Permeable Materials for Highway Drainage

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Although most highway departments design for saturated roadbed conditions, the removal of excess water to prevent prolonged flooding is necessary if maximum performance is to be obtained. Recognizing the need for adequate internal drainage of highways the California Division of Highways has been experimenting with various gradings in an effort to utilize blends of readily available concrete aggregates in drainage systems. The paper reviews past specifications for "permeable materials" and gives the results of an extensive series of laboratory permeability tests which were used in developing grading limits for a new class of permeable material. Gradation curves and permeabilities are given for typical combinations tested. Basic data for all of the tests are summarized in tables. The paper includes a brief discussion of a method for estimating the water-removing capabilities of blankets of permeable aggregates and a chart evaluating typical layers. Alternative designs utilizing two-layer systems are noted as a means for draining highway pavements when large quantities of water are anticipated.

•THE California Division of Highways tries to construct highway roadbeds so that they will not be prematurely damaged by traffic. Design soil strengths are determined by testing subgrade and base materials in a saturated condition (1). The intent is to obtain roads that will not be damaged by water entering the structural section, either through the surface, the shoulders, or from groundwater sources. Inasmuch as the climate in California varies from the extremely hot and dry Death Valley to the wet and cool north coastal areas and soil conditions are equally variable, it is frequently necessary to modify the California Standard Specifications by issuing special provisions for individual contracts for construction projects. Each job is designed to function for the conditions as they exist on that project. Throughout much of the state, water causes problems of instability; hence, "permeable materials" have been widely used in underdrains, pervious blankets, and stabilization trenches. The problem of using the right kind of aggregates to remove water quickly without clogging is a very difficult one. The problem has been studied for years, and the state has varied its practices in an attempt to do the best drainage job at least cost. From time to time, new classes of aggregates have been specified for drainage purposes. This paper describes a series of tests that were made using undersanded concrete aggregate mixtures in the development of a new class of permeable material now called Class 3.

BACKGROUND

Some of the trends in selecting aggregates for drainage purposes are given in Table 1. Before 1945, coarse material grading from 1 in. to 6 in. in size was used

Paper sponsored by Committee on Subsurface Drainage.

TABLE 1

SOME DRAINAGE AGGREGATES USED IN CALIFORNIA

Year of Stand. Specs.	Grading Requirements - % Passing												
	6 In.	$2\frac{1}{2}$ In.	2 In.	$1\frac{1}{2}$ In.	1 In.	$\frac{3}{4}$ In.	$\frac{3}{8}$ In.	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	No. 200
1927	100				0									
1940	100					0								
1945		100				40-100		15-50	5-30		0-5			0-2
1949		100				40-100		15-50	5-30		0-5			0-2
1954 Type A						100		80-100	60-90		20-50	10-25		0-4
Type B				100		90-100		55-85	35-65		15-35	10-25		0-3
Type C		100		80-100		60-95		35-65	25-50		5-25			0-3
1960 Type A							100	90-100						
Type B				100		90-100	65-85	45-65						
Type C			100	90-100		60-80		40-60						
- No. 4								100	65-90	45-70	20-40	8-16	0-4	0-2

for drain rock. In 1945 a graded aggregate from $2\frac{1}{2}$-in. maximum size down to the No. 200 sieve was specified. This grading was retained in the 1949 Standards, but in 1954 three classes (A, B, and C) were established. Class A was a fine-graded material $\frac{3}{4}$ in. and finer in size, Class B graded from $1\frac{1}{2}$-in. maximum and Class C from $2\frac{1}{2}$-in. maximum. Since 1954 further changes have been made with more classes established to give greater choice of sources for permeable material. The trend in recent years has been toward graded aggregates with sufficient fines to prevent the intrusion of soil into drainage systems. This practice came about because of bad experiences with the open rocks used before 1945. Many of the old drains were dug into a number of years after construction, and of those which had failed to function, a large percentage were found to have become badly clogged with soil. Some of these drains, chiefly those which had been installed in firm, resistant, or rocky formations, were still unclogged.

With the change to graded aggregates for drainage purposes control over the amount of fines in the aggregates became extremely important. Small increases in the amount of fines in graded aggregates can alter the permeability very markedly (Table 2). If the grading of these materials is not properly controlled their permeabilities can be so low that their capabilities for removal of water are greatly impaired. During the time that the 1960 Specifications were in force a considerable number of proposed or used aggregates were tested for permeability. Some typical results are given in Table 3.

In the study of drainage aggregates for removing water, it is useful to know how much water various aggregates can remove. If the permeability and hydraulic gradient are known or can reasonably be approximated, one can readily compute water-removing capacity. To develop Figure 1, the quantities of water that can be removed by relatively flat blankets of aggregate were calculated from Darcy's law,

$$Q = k\ i\ A \tag{1}$$

where Q represents the quantity of water that can flow in an aggregate layer with a coefficient of permeability; k is a hydraulic graident; i is assumed equal to the slope of the pavement; and A is a cross-sectional area. The lines (Fig. 1) are for flow through a 1-sq ft area. Hence, the quantities are those that can be removed by 1 sq ft of cross-sectional area. It can be 1 ft deep by 1 ft wide, 6 in. deep by 2 ft wide, etc. For example, Figure 1 shows that a material with a permeability of 10 ft/day on a 2 percent slope is capable of removing about 0.2 cu ft/day or 1.5 gal/day for each square foot of area. A material with a permeability of 100 ft/day can remove 2 cu ft or 15 gal per day.

Figure 1 points up the general nature of seepage within relatively flat drainage layers, such as those often constructed beneath highways. The water-removing potential of unit area varies with the per-

TABLE 2

PERCENT OF FINES VS PERMEABILITY[a]

% Passing No. 100	Test k (ft/day)
0	80-300
1	35-200
2	10-100
4	2-50
6	0.5-20
7	0.2-15

[a]Graded filter aggregate.

TABLE 3

TYPICAL DATA FOR 1960 PERMEABLE MATERIALS[a]

Test No.	Grading Analysis (% Passing)									Impact Test Max. Dens. (pcf)	Permeability at 95% R. C. (ft/day)
	3/4 In.	3/8 In.	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	No. 200		
56-613	100	90	54	39	26	15	9	8	4	127	3
57-1146		100	98	90	65	41	18	5	3	123	5
57-1197-A	95	72	60	52	40	25	11	4	2	134	4
60-1743-A	100	79	64	56	44	23	16	5	2	133	2
60-1745-A	100	71	51	40	31	23	12	4	2	138	3
60-2369	100	72	53	41	27	14	6	3	1	130	14
60-2840	100	82	74	66	52	33	15	6	3	127	12
60-3919	100	92	91	78	60	38	16	8	3	124	7
60-3918	100	58	42	35	29	19	10	4	4	134	2
60-4010-B	100	64	40	28	15	7	4	3	1	129	30
61-581-A	100	75	51	41	29	19	8	2	2	137	4
61-583-A	100	77	54	46	36	20	13	4	2	136	3
61-799	100	77	58	46	35	18	7	4	3	134	14
61-1575	100	97	54	37	24	15	6	2	2	135	10
61-1856	91	65	50	40	30	19	10	4	3	135	8
61-2421	100	79	60	46	31	19	9	4	3	132	6
61-2422	100	84	72	62	50	36	19	7	5	132	1

[a]Samples did not all pass 1960 Specifications; many were preliminary and were not used in the construction of highways.

