Bulletin No. 331 Series R, Structural Materials, 3

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director.

PORTLAND CEMENT MORTARS AND THEIR CONSTITUENT MATERIALS

RESULTS OF TESTS

MADE AT THE

STRUCTURAL-MATERIALS TESTING LABORATORIES
FOREST PARK, ST. LOUIS, MO., 1905-1907

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WASHINGTON
GOVERNMENT PRINTING OFFICE
1908

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ABBREVIATIONS USED IN REGISTER NUMBERS.

Ct.=cement.
Cr.=cinder.
Gl.=gravel.
Sd.=sand.
Se.=stone.
Sg.=slag.

INTRODUCTION.

By Joseph A. Holmes.

The records here reported are based on 25,000 tests, extending over more than one year of active field and laboratory work. The report may be divided into two parts—the first dealing with tensile, compressive, and other tests, including chemical analyses of Portland cement of different brands donated for the purpose, and of the mortars mixed therewith in which a standard sand was used; the second dealing with tests of mortars prepared by mixing typical Portland cement with 22 sands, 12 gravel screenings, and 25 stone screenings, procured from different parts of the United States and mixed in different proportions.

In order that tests extending over a period of years might be made with a relatively uniform cement, a quantity of Portland cement of seven different brands was obtained by donation. An equal amount of each of these brands was mixed together to form a typical Portland cement, and the mixture was stored away in air-tight cans (p. 10). Tests made to determine the quality and variation of the typical Portland cement were conducted in great detail both on the neat individual brands and the typical mix, and on 1:3 cement mortars made therefrom with standard sand.

The results of the tests showing variation in tensile strength with age of neat cement indicate clearly that the typical mix reached maximum tensile strength in 90 days, or at the same period at which this strength was reached by the separate brands; that it maintained the highest tensile strength for a period as long as that of the best of the individual brands, viz, to 180 days, and that the diminution in tensile strength thereafter to one year and beyond was less than for some brands and no greater than for the best (p. 23).

The tests of the standard-sand mortars showed maximum tensile strength of the mix at 90 days, or about the same as for the individual brands; more rapid falling off in tensile strength for the mix up to 180 days than for the individual brands; but an actual gain in strength beyond 180 days for the mix, as compared with a falling off for the separate brands (p. 24).

In the compressive tests the typical mix showed a rapid rise in strength, as did the individual brands, up to 90 days, and a less rapid but continual increase in compressive strength to the 360-day period for the mix as compared with some of the brands, four of which showed little or no gain in compressive strength after 180 days (p. 26).

Compressive tests of the 1:3 standard-sand mortars showed a more rapid gain up to 180 days for the typical mix than for the separate cement brands, and continued increase in compressive strength beyond 180 days for the mix, as against a less ratio of increase for several of the individual brands tested.

The general indications of these tests are that a cement exhibiting greater uniformity of behavior is likely to be procured by making a typical mix of several brands than by the use of any one standard brand of cement.

It should be borne in mind, however, that this statement is applicable only to the typical mixes used in these tests, and that it is possible that other mixtures of Portland cements might not yield the same results, but would show entirely different characteristics. Results of further investigations along these lines will be reported as soon as they become available.

A study of the percentage of gain in strength exhibited by the various cements and cement mortars tested shows the very important fact that though the cements may test low or high at 7 days, and though there may be varying percentages of increase during the four periods from 7 days to one year, yet after the 180-day and the 360-day tests the strengths of all the standard-sand mortars were reasonably close one to another. This indicates that early strengths may vary considerably without seriously affecting the later strength of the cement or mortar (p. 33).

The purpose of the investigations of the constituent materials of mortar was to ascertain as far as possible the properties of such materials collected in different parts of the United States. It is believed that the results of these tests made on material obtained near the large commercial centers of the country will indicate clearly to users of cement and of concrete where they may most conveniently and cheaply procure the requisite sand, gravel, etc., and how these should be mixed to attain the best result in tensile or compressive strength for each group of constituent materials.

A study of the data in this part of the report should afford means of determining the probable strength of mortar made from materials having similar properties, though gathered in different parts of the country, and should aid the constructor to decide which of the three materials—sand, gravel, or broken stone screenings—will best serve his purpose.

The tests whose results are here presented were made on mortars using different proportions of the typical Portland cement and sands, gravel screenings, and stone screenings collected in various parts of the country, the properties of which are discussed in the earlier part of the bulletin. The report describes the material, the locality of its occurrence, and the methods of screening, grading, etc., employed. The relative proportion of larger or smaller particles in the materials tested is not only described in detail and diagrammatically, but is well illustrated by reproductions of photographs made to exact scale.

Considering these tests in respect to the percentage of voids, it appears that the tensile strength decreases with the increase of void spaces. The strength of the mortars is invariably much greater when made from sands having a small percentage of voids than when made from sands having a large percentage. The strength of mortars of different proportions is also greater for those sands which have a small percentage of voids. This condition is the same in regard to both tensile strength and compressive strength, and indicates that the greatest strength can be obtained by the use of mortar in which the sand is uniformly graded. The same is true of tests of transverse strength, except that the difference is not so marked as in the tensile and compressive tests (p. 57).

The tests show a greater uniformity in general when made at the end of 180 days than when made for shorter periods. The early strength appears to be easily affected by alteration in environment, and the regularity in strength for the earlier periods appears to depend on the nature of the cement.

In tests of density of mortar, it appears that the density values are greatest for the least percentage of voids, and that the weight per cubic foot and the strength are greatest under the same conditions (p. 58).

In the tests of mortars made with gravel screenings only that material which passed a $\frac{1}{4}$-inch screen was used, and this amounted as a rule to less than 40 per cent of the sample received at the laboratory. As in the description of tests of mortars made with sand, complete details are given of the diameter of the particles in inches, with numbers of sieves passed; of the place in which samples were taken; and of physical and chemical tests. In these tests there is apparently a greater lack of uniformity in the increase of strength, probably owing to physical differences in the gravel screenings. In general the tensile strength seems to increase with the decrease in percentage of voids (p. 88). This is also true of the compressive strength. There was great irregularity in the results of the tests on account of the difficulty in obtaining a thoroughly uniform mass, especially when the material was composed of coarse grains of approximately one size. In this case it invariably happened that the cement and gravel screenings occurred in many of the test pieces in streaks, the cement accumulating on one side of the neck of the test briquet, thus reducing the active section and possibly furnishing one element of weakness (p. 88).

The tests of stone screenings collected in different parts of the country were made in the same manner as those described for sand and gravel screenings. Samples were also collected as described for the other tests. The results of these tests showed that in general the mortars made from screenings that are most nearly uniform in grading have greater strength than those made from the finer screenings, farthest removed from uniform grading. Also the strength of mortars made from the samples having a lower proportion of voids is greater than that of mortars made from screenings in which the voids are greater. This appears to be true also of the compressive tests, in which the strength of the mortar is greater for samples most uniform in grade. As shown by these tests the transverse strength does not vary much after ninety days (p. 108). The tests indicate that no definite law can be given by means of which the strength of mortars made from stone screenings can be approximately foretold from the mechanical conditions, because the strength of the stone itself from which the screenings are derived has an important bearing on the strength of the resulting mortar. The same tendency was observed in the stone-screenings mortars as in the gravel-screenings mortars for the cement to concentrate at one or more parts of the test-briquet sections.

This report is the third of a series now in process of publication by the technologic branch of the Geological Survey. It is preliminary to a group of reports which describe in detail the results of tests of various structural forms made of concrete and reenforced concrete at the structural-materials testing laboratories of the Survey at St. Louis. The first volume of this series is Bulletin No. 324, a report on the effects of the San Francisco earthquake and fire on structures and structural materials. Bulletin No. 329, the second of this series, describes in detail the organization, equipment, and methods of test adopted at these laboratories. The present bulletin, as summarized above, describes the investigations leading to the adoption of a typical Portland cement for testing purposes and the tests of mortars made by mixing sand and its substitutes—gravel and broken stone screenings—with such typical cement, as an experimental study in the progress of the survey of the constituent materials of cement mortars and concrete in the United States.

A succeeding bulletin will describe tests of the solid stone from the same quarries as those from which were obtained the stone screenings on which the tests described in this volume were made. These results may afford some basis for comparison of the relative values of mortars made from the stone screenings described herein. Other reports will deal with the results of tests of the constituent materials of concrete as distinguished from those of mortars, and with the results of additional tests of the constituent materials of mortars. These papers will be followed by a preliminary report of the results of tests of plain concrete beams and of cement-mortar building blocks. The same constituent materials have also been assembled in the form of reenforced concrete beams, reenforced concrete slabs, and plain and reenforced concrete columns, many tests on which have already been completed, and the results are now in preparation for publication. Other reports in this series will include results of investigations of shear and the modulus of elasticity in tension and compression.

Parallel with this series of reports of the results of tests being made at the St. Louis laboratories there is to be published a report on the results of a series of tests made in the testing laboratories of various technological institutions. These tests were made in cooperation with the structural-materials laboratories of the United States Geological Survey and the joint committee on concrete and reenforced concrete of the engineering societies.

In the supervision of the tests herein described and in the preparation of the report Mr. Richard L. Humphrey, engineer in charge, has had the constant active assistance of Mr. William Jordan, jr., assistant engineer.

PORTLAND CEMENT MORTARS AND THEIR CONSTITUENT MATERIALS: RESULTS OF TESTS, 1905-1907.

By Richard L. Humphrey and William Jordan, Jr.

GENERAL STATEMENT.

NATURE AND EXTENT OF THE INVESTIGATIONS.

Scope of the work.—A report on the results of the series of approximately 35,000 tests made at the structural-materials testing laboratories, Forest Park, St. Louis, Mo., of a number of sands, gravel and stone screenings, gravels, and crushed stone customarily used in cement mortars and concretes will be contained in two bulletins, the present volume dealing with investigations of these materials as constituents of mortar, and a later one as constituents of concrete.

These materials were collected in many different parts of the United States and were shipped to the laboratories in double sacks in order to avoid losing any fine material. At the time the samples were collected a report was made on the nature of the supply, the location, the approximate extent of the deposit, the manner of handling, and the market supplied.

The equipment and methods used in making these tests are fully described in Bulletin No. 329. The present bulletin contains the results of approximately 25,000 tests of 22 sands, 12 gravel screenings, and 25 stone screenings in the form of mortar, using different proportions of typical Portland cement (a mixture of seven different brands).

The purpose of the investigations of the constituent materials of mortar is to ascertain as far as possible the properties of the materials collected in different parts of the country, and to establish the relation existing between the unaltered materials and the mortars in which they are used.

It is hoped that these tabulated data will afford a means for determining the probable strength of mortar made from materials having similar properties, and thus eliminate the delay in practical work incident to testing the materials which are to be used. It will also afford a means of comparison of materials used in different parts of the country.

Register numbers.—Each sample of material received at the laboratories was given a register number, a record of which was made and filed in a card index. This register number, by which the sample was known, was so chosen that it indicated the nature of the material. For example, the material was represented by the first and last letters of its name, thus: "Ct." stands for cement, "Sd." for sand, "Gl." for gravel, "Cr." for cinder, "Sg." for slag, "Se." for stone. The first sample of cement was called "Ct. 1," the next "Ct. 2," etc. When a number of brands of cement were mixed, the mixture was given a number, and each sample taken from that mixture was given a subnumber; thus the second mix of cement was called "Ct. 133," and the first sample from that mix was called "Ct. 133–1," the second "Ct. 133–2," etc.

Outline of tests.—The Portland cement used in these investigations was tested for its physical properties, including its tensile and compressive strength neat for 1, 7, 28, 90, 180, and 360 days; and with three parts of standard Ottawa sand for 7, 28, 90, 180, and 360 days.

Portions of the sands, gravel screenings, and stone screenings, all of which passed a ¼-inch screen, were sifted through Nos. 10, 20, 30, 40, 50, 80, 100, and 200 sieves; they were mixed with typical Portland cement in proportions of 1:3 and 1:4, and tested for tensile, compressive, and transverse strength at 7, 28, 90, 180, and 360 days.

In addition, when there was sufficient material of approximately one size, say between Nos. 20 and 30 sieves or between Nos. 30 and 40 sieves, tests of strength for the same periods were made on what is designated in this bulletin "1:3 one-size" mortar.

TESTS OF STRENGTH.

Storage.—The test pieces were stored in a moist closet for 24 hours prior to removal from the molds, and were then immersed in running water, maintained at approximately 70° F., until tested.

Tension.—The briquets for the tests of tensile strength are of standard form, approximately 1 square inch in section.

The Fairbanks cement-testing machine, which is used in testing these briquets, has clips with rear horizontal straps for adjusting and is provided with roller bearings. Less than 1 per cent of all briquets tested at the laboratories have broken in the clips—the great majority of the test pieces breaking fairly in the center.

Compression.—The test pieces for tests of compressive strength are 2-inch cubes and are tested generally in a 40,000-pound hydraulic hand-operated machine; the other cubes, especially of neat cement, were tested in a 200,000-pound motor-driven screw machine.

The values given in the tables of the tests of compression are in pounds per square inch, and were found by dividing the total load on a test piece by its area, taken at 4 square inches.

Transverse.—Transverse test pieces are 1 inch square in cross section and 13 inches long, and were tested on a span of 12 inches. The surfaces in contact with the vertical sides of the mold were placed in a horizontal position in the testing machine, in order to insure a uniform depth of 1 inch.

Only the breaking load applied at the center of the span was recorded. The values given in the tables are the moduli of rupture in pounds per square inch, determined from the formula $s=\frac{Mc}{I}$.

In the present case $M=3\ W$ (inch-pounds), $c=\frac{1}{2}$ inch and $I=\frac{1}{12}$; therefore

$$s=\frac{3\ W\times\frac{1}{2}}{1/12}=18\ W.$$

That is, the value given in the table is in every case just 18 times the breaking load.

Results of tests.—The results of tests are given in tables and shown graphically wherever possible.

TESTS OF CEMENT.

INDIVIDUAL BRANDS AND TYPICAL PORTLAND CEMENT.

Acknowledgment of donations.—The cement used in these investigations was generously donated by the following companies:

Alpha Portland Cement Company, Alpha, N. J.
Atlas Portland Cement Company, Hannibal, Mo.
Bonneville Portland Cement Company, Siegfried, Pa.
Iola Portland Cement Company, Iola, Kans.
Lehigh Portland Cement Company, Mitchell, Ind.
Sandusky Portland Cement Company, Sandusky, Ohio.
Vulcanite Portland Cement Company, Vulcanite, N. J.

Method of tests.—The seven brands of cement were first tested separately, and afterwards thoroughly intermixed and the mixtures carefully tested. This procedure was followed in order to determine the relation between the properties of the individual brands and the properties of the mixtures made from them. It was found that the difference was so slight that in subsequent investigations the different brands of cement were thoroughly mixed as soon as received, and the mixture is called "typical Portland cement."

