.40	*	8.50	1.74	0.67	17.50	5.60	2.61
25[d]	2.20	*	6.50	0.49	0.56	15.00	5.81	2.53
26	2.66	12.00	12.00	3.20	2.85	***	***	
27[d]	2.66	6.00	***	***		***	***	
28	2.50	*	6.00	1.22	0.86	10.00	4.28	1.13
29	2.50	5.50	9.00	2.80	1.43	24.00	13.81	6.26
30	2.36	*	12.50	3.55	1.97	19.50	10.82	3.57
31	2.11	*	5.60	0.39	1.42	11.00	2.13	0.68

[d]Test with a 4 inches slot at the bottom of the filter layer.

were unknown. The writer has used graphical and numerical curve fitting by the method of least squares to obtain those relationships having the best correlation rather than try to fit some theoretical shape of curve. Maximum downward penetration depth of fines into the filter versus hydraulic radius is presented in Fig. 2. The correlation shown in the figure verifies the use of hydraulic radius as a means of repre -senting a graded filter. It should be noted when R becomes 2.40×10^{-2} inches or greater the filter performance becomes slightly erratic. For Test No. 26 with R equal to 3.0×10^{-2} inches the penetration for flow with a hydraulic gradient of 2.33 is almost equal that for a hydraulic gradient of 6.95.

The penetration for Test No. 28 appears to be low in Fig. 2. However, Test 29 had the same filter as Test No. 28 and exhibits a penetration closer to the expected value. Further, Test 28 was the only case in which visual penetration measurements disagreed signigicantly with data obtained from the point gradation samples taken at the end of each test. This conservative filter behavior at high R values is due to the coarse filters allowing internal movement and segregation of filter particles. The effect of hydraulic gradient on the maximum penetration would be expected to decrease exponentially as the hydraulic gradient increases. However, for the range of hydraulic gradients used in this investigation the percent increase in maximum penetration based on the available data varied as hydraulic gradient to the 0.97 power.

It should be noted that for the range of gradients used in this

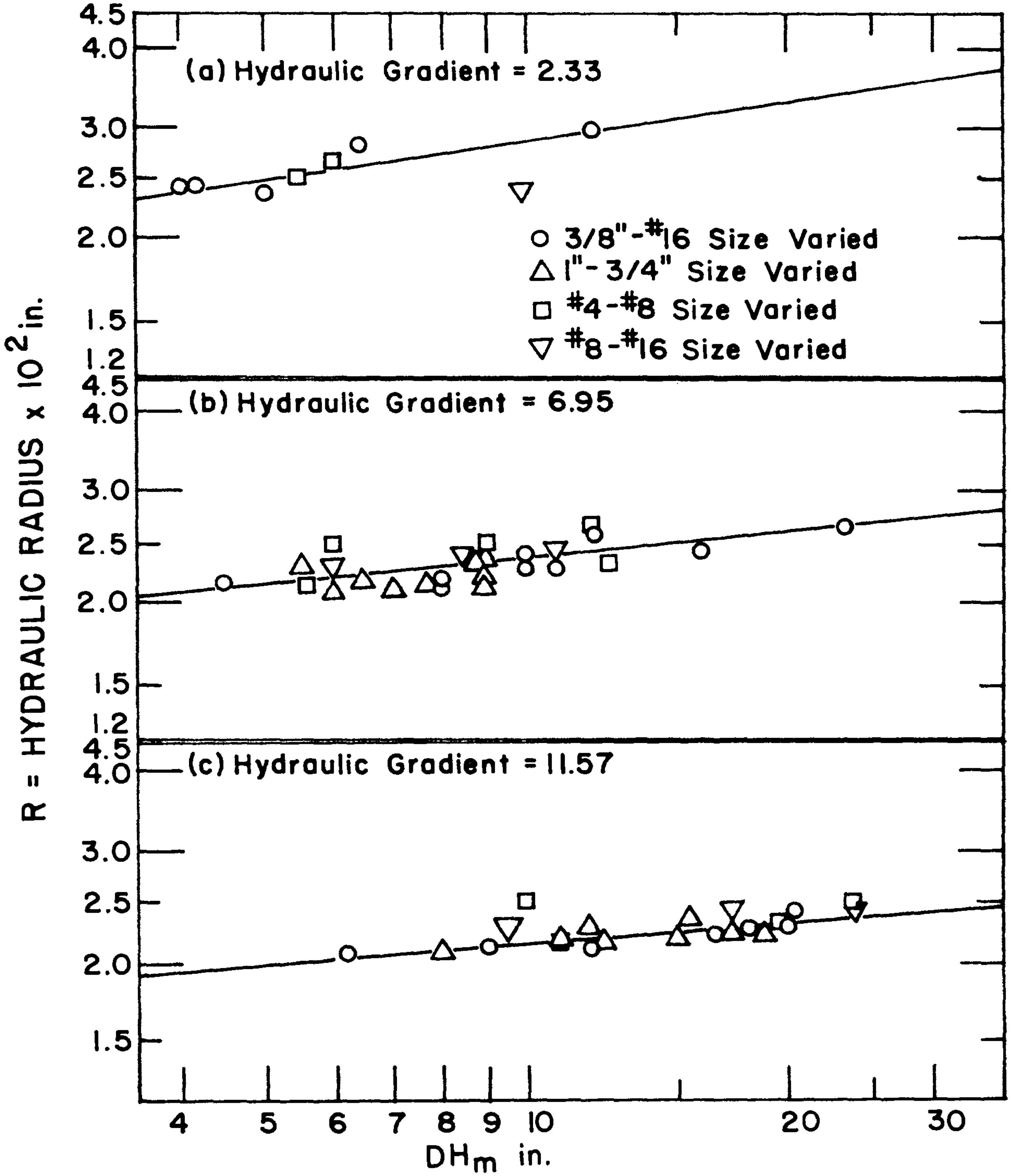

FIG. 2-LOGARITHMIC PLOT OF R VERSUS MAXIMUM DH

study the filter clogging was insufficient to cause pressure build up. Such pressure increase would have indicated serious decrease in filter permeability leading to unstable penetrations in the filter.

If a container is filled with spheres

$$R = e \frac{1}{6} D \qquad (3)$$

letting $e = 0.91$

then $D = R \times 6.60$

Extending the line shown in Fig. 2 (c) to penetration depth of one inch, R is found to 0.017 inches. The diameter of sphere equivalent to R = 0.017 inches is close to 0.112 inches. Dividing this diameter by the maximum size of the fines used yields 0.112/0.0234 a diameter ratio of 4.79. Sakthivadivel (4) found that for ratios less than 6.35 the fines did not enter the pores. However, many pores in a graded filter will be larger than the average and the above approximation supports the previous results.

Probabilities of penetration at various depths for each test were computed by dividing the length of observation over which penetration reached a specified depth by the total length (perimeter of test chamber) over which observations were made. These probabilities were related to the depth by the least square and graphical methods and the results of these computation are summarized in Table 4.

TABLE 4. -TABULATION OF COMPUTATIONS

(Flow Downward)

Hydraulic Gradient

Test No.	6.95 Coefficients B_0	B_1	Standard Error $S_{D\cdot P}$	Correlation Coefficient r	11.57 Coefficients B_0	B_1	Standard Error $S_{D\cdot P}$	Correlation Coefficient r
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1***								
2***								
3**	24.46	-11.90	2.52	-0.80				
4**	11.73	-4.92	0.58	-0.95				
5	11.49	-6.59	0.86	-0.90	22.53	-13.90	2.53	-0.86
6	8.73	-5.39	0.51	-0.96	18.31	-4.29	0.68	-0.89
7	5.70	-2.27	0.26	-0.95	9.14	-3.24	1.46	-0.69
8*					6.70	-3.54	0.36	-0.96
9	14.85	-13.99	1.91	-0.90	24.71	-6.97	0.98	-0.91
10	11.05	-7.53	0.55	-0.97	18.29	-10.29	1.96	-0.84
11	9.19	-6.42	0.50	-0.96	13.74	-5.96	1.59	-0.84
12	9.39	-6.82	0.70	-0.92	11.23	-7.22	0.76	-0.95
13	7.34	-4.35	0.31	-0.98	8.19	-4.93	0.25	-0.99
14	9.87	-6.18	0.38	-0.98	12.36	-7.72	0.65	-0.95
15	8.22	-5.31	0.40	-0.98	17.84	-5.29	1.01	-0.83
16	9.49	-6.15	0.44	-0.98	17.29	-6.93	1.45	-0.90
17	6.11	-1.93	0.75	-0.66	13.01	-9.68	0.79	-0.97
18***								
19	8.79	-2.88	1.02	-0.66	13.08	-8.88	1.26	-0.87
20	7.00	-3.87	0.44	-0.92	9.43	-6.99	0.33	-0.99
21	7.05	-3.13	0.69	-0.80	10.29	-5.44	0.27	-0.99
22	11.77	-8.55	0.55	-0.97	22.69	-17.05	2.22	-0.93
23	10.16	-9.23	1.50	-0.87	12.92	-10.66	1.41	-0.92
24	7.36	-4.60	0.98	-0.86	16.86	-14.02	1.25	-0.97
25	7.55	-4.46	0.63	-0.88	13.61	-9.61	0.61	-0.98
26**	12.09	-11.74	0.89	-0.95				
27***								
28	6.53	-3.44	0.24	-0.98	9.53	-4.89	0.23	-0.99
29	9.67	-6.39	0.24	-0.99	28.27	-22.06	2.07	-0.93
30	10.53	-7.90	0.95	-0.94	20.42	-13.80	1.10	-0.97
31	7.05	-4.37	0.42	-0.93	7.10	-3.69	0.83	-0.85

*** Indicates test failure under Hydraulic Gradient equivlent to both 6.95 and 11.57.

** Indicates test failure under Hydraulic Gradient equivlent to 11.57.

* Indicates penetration in the filter is less than 3 inches.

The coefficients B_0 and B_1 are for the equation

$$DH = B_0 + B_1 (P) \tag{4}$$

where DH is the depth of penetration, and P is the probability of penetration at that depth.

The correlation coefficients (r) show that these expressions yield a good relationship. To aid the reader in determining the magnitude of error, the standard error $S_{D\cdot P}$ which indicates the deviation between the actual depths and the corresponding depths predicted by Eq. 4 was included in Table 4. Since this value is based on the square of the difference between actual and predicted values, one point with high experimental error can have considerable effect. Statistically the probable error is 0.6745 times the standard error. The hydraulic radii were related graphically and numerically, with the B_0 and B_1 values of Eq. 4. After examining several relationships a simple exponential function was adopted to relate B_0 and B_1 to R. This multiple correlation resulted in the following equations:
For hydraulic gradient equal to 6.95

$$DH = 0.0662 \times (R \times 10^2)^{5.97} - 0.00258 \times (Rx10^2)^{13.06} \times P \tag{5}$$

For hydraulic gradient equal to 11.57

$$DH = 0.0163 \times (Rx10^2)^{8.28} - 0.000175 \times (Rx10^2)^{13.06} \times P \tag{6}$$

The standard error for a hydraulic gradient of 6.95 was 3.06 in. corresponding to a probable error of 2.06 in. However most of this error was on the conservative side. Standard error corresponding to a hydraulic gradient of 11.57 was 2.83 in. corresponding to probable error of 1.91 in. The largest error was again on the conservative side. It should be noted that this error included experimental error and error due to a random system.

PARTICLE MOVEMENT DUE TO UPWARD FLOW. - When the test apparatus was reversed to provide the condition of flow upward through the fine silica sand layer into a saturated filter, liquefaction was encountered.