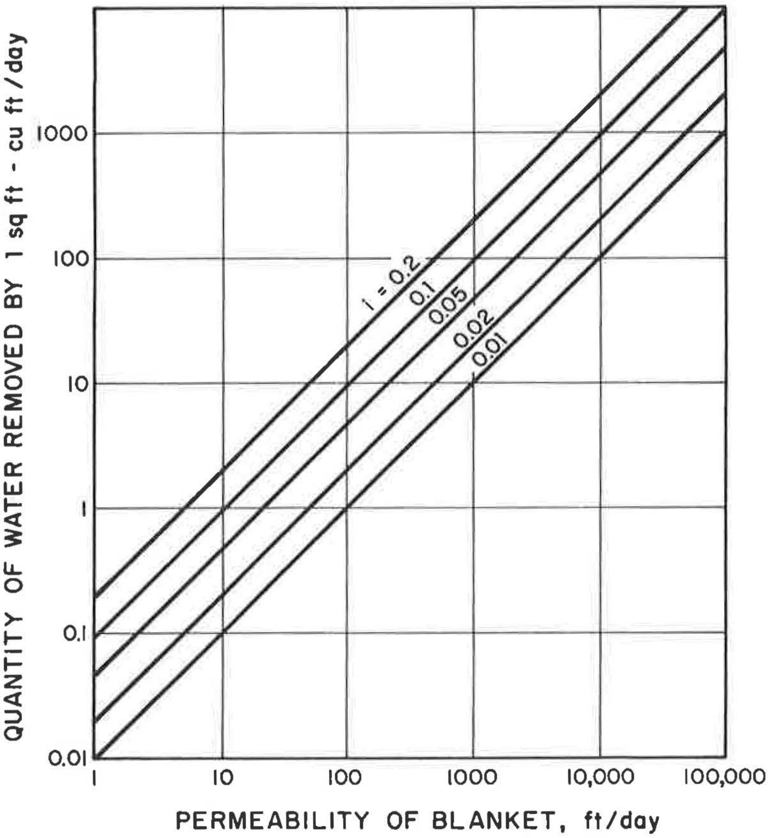

Figure 1. Water-removing capabilities of drainage blankets.

meability and the hydraulic gradient. If large quantities of water are anticipated, it is often necessary to specify high permeability aggregates, with little or no material finer than the No. 8 sieve. When these open-graded aggregates are used no erodible material can be in contact with the layer or the layer may become plugged by intrusion in the same way that French drains often become clogged. When this danger exists the open-graded aggregates must be separated from the erodible material by an intermediate layer of graded aggregate through which the material cannot move. Various "filter" criteria are available for establishing gradings that will provide permanent protection (2, 3, 4, 5). A system composed of two or more filter layers is called a "graded filter" (6). They have been a standard feature in the design of dams and levees for several decades, but have been rarely used in highway drainage. In situations where large quantities of water must be removed and erodible soils occur, they can often provide an economical solution. In other locations where moderate quantities of water are anticipated, the graded aggregates studied in the program are often used.

Materials meeting the 1960 specifications could be produced by blending fine and coarse concrete aggregate. In order to do this the concrete aggregates had to be toward the clean side of the specifications, the aggregate had to be relatively hard and durable, and care was necessary in blending, handling, and placing. The minus No. 4

TABLE 4

SUMMARY OF TEST DATA — PRELIMINARY TESTS

Sample No.	Grading Analysis - % Passing											Sand (%)	Impact Test Max. Density (pcf)	Permeability at 95% R. C. (ft/day)
	1 In.	3/4 In.	1/2 In.	3/8 In.	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	No. 200			
62-3480 F. sc.				100	48	6	1	1	1	1	1	0	114	4,000-5,000
Combined				100	63	26	16	10	5	2	2	25	123	140-160
samples				100	76	44	31	19	9	4	2	50	130	25-35
Conc. sand-lab stockpile					100	82	59	35	11	4	2	100	122	9-10
62-3479 M. sc.			100	98	9	2	2	2	1	1	1	0	114	7,000-8,000
Combined			100	99	27	18	13	9	4	3	2	20	124	140-150
samples			100	99	45	34	24	15	7	3	2	40	133	17
Conc. sand-lab stockpile					100	82	59	35	11	4	2	100	122	9-10
62-3478 C. sc.			100	47	5	2	1	1	1	1	1	0	116	11,000
Combined			100	55	20	14	10	6	3	2	2	15	123	1,500-2,000
samples			100	65	34	26	19	12	6	3	2	30	130	40-50
			100	76	53	42	31	19	10	3	2	50	132	28-30
Conc. sand-Lab stockpile					100	82	59	35	11	4	2	100	122	9-10
62-3926 P. gr.			100	95	33	8	2	0				0	119	2,500
Combined			100	96	44	24	14	8	3	2	2	20	128	70-80
samples			100	97	60	40	25	14	7	3	3	40	131	35-40
62-3927 Conc. sd.					100	88	59	29	15	5	5	100	120	30-35
62-4040 1 in. × No. 4 conc. ag.	96	70	33	15	0							0	121	3,200-4,000
Combined	97	77	46	32	19	14	10	7	4	1	1	20	131	30-40
samples	98	84	59	49	37	28	21	14	7	2	2	40	135	11-12
62-4039 Conc. sd.				100	92	71	51	35	20	7	5	100	122	8-10
62-4037 F. sc.				100	47	9	3	2	1	0		0	113	4,000-6,000
Combined				100	58	21	12	9	5	1	1	20	120	90-100
samples				100	65	33	23	15	8	3	2	40	128	24-30
62-4039 Conc. sd.				100	92	71	51	35	20	7	5	100	122	8-10
62-4038 Med. scr.				100	48	0						0	112	18,000-22,000
Combined				100	57	14	10	6	4	1	1	20	122	54-74
samples				100	69	28	21	14	8	3	2	40	128	22-24
62-4039 Conc. sd.				100	92	71	51	35	20	7	5	100	122	8-10
62-4036 C. sc.		100	92	70	3	1	0					0	116	10,000-11,000
Combined		100	94	76	21	14	10	7	4	1	1	20	129	50-60
samples		100	96	83	39	29	21	14	8	3	2	40	134	27-30
62-4039 Conc. sd.				100	92	71	51	35	20	7	5	100	122	8-10
62-4034 F. scr.				100	55	1	0					0	112	1,800-2,700
Combined				100	60	16	10	6	3	1	1	20	118	110-130
samples				100	70	33	20	9	5	2	1	40	123	60-68
62-4035 Conc. sd.				100	96	79	49	32	13	4	2	100	125	25
62-4031 3/4 in. × No. 4 conc. agg.		100	57	33	7	1	0					0	120	13,000-15,000
Combined		100	66	47	29	16	10	6	3	1	1	20	131	90-120
samples		100	74	61	42	32	20	13	5	2	1	40	137	20-25
62-4035 conc. sd.				100	96	79	49	32	13	4	3	100	125	25
62-4033 Med. scr.			100	97	23	14	8	5	2	1	1	0	113	3,000
Combined			100	98	37	27	16	10	5	2	2	20	124	90
samples			100	99	53	40	25	16	6	3	2	40	128	42
62-4035 conc. sd.				100	96	79	49	32	13	4	3	100	125	25
62-4032 c. scr.		100	97	64	8	2	1	1	1	1	1	0	113	12,000-13,000
Combined		100	97	73	25	17	11	7	4	2	2	20	123	120-150
samples		100	98	77	44	33	21	14	6	3	2	40	132	30-40
62-4035 conc. sd.				100	96	79	49	32	13	4	3	100	125	25

fraction could not contain more than 2 percent minus No. 200 material. Hence, the maximum allowable minus No. 200 in the permeable material was usually 1 percent or less. Producers found this difficult to achieve particularly if pit run material was soft or the percentage of fines was high.

The possibilities of using an undersanded mixture of coarse and fine concrete aggregate for permeable material to achieve somewhat higher permeability were known. One disadvantage of this material is the possibility of segregation and the resultant low permeability in the fine portion or infiltration in the coarse portion.

F. N. Hveem, Materials and Research Engineer (retired October 1963), felt that any disadvantages resulting from segregation might be more than compensated for by ease of production and higher permeability and directed the laboratory study. The tests were performed on readily available commercial aggregates.