Selection of samples.—The complete series of determinations of the physical properties of each brand necessitated a sample of 70 pounds from each barrel, and in order to get a representative sample the barrelful was spread on a concrete floor in a uniform layer over a space of about 8 square feet. This was marked off into 25 squares, and a portion from each square was taken in such amount as to give a 70-pound sample. Each of the 70-pound samples was spread over an 8-foot square and divided into 25 squares in the same manner as the larger samples, and a portion sufficient to give a 2-pound sample was taken from each of the smaller squares. This sample, which was given the sample register number, was placed in a glass jar and reserved for chemical analysis. This procedure gave a 68-pound sample for the physical test and a 2-pound sample for chemical analysis from each barrel.

Mixing of typical Portland cement.—The next step was to take 1 barrel (less the 70 pounds extracted) from each of the seven brands and thoroughly mix them together in a cubical mixer. This mixture was dumped on a concrete floor and spread in a layer of even thickness over about 8 square feet and was divided into 25 squares, from each of which sufficient cement was taken to make a 70-pound sample. The 70-pound sample from each mixture was given a register number and was used in the tests to represent the mixture from which it was taken. This operation was repeated ten times, since there were 10 barrels of each brand.

After the 70-pound sample had been taken from each mixture the balance was stored in hermetically sealed galvanized-iron cans, each of about 800 pounds capacity. In subsequent tests made with this mixed cement the 70-pound sample in each case is referred to as the "mix," while the mixture itself is called "typical Portland cement."

Chemical analyses.—The 2-pound sample taken from each barrel and from each mix of 7 barrels was very carefully analyzed for silica, alumina, ferric oxide, lime, magnesia, and sulphuric anhydride. In these analyses the methods recommended by the committee on uniformity in the technical analysis of materials for the Portland cement industry of the New York section of the Society for Chemical Industry were used, with the following exceptions: The silica was not purified with HFl and H_2SO_4; the precipitated iron and aluminum hydrates were dissolved in dilute HNO_3 instead of dilute HCl; the ignited CaO was dissolved in dilute HCl before precipitation; the magnesium was precipitated from a HNO_3 solution the second time; lastly, the SiO_2 was not determined in the ignited $(FeAl)_2O_3$.

The results of the chemical analyses are given in Table I. The seven different brands are designated A, B, C, D, E, F, and G, and at the close the 10 mixes are indicated.

TABLE I.—*Chemical analyses of seven Portland cements and resulting mixtures (results in per cent).*

Brand.	Register No.	SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	SO_3.	Undeter.
A	Ct. 1	22.03	7.72	3.26	62.66	2.42	1.13	0.78
	Ct. 2	22.12	7.43	3.23	62.33	2.31	1.21	1.37
	Ct. 13	22.19	7.15	3.35	62.60	2.28	1.14	1.29
	Ct. 17	21.80	7.01	3.66	62.45	2.44	1.27	1.37
	Ct. 21	21.75	7.09	3.56	62.68	2.47	1.14	1.31
	Ct. 34	21.90	6.97	3.48	62.51	2.32	1.23	1.59
	Ct. 41	21.87	6.82	3.57	62.59	2.25	1.14	1.76
	Ct. 48	22.14	7.56	3.23	62.45	2.34	1.27	1.01
	Ct. 55	21.99	7.45	3.23	62.47	2.42	1.15	1.29
	Ct. 62	22.12	7.15	3.33	62.53	2.48	1.23	1.16
	Average	21.99	7.24	3.39	62.53	2.37	1.19	1.29
B	Ct. 3	20.86	7.76	2.38	62.92	2.51	1.61	1.96
	Ct. 7	20.96	7.48	2.63	62.60	2.56	1.70	2.07
	Ct. 14	21.05	7.60	2.53	62.64	2.33	1.60	2.25
	Ct. 22	20.56	7.67	2.48	62.53	3.08	1.75	1.93
	Ct. 23	21.04	7.48	2.63	62.66	2.49	1.57	2.13
	Ct. 35	20.54	7.96	2.72	62.79	2.35	1.61	2.03
	Ct. 42	20.34	8.07	2.57	63.05	2.41	1.74	1.82
	Ct. 19	20.21	7.19	2.67	62.77	2.62	1.71	2.83
	Ct. 56	21.11	7.95	2.67	62.77	2.85	1.60	1.05
	Ct. 63	20.86	8.02	2.68	62.75	2.88	1.66	1.15
	Average	20.75	7.72	2.59	62.75	2.61	1.66	1.92
C	Ct. 4	20.83	8.38	2.49	63.23	3.20	1.35	.52
	Ct. 8	21.08	7.75	2.73	62.92	3.13	1.48	.91
	Ct. 15	21.04	8.08	2.58	63.32	3.19	1.42	.37
	Ct. 24	20.84	7.89	2.78	62.92	2.82	1.44	1.31
	Ct. 27	21.31	7.70	3.07	63.20	2.54	1.50	.68
	Ct. 36	20.60	8.27	2.58	63.03	2.86	1.55	1.11
	Ct. 43	21.01	7.75	2.57	63.03	2.67	1.47	1.50
	Ct. 50	20.95	7.98	2.53	62.51	2.78	1.40	1.85
	Ct. 57	20.52	7.63	3.07	62.89	2.69	1.49	1.71
	Ct. 64	20.66	7.68	2.57	62.79	2.62	1.48	2.20
	Average	20.88	7.91	2.69	62.98	2.85	1.46	1.22
D	Ct. 5	21.56	8.48	3.11	62.41	2.21	1.53	.70
	Ct. 9	21.50	8.27	3.23	62.43	2.21	1.60	.76
	Ct. 16	21.65	8.34	2.97	62.46	2.64	1.55	.39
	Ct. 25	21.38	8.42	2.87	62.58	2.27	1.39	1.09
	Ct. 30	21.93	7.46	3.23	62.64	2.46	1.53	.75
	Ct. 37	21.57	8.01	3.37	62.62	2.17	1.47	.79
	Ct. 44	21.93	7.46	3.23	62.64	2.40	1.53	.81
	Ct. 51	21.33	7.55	3.16	62.49	2.45	1.57	1.45
	Ct. 58	21.56	7.32	3.26	62.65	2.43	1.51	1.27
	Ct. 65	21.68	7.48	3.42	62.69	2.46	1.54	.73
	Average	21.61	7.88	3.18	62.56	2.37	1.52	.87

Brand.	Register No.	SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	SO_3.	Undeter.
E	Ct. 6	23.33	5.26	3.37	63.01	2.96	1.14	0.93
	Ct. 10	23.30	5.61	2.83	63.10	2.90	1.11	1.15
	Ct. 18	23.48	5.29	3.22	63.19	3.03	1.41	.38
	Ct. 26	23.34	5.46	3.17	63.05	3.10	1.33	.55
	Ct. 31	23.40	5.03	3.42	63.31	2.92	1.42	.50
	Ct. 38	22.86	5.40	3.42	63.44	3.20	1.35	.33
	Ct. 45	22.77	5.53	3.27	63.24	2.79	1.40	1.00
	Ct. 52	23.10	5.37	3.27	63.28	3.05	1.32	.61
	Ct. 59	23.30	5.24	3.37	63.01	3.05	1.42	.61
	Ct. 66	23.62	5.05	3.37	62.74	3.14	1.26	.82
	Average	23.25	5.32	3.27	63.14	3.01	1.32	.69
F	Ct. 11	22.32	7.29	2.98	62.38	1.62	1.66	1.75
	Ct. 19	22.21	7.24	2.92	62.30	1.28	1.49	2.56
	Ct. 28	22.14	7.14	3.01	62.21	1.38	1.66	2.46
	Ct. 32	21.90	7.19	2.97	62.41	1.36	1.37	2.80
	Ct. 39	22.18	7.48	3.09	62.35	1.72	1.57	1.61
	Ct. 46	22.34	7.41	3.04	62.45	1.75	1.64	1.37
	Ct. 53	21.94	7.90	3.08	62.43	1.74	1.65	1.26
	Ct. 60	22.04	7.18	3.04	62.36	1.78	1.61	1.99
	Ct. 67	22.15	7.08	3.04	62.37	1.82	1.55	1.99
	Average	22.14	7.32	3.02	62.36	1.61	1.58	1.98
G	Ct. 12	22.50	6.65	2.89	60.04	3.20	1.95	2.77
	Ct. 20	23.04	6.70	2.66	60.18	3.25	1.83	2.34
	Ct. 29	22.78	6.80	2.58	59.96	3.29	1.80	2.79
	Ct. 33	22.84	6.97	2.51	59.96	3.35	1.90	2.47
	Ct. 40	22.30	7.25	2.84	60.98	3.20	1.40	2.03
	Ct. 47	21.92	7.21	2.88	60.88	3.21	1.47	2.43
	Ct. 54	22.92	6.78	3.04	60.18	3.28	1.70	2.10
	Ct. 61	22.26	7.12	2.84	60.82	3.09	1.52	2.35
	Ct. 68	24.90	7.03	2.88	60.80	3.14	1.54	2.71
	Average	22.47	6.94	2.79	60.42	3.23	1.67	2.44
	Average A–G	21.86	7.19	2.99	62.42	2.58	1.48	1.47
Mix. 1	Ct. 69	22.28	6.92	3.11	62.89	2.81	1.40	.59
2	Ct. 70	22.16	6.65	3.07	62.44	2.77	1.43	1.48
3	Ct. 71	21.81	6.81	3.27	62.79	2.62	1.38	1.32
4	Ct. 72	22.34	6.92	3.22	62.60	2.71	1.47	.74
5	Ct. 73	22.10	6.94	3.12	62.80	2.66	1.47	.91
6	Ct. 74	22.18	6.71	3.17	62.70	2.55	1.41	1.28
7	Ct. 75	21.80	6.66	3.27	62.67	2.62	1.42	1.56
8	Ct. 76	21.79	6.77	3.32	62.90	2.45	1.40	1.37
9	Ct. 77	21.61	6.69	3.31	62.67	2.52	1.60	1.60
10	Ct. 78	21.98	6.75	3.22	62.89	2.69	1.65	.82
	Average	22.01	6.78	3.21	62.74	2.64	1.46	1.17

The register number given each sample is the same as that used in later tables giving the results of the physical tests, so that the chemical analysis of any particular sample can be compared with the physical properties of the cement from which the sample for chemical analysis was taken. But 9 samples of each of brands F and G were used, making a total of 68 samples of the individual brands and 10 samples of typical Portland cement analyzed and recorded in the table.

The average values for each brand are given at the bottom of its group, and the average value for the seven brands is given near the end of the table. For purposes of comparison, the average values for the 10 samples of typical Portland cement are also given in the last line. The small difference between the averages of the 68 samples, designated "Average A–G," and the averages of the 10 samples of typical Portland cement indicates that the typical Portland cements are representative of the individual brands.

PHYSICAL DETERMINATIONS.

Method.—A portion of the 68-pound sample taken from each of 68 barrels and from each of the 10 mixtures was subjected to the usual physical tests, consisting of determinations of specific gravity, temperatures of water and air, per cent of water for normal consistency, time of initial and final setting, fineness, constancy of volume (soundness), and the tensile and compressive strengths. The physical determinations were made at about the time of mixing the cements and before they were stored, and are given in Table II.

TABLE IIa.—*General physical properties of seven Portland cements and resulting mixtures.*

Brand.	Register No.	Specific gravity.	Temperature (° F.).		Water (per cent).	Time of set (minutes).				Fineness—per cent residue on sieve No.—		Soundness.
						By Vicat apparatus.		By Gilmore apparatus				
			Water.	Air.		Initial.	Final.	Initial.	Final.	100	200	
1	2	3	4	5	6	7	8	9	10	11	12	13
A	Ct. 1	3.116	76.2	79.0	20.5	119	307	120	280	7.5	23.9	Perfectly sound.
A	Ct. 2	3.102	76.1	78.0	20.3	119	307	124	296	7.7	24.3	
A	Ct. 13	3.108	76.1	79.2	20.5	77	364	214	379	7.6	24.2	Pat A warped $\frac{1}{32}$ inch.
A	Ct. 17	3.120	77.7	80.4	21.0	162	302	227	302	7.3	24.0	Do.
A	Ct. 21	3.148	76.2	80.1	21.0	132	349	234	357	7.7	24.0	Perfectly sound
A	Ct. 34	3.120	79.3	82.6	21.0	133	303	228	336	7.9	24.0	Do.
A	Ct. 41	3.164	73.4	70.3	21.0	150	345	210	375	6.9	24.8	Do.
A	Ct. 48	3.101	71.6	71.8	21.0	223	378	243	408	8.0	24.6	Do.
A	Ct. 55	3.115	73.6	77.4	21.5	172	362	207	387	7.0	24.4	Do.
A	Ct. 62	3.137	69.8	71.8	21.5	130	365	343	457	7.8	24.9	Do.
A	Average	3.123	75.0	77.1	20.9	142	338	215	358	7.5	24.3	
B	Ct. 3	3.100	76.4	80.0	22.5	57	180	140	246	1.0	14.1	Do.
B	Ct. 7	3.100	75.8	77.1	22.5	90	209	166	294	.7	13.8	Do.
B	Ct. 14	3.110	76.4	82.3	22.0	53	235	160	315	.6	17.4	Pat A warped $\frac{1}{32}$ inch.
B	Ct. 22	3.100	77.7	80.4	22.5	129	354	189	384	1.2	14.5	Perfectly sound.
B	Ct. 23	3.105	76.9	79.2	22.5	104	266	211	300	.9	14.5	Do.
B	Ct. 35	3.105	73.6	66.1	22.5	145	295	170	320	.8	15.4	Do.
B	Ct. 42	3.100	73.4	70.3	22.5	115	302	222	385	1.8	17.0	Do.
B	Ct. 49	3.100	71.8	70.4	22.5	155	325	230	380	1.0	16.0	Do.
B	Ct. 56	3.110	73.6	77.4	22.5	110	290	157	290	1.0	15.5	Do.
B	Ct. 63	3.110	71.6	73.8	22.5	215	277	277	307	1.0	13.4	Pat A warped $\frac{1}{16}$ inch.
B	Average	3.103	74.7	75.7	22.5	117	273	195	322	1.0	15.2	
C	Ct. 4	3.132	75.9	77.0	22.0	129	305	174	298	6.4	22.2	Perfectly sound.
C	Ct. 8	3.125	76.4	78.0	22.0	154	284	190	284	7.8	21.4	Do.
C	Ct. 15	3.140	76.0	82.3	22.0	99	318	249	387	7.2	23.3	Do.
C	Ct. 24	3.101	77.2	80.4	22.0	214	266	274	314	6.4	24.7	Pat A warped $\frac{1}{32}$ inch.
C	Ct. 27	3.150	78.8	81.0	22.0	120	347	240	355	6.8	25.6	Perfectly sound.
C	Ct. 36	3.155	73.6	66.1	22.0	180	290	250	320	6.0	24.8	Do.
C	Ct. 43	3.160	73.6	71.6	22.0	163	378	263	407	6.9	25.0	Do.
C	Ct. 50	3.100	71.8	74.0	22.0	200	406	293	435	6.0	23.5	Do.
C	Ct. 57	3.105	70.2	69.8	22.0	223	373	262	438	6.0	23.4	Do.
C	Ct. 64	3.125	71.6	73.8	22.0	205	290	270	370	6.4	22.4	Do.
C	Average	3.129	74.5	75.0	22.0	169	326	249	361	6.6	23.5	

TABLE IIa.—*General physical properties of seven Portland cements and resulting mixtures*—Continued.