This condition was not unexpected because the critical gradient of the fines layer was close to unity. Movement within the layer did produce a notable difference between the upward and downward flow cases. In downward flow the loss of material from the fines layer was uniform and did not have a significant influence. However, for upward flow eddy currents tended to concentrate the fine losses at one point making direct comparison of results for the two flow systems difficult. The hydraulic gradients have been adjusted with the help of hole observations and an intermediate gage reading in the center of fines layer. These adjusted gradients and other results of the tests involving upward flow are summarized in Table 5.

A comparison of measured maximum depths for upward flow and predicted values based on downward flow indicated a tendency for the upward penetration to correspond approximately with those for downward flow having a hydraulic gradient lower by 2.7. This difference is close to the estimated gradient of 2.6 required to yield velocity equal to fall velocity of the largest fines particles. However, upward

TABLE 5. -TABULATION OF TEST RESULTS

(Flow Upward)

Test No.	R in inches x 10^{+2}	Hydraulic Gradient Base	Hydraulic Gradient Adjusted	Standard Deviation in inches	Penetration in inches Average[a]	Penetration in inches Maximum
(1)	(2)	(3)	(4)	(5)	(6)	(7)
32	2.20	6.24	6.24	0.69	0.92	8.0
33	2.56	6.24	10.50	3.44	17.88	24.0
34	2.42	6.24	8.50	2.38	3.71	10.5
34	2.42	8.55	13.90	1.65	14.15	21.5
35	2.32	6.24	11.80	1.27	6.87	12.0
36	2.14	6.24	10.80	2.65	5.66	14.0
37	2.14	3.93	7.90	1.52	2.99	9.0
38	2.49	3.93	6.90	1.82	0.52	6.0
38	2.49	6.24	7.80	2.22	1.72	8.5
38	2.49	8.55	11.20	2.50	2.03	9.0
38	2.49	10.85	16.20	2.70	2.56	9.5
39	2.32	3.93	3.24	1.16	1.95	7.5
39	2.32	6.24	20.60	2.48	12.52	20.0
40	2.24	6.24	6.24	0.63	0.10	4.0
40	2.24	8.55	8.05	0.62	0.11	4.0
40	2.24	10.85	10.86	0.62	0.11	4.0
41	2.32	3.93	3.93	1.47	0.42	6.0
41	2.32	6.24	6.20	1.71	0.85	6.5
41	2.32	8.55	12.48	1.80	1.33	7.5
41	2.32	10.85	17.60	2.13	1.54	8.0

[a] Average Penetration in filter based on those values above the 3 inch line.

TABLE 6. -TABULATION OF COMPUTATIONS

(Flow Upward)

Test No.	Adjusted Hydraulic Gradient	Coefficients		Standard Error	Correlation Coefficient
		B_0	B_1	$S_{D\cdot P}$	r
(1)	(2)	(3)	(4)	(5)	(6)
32	6.24	8.91	-6.02	0.79	-0.89
33	10.50	25.42	-10.72	1.32	-0.90
34	8.50	11.31	-8.96	0.65	-0.97
34	3.90	20.62	-7.27	0.70	-0.95
35	11.80	11.46	-5.28	1.18	-0.81
36	10.80	14.60	-11.23	0.71	-0.98
37	7.90	9.90	-6.55	0.22	-0.99
38	6.90	6.80	-2.29	0.66	-0.75
38	7.80	10.62	-6.03	1.00	-0.85
38	11.20	11.11	-5.99	1.02	-0.84
38	16.20	11.68	-6.24	1.15	-0.82
39	3.24	8.34	-5.29	0.22	-0.99
39	20.60	20.06	-9.68	0.67	-0.97
40	6.24	4.57	-1.18	0.29	-0.85
40	8.05	4.56	-1.17	0.30	-0.85
40	10.86	4.56	-1.17	0.30	-0.85
41	3.93	6.98	-2.83	0.75	-0.76
41	6.20	7.73	-3.53	0.76	-0.81
41	12.48	9.21	-4.92	0.83	-0.85
41	17.60	9.87	-5.28	0.94	-0.84

penetration in a saturated filter has noticeably greater tendency to pipe causing increased penetration depths. With one minor exception (Test No. 36), piping caused penetrations less than those predicted from downward penetration for a hydraulic gradient of 11.57.

Another factor in the movement of fines in a saturated filter tending to increase the magnitude of penetration is the increased tendency for the fines to segregate. The relationships between probability of penetration and depth were determined as for downward penetration and are given in Table 6.

Observation and comparison of the B_1 values for tests 38 and 41 in which the fines entered the filter through a 4 x 6 inch slot with Test No. 25 having a similar slot confirms the tendency for greater spreading of the penetrating fines for downward movement. Eqs. 4 and 5 were for one relatively uniform gradation. Therefore, some thought needs to be given to extend this system to snother size of penetration fines. Consider a similar system in which all dimensions are changed by some constant. If a penetration is thought of as a series of steps passing through a number of pore spaces, a similar pattern of penetration exits. All lengths will vary by the same scale and Eq. 5 and 6 can be modified using a length ratio based on the size of the penetration fines. The revision would be simply to divide all lengths by a characteristic diameter of these fines. This concept is supported by the fact that for the considerably different filter gradations examined in this study a length parameter (R) leads to general correlation. The characteristic diameter of these fines could represent the particle size to be stopped by the filter.

In the writer's opinion, this characteristic size can be the d_{85} size normally used in filter design. This belief is supported by the fact that the projected diameter of a uniform filter yielding a maximum penetration depth of one inch was 0.112 in. Dividing this value by d_{85} of the penetrating fines or 0.0228 in. is 4.92. This ratio aggrees with normal filter design criteria. A remaining consideration is the hydraulic gradient. An almost linear variation of penetration with hydraulic gradient inplies a relationship between total flow and penetration. This implication leads to providing flows utilizing the same percentage of pore spaces. If the dimensions are divided by 1.5 the area of pore opening would be 1/2.25 time the original pore areas. The coefficient of permeability will be reduced approximately the same giving the desired flow rate. Therefore, it is practical to use the same hydraulic gradient for the non-dimensional equations.

SUMMARY AND CONCLUSIONS

The results of this experimental investigation show that an average hydraulic radius based on the volume of voids and an approximated total surface area of particle can be used as a length parameter to represent filters with different gradation patterns.

Confirmation has been obtained to the concept that fine particle penetration into a filter is dependent on the probability of the penetration path being blocked. This probability increases with depth. Therefore, an increased filter layer thickness will allow less rigid gradation requirements.

However, it was found that when the hydraulic radius (R) reached a value of 2.4×10^{-2} inches the action of the filter become somewhat erratic for a maximum size of penetrating fines of 0.0234 inches in diameter. This erratic action is probably due to internal segregation within the filter generally causing penetrating depth equal or less than expected.

It has been possible to develope relationships between the probability of penetration, hydraulic radius, and depth of penetration given by Eq. 5 and 6 for two different hydraulic gradients. For the range covered in this investigation, it was found that penetration depth varied almost linearly with hydraulic gradient.

The results of upward flow test indicated a greater tendency of piping. Also, a quick condition developing beneath the filter caused a concentration of the flow into the filter. Even with piping and increased hydraulic gradients the upward penetrations were less than the projected penetrations for flow downward with corresponding hydraulic gradients.

ACKNOWLEDGEMENTS

This investigation was supported by funds provided by the United States Department of the Interior, Office of Water Recources Research.

The writer of this thesis is deeply indebted to Dr. C. D. Muir, Professor of Civil Engineering, who served as research advisor. His help and guidance is sincerely thankful. And also the writer is greatly indebted to Professor Jerry, R. Bayless, and Dr. W. W. Yu for their guidance and encouragement.

A further word of appreciation is extended to Department of Civil Engineering, University of Missouri at Rolla for the use of equipment and a research scholarship.

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APPENDIX II. -NOTATION

The following symbols are used in this paper:

A_s = total surface area of the particles per cubic foot;

B_0, B_1 = coefficients of linear equation from least square method;

D = diameter of sphere particles;

DH = depth of penetration in filter;

DH_m = maximum depth of penetration in filters;

d_{15} = size at which 15 percent of the total soil particles are smaller;

d_{85} = size at which 85 percent of the total soil particles are smaller;

e = void ratio;

M = number of rows in the matrix;

P = probability of penetration;

P_0 = probability of penetration at a given point;

R = hydraulic radius;

APPENDIX III-TABLES FOR REFERENCE

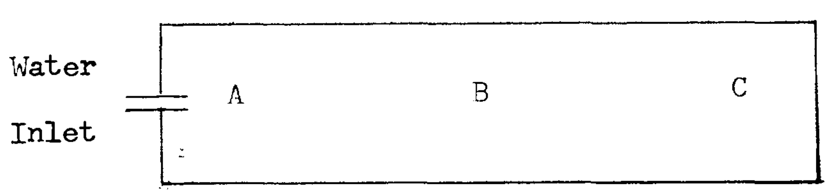
Table I

Filter Gradation Data at Various Locations

Test No. 1

Depth in Filter	Sample[1] Location	Percent Retained on Sieve[2] at Selected Points: #4	#10	#16	#30	#50	Pan
2"-3"	A	75.56	9.63	2.22	0	9.63	2.96
	C	71.04	13.55	2.81	0	9.35	3.27
9"-10"	A	77.99	12.27	1.81	0	5.77	2.17
	C	79.85	10.45	1.49	0	5.97	2.24
16"-17"	A	76.52	13.48	2.18	0	6.08	1.74
	C	81.25	10.10	0.96	0	5.77	1.92
	A	86.93	9.42	2.2	0.36	0.73	0.36
	C	81.08	13.52	2.25	0	2.25	0.9

Note 1: A, B, C, indicates the location of sample taken in the filter, as shown in the following diagram.



Note 2: Sieve No. indicates U.S. Standard Sieve-Designation.