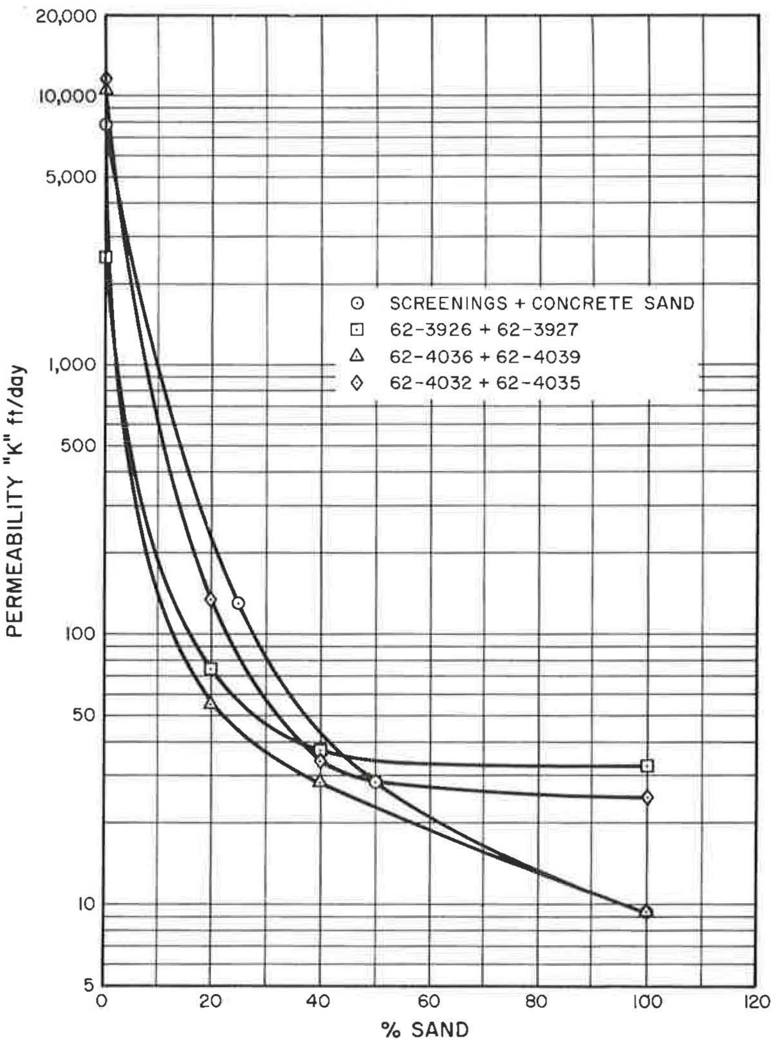

Figure 2. Permeability k vs percent sand.

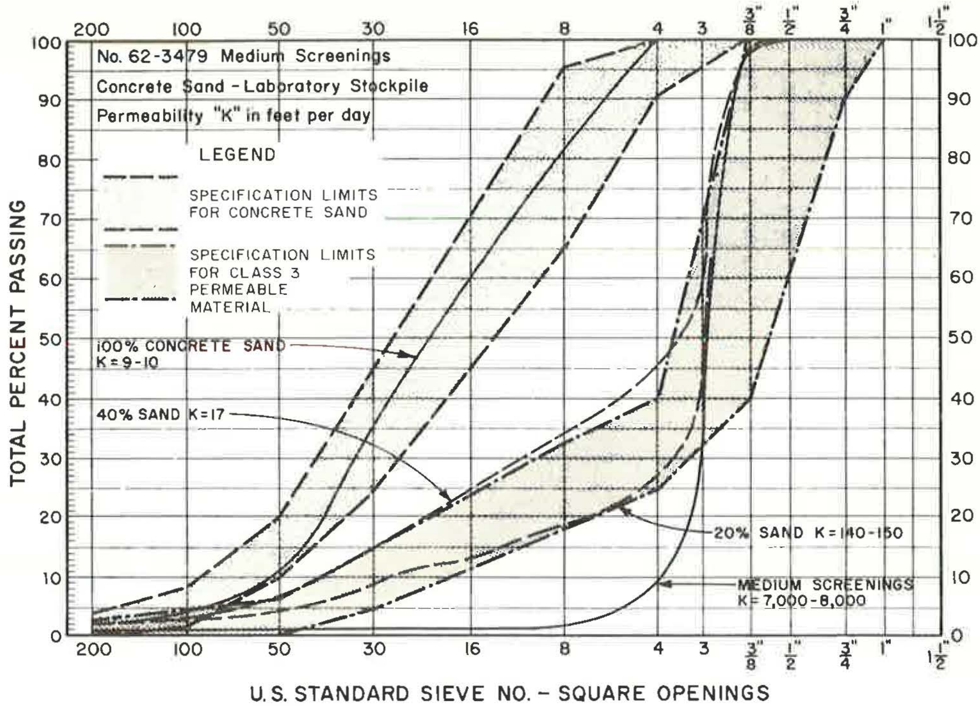

Figure 3. Grading curves for fine screenings and concrete sand (preliminary tests).

TESTING PROGRAM

Preliminary Tests

During the summer of 1962 samples of concrete sand and ¾ in. by No. 8 coarse aggregate were obtained from four aggregate producers. Constant-head permeability tests were run on each of the sand and aggregate samples and various combinations of the sand and the aggregate. These tests were made in 6-in. diameter constant-head permeameters using California Test Method No. 220-B. Specimens are tested using various compactive efforts and plots of permeability versus density are prepared. The results of this series are given in Table 4 and typical data are shown in Figures 3 through 7. The permeabilities of the combinations range from the same as the sand alone to about 4 times the permeability of the sand when the combinations contain approximately 60 percent of the aggregate. When the percent of aggregate in the combination was increased to 75 percent, the permeability ranged from 4 to 15 times that of the sand alone (Fig. 2). However, when the percentage of sand in the combination was 25 percent or lower, segregation of the coarse and fine portions was evident when the material was being placed in the test mold. This is in agreement with experience on construction projects with undersanded aggregates. It was therefore recognized that care would have to be exercised in placing such aggregates in highway construction to minimize segregation.

The findings of this testing, coupled with previous experience with various gradings or permeable materials, led to the development of the following grading specification for Class 3 permeable material:

Sieve Size	Percent Passing	Sieve Size	Percent Passing
1 In.	100	No. 8	18-33
¾ In.	90-100	No. 30	5-15
⅜ In.	40-100	No. 50	0-7
No. 4	25-40	No. 200	0-3

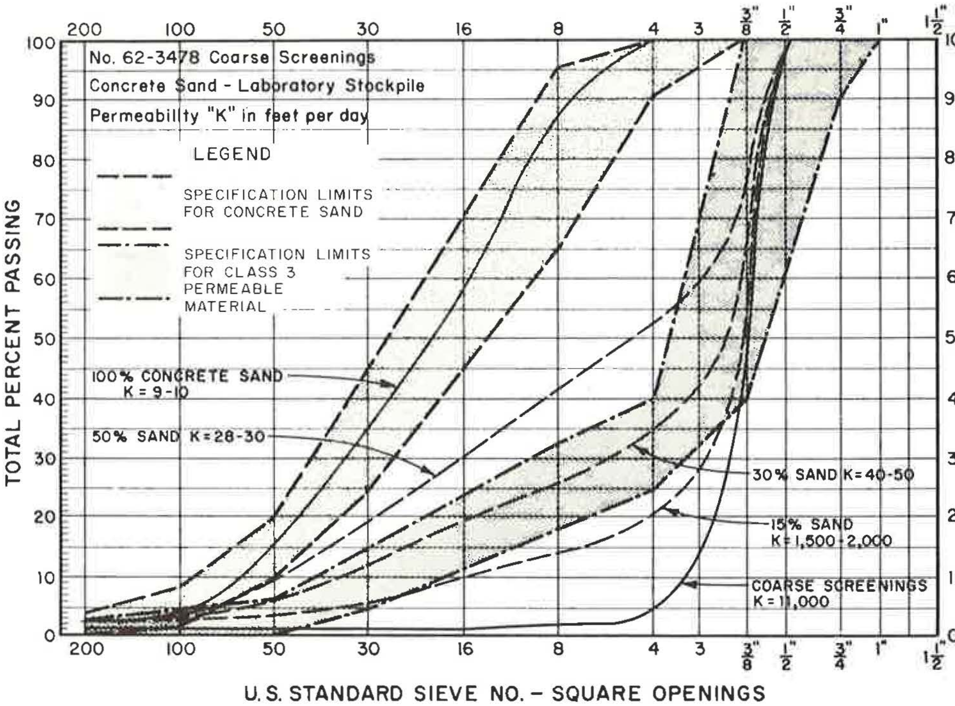

Figure 4. Grading curves for fine screenings and concrete sand (preliminary tests).