Brand.	Register No.	Specific gravity.	Temperature (° F.).		Water (per cent).	Time of set (minutes).				Fineness—per cent residue on sieve No.—		Soundness.
						By Vicat apparatus.		By Gilmore apparatus.				
			Water.	Air.		Initial.	Final.	Initial.	Final.	100	200	
1	2	3	4	5	6	7	8	9	10	11	12	13
D	Ct. 5	3.150	76.2	77.4	21.0	146	276	184	277	7.4	24.6	Pat A warped 1/16 inch.
D	Ct. 9	3.119	76.3	80.0	21.0	124	324	242	379	7.4	24.8	Do.
D	Ct. 16	3.140	76.7	83.2	21.0	95	320	225	365	7.8	24.6	Perfectly sound.
D	Ct. 25	3.107	77.1	81.2	21.0	214	305	229	374	7.7	23.8	Do.
D	Ct. 30	3.145	78.8	81.0	21.0	107	336	242	342	7.5	25.0	Do.
D	Ct. 37	3.117	73.4	71.6	21.0	185	325	215	380	7.4	24.7	Do.
D	Ct. 44	3.118	73.6	71.6	21.0	132	377	292	397	7.3	24.1	Do.
D	Ct. 51	3.132	71.6	72.1	21.0	270	445	315	492	7.6	24.6	Do.
D	Ct. 58	3.121	70.2	69.8	21.0	203	386	247	450	7.8	24.9	Do.
D	Ct. 65	3.117	70.2	69.4	21.0	210	473	248	470	7.7	23.6	Do.
D	Average	3.127	74.4	75.7	21.0	169	357	244	393	7.6	24.5	
E	Ct. 6	1.195	76.1	78.0	20.5	182	362	290	422	7.5	24.1	Do.
E	Ct. 10	3.111	76.6	79.0	20.5	148	293	168	298	7.7	24.9	Pat A warped 1/16 inch.
E	Ct. 18	3.154	76.2	79.1	21.0	193	388	275	455	7.2	24.0	Perfectly sound.
E	Ct. 26	3.121	77.1	79.1	21.0	201	370	258	421	7.5	25.0	Do.
E	Ct. 31	3.112	78.8	85.8	21.0	190	415	203	411	7.0	24.4	Do.
E	Ct. 38	3.148	73.4	71.6	21.0	198	348	243	388	6.4	23.8	Do.
E	Ct. 45	3.148	71.6	71.6	21.5	240	380	340	440	7.1	25.0	Do.
E	Ct. 52	3.143	71.6	72.1	21.5	270	480	270	490	7.2	24.2	Do.
E	Ct. 59	3.181	72.0	69.8	21.5	293	480	293	493	7.0	24.3	Do.
E	Ct. 66	3.169	70.2	69.4	21.5	217	457	265	443	7.4	24.3	Do.
E	Average	3.148	74.4	75.6	21.1	213	397	261	426	7.2	24.4	
F	Ct. 11	3.108	76.2	80.1	21.5	118	318	193	320	6.6	22.0	Pat A warped 1/32 inch.
F	Ct. 19	3.102	75.4	78.2	21.5	131	269	194	314	7.8	21.6	Perfectly sound.
F	Ct. 28	3.110	76.3	77.4	21.5	102	415	224	386	6.4	21.2	Pat A warped 1/16 inch.
F	Ct. 32	3.105	78.8	85.8	21.5	107	272	159	330	6.0	20.0	Perfectly sound.
F	Ct. 39	3.100	73.4	69.8	21.5	127	302	232	389	6.0	20.0	Pat A warped 1/32 inch.
F	Ct. 46	3.105	71.6	71.6	21.5	160	354	229	404	6.3	20.7	Perfectly sound.
F	Ct. 53	3.108	73.2	74.8	21.5	162	347	212	452	6.0	21.1	Pat A warped 1/32 inch.
F	Ct. 60	3.103	72.0	69.8	21.5	253	328	225	383	6.0	20.2	Perfectly sound.
F	Ct. 67	3.100	70.2	69.4	21.5	138	399	220	399	6.0	20.7	Do.
F	Average	3.104	74.1	75.2	21.5	144	334	210	375	6.3	20.7	

G	Ct. 12	3.100	75.8	81.0	21.0	106	233	190	275	4.0	23.1	Do.
	Ct. 20	3.100	77.1	80.2	21.0	174	354	219	359	6.4	21.2	Do.
	Ct. 29	3.100	76.3	78.1	20.5	95	346	225	388	4.9	23.0	Do.
	Ct. 33	3.115	79.3	82.6	21.0	73	313	223	388	4.8	24.5	Do.
	Ct. 40	3.100	73.4	69.8	21.0	152	363	215	403	4.4	24.8	Do.
	Ct. 47	3.105	71.6	71.8	20.5	205	400	265	430	4.6	24.0	Do.
	Ct. 54	3.100	73.2	74.8	20.5	145	340	200	442	4.5	23.1	Do.
	Ct. 61	3.106	69.8	71.8	20.5	142	370	242	452	4.9	23.3	Do.
	Ct. 68	3.100	70.0	66.9	20.5	185	397	216	453	4.9	24.1	Do.
	Average	3.103	74.1	75.2	20.7	142	346	222	399	4.8	23.4	
	Average A–G	3.120	74.5	75.7	21.4	156	339	228	376	5.9	22.3	
Mix. 1	Ct. 69	3.115	66.9	70.0	21.5	167	379	198	378	7.0	24.9	Do.
2	Ct. 70	3.120	66.9	70.0	22.5	235	422	250	430	7.3	24.7	Do.
3	Ct. 71	3.106	68.0	70.0	21.0	210	380	280	465	6.7	24.3	Do.
4	Ct. 72	3.120	68.0	70.0	21.0	195	385	260	445	6.7	24.7	Do.
5	Ct. 73	3.126	68.0	70.0	21.0	157	337	237	427	6.1	24.7	Do.
6	Ct. 74	3.119	71.2	72.3	21.5	209	368	253	430	6.9	24.7	Do.
7	Ct. 75	3.125	71.2	72.3	21.5	237	387	287	457	6.5	24.3	Do.
8	Ct. 76	3.127	71.2	72.3	21.5	220	395	270	445	7.1	24.5	Do.
9	Ct. 77	3.149	72.3	74.1	21.5	185	370	215	415	6.2	22.4	Do.
10	Ct. 78	3.116	72.3	74.1	21.5	182	402	227	449	5.2	23.8	Do.
	Average	3.122	69.6	71.5	21.5	200	383	248	434	6.6	24.3	

TABLE II*b*.—*Tensile strengths of seven Portland cements and resulting mixtures, neat and in standard mortar.*

Brand.	Register No.	Temperature (° F.).		Neat.							1:3 standard-sand mortar.					
				Water (per cent).	Tensile strength (pounds per square inch).						Water (per cent).	Tensile strength (pounds per square inch).				
		Water.	Air.		1 day.	7 days.	28 days.	90 days.	180 days	360 days		7 days.	28 days.	90 days.	180 days	360 days
1	2	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
A	Ct. 1	76.2	79.0	20.5	334	726	769	988	947	806	9.4	290	342	498	429	462
	Ct. 2	76.1	78.0	20.3	349	783	926	1,103	1,079	786	8.9	268	329	480	505	367
	Ct. 13	76.1	79.2	20.5	289	713	860	1,012	925	645	8.9	254	332	492	482	397
	Ct. 17	77.7	80.4	21.0	352	676	844	909	857	741	9.0	256	350	497	468	366
	Ct. 21	76.2	80.1	21.0	322	714	862	989	937	687	9.0	244	410	468	577	410
	Ct. 34	79.3	82.6	21.0	256	534	831	994	896	645	9.0	196	266	433	429	320
	Ct. 41	73.4	70.3	21.0	158	581	849	977	989	770	9.0	169	350	484	440	336
	Ct. 48	71.6	71.8	21.0	288	646	884	940	965	664	9.0	271	401	550	502	360
	Ct. 55	73.6	77.4	21.5	281	599	810	943	914	673	9.1	241	391	475	501	351
	Ct. 62	69.8	71.8	21.5	233	637	766	981	955	752	9.1	233	327	515	505	318
	Average	75.0	77.1	20.9	286	661	840	984	946	717	9.0	242	350	489	484	369
B	Ct. 3	76.4	80.0	22.5	530	820	725	955	955	669	9.3	310	323	510	522	388
	Ct. 7	75.8	77.1	22.5	588	872	787	840	834	618	9.3	297	334	493	485	357
	Ct. 14	76.4	82.3	22.0	569	821	833	861	1,042	659	9.2	308	349	510	486	416
	Ct. 22	77.7	80.4	22.5	629	766	727	863	638	651	9.3	280	355	517	310	376
	Ct. 23	76.9	79.2	22.5	464	718	801	961	852	569	9.3	277	348	458	497	410
	Ct, 35	73.6	66.1	22.5	360	762	786	903	893	604	9.3	323	386	529	485	415
	Ct, 42	73.4	70.3	22.5	316	764	673	907	857	726	9.3	306	404	568	520	348
	Ct. 49	71.8	70.4	22.5	390	616	767	865	873	637	9.3	317	409	555	506	355
	Ct. 56	73.6	77.4	22.5	418	724	759	880	898	618	9.3	319	370	508	507	382
	Ct. 63	71.6	73.8	22.5	424	656	902	908	942	704	9.3	292	476	473	505	331
	Average	74.7	75.7	22.5	469	752	776	894	878	646	9.3	303	375	512	482	378
C	Ct. 4	75.9	77.0	22.0	437	760	785	942	962	687	9.2	356	360	497	510	358
	Ct. 8	76.4	78.0	22.0	380	754	748	916	905	646	9.2	302	351	491	456	352
	Ct. 15	76.0	82.3	22.0	437	715	760	931	987	822	9.2	349	372	509	512	359
	Ct. 24	77.2	80.4	22.0	428	664	669	970	944	670	9.2	324	393	492	511	379
	Ct. 27	78.8	81.0	22.0	401	699	803	958	962	603	9.2	272	371	525	498	343
	Ct. 36	73.6	66.1	22.0	332	725	818	940	972	644	9.2	303	392	536	518	351
	Ct. 43	73.6	71.6	22.0	307	662	835	1,004	938	748	9.2	309	392	517	506	374
	Ct. 50	71.8	70.4	22.0	326	587	809	931	944	583	9.2	307	397	525	527	358
	Ct. 57	70.2	69.8	22.0	327	684	851	949	916	644	9.2	298	414	536	522	324
	Ct. 64	71.6	73.8	22.0	305	656	975	929	850	698	9.2	276	458	511	488	322
	Average	74.5	75.0	22.0	368	691	805	947	938	675	9.2	310	390	514	505	352

D	Ct. 5	76.2	77.4	21.0	396	734	786	977	1,035	716	9.0	322	345	541	545	360
	Ct. 9	76.3	80.0	21.0	377	709	753	750	911	694	9.0	301	368	511	511	369
	Ct. 16	76.7	83.2	21.0	394	701	604	984	967	648	9.0	276	372	502	519	385
	Ct. 25	77.1	81.2	21.0	255	703	863	984	937	692	9.0	315	403	504	488	398
	Ct. 30	78.8	81.0	21.0	364	671	716	984	986	623	9.0	242	379	525	557	344
	Ct. 37	73.4	71.6	21.0	258	586	810	927	973	773	9.0	262	383	515	520	327
	Ct. 44	73.6	71.6	21.0	278	649	787	958	962	710	9.0	304	341	527	501	391
	Ct. 51	71.6	72.1	21.0	319	616	843	981	1,005	690	9.0	277	387	507	532	327
	Ct. 58	70.2	69.8	21.0	322	674	804	1,017	973	817	9.0	284	400	543	514	371
	Ct. 65	70.2	69.4	21.0	253	658	960	907	972	749	9.3	215	474	513	443	500
	Average	74.4	75.7	21.0	322	670	793	947	972	711	9.0	280	385	519	513	377
E	Ct. 6	76.1	78.0	20.5	429	739	815	1,009	1,017	756	8.9	243	334	506	527	361
	Ct. 10	76.6	79.0	20.5	318	680	808	968	1,019	797	8.9	235	376	504	439	349
	Ct. 28	76.2	79.1	21.0	376	645	936	1,050	1,055	689	9.0	276	374	506	508	408
	Ct. 26	77.1	79.9	21.0	343	707	914	985	984	712	9.0	253	348	528	480	352
	Ct. 31	78.8	85.8	21.0	424	581	741	978	944	733	9.0	232	363	478	515	346
	Ct. 38	73.4	71.6	21.0	314	590	907	1,033	1,071	815	9.0	205	367	496	520	359
	Ct. 45	71.6	71.6	21.5	281	574	857	1,037	985	820	9.1	204	313	510	488	343
	Ct. 52	71.6	72.1	21.5	313	593	839	950	1,042	864	9.1	211	323	508	533	334
	Ct. 59	72.0	69.8	21.5	250	550	823	1,010	1,052	888	9.1	181	305	485	465	341
	Ct. 66	70.2	69.4	21.5	272	557	960	1,042	970	770						
	Average	74.4	75.6	21.1	338	622	860	1,016	1,021	784	9.0	227	345	502	497	355
F	Ct. 11	76.3	80.1	21.5	404	676	751	926	873	659	9.1	341	364	516	478	396
	Ct. 19	75.4	78.2	21.5	411	628	828	937	909	577	9.1	313	435	465	477	391
	Ct. 28	76.3	77.4	21.5	396	764	857	943	823	602	9.1	310	396	457	466	359
	Ct. 32	76.8	86.8	21.5	441	736	717	735	821	616	9.1	315	389	507	495	339
	Ct. 39	73.4	69.8	21.5	318	660	772	951	928	707	9.1	323	411	500	518	332
	Ct. 46	71.6	71.6	21.5	391	572	775	967	893	653	9.1	249	415	503	491	354
	Ct. 53	73.2	74.8	21.5	323	738	865	951	962	627	9.1	285	430	490	497	326
	Ct. 60	72.0	69.8	21.5	402	689	785	965	828	541	9.1	300	408	495	497	356
	Ct. 67	70.2	69.4	21.5	354	756	932	983	878	578	9.4	192	433	499	419	407
	Average	74.1	75.3	21.5	382	691	809	929	879	618	9.1	292	409	492	482	362
G	Ct. 12	79.8	81.0	21.0	426	623	728	936	975	744	9.0	251	307	509	394	379
	Ct. 20	77.1	80.2	21.0	473	566	721	929	928	642	9.0	251	311	523	525	379
	Ct. 29	76.3	78.1	20.5	447	663	810	916	846	653	8.9	257	323	498	515	365
	Ct. 33	79.3	82.6	21.0	455	553	765	807	916	658	9.0	199	354	538	515	381
	Ct. 40	73.4	69.8	21.0	324	561	807	877	961	709	9.0	209	321	487	471	327
	Ct. 47	71.6	71.8	20.5	400	636	736	930	955	774	8.9	222	365	490	499	381
	Ct. 54	73.2	74.8	20.5	376	589	715	905	865	724	8.9	247	355	525	534	369
	Ct. 61	69.8	71.8	20.5	381	543	766	936	878	810	8.9	193	328	416	480	349
	Ct. 68	70.0	66.9	20.5	319	606	876	922	907	744						
	Average	74.1	75.2	20.7	400	593	769	906	915	718	9.0	229	333	504	492	366
	Average A–G	74.5	75.7	21.4	262	669	808	945	937	696	9.1	270	370	505	494	366

TABLE IIb.—*Tensile strengths of seven Portland cements and resulting mixtures, neat and in standard mortar*—Continued.