Table I (continued)

Filter Gradation Data at Various Locations

Test No. 2

Depth in Filter	Sample Location	#4	#10	#16	#30	#50	Pan
2"-3"	A	72.48	14.29	3.94	0	7.39	1.98
	C	67.52	18.47	7.01	0	6.56	1.63
9"-10"	A	84.24	7.61	0.54	0	7.07	0.54
	C	84.88	9.9	2.09	0	2.43	0.7
16"-17"	A	81.89	12.93	3.02	0	1.73	0.43
	C	77.34	17.24	3.94	0	0.99	0.49
23"-24"	A	85.56	11.78	2.28	0	0.19	0.19
	C	88.66	8.82	1.89	0	0.42	0.21

Test No. 3

Depth in Filter	Sample Location	#4	#10	#16	#30	#50	Pan
2"-3"	A	70.19	9.21	2.19	0	13.37	5.04
	C	73.12	8.38	2.31	0	14.17	2.02
9"-10"	A	72.12	10.42	5.89	0.39	9.23	1.95
	C	73.2	9.79	3.4	0.21	10.42	2.98
16"-17"	A	81.54	14.13	2.96	0	0.91	0.45
	C	74.36	14.25	3.25	0.2	6.72	1.22
	A	86.59	9.86	2.74	0	0.27	0.54
	C	84.95	10.03	3.17	0	1.32	0.53

Table I (continued)

Filter Gradation Data at Various Locations

Test No. 4

Depth in Filter	Sample Location	Percent Retained on Sieve at Selected Points #4	#8	#16	#30	#50	Pan
2"-3"	A	74.92	10.79	5.08	0	6.67	2.54
	C	65.05	18.57	7.65	0.27	6.28	2.18
9"-10"	A	74.61	13.34	6.15	0	4.36	1.54
	C	72.42	12.71	6.23	0.24	6.48	1.92
16"-17"	A	74.23	11.12	5.31	0.25	7.07	2.02
	C	69.00	9.08	3.68	0	5.83	1.23
23"-24"	A	75.98	11.86	6.53	0.3	4.44	0.89
	C	76.82	10.78	6.47	0.27	4.58	1.08

Test No. 5

Depth in Filter	Sample Location	Percent Retained on Sieve at Selected Points #4	#8	#16	#30	#50	Pan
2"-3"	A	73.9	10.62	5.87	0	6.93	2.77
	C	72.5	12.8	5.45	0	6.53	2.72
9"-10"	A	83.08	7.95	4.1	0	3.33	1.54
	C	76.75	7.84	4.18	0	8.62	2.61
16"-17"	A	76.7	12.62	5.83	0.24	3.88	0.73
	C	79.00	9.52	5.32	0.28	4.76	1.12
23"-24"	A	84.52	9.54	5.16	0.26	0.26	0.26
	C	87.00	8.09	4.04	0	0.58	0.29

Table I (continued)

Filter Gradation Data at Various Locations

Test No. 6

Depth in Filter	Sample Location	Percent Retained on Sieve at Selected Points					
		#4	#8	#16	#30	#50	Pan
2"-3"	A	70.27	15.54	6.76	0	5.41	2.02
	C	75.54	12.58	5.59	0	4.19	2.1
9"-10"	A	73.24	13.38	7.04	0	4.93	1.41
	C	81.42	7.72	8.00	0.29	2.00	0.57
16"-17"	A	73.71	12.57	6.86	0	5.72	1.14
	C	79.94	11.3	6.22	0	1.98	0.57
23"-24"	A	77.75	14.13	7.77	0	0	0.35
	C	76.76	14.08	9.16	0	0	0

Test No. 7

Depth in Filter	Sample Location	Percent Retained on Sieve at Selected Points					
		#4	#8	#16	#30	#50	Pan
2"-3"	A	75.57	11.27	6.82	0.25	4.23	1.88
	C	76.95	10.27	6.67	0.28	3.89	1.94
9"-10"	A	77.92	10.38	6.39	0.2	3.99	1.12
	C	67.00	16.27	10.04	0.48	4.78	1.43
16"-17"	A	77.15	14.56	7.72	0.29	0	0.29
	C	80.27	13.38	6.02	0	0	0.34
23"-24"	A	72.92	24.58	11.46	0.52	0	0.52
	C	82.51	8.07	8.97	0.45	0	0.26

Table I (continued)

Filter Gradation Data at Various Locations

Test No. 8

Depth in Filter	Sample Location	Percent Retained on Sieve at Selected Points #4	#8	#16	#30	#50	Pan
	A	68.39	14.23	8.69	0	6.32	2.37
1"-2"	B	75.78	10.94	7.42	0	4.30	1.56
	C	66.66	17.73	9.93	0	4.26	1.42
	A	67.69	18.46	12.31	0	0.77	0.77
5"-6"	B	78.94	11.19	7.89	0	1.32	0.66
	C	74.70	14.46	9.64	0	0.60	0.60
	A	70.67	16.67	12.00	0.33	0	0.33
9"-10"	B	85.72	8.28	5.43	0	0	0.57
	C	77.58	13.92	8.24	0	0	0.26

Test No.9

Depth in Filter	Sample Location	Percent Retained on Sieve at Selected Points #4	#8	#16	#30	#50	Pan
	A	74.16	12.24	6.80	0	4.76	2.04
2"-3"	B	79.75	8.59	5.52	0	4.30	1.84
	C	70.42	12.43	8.28	0	6.51	2.36
	A	82.32	7.73	4.42	0	3.87	1.66
9"-10"	B	78.53	7.81	4.39	0	6.83	2.44
	C	75.00	8.80	5.29	0	8.79	2.32
	A	83.16	8.42	4.21	0	3.16	1.05
16"-17"	B	85.30	7.12	2.84	0	3.79	1.05
	C	77.94	13.60	5.52	0	2.21	0.74
	A	70.13	12.34	4.54	0	10.39	2.60
23"-24"	B	70.89	10.92	5.46	0	10.31	2.42
	C	81.77	10.42	5.21	0	2.08	0.52

Table I (continued)

Filter Gradation Data at Various Locations

Test No. 10

Depth in Filter	Sample Location	#4	#8	#16	#30	#50	Pan
2"-3"	A	71.21	13.58	7.06	0	5.98	2.17
	B	71.71	11.62	6.06	0	7.58	3.03
	C	71.18	10.92	6.98	0	7.86	3.06
9"-10"	A	70.75	10.74	11.85	0.37	5.18	1.11
	B	74.29	9.35	11.22	0	4.21	0.93
	C	70.26	13.39	9.45	0	5.72	1.18
16"-17"	A	78.07	15.00	6.16	0	0.39	0.39
	B	82.65	11.96	4.79	0	0.30	0.30
	C	77.73	15.09	6.15	0	0.85	0.28
23"-24"	A	80.92	8.87	9.92	0	0	0.38
	B	85.96	7.02	7.02	0	0	0
	C	83.69	8.51	7.09	0	0	0.71

Test No. 11

Depth in Filter	Sample Location	#4	#8	#16	#30	#50	Pan
2"-3"	A	67.35	17.96	6.94	0	6.12	1.63
	B	70.41	15.39	7.10	0	5.32	1.78
	C	66.88	16.24	5.84	0	7.79	3.25
9"-10"	A	81.78	9.74	6.36	0	1.70	0.42
	B	81.69	8.45	5.63	0	3.29	0.94
	C	76.90	10.55	6.53	0	5.02	1.00
16"-17"	A	82.09	11.79	6.12	0	0	0
	B	82.84	11.28	5.88	0	0	0
	C	78.31	12.46	8.03	0	0.80	0.40
23"-24"	A	72.20	18.93	7.69	0	0.59	0.59
	B	73.50	18.55	7.75	0	0	0
	C	73.29	18.49	8.22	0	0	0

Table I (continued)

Filter Gradation Data at Various Locations

Test No. 12

Depth in Filter	Sample Location	#4	#8	#16	#30	#50	Pan
	A	76.47	6.47	4.71	0	11.18	1.18
2"-3"	B	73.98	8.67	5.11	0	8.67	3.57
	C	70.19	8.62	5.30	0	11.92	3.97
	A	75.00	13.02	7.81	0	3.13	1.04
6"-7"	B	76.53	11.73	7.41	0	3.09	1.24
	C	75.00	12.50	9.00	0	2.50	1.00
	A	77.59	10.43	8.49	0	2.72	0.77
11"-12"	B	80.36	8.68	6.85	0	3.20	0.91
	C	78.14	12.10	8.37	0	0.93	0.46
	A	78.61	12.58	8.81	0	0	0
16"-17"	B	78.00	11.33	8.67	0	1.33	0.67
	C	76.73	13.21	9.12	0	0.31	0.63

Test No. 13

Depth in Filter	Sample Location	#4	#8	#16	#30	#50	Pan
	A	74.88	9.18	5.80	0	7.24	2.90
2"-3"	B	81.10	8.11	5.40	0	4.05	1.35
	C	80.23	7.34	4.52	0	5.65	2.26
	A	80.73	9.64	6.62	0	2.41	0.60
6"-7"	B	77.58	10.91	8.48	0	2.42	0.61
	C	74.73	13.22	9.19	0	2.29	0.57
	A	78.81	11.92	7.95	0	0.66	0.66
11"-12"	B	78.88	10.00	8.89	0	1.67	0.56
	C	77.58	12.12	9.09	0	0.61	0.61
	A	77.52	14.10	7.93	0	0	0.44
16"-17"	B	81.09	11.49	6.70	0	0	0
	C	78.97	13.07	7.96	0	0	0

Table I (continued)

Filter Gradation Data at Various Locations

Test No. 14

Depth in Filter	Sample Location	3/4"	#4	#8	#16	#30	#50	Pan
		Percent Retained on Sieve at Selected Points						
2"-3"	A	18.45	57.52	10.06	6.14	0	5.59	2.24
	B	22.78	55.56	8.88	5.56	0	4.44	2.78
	C	22.70	53.52	11.89	6.48	0	3.79	1.62
6"	A	5.46	67.22	11.77	7.57	0	5.88	2.10
	B	8.88	65.69	13.90	7.72	0	3.09	0.72
	C	12.89	64.09	9.67	5.99	0	5.52	1.84
9"-10"	A	8.51	63.30	13.83	9.04	0	4.26	1.06
	B	11.00	63.34	11.52	8.38	0	4.71	1.05
	C	10.88	61.40	14.13	10.33	0	2.72	0.54
16"-17"	A	15.05	68.28	9.14	6.99	0	0	0.54
	B	14.70	64.92	12.32	8.06	0	0	0
	C	13.47	72.65	8.16	5.72	0	0	0

Test No. 15

Depth in Filter	Sample Location	3/4"	#4	#8	#16	#30	#50	Pan
		Percent Retained on Sieve at Selected Points						
2"-3"	A	17.78	54.44	9.45	6.11	2.22	8.33	1.67
	B	21.47	53.40	8.90	5.76	0	7.33	3.14
	C	21.57	52.45	8.82	4.90	0	8.82	3.44
9"-10"	A	19.92	54.97	11.96	7.57	0	4.38	1.20
	C	16.32	57.43	12.42	7.80	0	4.61	1.42
16"-17"	A	16.04	61.33	12.76	8.64	0	0.82	0.41
	B	16.44	58.91	7.64	5.73	0	0.96	0.32
	C	28.00	56.61	8.24	5.50	0	1.10	0.55
23"-24"	A	13.04	65.21	12.08	9.67	0	0	0
	B	10.55	70.57	10.55	8.33	0	0	0
	C	12.45	68.20	9.22	10.13	0	0	0

Table I (continued)

Filter Gradation Data at Various Locations

Test No. 16

Depth in Filter	Sample Location	3/4"	#4	#8	#16	#30	#50	Pan
2"-3"	A	19.17	56.99	10.46	5.23	0	5.82	2.33
	B	21.80	53.83	9.62	5.13	0	6.41	3.21
	C	30.77	48.72	9.74	4.10	0	4.62	2.05
9"-10"	A	15.45	63.94	11.16	6.87	0	2.15	0.43
	B	9.17	66.82	11.35	8.30	0	3.49	0.87
	C	23.93	56.40	9.04	6.38	0	3.19	1.06
16"-17"	A	29.38	54.23	8.47	6.22	0	1.13	0.57
	B	21.42	54.22	13.86	9.24	0	0.84	0.42
	C	28.44	55.88	8.82	5.88	0	0.49	0.49
23"-24"	A	14.87	71.11	6.04	6.98	0	0	0
	B	18.84	62.33	10.88	7.53	0	0	0.42
	C	13.93	67.50	10.55	8.02	0	0	0

Test No. 17

Depth in Filter	Sample Location	3/4"	#4	#8	#16	#30	#50	Pan
2"-3"	A	25.63	44.3	12.33	6.90	0	7.88	2.96
	B	27.46	46.16	12.26	6.87	0	5.39	1.96
	C	25.57	47.48	13.25	6.39	0	5.94	1.37
6"	A	25.54	59.72	6.83	5.39	0	1.80	0.72
	B	25.39	55.38	9.23	6.92	0	2.31	0.77
	C	22.85	55.60	11.21	6.89	0	2.59	0.86
9"-10"	A	24.16	57.71	10.41	6.71	0	6.67	0.34
	B	26.80	55.85	10.19	6.03	0	0.75	0.38
	C	18.47	59.45	13.52	7.66	0	0.45	0.45
16"-17"	A	22.18	58.47	11.29	8.06	0	0	0
	B	32.80	53.69	7.72	5.79	0	0	0
	C	23.70	59.46	9.97	6.87	0	0	0