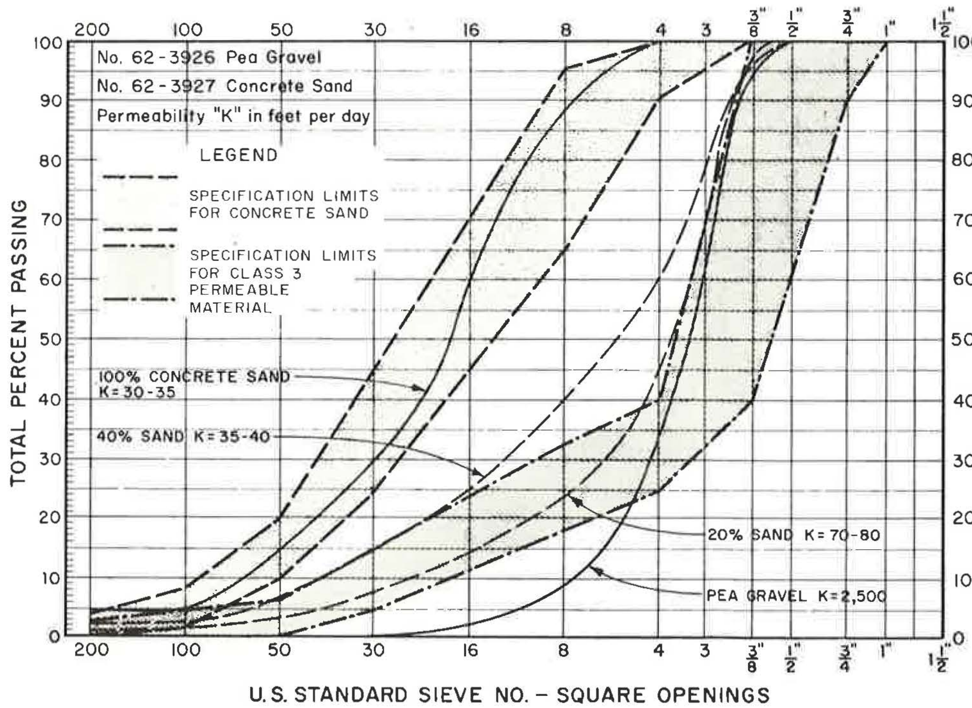

Figure 5. Grading curves for fine screenings and concrete sand (preliminary tests).

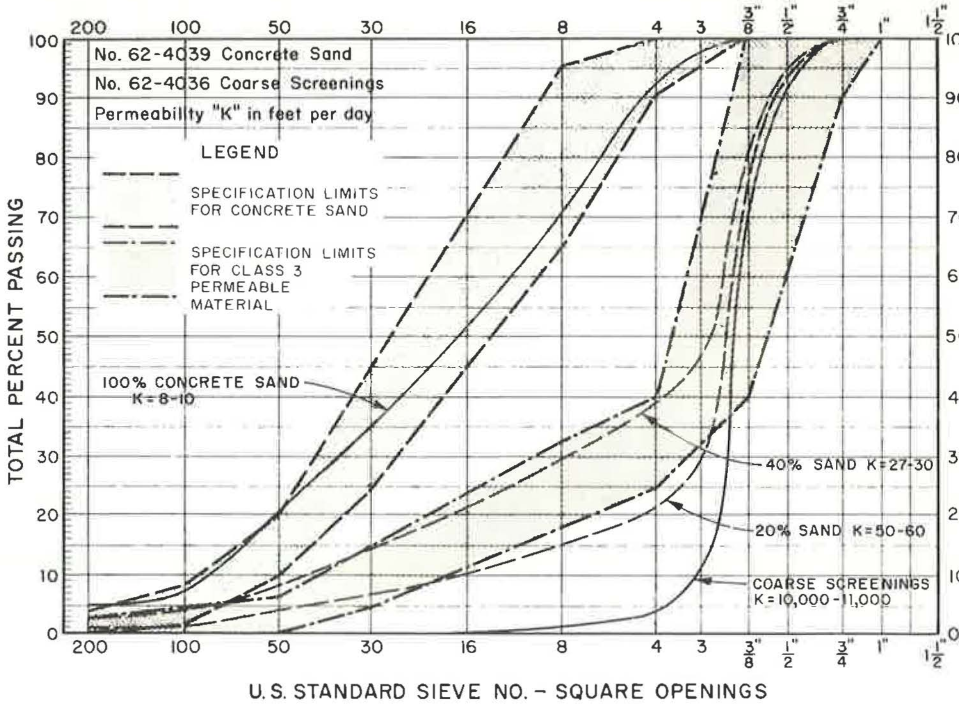

Figure 6. Grading curves for fine screenings and concrete sand (preliminary tests).

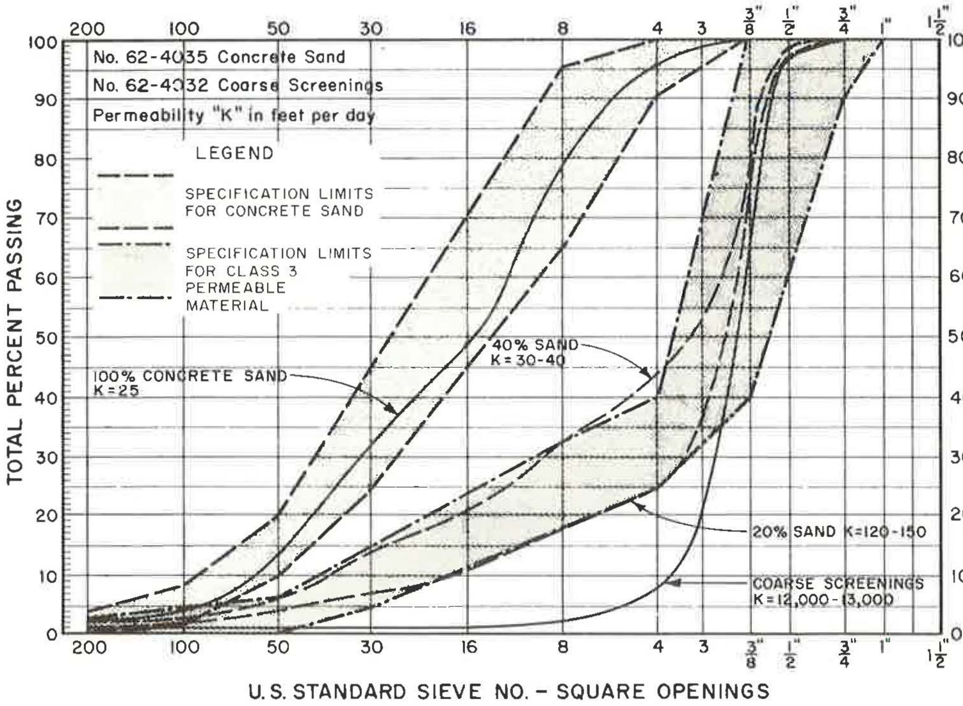

Figure 7. Grading curves for fine screenings and concrete sand (preliminary tests).

Additional Tests

In September 1962, a letter was sent to eight California Highway Districts asking for fine concrete aggregate, ¾ in. by No. 4 concrete aggregate, and permeable material sampled from plants which supply significant amounts of these aggregates for highway projects. The districts asked to participate in this sampling represented those using substantial amounts of permeable materials. A total of 70 samples were received; three were representative of the 1960 Standard Specification filter material, 32 were representative of fine concrete aggregate, and the remaining 35 were of various sizes of coarse concrete aggregate. Of the 32 fine concrete aggregate samples, 11 did not meet the California grading specifications for fine concrete aggregate, and one had a sand equivalent less than 70. These materials were used, since it was desired to obtain information about blends of borderline materials--those high in fines.