Brand.	Register No.	Temperature (°F.).		Neat.							1:3 standard-sand mortar.					
				Water (per cent).	Tensile strength (pounds per square inch).						Water (per cent).	Tensile strength (pounds per square inch).				
		Water.	Air.		1 day.	7 days.	28 days.	90 days.	180 days	360 days		7 days.	28 days.	90 days.	130 days	360 days
1	2	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Mix. 1	Ct. 69	66.9	70.0	21.5	300	685	872	962	952	776	9.4	248	491	527	455	466
2	Ct. 70	66.9	70.0	22.5	305	686	781	893	933	769	9.4	192	420	539	424	491
3	Ct. 71	68.0	70.0	21.0	366	708	870	954	966	712	9.3	208	472	481	418	473
4	Ct. 72	68.0	70.0	21.0	355	662	824	917	968	658	......	......	......	......	......	......
5	Ct. 73	68.0	70.0	21.0	334	771	878	921	929	663	......	......	......	......	......	......
6	Ct. 74	71.2	72.3	21.5	343	683	864	934	923	657	9.1	206	415	439	423	437
7	Ct. 75	71.2	72.3	21.5	346	644	846	998	988	718	9.4	206	448	464	450	466
8	Ct. 76	71.2	72.3	21.5	370	580	857	922	948	770	9.4	212	463	557	413	430
9	Ct. 77	72.3	74.1	21.5	363	682	850	962	999	752	9.4	217	463	560	446	439
10	Ct. 78	72.3	74.1	21.5	292	669	873	924	888	752	......	......	......	......	......	......
	Average	69.6	71.5	21.5	337	677	852	939	949	723	9.4	213	453	510	433	457

TABLE 11c.—*Compressive strengths of seven Portland cements and resulting mixtures, neat and in standard mortar.*

Brand.	Register No.	Neat.									1:3 standard-sand mortar.							
		Temperature (° F.).		Water (per cent).	Compressive strength (pounds per square inch).						Temperature (° F.).		Water (per cent).	Compressive strength (pounds per square inch).				
		Water.	Air.		1 day.	7 days.	28 days.	90 days.	180 days.	360 days.	Water.	Air.		1 day.	28 days.	90 days.	180 days.	360 days.
1	2	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
A	Ct. 1	79.2	79.0	20.5	....	6,371	8,531	13,237	15,292	11,631	....	....	....	....	....	....	....	....
	Ct. 2	77.7	80.4	20.3	1,262	6,084	9,427	12,319	13,367	12,616	78.8	81.0	8.9	985	1,776	2,439	2,617	2,367
	Ct. 13	73.2	74.8	20.5	983	4,957	8,308	8,653	12,176	12,534	73.6	77.4	8.9	1,022	1,633	3,213	3,611	3,125
	Ct. 17	70.9	72.3	21.0	1,739	6,402	9,724	11,334	12,653	12,756	70.5	59.0	9.0	1,287	1,521	2,603	2,375	4,012
	Ct. 21	70.7	70.0	21.0	1,395	6,961	8,877	9,369	10,888	11,537	68.0	70.0	9.0	1,328	1,554	2,918	3,009	3,562
	Ct. 34	65.8	64.1	21.0	424	3,283	5,875	9,291	10,161	11,358	70.7	61.7	9.0	594	1,554	2,344	2,609	3,987
	Ct. 41	66.0	73.0	21.0	418	3,917	8,090	9,445	10,208	8,346	70.7	68.0	9.0	1,184	1,298	2,870	3,045	3,208
	Ct. 48	69.8	68.3	21.0	304	3,221	5,463	10,475	10,829	12,559	....	....	....	....	....	....	....	....
	Ct. 55	70.5	64.6	21.5	298	2,138	6,114	9,194	9,500	11,318	....	....	....	....	....	....	....	....
	Ct. 62	69.8	68.0	21.5	305	3,009	5,558	9,390	11,346	10,495	....	....	....	....	....	....	....	....
	Average	71.1	71.5	20.9	792	4,634	7,597	10,271	11,642	11,515	72.1	69.5	9.0	1,067	1,556	2,731	2,878	3,377
B	Ct. 7	78.8	85.8	22.5	2,063	5,994	6,311	9,747	10,116	11,093	79.3	82.6	9.3	1,048	1,751	2,228	2,435	3,367
	Ct. 14	70.2	69.8	22.0	1,570	5,996	8,559	8,497	8,927	9,338	....	....	....	....	....	....	....	....
	Ct. 22	70.9	69.4	22.5	2,203	5,545	7,191	9,055	10,360	10,896	70.5	59.0	9.3	1,152	2,369	3,174	2,794	4,750
	Ct. 23	71.2	72.3	22.5	2,166	6,209	6,468	9,504	9,511	10,073	....	....	....	....	....	....	....	....
	Ct. 35	66.2	66.5	22.5	1,122	5,717	9,426	10,301	11,421	11,384	70.7	61.4	9.3	1,131	1,459	3,093	3,725	4,067
	Ct. 42	65.0	66.7	22.5	905	4,563	8,656	11,531	11,150	11,449	....	....	....	....	....	....	....	....
	Ct. 49	69.8	68.0	22.5	1,208	3,799	7,997	10,168	10,942	11,390	70.7	69.8	9.4	1,103	1,245	2,497	3,417	2,642
	Ct. 56	70.5	64.6	22.5	1,229	4,946	8,470	8,979	10,662	13,774	69.8	68.0	9.6	982	2,850	3,542	3,267	4,675
	Ct. 63	69.8	68.0	22.5	858	3,951	6,224	9,942	10,949	11,268	69.8	69.8	9.6	1,069	2,596	3,651	3,667	4,308
	Average	70.3	70.1	22.4	1,480	5,191	7,700	9,747	10,449	11,185	71.8	68.4	9.4	1,081	2,045	3,041	3,167	3,968
C	Ct. 4	76.2	80.1	22.0	....	8,503	10,683	12,196	11,054	10,970	76.2	79.1	9.2	1,379	3,052	3,900	4,048	4,217
	Ct. 8	73.6	66.1	22.0	1,667	8,131	13,064	9,971	14,794	12,896	73.4	71.6	9.2	1,568	3,304	3,608	3,507	3,658
	Ct. 15	72.0	69.8	22.0	1,200	6,832	7,141	9,943	10,904	9,905	....	....	....	....	....	....	....	....
	Ct. 24	72.3	74.0	22.0	1,508	8,121	7,360	11,996	10,184	12,079	70.7	60.0	9.2	1,664	3,108	2,830	3,642	3,777
	Ct. 27	66.2	67.6	22.0	1,153	7,804	11,168	11,855	11,874	13,228	70.0	64.0	9.2	1,515	3,014	3,703	3,505	3,825
	Ct. 36	65.8	66.2	22.0	1,151	6,934	8,622	10,236	12,000	10,704	70.7	61.7	9.2	1,157	3,142	3,220	3,483	4,295
	Ct. 43	70.3	68.7	22.0	1,222	6,288	9,717	11,763	11,730	11,827	....	....	....	....	....	....	....	....
	Ct. 50	69.8	68.0	22.0	642	5,821	8,967	10,038	12,351	11,975	69.8	68.0	9.5	1,397	1,928	2,845	3,245	3,983
	Ct. 57	70.5	64.6	22.0	1,012	5,080	7,803	10,912	12,642	13,485	69.8	69.8	9.5	1,412	2,333	4,084	3,425	4,300
	Ct. 64	71.7	61.0	22.0	717	4,887	6,828	11,732	12,839	14,084	71.7	61.0	9.5	1,383	2,500	3,815	4,338	4,833
	Average	70.8	68.6	22.0	1,141	6,840	9,135	11,064	12,037	12,115	71.5	66.9	9.3	1,434	2,798	3,501	3,649	4,111

TABLE IIc.—*Compressive strengths of seven Portland cements and resulting mixtures, neat and in standard mortar*—Continued.

Brand.	Register No.	Neat.									1:3 standard-sand mortar.							
		Temperature (° F.).		Water (per cent).	Compressive strength (pounds per square inch).						Temperature (° F.).		Water (per cent).	Compressive strength (pounds per square inch.)				
		Water.	Air.		1 day.	7 days.	28 days.	90 days.	180 days.	360 days.	Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
1	2	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
D	Ct. 5	77.1	80.2	21.0		6,332	12,952	12,232	15,276	16,146	76.9	79.2	9.0	1,066	3,105	3,917	4,337	4,384
	Ct. 9	73.4	69.8	21.0	1,349	9,015	12,021	11,996	13,154	16,690	73.4	70.3	9.0	1,898	3,545	3,677	4,406	3,308
	Ct. 16	69.8	71.8	21.0	1,132	6,321	9,520	12,246	11,413	12,440	71.8	61.6	9.0	1,155	1,850			
	Ct. 25	69.1	68.0	21.0	1,831	9,511	12,874	11,281	12,719	11,430	70.7	60.0	9.0	1,845	3,233	2,689	2,909	3,375
	Ct. 30	63.5	59.0	21.0	605	6,623	9,375	12,138	12,538	16,386	70.0	64.0	9.0	1,290	3,344	3,363	2,825	3,100
	Ct. 37	59.6	60.1	21.0	684	4,896	12,134	14,266	16,560	10,814	70.7	61.7	9.0	919	3,625	3,641	4,600	7,275
	Ct. 44	73.8	69.1	21.0	569	5,946	10,206	11,215	14,864	13,375	70.7	68.0	9.3	1,448	1,813	3,267	3,117	3,908
	Ct. 51	69.0	68.0	21.0	518	3,442	8,439	12,253	14,788	13,141	70.7	69.8	9.3	1,448	1,621	2,762	3,318	3,892
	Ct. 58	71.6	69.9	21.0	617	5,319	9,531	10,388	12,944	12,664								
	Ct. 65	71.7	61.0	21.0	525	4,264	6,996	10,811	13,064	12,987	70.7	69.8	9.3	730	2,033	3,681	3,700	4,200
	Average	69.9	67.7	21.0	876	6,166	10,405	11,883	13,731	13,607	71.7	67.2	9.1	1,311	2,637	3,375	3,652	4,180
E	Ct. 6	76.4	77.4	20.5	1,409	3,184	9,209	10,680	11,581	13,031	76.5	77.5	8.9	956	1,319	2,102	2,565	2,437
	Ct. 10	73.6	71.6	20.5	1,368	4,948	9,626	7,038	10,192	12,806	71.6	71.6	8.9	900	1,368	1,600	1,854	1,650
	Ct. 18	71.6	73.8	21.0		4,957	6,119	8,804	9,644	11,363	71.8	61.6	9.0	923	1,754	2,322		2,750
	Ct. 26	64.6	59.0	21.0	1,060	4,274	7,727	8,906	11,724	11,871	70.7	60.0	9.0	889	1,314	1,800	2,562	2,900
	Ct. 31	66.9	53.2	21.0	244	3,694	6,379	8,145	9,325	10,955	70.0	64.0	9.0	740	1,308	2,467	2,846	3,525
	Ct. 38	64.4	70.5	21.0	609	3,943	6,309	8,233	11,327	11,775	69.8	66.9	9.0	645	1,363	2,970	4,631	4,342
	Ct. 45	70.5	68.0	21.5	692	2,499	5,488	8,199	11,080	11,474	70.7	68.0	9.4	836	949	2,396	3,141	3,150
	Ct. 52	72.0	70.8	21.5	299	2,156	6,693	6,929	11,325	13,691								
	Ct. 59	71.6	69.9	21.5	365	2,314	6,113	10,604	11,394	11,257	69.8	68.0	9.4	912	955	2,503	2,858	2,917
	Ct. 66	71.7	61.0	21.5	283	1,762	5,084	9,405	11,858	11,880	69.8	69.8	9.4	867	1,746	2,824	3,275	3,633
	Average	70.3	67.5	21.1	703	3,373	6,875	8,694	10,945	12,010	71.2	67.5	9.1	852	1,542	2,332	2,959	3,034
F	Ct. 11	71.6	71.8	21.5	1,380	5,859	8,448	9,039	9,170	7,725	71.8	61.6	9.1	1,119	1,653			
	Ct. 19	70.2	69.4	21.5	1,380	5,845	8,827	9,542	11,148	11,900	71.8	61.6	9.1	1,123	1,775	2,463	2,947	2,788
	Ct. 28	61.9	62.9	21.5	2,163	4,569	9,503	8,673	11,521	10,973	70.5	59.0	9.1	888	1,396	2,140	2,346	3,167
	Ct. 32	68.0	59.3	29.5	879	5,358	9,030	10,101	12,500	10,877	70.0	64.0	9.0	1,066	1,843	2,871	2,906	3,717
	Ct. 39	73.0	70.0	21.5	1,369	6,058	7,929	8,937	10,135	10,320	69.8	66.1	9.1	1,138	1,607	3,793	4,531	5,025
	Ct. 46	69.8	68.3	21.5	924	3,096	6,098	9,193	9,324	11,739	70.7	69.8	9.4	1,124	1,646	2,673	3,302	3,750
	Ct. 53	72.0	70.8	21.5	803	4,625	7,734	10,917	11,597	12,425	70.7	69.8	9.4	1,074	1,086	3,206	3,780	3,842
	Ct. 60	71.6	69.9	21.5	950	2,934	6,878	11,067	11,879	11,066								
	Ct. 67	71.2	62.6	21.5	889	6,226	9,258	11,672	12,456	12,497	69.8	69.8	9.4	1,090	1,651	3,409	3,592	4,042
	Average	69.9	67.2	21.5	1,193	4,952	8,189	9,905	11,080	11,058	70.6	65.2	9.2	1,078	1,582	2,937	3,343	3,762