Table I (continued)

Filter Gradation Data at Various Locations

Test No. 18

Depth in Sample		Percent Retained on Sieve at Selected Points					
Filter	Location	#4	#8	#16	#30	#50	Pan
2"-3"	A	86.00	1.48	12.60	0	8.89	2.96
	B	90.10	0.66	9.27	0.66	8.66	3.31
	C	88.70	0.95	10.40	0.95	7.11	2.84
9"-10"	A	88.80	1.20	10.00	0.46	0.80	0.40
	B	92.10	0.57	7.34	0.57	5.08	2.26
	C	86.10	0.90	13.00	0.90	2.69	0.90
16"-17"	A	91.40	0.45	8.64	0.45	1.36	0.45
	B	92.20	0.86	6.90	0.43	5.61	2.15
	C	88.70	0.95	10.40	0.47	0.95	0.47
23"-24"	A	87.70	1.00	11.30	0.51	1.03	0.51
	B	88.60	0.85	11.60	0.42	0.21	0.85
	C	88.10	0.95	11.30	0.50	1.01	0.50

Test No. 19

Depth in Sample		Percent Retained on Sieve at Selected Points					
Filter	Location	#4	#8	#16	#30	#50	Pan
2"-3"	A	68.60	17.70	13.60	0	4.44	1.71
	B	72.40	15.80	11.80	0	7.88	2.46
	C	70.80	16.40	12.80	0	4.02	1.34
6"	A	81.20	11.20	7.73	0	0.43	0.43
	B	81.90	11.10	7.02	0	0	0
	C	85.40	9.09	5.46	0	1.36	0.45
9"-10"	A	84.70	9.87	5.38	0	0.90	0.45
	B	80.20	12.50	7.29	0	0	0
	C	70.30	16.80	12.90	0	0	0
16"-17"	A	77.90	13.50	6.54	0	0	0
	B	83.70	11.30	5.04	0	0	0
	C	73.30	17.10	9.59	0	0	0

Table I (continued)

Filter Gradation Data at Various Locations

Test No. 20

Depth in Filter	Sample Location	Percent Retained on Sieve at Selected Points #4	#8	#16	#30	#50	Pan
2"-3"	A	84.20	5.52	10.30	0.69	12.40	1.38
	B	80.60	6.29	13.10	0	7.43	2.86
	C	80.20	7.14	12.60	0.55	7.14	2.74
6"	A	85.70	6.19	8.10	0	0.95	0.48
	B	86.10	6.02	7.87	0	0.93	0.46
	C	85.60	5.41	9.01	0.45	0.90	0.45
9"-10"	A	79.70	7.73	12.60	0	0.48	0
	B	83.80	6.37	9.80	0	0.98	0.49
	C	82.90	5.43	11.60	0	0.39	0
16"-17"	A	85.20	3.94	10.80	0	0	0
	B	88.90	3.03	8.15	0	0	0
	C	82.70	6.85	10.50	0	0	0

Test No. 22

Depth in Filter	Sample Location	Percent Retained on Sieve at Selected Points #4	#8	#16	#30	#50	Pan
2"-3"	A	89.50	3.35	7.18	0.48	18.20	5.74
	B	91.20	4.40	4.40	0	20.1	5.66
	C	93.40	3.54	3.03	0	20.70	5.05
9"-10"	A	76.20	5.18	18.70	0.52	10.40	2.07
	B	78.10	6.18	15.70	0.56	8.99	2.81
	C	81.40	5.56	13.10	0.40	6.35	1.98
16"-17"	A	84.80	5.41	9.73	0	0.54	0
	B	93.30	2.37	4.27	0	0	0
	C	90.10	3.88	6.03	0	4.31	0.43
23"-24"	A	90.80	2.30	6.91	0	0	0
	B	90.00	2.09	7.85	0	0	0
	C	84.50	3.11	12.40	0.52	0	0.52

Table I (continued)

Filter Gradation Data at Various Locations

Test No. 21

Depth in Filter	Sample Location	Percent Retained on Sieve at Selected Points 3/4"	#4	#8	#16	#30	#50	Pan
2"-3"	A	4.82	57.75	15.50	11.23	0	8.02	2.68
	B	4.79	66.50	12.44	9.57	0	4.79	1.91
	C	5.63	64.06	12.99	9.09	0	6.07	2.16
6"	A	9.92	67.23	12.50	8.19	0	1.72	0.43
	B	1.55	75.75	12.37	8.76	0	2.06	0.52
	C	5.10	67.86	14.80	10.20	0	1.53	0.51
9"-10"	A	5.96	73.61	11.92	7.66	0	0.85	0
	B	10.61	74.24	9.09	6.06	0	0	0
	C	5.13	74.87	12.31	7.18	0	0.51	0
16"-17"	A	14.10	67.50	11.54	6.84	0	0	0
	B	10.71	76.59	7.94	4.76	0	0	0
	C	6.63	75.01	11.73	6.63	0	0	0

Test No. 23

Depth in Filter	Sample Location	Percent Retained on Sieve at Selected Points 3/4"	#4	#8	#16	#30	#50	Pan
2"-3"	A	8.97	52.89	13.01	11.22	0	10.77	3.14
	B	20.78	50.73	10.14	6.76	0	8.69	2.90
	C	13.70	53.30	13.20	9.14	0	8.63	2.03
9"-10"	A	18.53	59.84	11.97	8.50	0	0.77	0.39
	B	21.73	55.23	12.18	8.26	0	2.17	0.43
	C	23.83	49.41	14.15	10.44	0	1.81	0.36
16"-17"	A	10.94	69.23	12.24	7.17	0	0.42	0
	B	19.81	65.10	10.37	4.72	0	0	0
	C	20.25	65.47	9.52	4.76	0	0	0
23"-24"	A	28.79	60.14	7.75	3.32	0	0	0
	B	33.45	56.15	7.06	3.34	0	0	0
	C	23.33	65.00	8.00	3.67	0	0	0

Table I (continued)

Filter Gradation Data at Various Locations

Test No. 24

Depth in Filter	Sample Location	#4	#8	#16	#30	#50	Pan
		Percent Retained on Sieve at Selected Points					
2"-3"	A	71.22	4.87	13.17	0.49	7.81	2.44
	B	75.52	4.08	9.69	0	8.16	2.55
	C	75.75	5.11	8.51	0	8.08	2.55
6"	A	84.49	4.74	6.89	0	3.02	0.86
	B	82.05	5.13	6.96	0	4.03	1.83
	C	85.78	4.00	8.00	0	1.78	0.44
9"-10"	A	81.65	5.31	12.08	0	0.96	0
	B	83.48	4.35	9.13	0	2.61	0.43
	C	86.64	3.69	7.83	0	1.38	0.46
16"-17"	A	84.23	6.90	8.87	0	0	0
	B	88.94	5.31	5.31	0	0.44	0
	C	89.70	4.72	5.15	0	0.43	0

Test No. 25

Depth in Filter	Sample Location	3/4"	#4	#8	#16	#30	#50	Pan
		Percent Retained on Sieve at Selected Points						
2"-3"	A	11.47	61.21	10.38	4.92	0	9.29	2.73
	B	13.97	57.55	10.05	5.59	0	10.05	2.79
	C	9.13	63.48	9.13	4.35	0	10.43	3.48
6"	A	12.79	64.54	10.47	9.88	0	1.74	0.58
	B	9.14	66.50	8.63	9.64	0	4.57	1.52
	C	23,67	59.18	6.94	6.94	0	2.45	0.82
9"-10"	A	5.58	73.23	10.78	8.92	0	1.12	0.37
	B	13.34	66.22	9.33	7.11	0	3.11	0.89
	C	7.63	57.82	15.26	12.86	0	5.22	1.21
16"-17"	A	15.28	61.56	14.42	7.86	0	0.44	0.44
	B	4.59	66.50	20.19	8.72	0	0	0
	C	9.91	65.76	15.32	9.01	0	0	0

Table I (continued)

Filter Gradation Data at Various Locations

Test No. 26

Depth in Filter	Sample Location	#4	#8	#16	#30	#50	Pan
		Percent Retained on Sieve at Selected Points					
2"-3"	A	74.71	5.88	4.12	0	11.17	4.12
	B	80.12	4.45	2.27	0	9.66	3.42
	C	81.93	4.52	3.23	0	7.74	2.58
9"-10"	A	80.49	5.23	6.27	0	5.92	2.09
	B	75.98	5.84	6.49	0	8.44	3.25
	C	74.20	5.53	7.83	0	10.13	2.31
16"-17"	A	86.15	5.13	3.59	0	4.10	1.03
	B	91.55	2.67	2.22	0	2.67	0.89
	C	87.72	4.82	2.63	0	3.95	0.88
23"-24"	A	79.47	7.90	6.84	0	4.74	1.05
	B	82.80	5.43	3.17	0	6.79	1.81
	C	81.94	5.73	6.17	0	4.84	1.32

Test No. 27

Depth in Filter	Sample Location	#4	#8	#16	#30	#50	Pan
		Percent Retained on Sieve at Selected Points					
2"-3"	A	81.28	5.85	4.68	0	5.85	2.34
	B	86.01	2.59	2.59	0	6.22	2.59
	C	78.09	5.62	4.49	0	8.43	3.37
9"-10"	A	77.16	6.89	6.03	0	7.76	2.16
	B	77.40	6.21	6.78	0	7.91	1.70
	C	81.75	6.57	5.47	0	4.75	1.46
16"-17"	A	77.61	7.46	6.47	0	6.97	1.49
	B	84.86	6.88	4.13	0	3.21	0.92
	C	81.95	6.70	4.64	0	5.16	1.55
23"-24"	A	86.72	4.98	2.91	0	4.56	0.83
	B	86.07	5.97	4.48	0	2.98	0.50
	C	83.26	5.74	4.78	0	5.26	0.96

Table I (continued)

Filter Gradation Data at Various Locations

Test No. 28

Depth in Filter	Sample Location	Percent Retained on Sieve at Selected Points #4	#8	#16	#30	#50	Pan
2"-3"	A	75.79	6.71	6.71	0	7.82	2.79
	B	81.53	6.51	6.52	0	3.81	1.63
	C	77.15	6.60	6.60	0	7.11	1.54
9"-10"	A	82.67	7.11	6.22	0	3.11	0.89
	B	85.39	6.18	5.06	0	2.81	0.56
	C	85.72	6.12	5.61	0	2.04	0.51
16"-17"	A	84.96	6.77	7.14	0	0.75	0.38
	B	91.56	4.00	3.11	0	1.33	0
	C	86.62	6.44	6.44	0	0.50	0
23"-24"	A	88.70	5.65	5,65	0	0	0
	B	93.65	2.78	3.57	0	0	0
	C	88.27	4.59	7.24	0	0	0