The coarse aggregate samples were scalped on the ¾-in. sieve, where necessary, and combined with the sand fraction so that the combined grading would be on the fine side of the Class 3 specifications. Three sources could not be combined to meet the Class 3 grading specifications without altering the as-received grading.

Sand equivalent tests were performed on the fine concrete aggregate samples, and a California durability test was performed on all samples. The maximum density was determined, by the California impact test, on all combinations of gradings used in the permeability tests. Permeabilities are given for specimens compacted to 95 percent of the maximum density determined by the impact test.

The test data are given in Table 5. Typical gradings of the combined samples are plotted (Figs. 8 through 14) and the value of k, the coefficient of permeability, is shown beside each grading curve.

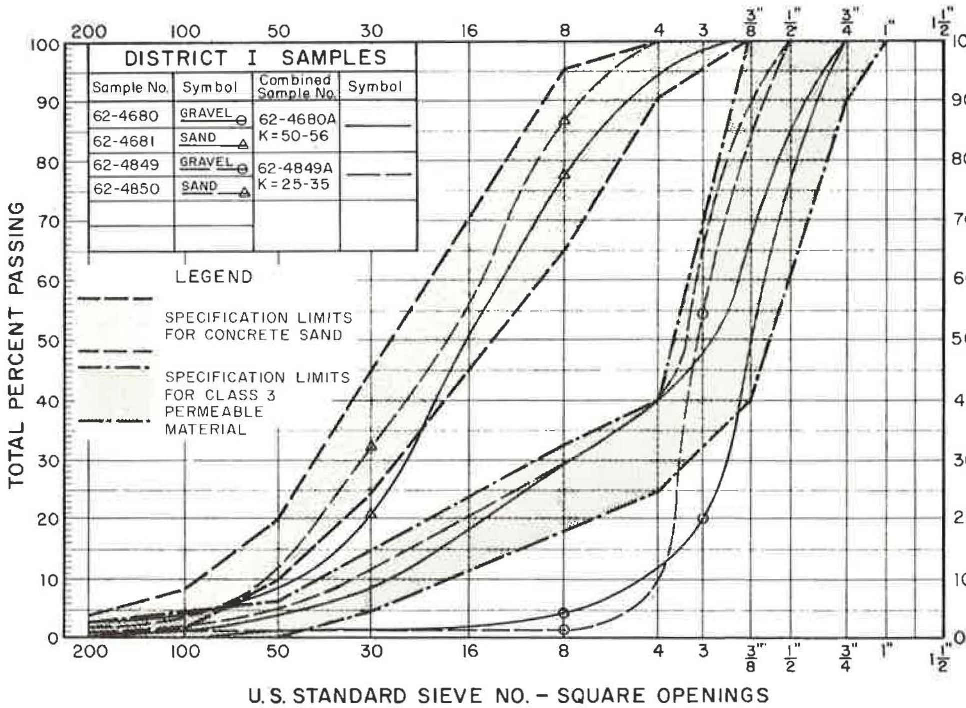

Figure 8. Grading curves for sand and gravel (additional tests).

TABLE 5

SUMMARY OF TEST DATA—ADDITIONAL TESTS

Sample No.	Grading Analysis % Passing											Sand (%)	S. E.	Impact Test Max. Density (pcf)	Permeability k at 95% R. C. (ft/day)	Durability Factor (D)
	1 In.	3/4 In.	1/2 In.	3/8 In.	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	No. 200					
DIST. I:																
62-4680 As recd.	100	98	75	49	12	4	2	1	1	0	0					76
62-4680 As used		100	77	50	12	4	2	1	1	0	0					
62-4681				100	94	77	50	21	8	4	3		92			70
62-4680A		100	85	67	40	29	18	8	4	1	1	34		134	50-56	
62-4849			100	84	10	1	1	1	1	1	0					60
62-4850					100	86	57	32	12	3	2		89			46
62-4849A			100	89	40	29	20	12	5	2	1	33		131	25-35	
DIST. II:																
62-4584 As recd.	100	97	51	18	2	1	1	1	1	1	1					78
62-4584 As used		100	53	19	2	1	1	1	1	1	1					
62-4585				100	90	82	66	40	16	4	2		91			74
62-4584A		100	70	48	36	31	25	15	6	2	2	36		139	19-24	
62-4586 As recd.	100	96	72	30	1	0	0	0	0	0	0					59
62-4586 As used		100	75	31	1	0	0	0	0	0	0					
62-4587				100	99	90	76	51	19	5	2		90			75
62-4586A		100	83	52	31	27	23	15	6	2	0	30		134	20-30	
62-4588 As recd.	100	92	45	22	0	0	0	0	0	0	0					74
62-4588 As used		100	49	24	0	0	0	0	0	0	0					
62-4589				100	94	78	52	34	19	8	4		77			63
62-4588A		100	69	54	37	30	20	13	7	3	2	39		138	9-10	
62-4588B		100	64	47	28	23	16	10	6	2	1	30		134	45-60	
DIST. III:																
62-4581 As recd.	100	99	75	42	2	1	1	0	0	0	0					85
62-4581 As used		100	76	42	2	1	1	0	0	0	0					
62-4582				100	93	77	67	47	21	6	3		82			63
62-4581A		100	84	61	31	26	22	15	7	2	1	32		139	15-25	
62-4638 As recd.	100	96	40	12	2	1	1	1	1	0	0					78
62-4638 As used				100	0	0	0	0	0	0	0					
62-4639				100	92	78	54	36	18	7	5		88			73
62-4638A				100	46	39	27	18	9	4	3	50		134	10-12	
62-4638B				100	40	34	23	15	8	3	2	43		134	10-13	
62-4642 As recd.	100	91	55	33	4	1	1	1	0	0	0					73
62-4642 As used		100	60	36	4	1	1	1	0	0	0					
62-4643					100	79	54	35	17	5	3		76			68
62-4642A		100	75	60	40	31	22	14	6	2	1	38		136	17-23	
62-4827 As recd.	100	75	29	14	1	1	1	1	0	0	0					82
62-4827 As used		100	39	19	1	1	1	1	0	0	0					
62-4828				100	95	82	66	43	14	6	3		92			82
62-4827A		100	59	46	32	28	23	15	5	2	1	33		133	21-26	
62-4829 As recd.	99	86	50	28	1	0	0	0	0	0	0					93
62-4829 As used		100	58	33	1	0	0	0	0	0	0					
62-4830				100	87	57	43	29	14	4	2		98			82
62-4829A		100	75	60	36	23	17	12	6	2	1	40		131	25-30	
62-5004		100	55	23	3	2	1	1	1	1	1					76
62-5005				100	93	78	60	41	20	6	3		94			72
62-5004A		100	69	48	32	26	20	14	7	3	2	32		127	27-33	
DIST. IV:																
62-4607 As recd.	100	89	55	29	1	0	0	0	0	0	0					70
62-4607 As used		100	62	33	1	0	0	0	0	0	0					
62-4608				100	97	81	62	41	16	5	3		88			73
62-4607A		100	76	58	37	30	23	15	6	2	1	37		134	28-35	
62-4609 As recd.	100	92	25	6	1	1	1	1	1	1	0					54
62-4609 As used		100	27	7	1	1	1	1	1	1	0					
62-4610				100	97	77	53	35	18	8	6		81			37
62-4609A		100	67	50	40	32	22	14	7	4	2	41		138	9-12	
62-4609B		100	65	55	50	40	28	18	9	4	3	48		137	9-12	
62-4611 As recd.	100	99	76	41	6	2	1	1	1	1	1					78
62-4611 As used		100	77	41	6	2	1	1	1	1	1					
62-4612					100	91	55	30	14	6	4		82			62