G	Ct. 12	71.8	70.4	21.0	992	4,966	7,408	9,115	9,848	12,884	71.6	72.1	9.0	960	1,489	2,445	3,317	3,283
	Ct. 20	66.9	70.0	21.0	1,951	5,188	7,510	8,729	9,046	12,007	71.8	61.6	9.0	1,085	1,821	2,371	3,199	3,538
	Ct. 29	70.5	70.5	20.5	2,014	3,538	5,246	10,226	8,790	12,668	70.5	59.0	8.9	768	1,485	2,163	2,244	3,508
	Ct. 33	64.7	64.5	21.0	390	2,951	6,484	9,879	11,759	14,019	...	...	...	...	...	...	...	...
	Ct. 40	71.0	70.2	21.0	553	3,643	6,247	9,280	10,034	9,490	...	...	...	...	...	...	...	...
	Ct. 47	69.8	68.3	20.5	253	3,355	5,186	9,177	9,954	13,511	70.7	68.0	9.4	907	1,294	2,661	3,818	4,383
	Ct. 54	72.0	70.8	20.5	353	3,574	5,268	6,800	10,464	12,648	69.8	68.0	9.3	1,003	1,282	2,361	3,212	4,133
	Ct. 61	69.8	68.0	20.5	867	2,863	4,785	7,605	11,512	12,151	69.8	69.8	8.8	929	1,209	2,497	2,688	4,158
	Ct. 68	71.2	62.5	20.5	862	4,102	5,186	8,541	11,947	13,807	...	...	...	...	...	...	...	...
	Average	69.7	68.4	20.7	915	3,798	5,924	8,817	10,373	12,576	70.7	66.4	9.1	942	1,430	2,416	3,080	3,834
	Average A–G	70.3	68.7	21.4	1,014	5,009	8,007	10,080	11,503	12,028	71.4	67.3	9.2	1,117	1,943	3,002	3,270	3,741
Mix. 1	Ct. 69	71.2	62.6	21.5	1,121	4,884	8,568	8,561	12,475	14,273	71.6	71.6	9.6	973	2,339	3,863	4,400	4,771
2	Ct. 70	70.8	68.5	22.5	793	5,195	7,006	11,050	11,623	13,247	71.6	71.6	9.6	925	1,721	1,598	3,725	4,238
3	Ct. 71	70.8	68.5	21.0	1,114	3,600	8,457	10,533	10,047	14,075	...	...	...	...	...	...	...	...
4	Ct. 72	70.8	68.5	21.5	918	5,275	8,505	10,734	10,993	12,456	71.6	71.6	9.4	1,006	1,755	3,369	3,975	4,047
5	Ct. 73	71.6	59.7	21.0	967	6,671	8,003	9,573	11,094	12,234	...	...	...	...	...	...	...	...
6	Ct. 74	71.6	59.7	23.0	1,057	4,039	8,579	10,334	12,359	12,146	71.6	64.4	9.6	959	2,133	3,538	4,050	4,525
7	Ct. 75	71.6	59.7	21.5	996	2,996	8,013	10,023	11,813	12,051	68.0	62.0	9.4	885	2,103	3,815	4,375	5,200
8	Ct. 76	71.4	67.6	23.0	1,103	4,400	7,087	9,699	12,362	12,607	68.0	62.0	9.4	846	2,209	3,201	3,608	4,500
9	Ct. 77	71.4	67.6	23.0	1,044	5,053	7,354	11,068	11,598	12,427	68.0	62.0	9.4	903	2,253	3,795	4,162	4,775
10	Ct. 78	71.4	67.6	23.0	632	4,459	7,627	11,759	10,663	12,837	...	...	...	...	...	...	...	...
	Average	71.3	65.0	22.0	975	4,657	7,920	10,333	11,503	12,835	70.1	66.5	9.5	928	2,059	3,311	4,042	4,579

Specific gravity.—The specific gravity was determined after heating a small quantity of cement to 212° F. for 5 hours. In subsequent work the samples will also be ignited. Values of specific gravity in the table vary from 3.100 to 3.195. The variation for any individual brand is much smaller than the total variation. The average of all seven brands is 3.120, while the average of the 10 mixes is 3.122.

Time of setting.—In the investigations of the time of setting, the temperature of the water and of the air at the time of molding, the percentage of water which was necessary to bring the cement to normal consistency, and the time of both the initial and final setting, as determined by both the Vicat and Gilmore apparatus, were determined and recorded.

The time elapsing before both initial and final set as determined by the Gilmore needle is in almost every case greater than that determined by the Vicat needle.

Fineness.—Of the 68 samples of the seven individual brands only a few reached as high as 25 per cent residue on the No. 200 sieve. Five brands, namely, A, C, D, E, and G, were found to be of approximately equal fineness.

Constancy of volume.—In order to determine the constancy of volume by the appearance of the pat, two normal and two accelerated tests were made of each sample. The normal tests consisted of the maintenance of pats in air and in water for 28 days at a temperature as nearly 70° F. as practicable. The accelerated tests consisted in keeping one pat exposed in an atmosphere of steam and another immersed in boiling water for 5 hours.

In all the accelerated tests and nearly all the normal tests the pats remained unaltered, the exceptions being noted in each case under " Soundness " (column 13, p. 13) in the table. Where the pats have passed all the forms of tests it is indicated by the phrase " Perfectly sound." Where the pats failed to pass the tests without change it is indicated by " Pat — warped — inch," the letter "A" being used for the 28-day normal air tests and " B " for the 28-day normal water tests.

Tensile strength.—Tensile and compressive tests were made of samples taken from each barrel, also from each of the 10 mixtures. These tests for both the neat cement and 1:3 standard-sand mortars (using Ottawa sand screened to 20–30 size) were made in sets of three at ages of 7, 28, 90, 180, and 360 days. For the neat cement a 1-day test was also made.

The results of the tensile tests are given in Table II*b* (p 16), each value being the average of three tests. All the tests of each individual brand are grouped together and given a single letter for identification. The register numbers in this table are the same as those in Table I (p. 11), so that the results of tests of physical properties of any sample can be compared with the chemical analysis. The temperatures of the water and of the air given in this table are those observed at the time of making the test pieces. The percentage of water is that required to secure a normal consistency and was determined in advance in each case. At the bottom of each group

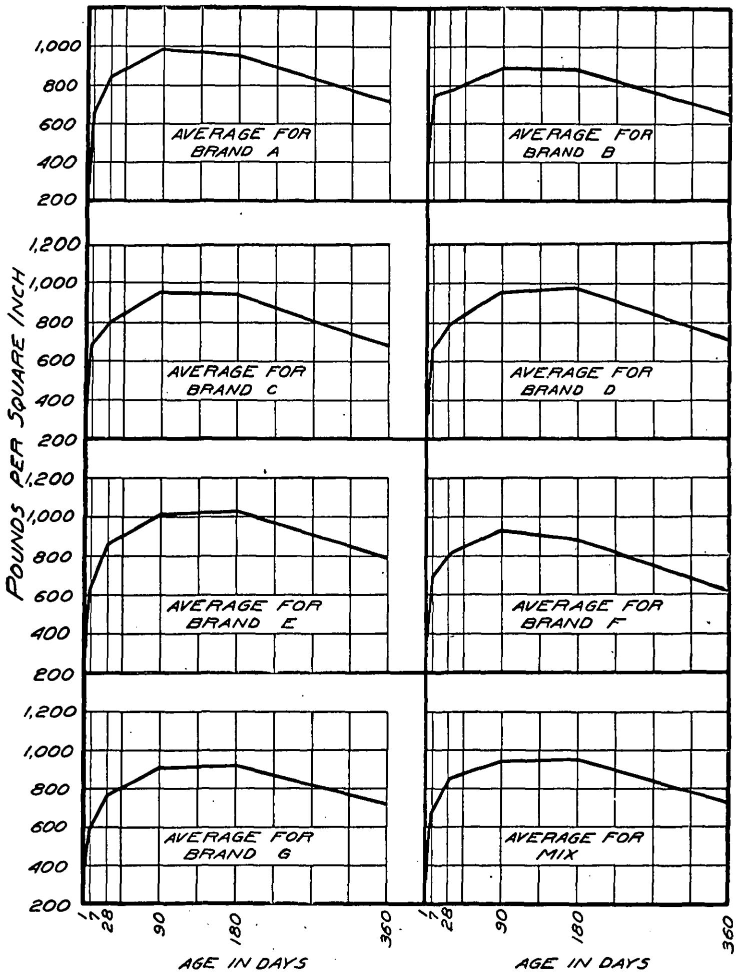


FIG. 1.—Curves showing variation of tensile strength with age of neat cement.

are given the average values for that brand and at the bottom of the table are given the averages for the 10 mixes. Between brand G and the mixes there is a line which gives the averages of all the 68 samples taken from the seven individual brands.

Effect of age on tensile strength.—The average results of tests to determine the effect of age on tensile strength for each individual brand and for the 10 mixes are plotted in figs. 1 and 2. Fig. 1

shows the results for neat cement and fig. 2 the results for 1:3 standard-sand mortar. In both these diagrams it is noticeable that there is an increase in strength up to 90 days, almost uniform strength from 90 to 180 days, and a decided falling off in almost every case to 360 days. It should be observed that in fig. 2 the curve showing the variation of strength with age of the average of the 10 mixes does

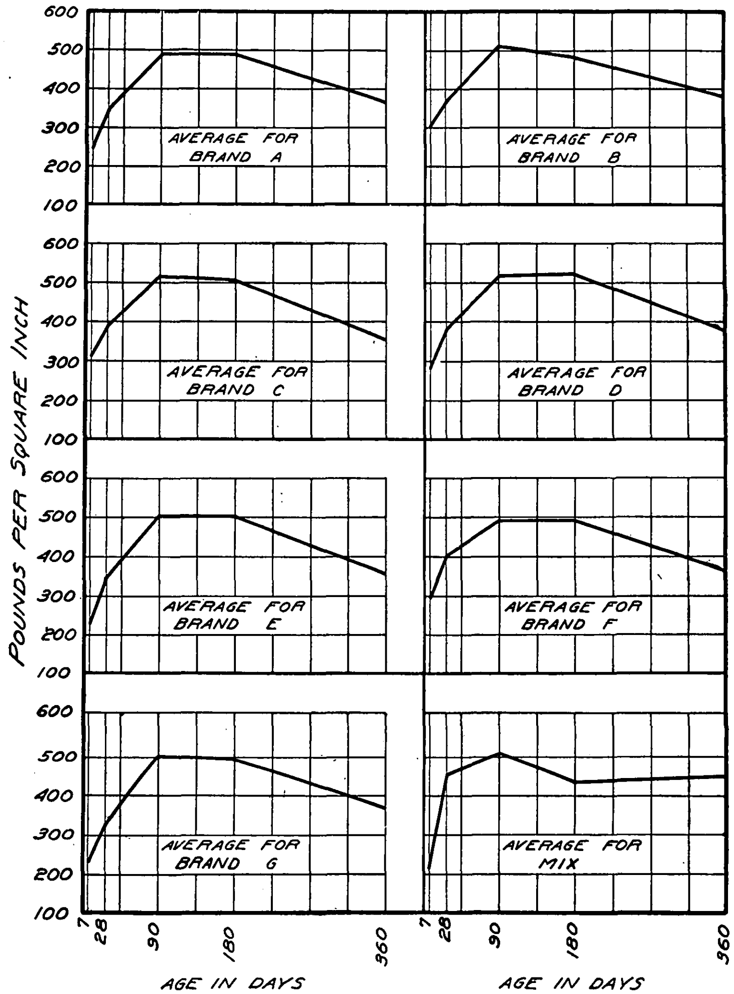


FIG. 2.—Curves showing variation of tensile strength with age of 1:3 standard-sand mortar.

not correspond exactly in shape to the curves for the seven brands. In this case the maximum strength is attained at 90 days ,and there is a falling off to 180 days. Afterwards the strength is almost constant to 360 days.

Compressive strength.—The results of the compressive tests of the cubes are given in Table IIc (p. 19). The register numbers being the same, the compressive strength can be compared with the chemical composition, Table I (p. 11), and with the other physical properties in the preceding sections of Table II (pp. 13–18).

The irregularity in the results of the 1-day and 7-day compression tests of neat cement can probably be accounted for by the conditions in the laboratory while these tests were being made. The galvanized-iron cans that are now used for storing cement had not been procured in sufficient numbers at the time of mixing these test pieces, and a large amount was stored in sacks, where it was subject to the action of moisture in the air. The lack of a sufficient number of cube molds and the delay in obtaining sufficient Ottawa sand rendered it necessary to continue the molding of the test pieces over several months through the winter of 1905–6. Furthermore, the exposition buildings used by the laboratories were ill adapted for the work, and the installation of the necessary heating plant was not completed until after these tests were made. During this period the temperature frequently dropped at night as low as 40°, which retarded the hardening and reduced the early strength. In the tests at the end of 180 days the regularity and uniformity in the results seem to indicate that these early conditions had little effect on the final strength. The blank spaces in Table II indicate breaks in the series, where no test pieces were made, on account of the poor condition of the cement. No cement was tested if there was any indication of its having been injured by the moisture in the air.

The experience with the first cements was very valuable in indicating the care that should be taken in storing cement. At the present time the cement is dumped out of the sacks as soon as received, mixed in the cubical mixer, and stored in air-tight cans. As an additional precaution, all similar test pieces are molded at the same time. A complete heating system has now been installed, making it possible to control the temperature of the laboratories.

The temperatures given in this table are the temperatures of the water and of the air in the laboratory at the time of molding the test pieces. The neat test pieces and the 1:3 mortar test pieces were molded at different times, so different temperatures are given in the table. The percentage of water used in the test pieces was determined in advance.

The averages for each brand are given at the bottom of the group and the averages for the 68 tests on the individual brands are given near the bottom of the table, in the line marked "Average A–G." The averages for the 10 mixes are given at the bottom of the table.