Test No. 29

Depth in Filter	Sample Location	Percent Retained on Sieve at Selected Points #4	#8	#16	#30	#50	Pan
2"-3"	A	72.40	7.29	9.89	0	7.81	2.61
	B	76.59	4.79	4.79	0	10.11	3.72
	C	70.49	7.89	11.10	0	7.89	2.63
9"-10"	A	77.64	6.75	6.75	0	6.75	2.11
	B	83.74	5.62	4.31	0	4.78	1.91
	C	81.81	7.12	5.93	0	3.95	1.19
16"-17"	A	75.80	7.76	10.96	0	5.05	1.01
	B	82.83	7.07	4.04	0	4.57	0.91
	C	83.92	6.70	5.36	0	3.13	0.89
23"-24"	A	86.56	4.48	6.72	0	1.79	0.45
	B	86.13	4.78	4.78	0	3.35	0.96
	C	84.09	5.68	6.25	0	3.41	0.57

Table I (continued)

Filter Gradation Data at Various Locations

Test No. 30

Depth in Filter	Sample Location	Percent Retained on Sieve at Selected Points #4	#8	#16	#30	#50	Pan
2"-3"	A	76.10	6.29	5.66	0	8.81	3.14
	B	77.34	5.33	4.67	0	9.33	3.33
	C	74.61	4.48	4.48	0.50	11.95	3.98
9"-10"	A	78.84	6.62	7.49	0	5.73	1.32
	B	76.14	5.68	6.82	0	9.09	2.27
	C	77.23	6.04	7.43	0	7.90	1.40
16"-17"	A	80.22	5.65	9.04	0	4.52	0.57
	B	77.55	4.81	7.48	0	9.09	1.07
	C	77.15	4.57	8.57	0	8.57	1.14
23"-24"	A	83.89	5.70	9.84	0	0.57	0
	B	79.70	5.80	14.50	0	0	0
	C	85.46	4.07	10.47	0	0	0

Test No. 31

Depth in Filter	Sample Location	Percent Retained on Sieve at Selected Points #4	#8	#16	#30	#50	Pan
2"-3"	A	69.63	7.33	16.23	0	5.24	1.57
	B	73.62	5.52	11.66	0	6.74	2.46
	C	68.28	6.45	13.98	0	8.60	2.69
6"	A	80.10	5.75	12.83	0	0.88	0.44
	B	82.62	4.74	10.00	0	2.11	0.53
	C	76.55	6.14	13.96	0	2.79	0.56
9"-10"	A	73.04	6.86	19.12	0.49	0.49	0
	B	76.64	7.06	12.50	0	3.26	0.54
	C	79.82	6.72	12.11	0	0.90	0.45
16"-17"	A	84.37	5.69	9.47	0	0.47	0
	B	89.29	4.76	5.95	0	0	0
	C	86.98	4.18	8.84	0	0	0

Table I (continued)

Filter Gradation Data at Various Locations

Test No. 32

Depth in Filter	Sample Location	Percent Retained on Sieve at Selected Points						
		3/4"	#4	#8	#16	#30	#50	Pan
	A	18.18	75.23	5.05	1.52	0	0	0
2"-3"	B	25.24	64.21	7.34	3.21	0	0	0
	C	20.60	66.95	8.16	4.29	0	0	0
	A	4.35	75.78	12.42	6.83	0	0.62	0
6"	B	8.92	75.60	9.38	6.10	0	0	0
	C	15.63	65.00	11.25	8.12	0	0	0
	A	10.42	62.50	13.02	9.37	0	3.65	1.04
10"-11"	B	14.37	56.90	13.17	10.17	0	4.19	1.20
	C	6.25	59.38	15.10	10.42	0	6.77	2.08

Test No. 33

Depth in Filter	Sample Location	Percent Retained on Sieve at Selected Points					
		#4	#8	#16	#30	#50	Pan
	A	94.26	5.17	0.57	0	0	0
24"-23"	B	94.86	4.57	0.57	0	0	0
	C	96.74	3.26	0	0	0	0
	A	80.46	9.54	6.82	0	2.73	0.45
17"-16"	B	84.50	8.02	4.81	0	2.14	0.53
	C	81.95	10.73	6.83	0	0.49	0
	A	76.21	10.20	9.22	0	3.40	0.97
10"-9"	B	78.92	9.04	7.83	0	3.01	1.20
	C	80.35	8.67	8.09	0	2.31	0.58
	A	78.50	9.21	6.58	0	4.39	1.32
3"-2"	B	82.67	8.42	4.46	0	3.46	0.99
	C	84.59	7.94	3.27	0	3.27	0.93

Table I (continued)

Filter Gradation Data at Various Locations

Test No. 34

Depth in Filter	Sample Location	#4	#8	#16	#30	#50	Pan
		Percent Retained on Sieve at Selected Points					
24"-23"	A	81.93	10.97	7.10	0	0	0
	B	88.00	9.14	2.29	0	0	0.57
	C	94.59	4.87	0.54	0	0	0
17"-16"	A	84.62	6.55	4.27	0	3.14	1.42
	B	78.19	8.98	3.85	0	5.77	3.21
	C	73.63	11.72	7.12	0	4.60	2.93
10"-9"	A	79.20	5.58	4.06	0	8.12	3.04
	B	83.34	5.39	3.92	0	4.41	2.94
	C	78.39	7.03	3.52	0	8.04	3.02
3"-2"	A	73.08	9.40	5.98	0	7.69	3.85
	B	79.87	8.44	3.90	0	5.19	2.60
	C	76.14	3.98	2.84	0	11.93	5.11

Test No. 35

Depth in Filter	Sample Location	#4	#8	#16	#30	#50	Pan
		Percent Retain on Sieve at Selected Points					
24"-23"	A	86.50	9.46	4.12	0	0	0
	B	93.30	4.83	1.93	0	0	0
	C	94.00	4.52	1.94	0	0	0
17"-16"	A	89.10	7.14	3.81	0	0	0
	B	87.70	7.60	4.68	0	0	0
	C	85.10	9.58	6.44	0	0	0
10"-9"	A	72.10	15.80	9.01	0	2.25	0.90
	B	74.40	12.80	8.14	0	2.91	1.74
	C	72.30	14.10	8.70	0	3.43	1.71
3"-2"	A	72.30	12.40	7.43	0	4.95	2.97
	B	78.90	8.72	5.51	0	4.59	2.29
	C	76.90	9.14	5.92	0	5.38	2.96

Table I (continued)

Filter Gradation Data at Various Locations

Test No. 36

Depth in Filter	Sample Location	Percent Retained on Sieve at Selected Points #4	#8	#16	#30	#50	Pan
24"-23"	A	81.50	11.70	6.80	0	0	0
	B	78.30	12.60	9.15	0	0	0
	C	71.40	17.80	10.80	0	0	0
17"-16"	A	77.70	13.30	9.05	0	0	0
	B	79.40	12.10	8.49	0	0	0
	C	78.50	12.90	8.60	0	0	0
10"-9"	A	73.50	15.30	8.67	0	2.04	0.51
	B	69.00	14.10	9.60	0	5.65	1.70
	C	71.00	12.60	10.01	0	7.25	1.93
3"-2"	A	73.20	11.00	8.42	0	5.26	2.10
	B	77.40	8.04	6.54	0	6.03	2.01
	C	74.40	8.84	8.36	0	6.05	2.32

Test No. 37

Depth in Filter	Sample Location	Percent Retained on Sieve at Selected Points #4	#8	#16	#30	#50	Pan
24"-23"	A	92.60	3.98	3.41	0	0	0
	B	90.90	4.55	4.55	0	0	0
	C	92.00	4.60	3.89	0	0	0
17"-16"	A	84.40	6.09	4.78	0	3.48	1.30
	B	85.50	3.61	2.58	0	6.18	2.06
	C	89.80	5.02	5.02	0	0	0
10"-9"	A	75.60	6.60	9.14	0	6.60	2.03
	B	82.00	4.00	6.00	0	6.00	2.00
	C	75.00	5.00	8.57	0	8.57	2.86
3"-2"	A	80.20	4.57	4.06	0	8.64	2.54
	B	84.00	4.50	3.08	0	6.00	2.50
	C	76.20	7.00	6.17	0	7.82	2.88

Table I (continued)

Filter Gradation Data at Various Locations

Test No. 38

Depth in Filter	Sample Location	Percent Retained on Sieve at Selected Points #4	#8	#16	#30	#50	Pan
	A	73.20	13.00	11.40	0	0	0
24"-23"	B	89.40	6.92	3.72	0	0	0
	C	82.00	11.00	7.10	0	0	0
	A	89.20	5.92	4.84	0	0	0
17"-16"	B	89.90	5.77	4.33	0	0	0
	C	90.70	4.83	4.35	0	0	0
	A	89.70	4.12	4.64	0	1.03	0.52
10"-9"	B	87.60	4.29	4.29	0	2.58	1.29
	C	85.30	7.65	7.10	0	0	0
	A	78.20	7.11	7.11	0	6.10	1.52
3"-2"	B	80.00	6.67	7.14	0	4.76	1.43
	C	80.51	5.72	6.19	0	6.19	1.43

Test No. 39

Depth in Filter	Sample Location	Percent Retained on Sieve at Selected Points #4	#8	#16	#30	#50	Pan
	A	94.00	3.83	2.18	0	0	0
24"-23"	B	95.10	2.97	1.98	0	0	0
	C	89.50	4.65	5.82	0	0	0
	A	83.50	5.34	9.78	0	0.89	0.44
17"-16"	B	85.40	5.37	7.81	0	0.98	0.49
	C	85.00	5.53	7.22	0	2.01	0.50
	A	80.20	5.06	8.44	0	5.06	1.69
10"-9"	B	80.40	5.06	8.43	0	4.50	1.69
	C	76.00	6.14	10.40	0	5.66	1.89
	A	79.40	4.45	6.07	0	7.70	2.43
3"-2"	B	84.50	3.87	5.53	0	4.42	1.66
	C	80.30	4.33	6.25	0	7.21	1.92

Table I (continued)

Filter Geadation Data at Various Locations

Test No. 40

Depth in Filter	Sample Location	Percent Retained on Sieve at Selected Points #4	#8	#16	#30	#50	Pan
	A	92.27	4.35	3.38	0	0	0
24"-23"	B	92.72	4.85	2.43	0	0	0
	C	89.79	5.11	5.11	0	0	0
	A	85.79	7.39	6.82	0	0	0
16"-17"	B	86.47	7.25	6.28	0	0	0
	C	84.42	6.16	9.42	0	0	0
	A	81.87	7.14	10.99	0	0	0
9"-10"	B	84.08	6.47	9.45	0	0	0
	C	81.48	6.48	12.04	0	0	0
	A	79.09	7.38	8.20	0	4.10	1.22
2"-3"	B	77.89	7.37	9.67	0	4.15	0.92
	C	81.50	7.05	8.37	0	2.64	0.44

Test No. 41 lost data.