62-4616				100	91	63	45	28	12	4	3		86			63
62-4615A		100	81	63	37	26	19	11	5	2	1	40		134	23-35	
62-4617 As recd.	100	86	23	3	1	1	1	1	1	1	0					46
62-4617 As used		100	27	3	1	1	1	1	1	1	0					
62-4618				100	99	91	54	34	16	4	2		85			46
62-4617A		100	48	37	36	33	20	13	7	2	1	35		134	28-35	
62-4619 As recd.	100	95	52	16	1	0	0	0	0	0	0					67
62-4619 As used		100	55	17	1	0	0	0	0	0	0					
62-4620					100	99	58	33	15	5	2		88			67
62-4619A		100	70	45	34	33	19	11	5	2	1	33		134	20-30	
DIST. V:																
62-4929 As recd.	98	71	37	19	1	1	1	1	1	0	0					78
62-4929 As used		100	52	27	1	1	1	1	1	0	0					
62-4930				100	86	65	45	23	8	3	1		94			85
62-4929A		100	70	54	33	29	24	15	5	1	0	33		131	20-30	
62-4931 As recd.	100	99	64	35	3	2	1	1	1	1	0					76
62-4931 As used		100	65	35	3	2	1	1	1	1	0					
62-4932						100	77	43	21	6	4		84			66
62-4931A		100	76	55	32	31	25	14	7	3	1	30		130	23-33	
62-4933 As recd.	97	77	43	24	1	0	0	0	0	0	0					78
62-4933 As used		100	56	31	1	0	0	0	0	0	0					
62-4928				100	98	89	74	46	16	3	1		91			85
62-4933A		100	70	54	33	29	24	15	5	1	0	33		131	20-30	
62-4934 As recd.	100	96	49	21	2	1	1	1	1	1	1					80
62-4934 As used		100	51	22	2	1	1	1	1	1	1					
62-4935					100	89	60	36	18	9	6		77			66
62-4934A		100	86	54	32	28	19	12	7	4	3	30		144	13-17	
DIST. VII:																
62-4694 As recd.	100	67	9	2	1	1	1	1	1	1	1					62
62-4694 As used		100	13	3	1	1	1	1	1	1	1					
62-4695					100	83	53	25	11	7	6		65			71
62-4694A		100	58	52	41	34	22	11	5	4	3	40		133	15-19	
62-4696 As recd.	98	87	60	35	6	3	2	2	1	1	1					82
62-4696 As used		100	69	40	7	3	2	2	1	1	1					
62-4697				100	96	83	69	47	20	5	2		93			86
62-4696A		100	78	58	34	32	22	15	7	2	1	30		134	10-13	
62-4763 As recd.	98	81	43	19	2	1	1	1	1	1	1					73
62-4763 As used		100	53	23	2	1	1	1	1	1	1					
62-4764				100	96	84	70	44	18	5	2		89			81
62-4763A		100	68	48	32	28	23	15	7	3	2	32		132	15-19	
62-4777 As recd.	100	86	14	4	1	1	1	1	1	0	0					82
62-4777 As used		100	16	5	1	1	1	1	1	0	0					
62-4778				100	98	85	65	41	20	7	4		82			78
62-4777A		100	44	38	35	30	24	15	8	3	1	35		137	6-8	
DIST. X:																
62-4626 As recd.	100	95	53	29	4	2	1	1	1	1	1					82
62-4626 As used		100	56	31	4	2	1	1	1	1	1					
62-4627				100	97	85	68	41	16	5	3		89			83
62-4626A		100	71	55	37	31	25	15	7	3	2	35		135	13-18	
62-4628 As recd.	100	98	74	39	3	1	0	0	0	0	0					70
62-4628 As used		100	76	40	3	1	0	0	0	0	0					
62-4629				100	99	83	66	45	15	3	2		85			78
62-4628A		100	84	60	36	29	22	15	5	1	1	34		135	27-34	
62-4735			100	95	9	0	0	0	0	0	0					76
62-4736				100	98	88	71	38	14	5	2		90			78
62-4735A			100	97	40	31	25	12	5	2	1	35		132	24-34	
DIST. XI:																
62-4842 As recd.	100	87	44	23	3	2	1	1	1	1	0					59
62-4842 As used		100	51	26	3	2	1	1	1	1	0					
62-4843				100	92	73	60	43	17	5	2		81			52
62-4842A		100	67	50	32	25	21	15	7	3	1	33		127	32-42	
62-4844 As recd.	100	96	46	12	0	0	0	0	0	0	0					78
62-4844 As used		100	48	13	0	0	0	0	0	0	0					
62-4845					100	88	69	41	20	8	4		83			81
62-4844A		100	56	35	26	23	18	11	7	2	1	26		126	45-60	
62-4846		100	45	16	2	1	1	1	1	0	0					71
62-4847				100	95	76	58	42	13	3	1		89			61
62-4846A		100	64	45	33	27	21	15	5	1	0	34		126	45-60	

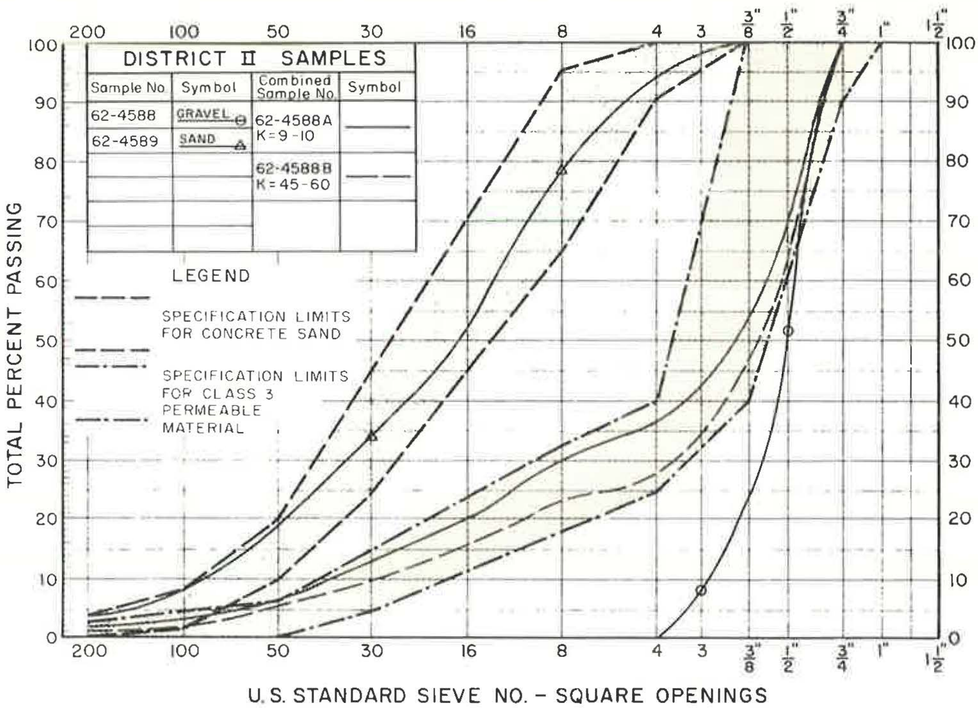

Figure 9. Grading curves for sand and gravel (additional tests).