Effect of age on compressive strength.—The results given in Table II are illustrated in figs. 3 and 4, for neat cement and 1:3 standard-sand mortar, respectively. In each of these figures the curves for the seven brands and for the average of the 10 mixes are shown in separate diagrams. The difficulties already mentioned account for the difference between the curves in these two figures, which are greater than those for the tensile tests (figs. 1 and 2). These curves differ from the curves showing the variation in tensile strength with age, in that the compressive strength continues to increase up to 360

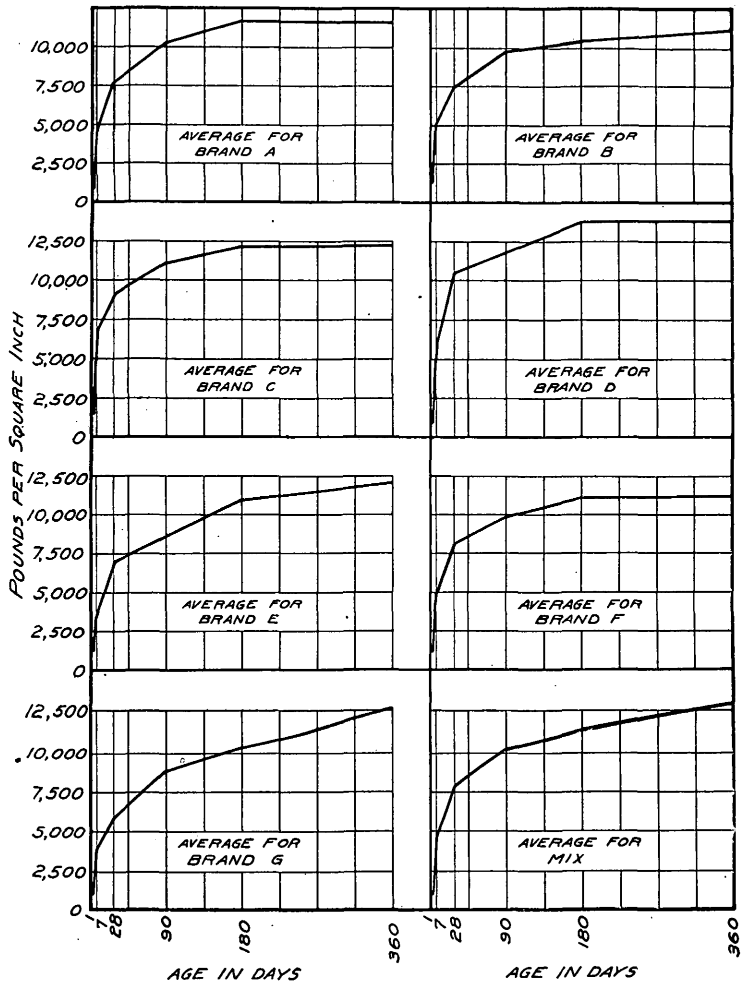


FIG. 3.—Curves showing variation of compressive strength with age of neat cement.

days, and the falling off noticed in the tension tests after 180 days is not apparent.

Percentage of gain in strength.—In order to determine the percentage of gain in strength from 7 to 28, from 7 to 90, from 7 to 180, and from 7 to 360 days for cements having different strengths at 7 days, Tables III, IV, V, and VI, based on the results given in the preceding table, have been prepared, showing the tensile and compressive strengths of the different test pieces. The actual strengths are inserted for purposes of reference. The four right-hand columns in each table contain the percentages of gain. A round-number grouping is also shown, and at the bottom of each group the average strengths and average percentages are given.

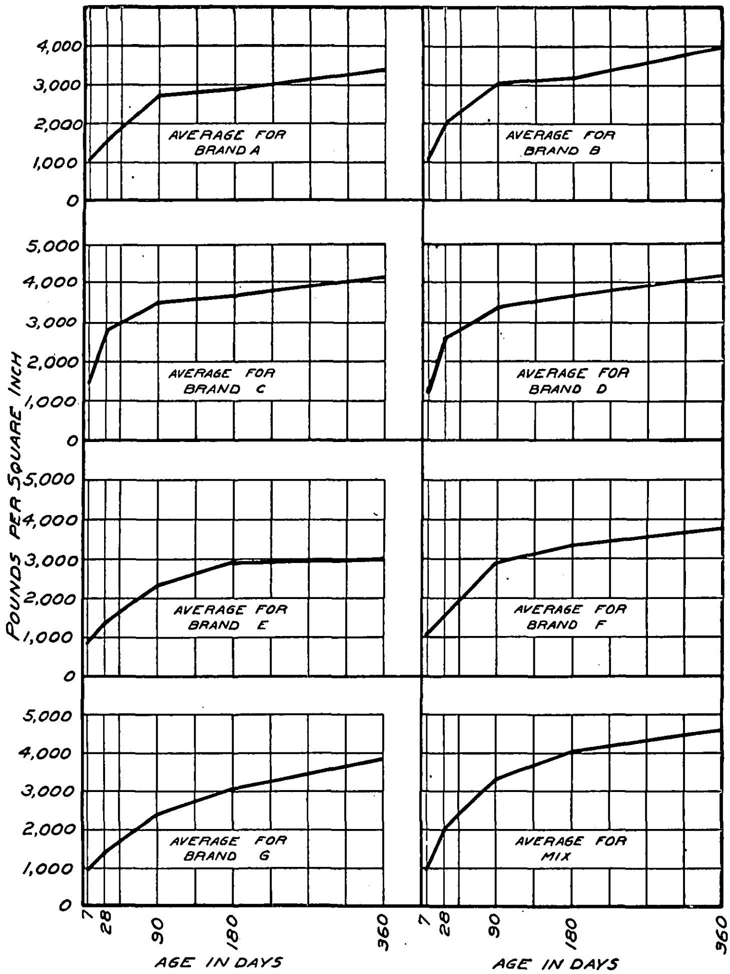


FIG. 4.—Curves showing variation of compressive strength with age of 1 : 3 standard-sand mortar.

Table III gives the percentage of gain in tensile strength of neat cement for the four periods named. The results are arranged consecutively in the order of the strength of the test pieces at 7 days, the lowest values being given first. It can readily be seen that for cement testing low at 7 days the increase in strength is much greater than for those testing high at 7 days.

TABLE III.—*Gain in tensile strength of neat cement from 7 to 28, 7 to 90, 7 to 180, and 7 to 360 days.*

Pounds per square inch at 7 days.	Register No.	Tensile strength (pounds per square inch).					Per cent of gain (based on strength at 7 days).			
		7 days.	28 days.	90 days.	180 days.	360 days.	7–28 days.	7–90 days.	7–180 days.	7–360 days.
Below 550.	Ct. 34	534	831	994	896	645	56	86	68	21
	Ct. 61	543	766	936	878	810	41	72	62	49
	Ct. 59	550	823	1,010	1,052	888	50	84	91	61
	Average	542	807	980	942	781	49	81	74	44
Between 550 and 600.	Ct. 33	553	765	807	916	658	38	46	66	19
	Ct. 66	557	960	1,042	970	777	72	87	74	40
	Ct, 40	561	807	877	961	709	44	56	71	26
	Ct. 20	566	721	929	928	642	27	64	64	13
	Ct. 46	572	775	967	893	653	35	69	56	14
	Ct. 45	574	857	1,037	985	820	49	81	72	43
	Ct. 76	580	857	922	948	770	48	59	64	33
	Ct. 31	581	741	978	944	733	28	68	63	26
	Ct. 41	581	849	977	989	770	46	68	70	33
	Ct. 37	586	810	927	973	773	38	58	66	32
	Ct. 50	587	809	931	944	583	38	59	61	−1
	Ct. 54	589	715	905	865	725	21	54	47	23
	Ct. 38	590	907	1,033	1,071	815	54	75	82	38
	Ct. 52	593	839	950	1,042	864	41	60	76	76
	Ct. 55	599	810	943	914	673	35	57	53	12
	Average	578	815	948	956	731	41	64	65	26
Between 600 and 650.	Ct. 68	606	876	922	907	744	45	52	50	23
	Ct. 51	616	843	981	1,005	690	37	59	63	12
	Ct. 49	616	767	865	873	637	25	40	42	3
	Ct. 12	623	728	936	975	744	17	50	57	19
	Ct. 19	628	828	937	909	577	32	49	45	−8
	Ct. 47	636	736	930	955	774	16	46	50	22
	Ct. 62	637	766	981	955	752	20	54	50	18
	Ct. 75	644	846	998	988	718	31	55	53	11
	Ct. 18	645	936	1,050	1,055	689	45	63	64	7
	Ct. 48	646	884	940	965	664	37	46	49	3
	Ct. 44	649	787	958	962	710	21	48	48	9
	Average	631	818	954	959	700	30	51	52	11
Between 650 and 700.	Ct. 63	656	902	908	942	704	38	38	44	7
	Ct. 64	656	975	929	850	698	49	42	30	6
	Ct. 65	658	960	907	972	749	46	38	48	14
	Ct. 39	660	772	951	928	707	17	44	41	7
	Ct. 43	662	835	1,004	938	748	26	52	42	13
	Ct. 72	662	824	917	968	658	24	39	46	− 1
	Ct. 29	663	810	916	846	653	22	38	28	− 1
	Ct. 24	664	669	970	944	670	21	46	42	1
	Ct. 78	669	873	924	888	752	30	38	33	12
	Ct. 30	671	716	984	986	623	7	47	47	− 7
	Ct. 58	674	804	1,017	973	817	19	51	44	21
	Ct. 17	676	844	909	857	741	25	34	27	10
	Ct. 11	676	751	926	873	659	11	37	29	− 2
	Ct. 10	680	808	968	1,091	797	19	42	61	17
	Ct. 77	682	850	962	999	752	25	41	46	10
	Ct. 74	683	864	934	923	657	27	37	35	− 4
	Ct. 57	684	851	949	916	644	24	39	34	− 6
	Ct. 69	685	872	962	952	776	27	40	39	13
	Ct. 70	686	781	893	933	769	14	30	36	12
	Ct. 60	689	785	965	828	541	14	40	20	−21
	Ct. 27	699	803	958	962	603	15	37	38	−14
	Average	673	826	945	932	701	23	40	38	4
Between 700 and 750.	Ct. 16	701	604	984	967	648	14	40	38	− 8
	Ct. 25	703	863	984	937	692	23	40	33	− 2
	Ct. 26	707	914	985	984	712	29	39	39	1
	Ct. 71	708	870	954	966	712	23	35	36	1
	Ct. 9	709	753	750	911	695	6	6	28	− 2
	Ct. 13	713	860	1,012	925	645	21	42	30	−10
	Ct. 21	714	862	989	937	686	21	39	31	− 4
	Ct. 15	715	760	931	987	822	6	30	38	15
	Ct. 23	718	801	961	852	569	12	34	19	−21
	Ct. 56	724	759	880	898	618	5	22	24	−15
	Ct. 36	725	818	940	976	644	13	30	35	−11
	Ct. 1	726	769	988	947	806	6	36	30	−11
	Ct. 5	734	786	977	1,035	716	7	33	41	− 2
	Ct. 32	736	717	735	821	616	− 3	0	12	−16
	Ct. 53	738	865	951	962	627	17	29	30	−15
	Ct. 6	739	815	1,009	1,017	756	10	37	38	2
	Average	719	801	939	945	685	11	31	31	− 5

TABLE III.—*Gain in tensile strength of neat cement from 7 to 28, 7 to 90, 7 to 180, and 7 to 360 days*—Continued.

Pounds per square inch at 7 days.	Register No.	Tensile strength (pounds per square inch).					Per cent of gain (based on strength at 7 days).			
		7 days.	28 days.	90 days.	180 days.	360 days.	7-28 days.	7-90 days.	7-180 days.	7-360 days.
Between 750 and 800.	Ct. 8	754	748	916	905	646	−1	21	20	−14
	Ct. 67	756	932	983	878	578	23	30	16	−24
	Ct. 4	760	785	942	962	687	3	24	27	−10
	Ct. 35	762	786	903	893	604	3	19	17	−21
	Ct. 42	764	673	907	857	726	−12	19	12	−5
	Ct. 28	764	857	943	823	603	12	23	8	−21
	Ct. 22	766	727	863	638	651	−5	13	−17	−15
	Ct. 73	771	878	921	929	663	14	19	20	−14
	Ct. 2	783	926	1,103	1,079	772	18	41	38	−1
	Average	764	812	942	885	659	6	23	16	−14
Above 800.	Ct. 3	820	725	955	955	669	−12	16	16	−18
	Ct. 14	821	833	861	1,042	659	−1	5	27	−20
	Ct. 7	872	787	840	834	618	−10	−4	−4	−29
	Average	838	782	885	944	649	−7	6	13	−23

Table IV gives the percentage of gain in tensile strength of 1:3 standard-sand mortar test pieces for the four periods. In this table also the gain for the test pieces testing low at 7 days is much greater than for the test pieces testing high at 7 days. The percentage of increase for the 1:3 standard-sand mortars appears to be much greater than for the neat cements.

TABLE IV.—*Gain in tensile strength of 1:3 standard-sand mortar from 7 to 28, 7 to 90, 7 to 180, and 7 to 360 days.*

Pounds per square inch at 7 days.	Register No.	Tensile strength (pounds per square inch).					Per cent of gain (based on strength at 7 days).			
		7 days.	28 days.	90 days.	180 days.	360 days.	7-28 days.	7-90 days.	7-180 days.	7-360 days.
Below 200.	Ct. 41	169	350	484	440	336	107	186	160	99
	Ct. 59	181	305	485	465	341	69	168	157	88
	Ct. 67	192	433	499	419	407	126	160	118	112
	Ct. 70	192	420	539	424	491	119	181	121	156
	Ct. 61	193	328	460	480	349	70	138	149	81
	Ct. 34	196	266	433	429	320	36	121	119	63
	Ct. 33	199	354	538	515	381	78	170	159	92
	Average	189	351	491	453	375	86	161	140	98
Between 200 and 250.	Ct. 45	204	313	510	488	343	53	150	139	68
	Ct. 38	205	367	496	520	359	79	142	154	75
	Ct. 74	206	415	439	423	437	101	113	105	112
	Ct. 75	206	448	464	450	466	117	125	118	126
	Ct. 71	208	472	481	418	473	127	131	101	127
	Ct. 40	209	321	487	471	327	54	133	125	57
	Ct. 52	211	323	508	533	334	53	141	153	58
	Ct. 76	212	463	557	413	430	118	163	95	103
	Ct. 65	215	474	513	443	500	120	139	106	133
	Ct. 77	217	463	560	446	439	113	158	106	102
	Ct. 47	222	365	490	499	381	64	121	125	72
	Ct. 31	232	363	478	515	346	56	106	122	49
	Ct. 62	233	327	515	505	318	40	121	117	37
	Ct. 10	235	376	504	439	349	60	114	87	49
	Ct. 55	241	391	475	501	351	62	97	108	46
	Ct. 30	242	379	525	557	344	57	117	130	42
	Ct. 6	243	334	506	527	361	37	108	117	49
	Ct. 17	244	410	468	577	366	68	92	136	50
	Ct. 54	247	355	525	534	369	44	113	116	49
	Ct. 69	248	491	527	455	466	98	113	84	88
	Ct. 46	249	415	503	491	354	67	102	97	42
	Average	225	394	501	486	386	76	124	116	72

Table IV.—*Gain in tensile strength of 1 : 3 standard-sand mortar from 7 to 28, 7 to 90, 7 to 180, 7 to 360 days*—Continued.