Table II

Filter Penetration Data

Test No. 1

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width Of Penetration in Filter		
24	0.0	58.0	58.0
23	0.0	58.0	58.0
22	0.0	58.0	58.0
21	0.0	58.0	58.0
20	0.0	58.0	58.0
19	0.0	58.0	58.0
18	0.0	58.0	58.0
17	0.0	58.0	58.0
16	0.0	58.0	58.0
15	0.0	58.0	58.0
14	0.0	58.0	58.0
13	0.0	58.0	58.0
12	3.0	58.0	58.0
11	3.0	58.0	58.0
10	23.0	58.0	58.0
9	23.0	58.0	58.0
8	23.0	58.0	58.0
7	23.0	58.0	58.0
6	23.0	58.0	58.0
5	35.0	58.0	58.0
4	35.0	58.0	58.0
3	35.0	58.0	58.0

Table II (continued)

Filter Penetration Data

Test No. 2

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter		
24	0.0	58.0	58.0
23	0.0	58.0	58.0
22	0.0	58.0	58.0
21	0.0	58.0	58.0
20	0.0	58.0	58.0
19	0.0	58.0	58.0
18	0.0	58.0	58.0
17	0.0	58.0	58.0
16	0.0	58.0	58.0
15	0.0	58.0	58.0
14	0.0	58.0	58.0
13	0.0	58.0	58.0
12	0.0	58.0	58.0
11	0.0	58.0	58.0
10	0.0	58.0	58.0
9	0.0	58.0	58.0
8	0.0	58.0	58.0
7	7.0	58.0	58.0
6	12.5	58.0	58.0
5	17.5	58.0	58.0
4	17.5	58.0	58.0
3	17.5	58.0	58.0

Table II (continued)

Filter Penetration Data

Test No. 3

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	58.0
23	0.0	0.0	58.0
22	0.0	35.0	58.0
21	0.0	35.0	58.0
20	0.0	35.0	58.0
19	0.0	40.0	58.0
18	0.0	40.0	58.0
17	0.0	40.0	58.0
16	0.0	40.0	58.0
15	0.0	40.0	58.0
14	0.0	40.0	58.0
13	0.0	50.0	58.0
12	0.0	58.0	58.0
11	0.0	58.0	58.0
10	0.0	58.0	58.0
9	0.0	58.0	58.0
8	0.0	58.0	58.0
7	3.0	58.0	58.0
6	14.5	58.0	58.0
5	25.0	58.0	58.0
4	39.0	58.0	58.0
3	39.0	58.0	58.0

Table II (continued)

Filter Penetration Data

Test No. 4

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter		
24	0.0	0.0	58.0
23	0.0	0.0	58.0
22	0.0	0.0	58.0
21	0.0	0.0	58.0
20	0.0	0.0	58.0
19	0.0	0.0	58.0
18	0.0	0.0	58.0
17	0.0	0.0	58.0
16	0.0	0.0	58.0
15	0.0	0.0	58.0
14	0.0	0.0	58.0
13	0.0	0.0	58.0
12	0.0	4.0	58.0
11	0.0	34.0	58.0
10	0.0	34.0	58.0
9	0.0	46.0	58.0
8	0.0	46.0	58.0
7	0.0	58.0	58.0
6	0.0	58.0	58.0
5	0.0	58.0	58.0
4	0.0	58.0	58.0
3	0.0	58.0	58.0

Table II (continued)

Filter Penetration Data

Test No. 5

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	0.0
23	0.0	0.0	0.0
22	0.0	0.0	0.0
21	0.0	0.0	5.5
20	0.0	0.0	5.5
19	0.0	0.0	22.0
18	0.0	0.0	29.5
17	0.0	0.0	29.5
16	0.0	0.0	29.5
15	0.0	0.0	29.5
14	0.0	0.0	41.0
13	0.0	0.0	41.0
12	0.0	0.0	47.0
11	0.0	0.0	47.0
10	0.0	8.0	47.0
9	0.0	11.0	47.0
8	0.0	22.0	47.0
7	0.0	23.0	47.0
6	0.0	27.0	47.0
5	0.0	35.0	47.0
4	4.0	35.0	47.0
3	4.0	35.0	47.0

Table II(continued)

Filter Penetration Data

Test No. 6

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	0.0
23	0.0	0.0	0.0
22	0.0	0.0	0.0
21	0.0	0.0	0.0
20	0.0	0.0	0.0
19	0.0	0.0	0.0
18	0.0	0.0	17.0
17	0.0	0.0	40.0
16	0.0	0.0	41.5
15	0.0	0.0	41.5
14	0.0	0.0	58.0
13	0.0	0.0	58.0
12	0.0	0.0	58.0
11	0.0	0.0	58.0
10	0.0	7.5	58.0
9	0.0	11.5	58.0
8	0.0	14.5	58.0
7	0.0	24.0	58.0
6	0.0	44.0	58.0
5	12.0	56.0	58.0
4	29.0	58.0	58.0
3	29.0	58.0	58.0

Table II (continued)

Filter Penetration Data

Test No. 7

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	0.0
23	0.0	0.0	0.0
22	0.0	0.0	0.0
21	0.0	0.0	0.0
20	0.0	0.0	0.0
19	0.0	0.0	0.0
18	0.0	0.0	0.0
17	0.0	0.0	0.0
16	0.0	0.0	0.0
15	0.0	0.0	0.0
14	0.0	0.0	0.0
13	0.0	0.0	0.0
12	0.0	0.0	0.0
11	0.0	0.0	0.0
10	0.0	0.0	0.0
9	0.0	0.0	52.0
8	0.0	0.0	52.0
7	0.0	0.0	52.0
6	0.0	0.0	52.0
5	0.0	26.0	58.0
4	0.0	32.5	58.0
3	0.0	32.5	58.0

TableII (continued)

Filter Penetration Data

Test No. 8

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	0.0
23	0.0	0.0	0.0
22	0.0	0.0	0.0
21	0.0	0.0	0.0
20	0.0	0.0	0.0
19	0.0	0.0	0.0
18	0.0	0.0	0.0
17	0.0	0.0	0.0
16	0.0	0.0	0.0
15	0.0	0.0	0.0
14	0.0	0.0	0.0
13	0.0	0.0	0.0
12	0.0	0.0	0.0
11	0.0	0.0	0.0
10	0.0	0.0	0.0
9	0.0	0.0	0.0
8	0.0	0.0	0.0
7	0.0	0.0	5.0
6	0.0	0.0	10.5
5	0.0	0.0	43.5
4	0.0	0.0	49.5
3	0.0	0.0	49.5

Table II (continued)

Filter Penetration Data

Test No.9

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	19.0
23	0.0	0.0	19.0
22	0.0	0.0	19.0
21	0.0	0.0	39.5
20	0.0	0.0	52.0
19	0.0	0.0	52.0
18	0.0	0.0	52.0
17	0.0	0.0	56.0
16	0.0	1.0	56.0
15	0.0	1.0	56.0
14	0.0	1.0	56.0
13	0.0	1.0	56.0
12	0.0	1.0	56.0
11	0.0	1.0	56.0
10	0.0	11.5	56.0
9	0.0	11.5	56.0
8	0.0	25.5	56.0
7	0.0	27.5	56.0
6	0.0	27.5	56.0
5	0.0	35.5	56.0
4	0.0	51.0	56.0
3	0.0	51.0	56.0

Table II (continued)

Filter Penetration Data

Test No. 10

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	0.0
23	0.0	0.0	0.0
22	0.0	0.0	0.0
21	0.0	0.0	0.0
20	0.0	0.0	5.5
19	0.0	0.0	5.5
18	0.0	0.0	12.0
17	0.0	0.0	13.0
16	0.0	0.0	13.0
15	0.0	0.0	13.0
14	0.0	0.0	13.0
13	0.0	0.0	13.0
12	0.0	2.5	40.0
11	0.0	10.0	58.0
10	0.0	15.5	58.0
9	0.0	15.5	58.0
8	0.0	30.5	58.0
7	0.0	36.0	58.0
6	0.0	48.0	58.0
5	0.0	58.0	58.0
4	0.0	58.0	58.0
3	0.0	58.0	58.0

Table II (continued)

Filter Penetration Data

Test No. 11

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	0.0
23	0.0	0.0	0.0
22	0.0	0.0	0.0
21	0.0	0.0	0.0
20	0.0	0.0	0.0
19	0.0	0.0	0.0
18	0.0	0.0	0.0
17	0.0	0.0	1.0
16	0.0	0.0	2.0
15	0.0	0.0	2.0
14	0.0	0.0	2.0
13	0.0	0.0	3.0
12	0.0	0.0	8.5
11	0.0	0.0	47.5
10	0.0	0.0	47.5
9	0.0	0.0	53.5
8	0.0	0.5	58.0
7	0.0	9.0	58.0
6	0.0	14.0	58.0
5	0.0	25.0	58.0
4	0.0	38.0	58.0
3	0.0	38.0	58.0

Table II (continued)

Filter Penetration Data

Test No. 12

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	0.0
23	0.0	0.0	0.0
22	0.0	0.0	0.0
21	0.0	0.0	0.0
20	0.0	0.0	0.0
19	0.0	0.0	0.0
18	0.0	0.0	0.0
17	0.0	0.0	0.0
16	0.0	0.0	0.0
15	0.0	0.0	0.0
14	0.0	0.0	0.0
13	0.0	0.0	0.0
12	0.0	0.0	5.5
11	0.0	0.0	10.0
10	0.0	0.0	12.0
9	0.0	0.0	17.0
8	0.0	8.5	26.0
7	0.0	9.5	37.0
6	0.0	14.5	54.0
5	0.0	21.5	57.0
4	0.0	39.5	57.0
3	0.0	39.5	57.0

Table II (continued)

Filter Penetration Data

Test No. 13

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	0.0
23	0.0	0.0	0.0
22	0.0	0.0	0.0
21	0.0	0.0	0.0
20	0.0	0.0	0.0
19	0.0	0.0	0.0
18	0.0	0.0	0.0
17	0.0	0.0	0.0
16	0.0	0.0	0.0
15	0.0	0.0	0.0
14	0.0	0.0	0.0
13	0.0	0.0	0.0
12	0.0	0.0	0.0
11	0.0	0.0	0.0
10	0.0	0.0	0.0
9	0.0	0.0	0.0
8	0.0	0.0	6.0
7	0.0	4.0	14.5
6	0.0	15.0	30.0
5	0.0	35.5	46.0
4	0.0	46.0	51.5
3	0.0	46.0	51.5

Table II (continued)

Filter Penetration Data

Test No. 14

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	0.0
23	0.0	0.0	0.0
22	0.0	0.0	0.0
21	0.0	0.0	0.0
20	0.0	0.0	0.0
19	0.0	0.0	0.0
18	0.0	0.0	0.0
17	0.0	0.0	0.0
16	0.0	0.0	0.0
15	0.0	0.0	0.0
14	0.0	0.0	0.0
13	0.0	0.0	9.0
12	0.0	0.0	9.0
11	0.0	0.0	27.0
10	0.0	0.0	27.0
9	0.0	4.0	30.0
8	0.0	14.5	33.0
7	0.0	20.0	45.0
6	0.0	37.5	58.0
5	0.0	43.5	58.0
4	0.0	45.0	58.0
3	0.0	45.0	58.0

Table II (continued)

Filter Penetration Data

Test No. 15

Penetration Depth(in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	0.0
23	0.0	0.0	0.0
22	0.0	0.0	0.0
20	0.0	0.0	0.0
19	0.0	0.0	6.0
18	0.0	0.0	6.0
17	0.0	0.0	15.0
16	0.0	0.0	18.0
15	0.0	0.0	18.0
14	0.0	0.0	58.0
13	0.0	0.0	58.0
12	0.0	0.0	58.0
11	0.0	0.0	58.0
10	0.0	0.0	58.0
9	0.0	12.0	58.0
8	0.0	16.0	58.0
7	0.0	21.5	58.0
6	0.0	30.0	58.0
5	0.0	48.0	58.0
4	0.0	51.0	58.0
3	0.0	51.0	58.0

Table II (continued)