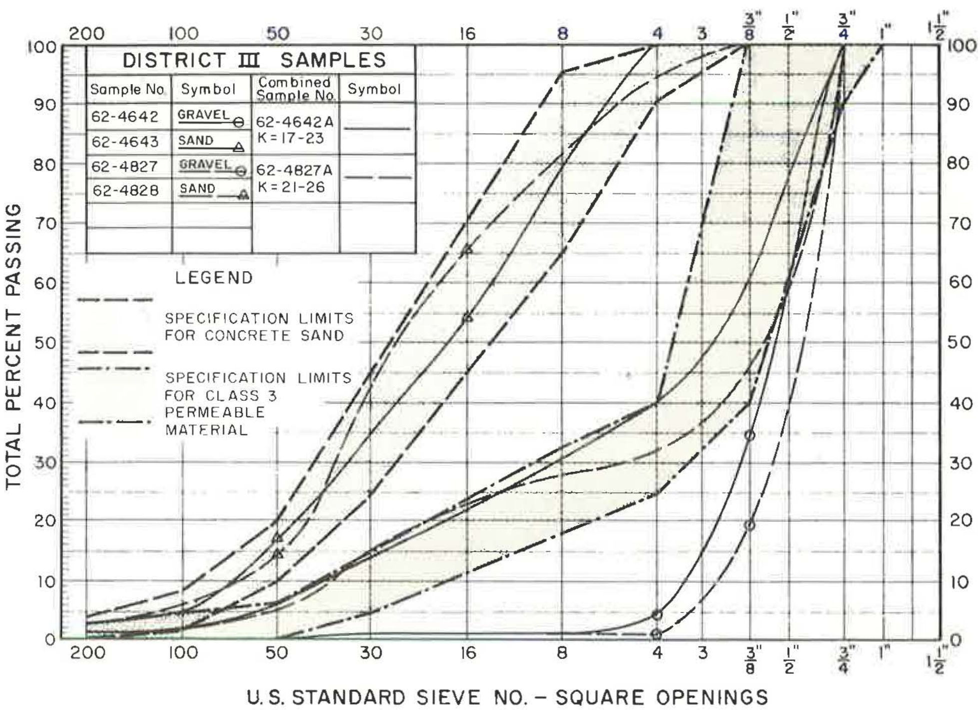

Figure 10. Grading curves for sand and gravel (additional tests).

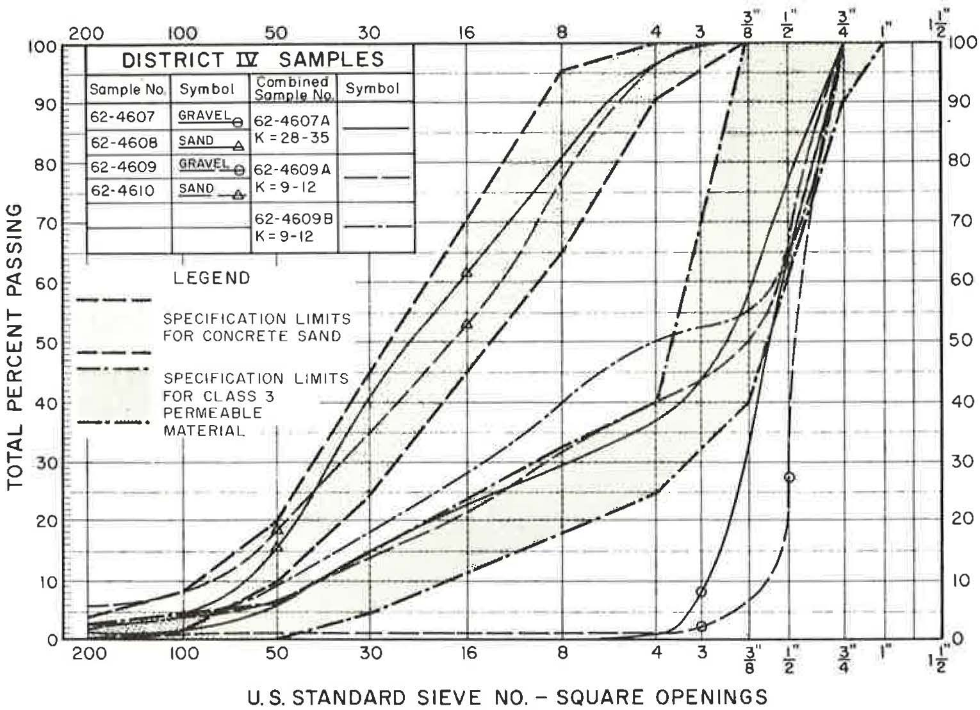

Figure 11. Grading curves for sand and gravel (additional tests).

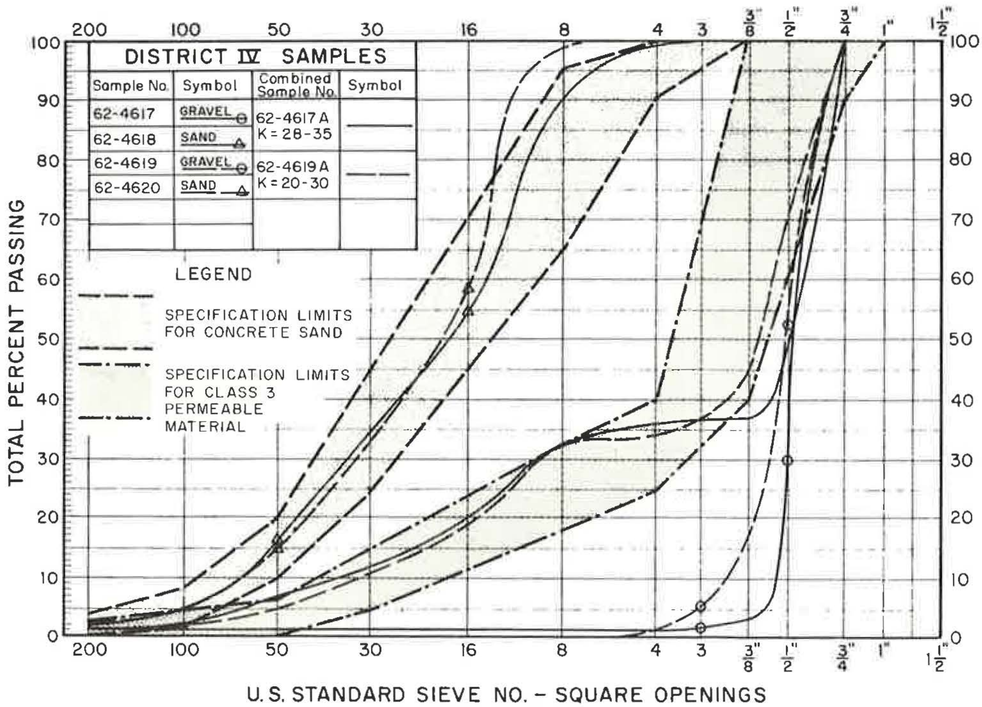

Figure 12. Grading curves for sand and gravel (additional tests).

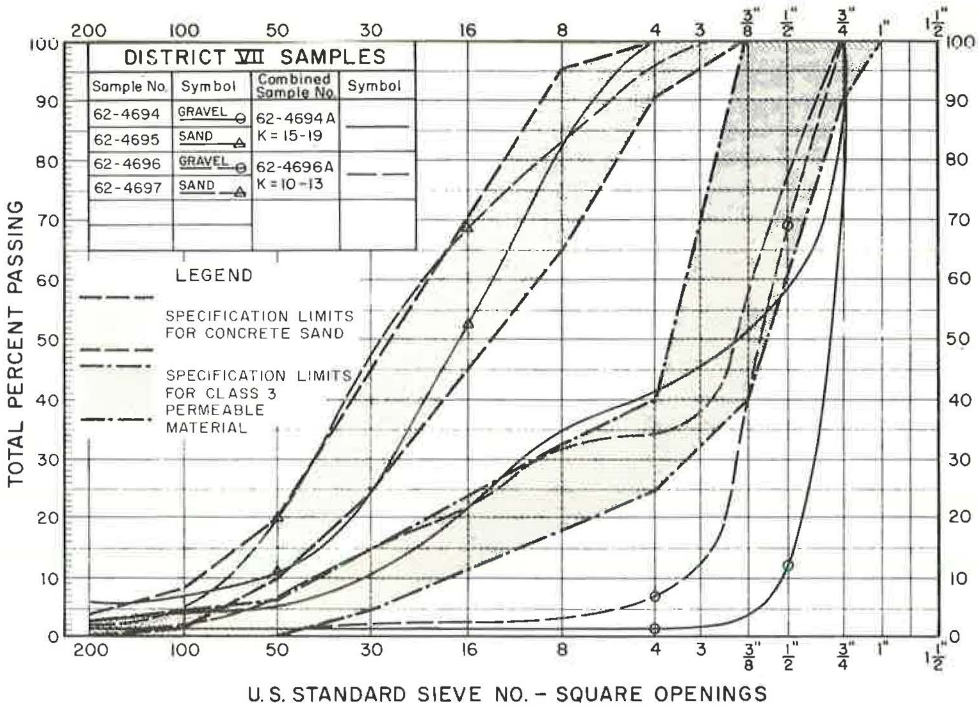

Figure 13. Grading curves for sand and gravel (additional tests).