Pounds per square inch at 7 days.	Register No.	Tensile strength (pounds per square inch).					Per cent of gain (based on strength at 7 days).			
		7 days.	28 days.	90 days.	180 days.	360 days.	7-28 days.	7-90 days.	7-180 days.	7-360 days.
Between 250 and 300.	Ct. 12	251	307	509	394	379	22	103	57	51
	Ct. 20	251	311	523	525	379	24	108	109	51
	Ct. 26	253	348	528	480	352	38	109	90	39
	Ct. 13	254	332	492	482	397	31	94	90	56
	Ct. 21	256	350	497	468	410	37	94	83	60
	Ct. 29	257	323	498	515	365	26	94	100	42
	Ct. 37	262	383	515	520	325	46	97	98	24
	Ct. 2	268	329	480	505	367	23	79	88	37
	Ct. 48	271	401	550	502	360	48	103	85	33
	Ct. 27	272	371	525	498	343	36	93	83	26
	Ct. 64	276	458	511	488	322	66	85	77	17
	Ct. 16	276	372	502	519	385	35	82	88	40
	Ct. 18	276	374	506	508	408	36	83	84	48
	Ct. 51	277	387	507	532	331	40	83	92	20
	Ct. 22	280	355	517	310	376	27	85	11	34
	Ct. 23	277	348	458	497	410	26	65	79	48
	Ct. 58	284	400	543	514	371	41	91	81	31
	Ct. 53	285	430	49	497	326	51	72	74	14
	Ct. 1	290	342	498	429	462	18	72	48	59
	Ct. 63	292	476	473	505	331	63	62	73	13
	Ct. 7	297	334	493	485	357	12	66	63	20
	Ct. 57	298	414	536	522	328	39	80	75	10
	Ct. 60	300	408	495	497	356	36	65	66	19
	Average	274	372	506	487	366	36	85	78	34
Between 300 and 350.	Ct. 9	301	368	511	511	369	22	70	70	23
	Ct. 8	302	351	491	456	352	16	63	51	17
	Ct. 36	303	392	536	518	351	29	77	71	16
	Ct. 44	304	341	527	501	391	12	73	65	29
	Ct. 42	306	404	568	520	348	32	86	70	14
	Ct. 50	307	397	525	527	358	29	71	72	17
	Ct. 14	308	349	510	486	416	13	66	58	35
	Ct. 43	309	392	517	506	374	27	67	64	21
	Ct. 3	310	323	510	522	354	4	65	68	14
	Ct. 28	310	396	457	466	359	28	47	50	16
	Ct. 19	313	435	465	477	391	39	49	52	25
	Ct. 25	315	403	504	488	398	28	60	55	26
	Ct. 32	315	389	507	495	339	23	61	57	8
	Ct. 49	317	409	555	506	355	29	75	60	12
	Ct. 56	319	370	508	507	382	16	59	59	20
	Ct. 5	322	345	541	545	360	7	68	69	12
	Ct. 39	323	411	500	518	332	27	55	60	3
	Ct. 35	323	386	529	485	415	20	64	50	29
	Ct. 24	324	393	492	511	379	21	52	58	17
	Ct. 11	341	364	516	478	396	7	51	40	16
	Ct. 15	349	372	509	512	359	7	46	47	3
	Average	315	380	513	502	370	21	63	59	17

Table V gives the percentage of gain in compressive strength of neat cement for the four periods named. In this case, also, it can be seen from the table that the percentage of gain for the test pieces testing low at 7 days is much greater than for the test pieces testing high at 7 days. The percentages of increase are greater in every case than those of tensile strength of neat cement or 1:3 standard-sand mortar.

TABLE V.—*Gain in compressive strength of neat cement from 7 to 28, 7 to 90, 7 to 180, and 7 to 360 days.*

Pounds per square inch at 7 days.	Register No.	Compressive strength (pounds per square inch).					Per cent of gain (based on strength at 7 days).			
		7 days.	28 days.	90 days.	180 days.	360 days.	7–28 days.	7–90 days.	7–180 days.	7–360 days.
Between 2,000 and 3,000.	Ct. 55	2,138	6,114	9,194	9,500	11,318	186	330	344	430
	Ct. 52	2,156	6,693	6,929	11,325	13,691	210	221	426	535
	Ct. 59	2,314	6,113	10,604	11,394	11,257	164	358	392	387
	Ct. 45	2,499	5,488	8,199	11,080	11,474	120	228	344	359
	Ct. 61	2,863	4,785	7,605	11,512	12,152	67	166	302	324
	Ct. 60	2,934	6,878	11,067	11,879	11,066	134	277	305	277
	Ct. 33	2,951	6,484	9,879	11,759	14,019	120	235	299	375
	Ct. 75	2,996	8,013	10,023	11,813	12,050	167	235	295	302
	Average	2,606	6,321	9,188	11,203	12,128	146	256	331	366
Between 3,000 and 4,000.	Ct. 62	3,009	5,558	9,390	11,346	10,495	85	212	277	249
	Ct. 46	3,096	6,098	9,193	9,324	11,739	97	197	201	279
	Ct. 6	3,184	9,209	10,680	11,581	13,031	189	235	264	309
	Ct. 48	3,221	5,463	10,475	10,829	12,559	70	225	236	290
	Ct. 34	3,283	5,875	9,291	10,161	11,358	79	183	209	246
	Ct. 47	3,355	5,186	9,177	9,954	13,511	55	174	197	303
	Ct. 51	3,442	8,439	12,253	14,788	13,141	145	256	329	282
	Ct. 29	3,538	5,246	10,226	8,790	12,668	48	189	148	258
	Ct. 54	3,574	5,268	6,800	10,464	12,648	47	90	193	254
	Ct. 71	3,600	8,457	10,533	10,047	14,075	135	193	179	291
	Ct. 40	3,643	6,247	9,280	10,034	9,490	71	155	175	160
	Ct. 31	3,694	6,379	8,145	9,325	10,955	73	120	152	197
	Ct. 49	3,799	7,997	10,168	10,942	11,390	111	168	188	200
	Ct. 41	3,917	8,090	9,445	10,208	8,346	107	141	161	113
	Ct. 38	3,943	6,309	8,233	11,327	11,773	60	109	187	199
	Ct. 63	3,951	6,224	9,942	10,949	11,262	58	152	177	185
	Average	3,516	6,628	9,577	10,629	11,778	89	175	202	235
Between 4,000 and 5,000.	Ct. 74	4,039	8,579	10,334	12,359	12,146	112	156	206	201
	Ct. 68	4,102	5,186	8,541	11,947	13,807	26	108	191	237
	Ct. 65	4,254	6,996	10,811	13,064	12,987	64	154	207	205
	Ct. 26	4,274	7,727	8,906	11,724	11,871	81	108	174	178
	Ct. 76	4,400	7,087	9,699	12,362	12,607	61	120	181	187
	Ct. 78	4,459	7,627	11,759	10,663	12,865	71	164	139	189
	Ct. 42	4,563	8,656	11,531	11,150	11,449	90	153	144	151
	Ct. 28	4,569	9,503	8,673	11,521	10,973	108	90	152	140
	Ct. 53	4,625	7,734	10,917	11,597	12,425	67	136	151	169
	Ct. 69	4,884	8,568	8,561	12,475	14,273	75	75	155	192
	Ct. 64	4,887	6,828	11,732	12,839	14,084	40	140	163	188
	Ct. 37	4,896	12,134	14,266	16,550	10,814	148	191	238	121
	Ct. 18	4,957	6,119	8,804	9,644	11,363	23	78	94	129
	Ct. 56	4,946	8,470	8,979	10,662	13,774	71	82	116	179
	Ct. 10	4,948	9,626	7,038	10,192	12,806	95	42	106	159
	Ct. 13	4,957	8,308	8,653	12,176	13,033	68	75	146	163
	Ct. 12	4,966	7,408	9,115	9,848	12,825	49	84	98	160
	Average	4,631	8,033	9,901	11,810	12,597	73	115	155	172
Between 5,000 and 6,000.	Ct. 77	5,053	7,354	11,068	11,598	12,477	46	119	130	147
	Ct. 57	5,080	7,803	10,912	12,642	13,485	54	115	149	166
	Ct. 20	5,188	7,510	8,729	9,046	12,007	45	68	74	131
	Ct. 72	5,275	8,505	10,734	10,993	12,456	61	104	108	136
	Ct. 70	5,195	7,006	11,050	11,623	13,247	35	113	124	155
	Ct. 58	5,319	9,531	10,388	12,944	12,664	79	95	144	138
	Ct. 32	5,358	9,030	10,101	12,500	10,877	69	89	134	103
	Ct. 22	5,545	7,191	9,055	10,360	10,896	30	63	87	97
	Ct. 35	5,717	9,426	10,301	11,421	11,384	65	80	100	99
	Ct. 50	5,821	8,967	10,038	12,351	11,978	54	72	112	106
	Ct. 19	5,845	8,827	9,542	11,138	11,900	51	63	91	104
	Ct. 11	5,859	8,448	9,039	9,170	7,725	44	54	57	32
	Ct. 44	5,946	10,206	11,215	14,864	13,375	72	89	150	125
	Ct. 7	5,994	6,311	9,746	10,106	11,094	5	63	69	85
	Ct. 14	5,996	8,559	8,497	8,927	9,338	43	42	49	56
	Average	5,546	8,312	10,028	11,313	11,660	58	82	104	110
Between 6,000 and 7,000.	Ct. 39	6,058	7,929	8,937	10,135	10,320	31	48	67	71
	Ct. 2	6,084	9,427	12,319	13,367	12,618	55	102	120	108
	Ct. 23	6,209	6,468	9,504	9,511	10,073	4	53	53	62
	Ct. 67	6,226	9,258	11,672	12,456	12,497	49	87	100	101
	Ct. 43	6,288	9,717	11,763	11,730	11,827	55	87	87	88
	Ct. 16	6,321	9,520	12,246	11,413	12,440	51	94	81	97
	Ct. 5	6,332	12,952	12,232	15,276	16,146	105	93	141	155
	Ct. 1	6,371	8,531	13,237	15,292	11,631	34	108	140	83

TABLE V.—*Gain in compressive strength of neat cement from 7 to 28, 7 to 90, 7 to 180, and 7 to 360 days*—Continued.

Pounds per square inch at 7 days.	Register No.	Compressive strength (pounds per square inch).					Per cent of gain (based on strength at 7 days).			
		7 days.	28 days.	90 days.	180 days.	360 days.	7-28 days.	7-90 days.	7-180 days.	7-360 days.
Between 6,000 and 7,000.	Ct. 17	6,402	9,724	11,334	12,653	12,756	52	77	98	99
	Ct. 30	6,623	9,375	12,138	12,538	16,386	42	83	89	147
	Ct. 73	6,671	8,003	9,573	11,094	12,234	20	44	66	83
	Ct. 15	6,832	7,141	9,943	10,904	9,905	5	46	60	45
	Ct. 36	6,934	8,622	10,236	12,000	10,704	24	48	73	55
	Ct. 21	6,961	8,877	9,369	10,888	11,537	28	35	56	66
	Average	6,451	8,967	11,036	12,090	12,219	40	72	87	89
Above 7,000.	Ct. 27	7,804	11,168	11,855	11,874	13,228	43	52	52	70
	Ct. 8	8,131	13,064	9,971	14,794	12,896	61	23	82	59
	Ct. 4	8,503	10,683	12,196	11,054	10,970	26	43	30	29
	Ct. 9	9,015	12,021	11,996	13,154	16,690	33	33	46	85
	Ct. 25	9,511	12,874	11,281	12,719	11,430	35	19	34	20
	Average	8,593	11,962	11,460	12,719	13,043	40	34	48	51

Table VI gives the percentage of gain in the compressive strength of 1:3 standard-sand mortar for the four periods. Although the percentage of gain for the test pieces testing high at 7 days is less than for those that test low at 7 days, a very large increase is still shown throughout this table.

TABLE VI.—*Gain in compressive strength of 1:3 standard-sand mortar from 7 to 28, 7 to 90, 7 to 180, and 7 to 360 days.*

Pounds per square inch at 7 days.	Register No.	Compressive strength (pounds per square inch).					Per cent of gain (based on strength at 7 days).			
		7 days.	28 days.	90 days.	180 days.	360 days.	7-28 days.	7-90 days.	7-180 days.	7-360 days.
Below 800.	Ct. 34	594	1,554	2,344	2,609	3,988	162	295	338	571
	Ct. 38	645	1,363	2,970	4,631	4,342	111	360	617	573
	Ct. 65	730	2,033	3,681	3,700	4,200	178	404	393	475
	Ct. 31	740	1,308	2,467	2,846	3,525	77	233	284	376
	Ct. 29	768	1,485	2,163	2,244	3,575	93	182	192	366
	Average	695	1,549	2,725	3,206	3,926	124	295	361	465
Between 800 and 900.	Ct. 45	836	949	2,396	3,141	3,150	14	187	276	277
	Ct. 76	846	2,209	3,201	3,608	4,500	161	278	326	432
	Ct. 66	867	1,746	2,824	3,275	3,633	101	226	278	319
	Ct. 75	885	2,103	3,813	4,375	5,200	138	331	394	488
	Ct. 28	888	1,396	2,140	2,346	3,167	57	141	164	257
	Ct. 26	889	1,314	1,800	2,562	2,900	48	102	188	226
	Ct. 10	900	1,368	1,600	1,854	1,650	52	78	106	83
	Average	873	1,584	2,539	3,023	3,457	82	192	246	296
Between 900 and 1,000.	Ct. 77	903	2,253	3,795	4,162	4,775	150	320	361	429
	Ct. 47	907	1,294	2,661	3,818	4,383	43	193	321	383
	Ct. 59	912	955	2,503	2,858	2,917	5	174	213	220
	Ct. 37	919	3,125	3,641	4,600	7,275	240	296	292	692
	Ct. 18	923	1,754	2,322	....	2,750	90	152	....	198
	Ct. 61	929	1,209	2,497	2,688	4,158	30	169	189	343
	Ct. 74	959	2,133	3,538	4,050	4,495	122	269	322	370
	Ct. 6	956	1,319	2,102	2,505	2,437	38	120	162	155
	Ct. 12	960	1,489	2 445	3,317	3,283	55	155	246	242
	Ct. 69	973	2,239	3,863	4,400	4,771	130	297	352	390
	Ct. 56	982	2,850	3,542	3,267	4,675	190	261	243	376
	Ct. 2	985	1,776	2,439	2,617	2,367	80	148	166	140
	Average	942	1,866	2,946	3,480	4,024	98	213	269	327

TABLE VI.—*Gain in compressive strength of 1:3 standard-sand mortar from 7 to 28, 7 to 90, 7 to 180, and 7 to 360 days*—Continued.