Filter Penetration Data

Test No. 16

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	0.0
23	0.0	0.0	0.0
22	0.0	0.0	0.0
21	0.0	0.0	0.0
20	0.0	0.0	0.0
19	0.0	0.0	1.0
18	0.0	0.0	4.0
17	0.0	0.0	7.0
16	0.0	0.0	11.0
15	0.0	0.0	11.0
14	0.0	0.0	55.5
13	0.0	0.0	55.5
12	0.0	0.0	56.0
11	0.0	0.0	56.0
10	0.0	0.0	56.0
9	0.0	12.0	58.0
8	0.0	16.0	58.0
7	0.0	21.0	58.0
6	0.0	30.0	58.0
5	0.0	48.0	58.0
4	0.0	51.0	58.0
3	0.0	51.0	58.0

Table II (continued)

Filter Penetration Data

Test No. 17

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter(in.)		
24	0.0	0.0	0.0
23	0.0	0.0	0.0
22	0.0	0.0	0.0
21	0.0	0.0	0.0
20	0.0	0.0	0.0
19	0.0	0.0	0.0
18	0.0	0.0	0.0
17	0.0	0.0	0.0
16	0.0	0.0	0.0
15	0.0	0.0	0.0
14	0.0	0.0	0.0
13	0.0	0.0	0.0
12	0.0	0.0	2.0
11	0.0	0.0	2.0
10	0.0	0.0	2.0
9	0.0	0.0	20.5
8	0.0	0.0	20.5
7	0.0	0.0	20.5
6	0.0	2.0	37.0
5	0.0	3.0	40.0
4	0.0	4.0	45.0
3	0.0	4.0	45.0

Table II (continued)

Filter Penetration Data

Test No. 18

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	58.0	58.0
23	0.0	58.0	58.0
22	0.0	58.0	58.0
21	0.0	58.0	58.0
20	0.0	58.0	58.0
19	0.0	58.0	58.0
18	0.0	58.0	58.0
17	0.0	58.0	58.0
16	0.0	58.0	58.0
15	0.0	58.0	58.0
14	0.0	58.0	58.0
13	0.0	58.0	58.0
12	0.0	58.0	58.0
11	0.0	58.0	58.0
10	0.0	58.0	58.0
9	0.0	58.0	58.0
8	0.0	58.0	58.0
7	0.0	58.0	58.0
6	0.0	58.0	58.0
5	0.0	58.0	58.0
4	0.0	58.0	58.0
3	0.0	58.0	58.0

Table II (continued)

Filter Penetration Data

Test No. 19

Penetration Depth(in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	0.0
23	0.0	0.0	0.0
22	0.0	0.0	0.0
21	0.0	0.0	0.0
20	0.0	0.0	0.0
19	0.0	0.0	0.0
18	0.0	0.0	0.0
17	0.0	0.0	0.0
16	0.0	0.0	0.0
15	0.0	0.0	0.0
14	0.0	0.0	0.0
13	0.0	0.0	0.0
12	0.0	0.0	0.0
11	0.0	0.0	2.0
10	0.0	0.0	2.0
9	0.0	0.0	2.5
8	0.0	1.0	5.0
7	0.0	2.0	7.0
6	0.0	5.5	21.5
5	0.0	6.5	23.0
4	0.0	6.5	25.0
3	0.0	6.5	25.0

Table II (continued)

Filter Penetration Data

Test No. 20

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	0.0
23	0.0	0.0	0.0
22	0.0	0.0	0.0
21	0.0	0.0	0.0
20	0.0	0.0	0.0
19	0.0	0.0	0.0
18	0.0	0.0	0.0
17	0.0	0.0	0.0
16	0.0	0.0	0.0
15	0.0	0.0	0.0
14	0.0	0.0	0.0
13	0.0	0.0	0.0
12	0.0	0.0	0.0
11	0.0	0.0	0.0
10	0.0	0.0	3.0
9	0.0	0.0	5.0
8	0.0	0.0	16.5
7	0.0	0.0	25.3
6	0.0	1.2	30.3
5	0.0	9.7	45.3
4	0.0	15.7	55.8
3	0.0	15.7	55.8

Table II (continued)

Filter Penetration Data

Test No. 21

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	0.0
23	0.0	0.0	0.0
22	0.0	0.0	0.0
21	0.0	0.0	0.0
20	0.0	0.0	0.0
19	0.0	0.0	0.0
18	0.0	0.0	0.0
17	0.0	0.0	0.0
16	0.0	0.0	0.0
15	0.0	0.0	0.0
14	0.0	0.0	0.0
13	0.0	0.0	0.0
12	0.0	0.0	0.0
11	0.0	0.0	6.0
10	0.0	0.0	16.5
9	0.0	0.0	18.2
8	0.0	0.0	37.4
7	0.0	0.0	46.0
6	1.2	1.2	55.5
5	9.7	9.7	58.0
4	15.7	15.7	58.0
3	15.7	15.7	58.0

Table II (continued)

Filter Penetration Data

Test No. 22

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	6.5
23	0.0	0.0	6.5
22	0.0	0.0	6.5
21	0.0	0.0	10.2
20	0.0	0.0	13.2
19	0.0	0.0	18.2
18	0.0	0.0	18.2
17	0.0	0.0	18.2
16	0.0	0.0	18.2
15	0.0	0.0	18.2
14	0.0	0.0	18.2
13	0.0	0.0	18.2
12	0.0	0.0	18.2
11	0.0	14.0	38.2
10	8.0	18.0	38.2
9	14.0	26.3	54.8
8	15.0	28.3	58.0
7	16.5	29.6	58.0
6	27.5	37.1	58.0
5	42.7	53.9	58.0
4	47.2	55.4	58.0
3	47.2	55.4	58.0

Table II (continued)

Filter Penetration Data

Test No. 23

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	0.0
23	0.0	0.0	0.0
22	0.0	0.0	0.0
21	0.0	0.0	0.0
20	0.0	0.0	0.0
19	0.0	0.0	0.0
18	0.0	0.0	0.0
17	0.0	0.0	0.0
16	0.0	0.0	1.0
15	0.0	0.0	1.0
14	0.0	0.0	3.0
13	0.0	1.5	5.2
12	0.0	1.5	5.2
11	0.0	1.5	5.2
10	0.0	1.5	8.7
9	0.0	6.6	20.2
8	0.0	12.6	26.5
7	0.0	14.6	33.3
6	0.0	25.7	46.3
5	0.0	39.2	58.0
4	0.0	57.3	58.0
3	0.0	57.3	58.0

Table II (continued)

Filter Penetration Data

Test No. 24

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	0.0
23	0.0	0.0	0.0
22	0.0	0.0	0.0
21	0.0	0.0	0.0
20	0.0	0.0	0.0
19	0.0	0.0	0.0
18	0.0	0.0	1.0
17	0.0	0.0	1.0
16	0.0	0.0	7.5
15	0.0	0.0	7.5
14	0.0	0.0	7.5
13	0.0	0.0	7.5
12	0.0	0.0	9.5
11	0.0	0.0	18.5
10	0.0	0.0	18.5
9	0.0	2.0	34.0
8	0.0	3.5	44.0
7	0.0	5.3	44.0
6	0.0	6.8	48.5
5	0.0	41.8	52.5
4	0.0	57.0	58.0
3	0.0	57.0	58.0

Table II (continued)

Filter Penetration Data

Test No. 25

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	0.0
23	0.0	0.0	0.0
22	0.0	0.0	0.0
21	0.0	0.0	0.0
20	0.0	0.0	0.0
19	0.0	0.0	0.0
18	0.0	0.0	0.0
17	0.0	0.0	0.0
16	0.0	0.0	0.0
15	0.0	0.0	0.0
14	0.0	0.0	6.0
13	0.0	0.0	9.5
12	0.0	0.0	9.5
11	0.0	0.0	28.5
10	0.0	0.0	28.5
9	0.0	0.0	33.7
8	0.0	0.0	38.0
7	0.0	0.5	38.0
6	0.0	0.5	51.5
5	0.0	12.3	58.0
4	0.0	27.8	58.0
3	0.0	27.8	58.0

Table II (continued)

Filter Penetration Data

Test No. 26

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	58.0
23	0.0	0.0	58.0
22	0.0	0.0	58.0
21	0.0	0.0	58.0
20	0.0	0.0	58.0
19	0.0	0.0	58.0
18	0.0	0.0	58.0
17	0.0	0.0	58.0
16	0.0	0.0	58.0
15	0.0	0.0	58.0
14	0.0	0.0	58.0
13	0.0	0.0	58.0
12	0.0	1.0	58.0
11	0.0	14.5	58.0
10	0.0	14.5	58.0
9	0.0	19.2	58.0
8	0.0	20.2	58.0
7	0.0	25.7	58.0
6	0.0	26.9	58.0
5	0.0	32.3	58.0
4	0.0	49.6	58.0
3	0.0	55.6	58.0

Table II (continued)

Filter Penetration Data

Test No. 27

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter		
24	0.0	58.0	58.0
23	0.0	58.0	58.0
22	0.0	58.0	58.0
21	0.0	58.0	58.0
20	0.0	58.0	58.0
19	0.0	58.0	58.0
18	0.0	58.0	58.0
17	0.0	58.0	58.0
16	0.0	58.0	58.0
15	0.0	58.0	58.0
14	0.0	58.0	58.0
13	0.0	58.0	58.0
12	0.0	58.0	58.0
11	0.0	58.0	58.0
10	0.0	58.0	58.0
9	0.0	58.0	58.0
8	0.0	58.0	58.0
7	0.0	58.0	58.0
6	0.0	58.0	58.0
5	0.0	58.0	58.0
4	0.0	58.0	58.0
3	0.0	58.0	58.0

Table II (continued)

Filter Penetration Data

Test No. 28

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	0.0
23	0.0	0.0	0.0
22	0.0	0.0	0.0
21	0.0	0.0	0.0
20	0.0	0.0	0.0
19	0.0	0.0	0.0
18	0.0	0.0	0.0
17	0.0	0.0	0.0
16	0.0	0.0	0.0
15	0.0	0.0	0.0
14	0.0	0.0	0.0
13	0.0	0.0	0.0
12	0.0	0.0	0.0
11	0.0	0.0	0.0
10	0.0	0.0	3.0
9	0.0	0.0	15.7
8	0.0	0.0	28.2
7	0.0	0.0	43.4
6	0.0	12.4	56.2
5	0.0	33.7	58.0
4	0.0	39.4	58.0
3	0.0	39.4	58.0

Table II (continued)

Filter Penetration Data

Test No. 29

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	23.8
23	0.0	0.0	23.8
22	0.0	0.0	23.8
21	0.0	0.0	25.8
20	0.0	0.0	25.8
19	0.0	0.0	28.0
18	0.0	0.0	30.5
17	0.0	0.0	30.5
16	0.0	0.0	32.5
15	0.0	0.0	32.5
14	0.0	0.0	39.7
13	0.0	0.0	39.7
12	0.0	0.0	39.7
11	0.0	0.0	39.7
10	0.0	0.0	39.7
9	0.0	4.0	51.7
8	0.0	16.7	51.7
7	0.0	30.5	57.2
6	0.0	36.0	57.2
5	0.0	42.0	57.2
4	0.0	50.0	57.2
3	0.0	50.0	57.2

Table II (continued)

Filter Penetration Data

Test No. 30

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter (in.)		
24	0.0	0.0	0.0
23	0.0	0.0	0.0
22	0.0	0.0	0.0
21	0.0	0.0	0.0
20	0.0	0.0	4.0
19	0.0	0.0	7.2
18	0.0	0.0	15.2
17	0.0	0.0	26.6
16	0.0	0.0	26.6
15	0.0	0.0	26.6
14	0.0	0.0	32.6
13	0.0	2.5	36.3
12	0.0	2.5	36.3
11	0.0	2.5	53.0
10	0.0	9.8	53.0
9	0.0	15.2	53.0
8	0.0	22.2	53.0
7	0.0	25.2	55.5
6	0.0	31.2	58.0
5	0.0	54.7	58.0
4	0.0	58.0	58.0
3	0.0	58.0	58.0