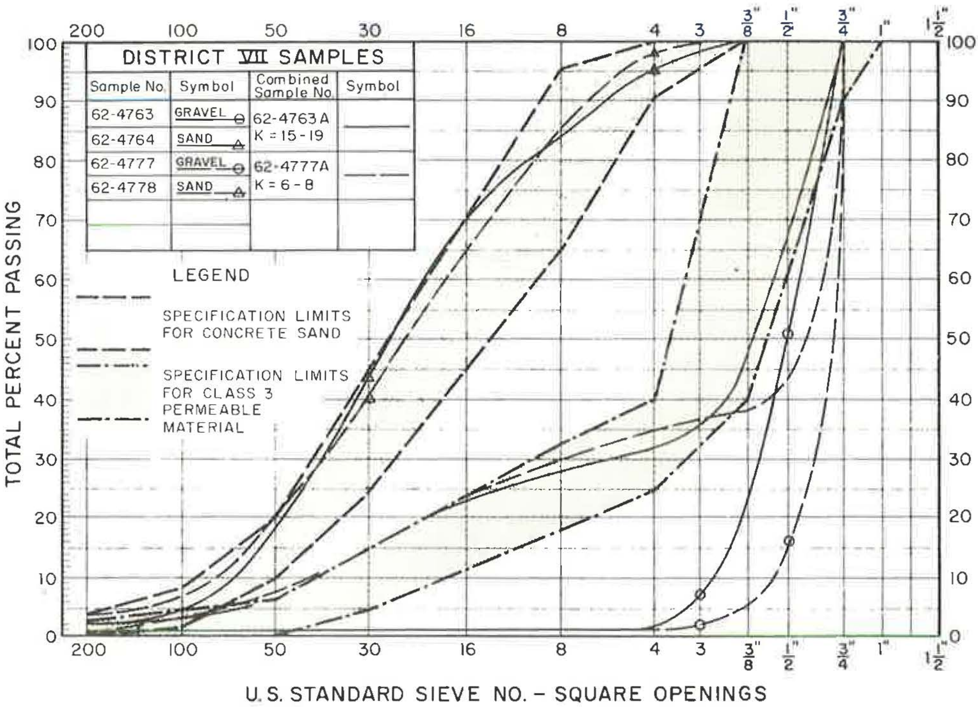

Figure 14. Grading curves for sand and gravel (additional tests).

Analysis of Test Data

Most of the test specimens had between 30 and 40 percent passing the No. 4 sieve and permeabilities ranging from 15 to 35 ft/day which is higher than for many of the graded filter aggregates previously specified. Decreasing the amount of material passing the No. 4 sieve below 40 percent increases the permeability, because mixes having less than this amount of fines tend to become undersanded. At higher amounts of fines the permeability generally falls off rapidly since there is then an excess of fines above that needed to fill the spaces between the larger aggregates, and the permeability is determined almost entirely by the grading and plasticity of the fine matrix.

The test data indicate that the materials tested have comparatively good permeabilities at maximum impact test densities less than about 132 pcf (Fig. 15), but much lower permeabilities at higher densities. Evidently at higher densities the pore spaces reduce very rapidly from rearrangements of the particles and possibly from a breakdown of particles into smaller sizes.

It has been known for many years that the permeability of aggregates and soils depends on the sizes of the pore spaces through which the water flows. In materials which have a narrow range of sizes, such as uniform sands and pea gravels, the permeability varies approximately with the square of the average grain size. Thus, ¾ in. to ½ in. rock was found to have a permeability of 38,000 ft/day, and No. 4 to No. 8 aggregate a permeability of 8,000 ft/day. As the range of sizes in a mixture increases its permeability decreases. Mixing 80 percent of minus No. 8 to dust with 20 percent of No. 4 to No. 8 aggregate lowered the permeability from 8,000 ft/day to only 1 ft/day. The mixture contained 10 percent -200 material. The data (Table 2) showed that the permeability of graded aggregates can change very drastically with small changes in the quantity of fines.

In consideration of the above factors, it is evident that the processing and placing of graded drainage aggregates must be controlled very carefully if these aggregates are to serve the intended purpose; that is, the safe removal of water. As previously noted, when large quantities of water are anticipated it may be necessary to utilize open-graded layers of high permeability protected against soil intrusion by intervening filter layers.

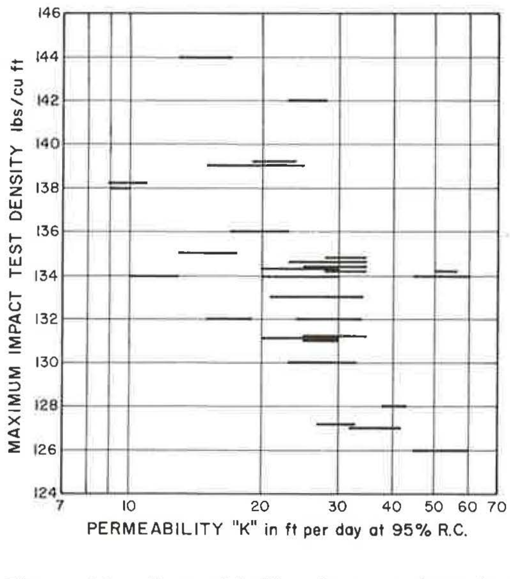

Figure 15. Permeability k vs maximum impact density.

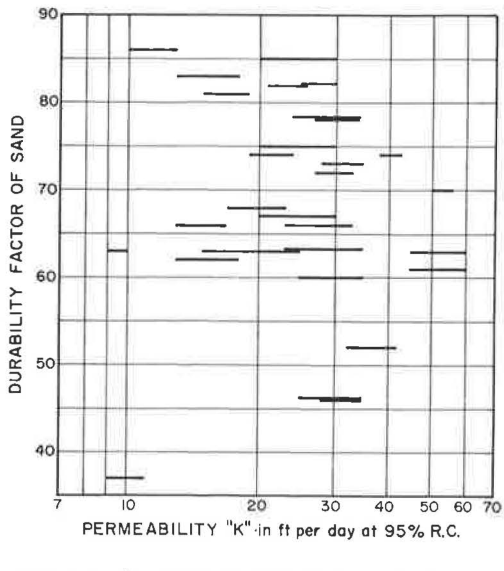

Figure 16. Durability vs permeability.

With reference to this testing program, there appears to be no relationship between the permeability and the durability factor, when the durability factor is above 40 (Fig. 16). This is probably due to the relatively high quality of the aggregates used in the tests. Only one sample had a durability factor of less than 40. The term durability factor relates to the new aggregate durability test, California No. 229.

CONCLUSIONS

In general the gradings of the blends were on the fine side of the limits of the Class 3 Standard Specials. The permeability coefficients determined by the tests average two or three times greater than those of the 1960 Standard Specifications material. In actual practice, somewhat higher permeabilities may be expected since permeability can be increased by holding the percentage of minus No. 4 to a range of 25 or 30 percent.

The use of blended mixtures permits liberal flexibility of production since a variety of aggregate gradings can be utilized. "Gap graded" blends can be avoided by adding an intermediate size aggregate. Since readily available commercial aggregates can be used, a savings in cost is anticipated over a period of time.

Care must be exercised in the handling of these undersanded mixtures to guard against segregation. Keeping the mixtures thoroughly dampened greatly minimizes segregation during placement.

It is important to emphasize that there is a need for analyzing the hydraulic conditions within drainage systems, of estimating the probable quantities of water that blankets and underdrains may be required to remove, and of designing drainage systems that are capable of doing the required job (7).

Darcy's law can be used both for estimating inflow quantities and for designing drainage systems. Charts such as Figure 1 can aid in the selection of classes of aggregates and design details that will keep structural section flooding to a minimum. Drainage is playing an important part in the design of modern highways. It is not obtained automatically. By examining accepted practices critically and being willing to experiment with new materials and methods, engineers should be able to design improved highways.

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