Table II (continued)

Filter Penetration Data

Test No. 31

Penetration Depth (in.)	0 Psi	2 Psi	4 Psi
	The Width of Penetration in Filter		
24	0.0	0.0	0.0
23	0.0	0.0	0.0
22	0.0	0.0	0.0
21	0.0	0.0	0.0
20	0.0	0.0	0.0
19	0.0	0.0	0.0
18	0.0	0.0	0.0
17	0.0	0.0	0.0
16	0.0	0.0	0.0
15	0.0	0.0	0.0
14	0.0	0.0	0.0
13	0.0	0.0	0.0
12	0.0	0.0	0.0
11	0.0	0.0	2.0
10	0.0	0.0	2.0
9	0.0	0.0	2.0
8	0.0	0.0	3.0
7	0.0	0.0	6.0
6	0.0	7.0	9.8
5	0.0	17.8	52.0
4	0.0	25.3	58.0
3	0.0	26.3	58.0

Table II(continued)

Filter Penetration Data

Test No. 32

Penetration Depth (in.)	2 Psi	3 Psi	4 Psi	5 Psi	6 Psi
	The Width of Penetration in Filter				
24	0.0		0.0		
23	0.0		0.0		
22	0.0		0.0		
21	0.0		0.0		
20	0.0		0.0		
19	0.0		0.0		
18	0.0		0.0		
17	0.0		0.0		
16	0.0		0.0		
15	0.0		0.0		
14	0.0		0.0		
13	0.0		0.0		
12	0.0		0.0		
11	0.0		0.0		
10	0.0		0.0		
9	0.0		0.0		
8	0.0		1.0		
7	0.0		2.2		
6	0.0		4.5		
5	0.0		17.0		
4	0.0		34.5		
3	0.0		34.5		

Table II (continued)

Filter Penetration Data

Test No. 33

Penetration Depth (in.)	2 Psi	3 Psi	4 Psi	5 Psi	6 Psi
	The Width of Penetration in Filter (in.)				
24	0.0		32.0		
23	0.0		32.0		
22	0.0		32.0		
21	0.0		32.0		
20	0.0		36.0		
19	0.0		36.0		
18	0.0		42.0		
17	0.0		48.0		
16	0.0		53.5		
15	0.0		58.0		
14	0.0		58.0		
13	0.0		58.0		
12	0.0		58.0		
11	0.0		58.0		
10	0.0		58.0		
9	0.0		58.0		
8	0.0		58.0		
7	0.0		58.0		
6	0.0		58.0		
5	0.0		58.0		
4	0.0		58.0		
3	0.0		58.0		

Table II (continued)

Filter Penetration Data

Test No. 34

Penetration Depth (in.)	2 Psi	3 Psi	4 Psi	5 Psi	6 Psi
	The Width of Penetration in Filter (in.)				
24	0.0		0.0	0.0	
23	0.0		0.0	0.0	
22	0.0		0.0	3.0	
21	0.0		0.0	9.0	
20	0.0		0.0	10.5	
19	0.0		0.0	15.0	
18	0.0		0.0	19.5	
17	0.0		0.0	34.5	
16	0.0		0.0	43.5	
15	0.0		0.0	58.0	
14	0.0		0.0	58.0	
13	0.0		0.0	58.0	
12	0.0		0.0	58.0	
11	0.0		14.5	58.0	
10	0.0		17.5	58.0	
9	0.0		17.5	58.0	
8	0.0		22.5	58.0	
7	0.0		28.2	58.0	
6	0.0		34.2	58.0	
5	0.0		41.2	58.0	
4	0.0		54.7	58.0	
3	0.0		54.7	58.0	

Table II (continued)

Filter Penetration Data

Test No. 35

Penetration Depth (in.)	2 Psi	3 Psi	4 Psi	5 Psi	6 Psi
	The Width of Penetration in Filter (in.)				
24	0.0		0.0		
23	0.0		0.0		
22	0.0		0.0		
21	0.0		0.0		
20	0.0		0.0		
19	0.0		0.0		
18	0.0		0.0		
17	0.0		0.0		
16	0.0		0.0		
15	0.0		0.0		
14	0.0		0.0		
13	0.0		0.0		
12	0.0		3.0		
11	0.0		44.5		
10	0.0		44.5		
9	0.0		47.5		
8	0.0		51.5		
7	0.0		53.5		
6	0.0		56.5		
5	0.0		59.5		
4	0.0		59.5		
3	0.0		59.5		

Table II (continued)

Filter Penetration Data

Test No. 36

Penetration Depth (in.)	2 Psi	3 Psi	4 Psi	5 Psi	6 Psi
	The Width of Penetration in Filter (in.)				
24	0.0	0.0	0.0		
23	0.0	0.0	0.0		
22	0.0	0.0	0.0		
21	0.0	0.0	0.0		
20	0.0	0.0	0.0		
19	0.0	0.0	0.0		
18	0.0	0.0	0.0		
17	0.0	0.0	0.0		
16	0.0	0.0	0.0		
15	0.0	0.0	0.0		
14	0.0	0.0	6.3		
13	0.0	0.0	9.0		
12	0.0	0.0	9.0		
11	0.0	0.0	28.5		
10	0.0	0.0	28.5		
9	0.0	0.0	32.5		
8	0.0	0.0	39.2		
7	0.0	0.0	42.6		
6	0.0	0.0	44.1		
5	0.0	0.0	48.6		
4	0.0	0.0	55.2		
3	0.0	0.0	55.2		

Table II (continued)

Filter Penetration Data

Test No. 37

Penetration Depth (in.)	2 Psi	3 Psi	4 Psi	5 Psi	6 Psi
	The Width of Penetration in Filter (in.)				
24	0.0	0.0			
23	0.0	0.0			
22	0.0	0.0			
21	0.0	0.0			
20	0.0	0.0			
19	0.0	0.0			
18	0.0	0.0			
17	0.0	0.0			
16	0.0	0.0			
15	0.0	0.0			
14	0.0	0.0			
13	0.0	0.0			
12	0.0	0.0			
11	0.0	0.0			
10	0.0	0.0			
9	0.0	11.1			
8	0.0	18.6			
7	0.0	27.8			
6	0.0	34.8			
5	0.0	45.8			
4	0.0	50.0			
3	0.0	50.0			

Table II (continued)

Filter Penetration Data

Test No. 38

Penetration Depth (in.)	2 Psi	3 Psi	4 Psi	5 Psi	6 Psi
	The Width of Penetration in Filter (in.)				
24	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	4.8
9	0.0	0.0	3.6	9.1	18.5
8	0.0	0.0	12.7	16.7	23.5
7	0.0	0.0	17.8	22.0	25.3
6	0.0	8.8	21.3	24.0	26.8
5	0.0	11.3	25.0	25.8	28.8
4	0.0	12.9	26.5	27.0	29.3
3	0.0	12.9	26.5	27.0	29.3

Table II (continued)

Filter Penetration Data

Test No. 39

Penetration	2 Psi	3 Psi	4 Psi	5 Psi	6 Psi
	The Width of Penetration in Filter (in.)				
24	0.0	0.0	0.0		
23	0.0	0.0	0.0		
22	0.0	0.0	0.0		
21	0.0	0.0	0.0		
20	0.0	0.0	9.5		
19	0.0	0.0	11.7		
18	0.0	0.0	13.9		
17	0.0	0.0	24.5		
16	0.0	0.0	35.0		
15	0.0	0.0	35.0		
14	0.0	0.0	36.5		
13	0.0	0.0	45.5		
12	0.0	0.0	58.0		
11	0.0	0.0	58.0		
10	0.0	0.0	58.0		
9	0.0	0.0	58.0		
8	0.0	6.0	58.0		
7	0.0	16.0	58.0		
6	0.0	21.0	58.0		
5	0.0	36.0	58.0		
4	0.0	46.3	58.0		
3	0.0	46.3	58.0		

Table II (continued)

Filter Penetration Data

Test No. 40

Penetration Depth (in.)	2 Psi	3 Psi	4 Psi	5 Psi	6 Psi
	The Width of Penetration in Filter (in.)				
24	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	8.5	8.2	8.2
3	0.0	0.0	8.5	8.2	8.2

Table II (continued)

Filter Penetration Data

Test No. 41

Penetration Depth (in.)	2 Psi	3 Psi	4 Psi	5 Psi	6Psi
	The Width of Penetration in Filter (in.)				
24	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	4.8	9.7
7	0.0	0.0	4.5	11.3	14.3
6	0.0	5.1	13.3	18.4	22.3
5	0.0	10.7	17.9	23.6	23.8
4	0.0	13.0	19.9	25.1	24.8
3	0.0	13.0	19.9	25.1	24.8

Table III

Time To Equilibrium

(Flow Downward)

Test No. (1)	$R \times 10^{-2}$ in inches (2)	Hydraulic Gradient 2.33 (3)	6.95 (4)	11.57 (5)
1	3.0	1.50	1.25	
2	2.83	1.17	4.50	
3	2.70	1.50	10.33	
4	2.57	2.50	6.00	15.17
5	2.45	1.50	5.50	7.00
6	2.34	2.25	5.50	8.50
7	2.17	2.00	5.00	9.00
8	2.08	2.25	2.00	6.50
9	2.45	2.00	6.50	5.00
10	2.34	2.00	10.75	8.00
11	2.24	1.75	6.50	5.00
12	2.15	1.75	5.50	7.15
13	2.10	2.50	10.17	7.50
14	2.18	2.50	12.25	6.00
15	2.23	3.25	8.50	13.50
16	2.29	3.00	8.67	10.50
17	2.33	2.00	9.00	7.50
18	2.50	3.00	4.50	
19	2.15	3.00	8.33	10.67
20	2.29	1.67	10.00	12.50
21	2.15	0.00	6.00	12.67
22	2.40	7.00	3.50	6.17
23	2.32	0.33	11.67	6.50
24	2.40	1.00	9.33	7.20
25	2.20	1.00	6.50	6.50
26	2.66	3.00	2.50	9.00
27	2.66	2.67	15.50	2.17
28	2.50	0.50	10.00	15.50
29	2.50	2.75	10.00	8.50
30	2.36	0.50	3.50	5.75
31	2.11	3.00	3.00	13.50

Note Time in hours

Table IV

Time To Equilibrium

(Flow Upward)

Test	$R \times 10^{-2}$	Base Hydraylic Gradient			
No. (1)	in inches (2)	3.93 (3)	6.24 (4)	8.55 (5)	10.85 (6)
32	2.20		7.50		
33	2.56		9.00		
34	2.42		10.17	4.25	
35	2.32		20.15		
36	2.14	11.17	11.00		
37	2.14	16.75			
38	2.49	8.75	12.25		4.00
39	2.32	8.75	11.50		
40	2.24	5.50	8.50	3.50	2.50
41	2.32	13.00	6.00	5.00	2.50

Note Empty spaces indicate no measurement under corresponding hydraulic gradient.

VITA

William Chuan Shen was born on September 18, 1943, in Chung-King, China. He graduated from Pan-Chiaw High School in 1961 and got B.E. Degree from Chung Yuan Christian College of Science and Engineering in 1967.

After military service, he came to the United States and enrolled in the Graduate School of the University of Missouri-Rolla in January, 1969.