Pounds per square inch at 7 days.	Register No.	Compressive strength (pounds per square inch).					Per cent of gain (based on strength at 7 days).			
		7 days.	28 days.	90 days.	180 days.	360 days.	7–28 days.	7–90 days.	7–180 days.	7–360 days.
Between 1,000 and 1,100.	Ct. 54	1,003	1,282	2,361	3,212	4,133	28	135	220	312
	Ct. 72	1,006	1,755	3,369	3,975	4,044	74	235	295	302
	Ct. 13	1,022	1,633	3,213	3,611	3,125	60	214	253	206
	Ct. 7	1,048	1,751	2,228	2,435	3,367	67	113	132	231
	Ct. 5	1,066	3,105	3,917	4,337	4,384	191	267	307	312
	Ct. 32	1,066	1,843	2,871	2,906	3,717	73	169	173	243
	Ct. 63	1,069	2,596	3,651	3,667	4,308	143	241	243	303
	Ct. 53	1,074	1,086	3,205	3,780	3,842	1	198	252	258
	Average	1,044	1,881	3,102	3,490	3,865	80	197	234	270
Between 1,100 and 1,200.	Ct. 49	1,103	1,245	2,497	3,117	2,642	13	126	183	139
	Ct. 11	1,119	1,653	....	....	....	48	....	....	....
	Ct. 19	1,123	1,775	2,463	2,947	2,788	58	119	162	148
	Ct. 46	1,124	1,646	2,673	3,302	3,750	46	138	194	234
	Ct. 35	1,131	1,459	3,093	3,725	4,067	29	173	229	213
	Ct. 39	1,138	1,607	3,793	4,531	5,025	41	233	298	342
	Ct. 22	1,152	2,369	3,174	2,794	4,750	106	176	143	312
	Ct. 16	1,155	1,850	....	....	....	60	....	....	....
	Ct. 36	1,157	3,142	3,220	3,483	4,292	172	178	201	271
	Ct. 41	1,184	1,298	2,870	3,045	3,208	10	142	157	171
	Average	1,139	1,804	2,973	3,368	3,815	58	161	196	235
Between 1,200 and 1,500.	Ct. 17	1,287	1,521	2,603	2,375	4,012	18	102	84	213
	Ct. 30	1,290	3,344	3,363	2,825	3,100	159	161	119	140
	Ct. 21	1,328	1,554	2,918	3,008	3,687	17	120	127	178
	Ct. 4	1,379	3,052	3,900	4,048	4,217	121	183	201	206
	Ct. 64	1,383	2,500	3,815	4,338	4,833	81	176	214	250
	Ct. 50	1,397	1,928	2,845	3,245	3,983	38	104	132	185
	Ct. 57	1,412	2,333	4,084	3,425	4,300	65	189	113	205
	Ct. 44	1,448	1,813	3,267	3,117	3,908	25	126	115	170
	Ct. 51	1,448	1,621	2,762	3,318	3,892	12	91	129	169
	Average	1,375	2,185	3,284	3,300	3,992	60	129	140	190
Above 1,500.	Ct. 27	1,515	3,014	3,703	3,505	3,825	99	144	131	153
	Ct. 8	1,568	3,304	3,608	3,507	3,658	111	130	124	133
	Ct. 24	1,664	3,108	2,830	3,642	4,042	87	70	119	143
	Ct. 25	1,845	3,293	2,689	2,909	3,375	78	46	58	83
	Ct. 9	1,898	3,545	3,677	4,405	3,475	87	94	132	183
	Average	1,698	3,253	3,301	3,594	3,675	92	97	112	116

A study of Table II (pp. 13–21) reveals the very important fact that no matter whether the cements test low or high at 7 days, and despite the varying percentages of increase for the four periods, the 180-day and the 360-day strengths are all reasonably close to one another. This fact shows that early strengths may vary considerably without seriously affecting the later strength of the cement or mortar.

The percentages of gain given in Tables III, IV, V, and VI are illustrated graphically in fig. 5. The strength in pounds per square inch at 7 days is plotted horizontally and the average percentage of increase in strength for each group of three is plotted vertically. The decrease in every case in the percentage of gain with the increase in strength at 7 days is readily apparent from these curves, which are plotted from the averages of about 5,000 tests, and serves to indicate probable strengths for periods beyond the 7-day strengths.

STRENGTH TESTS OF TYPICAL PORTLAND CEMENTS USED IN TESTS OF MORTARS OF SAND, OF GRAVEL SCREENINGS, AND OF STONE SCREENINGS.

Method of tests.—After the molding of the test pieces of the seven individual brands and of the 10 mixes was finished the typical Portland cement was mixed with varying proportions of the various sands, gravel screenings, and stone screenings. In every case when a set

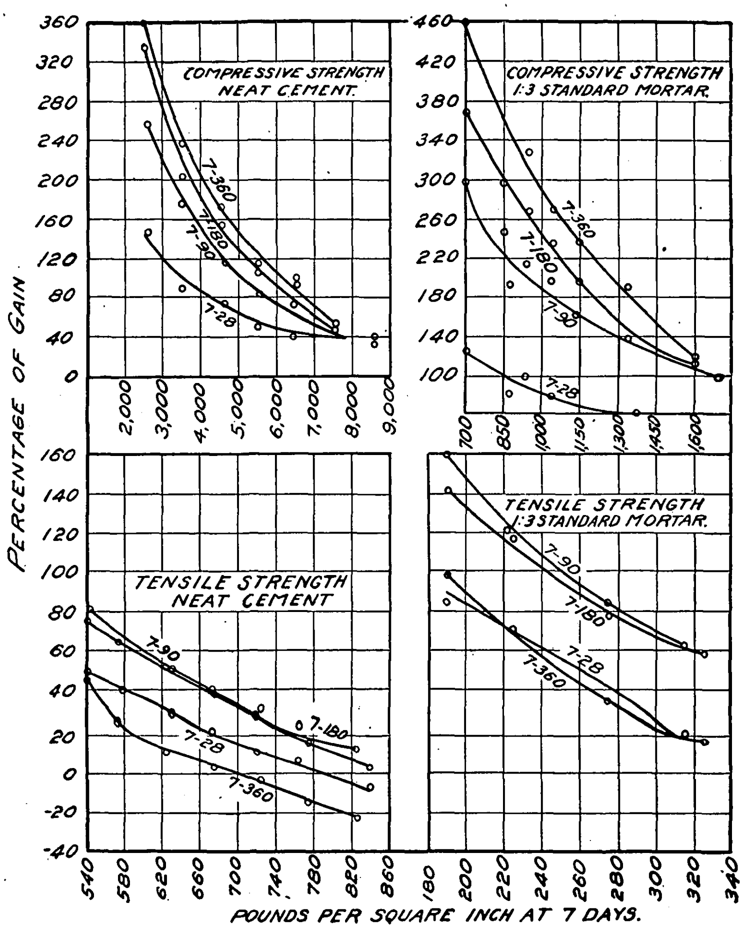


FIG. 5.—Gain in tensile and compressive strengths of neat cement and 1 : 3 standard-sand mortar, at 28, 90, 180, and 360 days; percentages based on strength at 7 days.

of mortar test pieces was made a set of neat-cement test pieces was also made at the same time from the same cement for tension, compression, and transverse tests, in order to afford a basis of comparison between the strengths of the different mortars. In order to identify the parallel cement tests, the register numbers of the sample used in these tests were given in the mortar tables opposite the register numbers of the materials with which they were used.

Tensile strength.—The results of the tension tests are given in Table VII*a*, each value being the average of three tests. The first mixture of seven brands was given the register number Ct. 79, and all samples taken from this were given the same register number and a second number to indicate the number of the sample. For example,

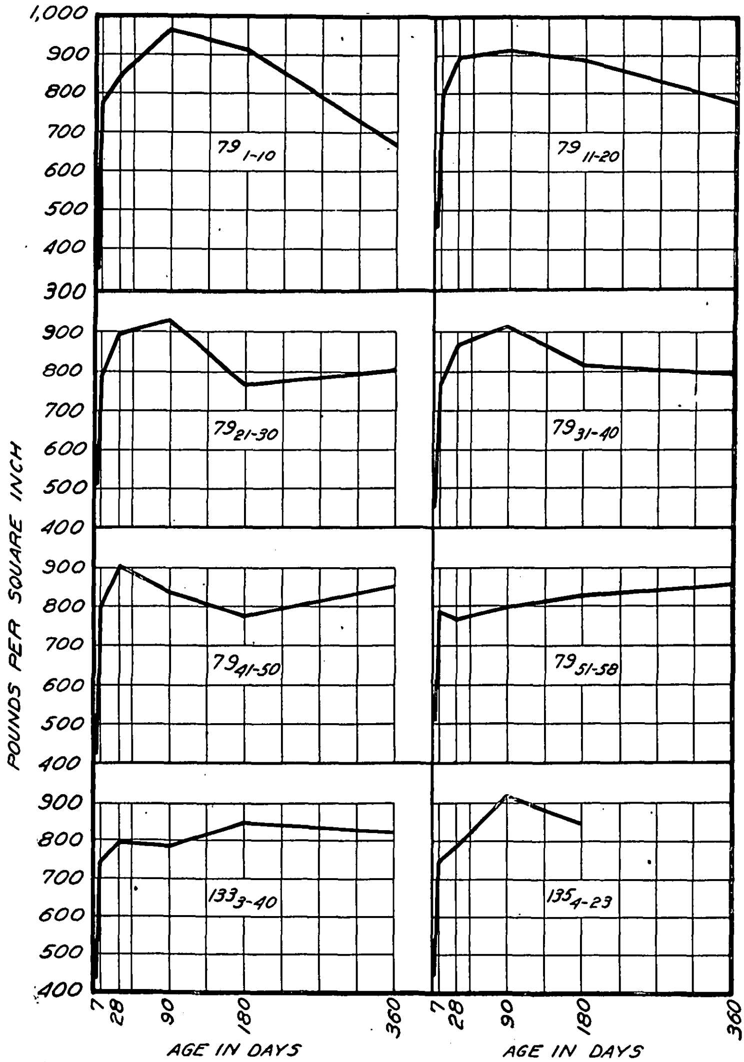


FIG. 6.—Curves showing variation of tensile strength with age of typical Portland cement.

the first register number given in Table VII*a* is Ct. 79–1, the next Ct. 79–2, etc., and so also for Tables VII*b* and VII*c*.

Table VII*a* affords an opportunity to study the effect of storage in air-tight cans on the tensile strength of the typical Portland cement used in the mortars. The results given near the top were obtained from samples taken from the can early in the work, those given near the end of the table being obtained almost a year later. The cement used in the later tests was approximately one year older than that used in the first tests.

The variation of strength of these tensile-test pieces with age is shown in fig. 6, each of the separate averages being represented by an individual curve. The curves shown in fig. 6 are less uniform and not so much alike as those in fig. 1 (p. 23).

TABLE VIIa.—*Tensile strength of typical Portland cement used in mortar tests.*

Register No.	Temperature (° F.).		Water (per cent).	Tensile strength (pounds per square inch.)					
	Water.	Air.		1 day.	7 days.	28 days.	90 days.	180 days.	360 days.
79-1	66.2	67.6	21.5	417	777	870	912	949	727
79-2	63.5	59.0	21.5	294	650	917	973	863	549
79-3	66.9	53.2	21.5	278	698	851	977	952	721
79-4	68.0	59.3	21.5	330	788	890	934	911	720
79-5	66.2	66.2	21.5	282	803	697	1,006	959	656
79-6	65.8	64.1	21.5	325	767	861	1,000	902	636
79-7	66.2	66.5	21.5	305	814	805	948	869	666
79-8	65.8	66.2	21.5	368	813	831	990	871	652
79-9	63.6	51.4	21.5	348	761	823	967	897	681
79-10	59.8	69.4	20.5	438	847	916	952	979	678
Average	65.2	62.3	21.4	339	772	846	966	915	669
79-11	74.0	70.0	20.5	500	733	852	955	996	716
79-12	71.5	68.0	20.5	472	788	864	958	931	638
79-13	70.5	68.0	20.5	456	772	897	965	867	716
79-14	71.6	68.0	20.5	422	843	790	1,018	833	713
79-15	71.0	69.0	20.5	379	769	887	813	858	788
79-16	71.6	59.7	20.5	461	821	886	817	865	823
79-17	71.2	67.6	20.5	532	810	949	918	849	856
79-18	69.0	68.9	20.5	525	823	982	903	942	825
79-19	74.8	66.2	20.5	374	823	954	811	927	868
79-20	69.8	67.2	20.5	392	749	859	967	823	845
Average	71.5	67.3	20.5	451	793	892	913	889	779
79-21	70.5	54.3	20.5	433	806	914	909	860	782
79-22	71.6	68.2	20.5	517	822	954	968	859	788
79-23	71.2	68.0	20.5	560	949	987	923	842	835
79-24	70.7	52.0	20.5	427	790	909	912	665	828
79-25	71.6	73.4	20.5	568	766	831	890	773	821
79-26	69.8	68.0	20.5	546	778	948	943	738	755
79-27	70.7	64.4	20.5	577	757	922	958	727	825
79-28	71.0	59.2	20.5	577	707	939	990	762	797
79-29	70.7	70.7	20.5	483	803	793	899	705	782
79-30	70.7	70.5	20.5	539	774	748	903	736	811
Average	70.9	64.9	20.5	513	795	895	930	767	802
79-31	70.7	70.0	20.5	542	837	904	907	945	827
79-32	70.7	62.6	20.5	500	803	890	921	827	737
79-33	69.8	63.0	20.5	506	738	693	860	836	665
79-34	69.8	69.8	20.5	522	697	780	972	860	833
79-35	70.0	70.4	20.5	293	927	836	829	844	811
79-36	68.0	68.9	20.5	506	808	923	927	778	798
79-37	68.0	68.4	20.5	377	660	963	950	924	808
79-38	69.8	68.0	20.5	396	745	838	856	708	831
79-39	71.5	70.0	20.5	521	725	894	925	861	815
79-40	69.8	70.0	20.5	398	761	948	966	754	815
Average	69.8	68.1	20.5	456	770	867	911	814	794
79-41	68.0	64.4	20.5	321	720	909	753	718	841
79-42	69.8	64.4	20.5	309	787	864	872	660	854
79-43	68.0	68.0	20.5	371	789	936	867	815	851
79-44	68.0	62.6	20.5	447	641	972	825	776	805
79-45	68.0	64.4	20.5	351	761	903	938	772	852
79-46	71.6	71.6	20.5	521	817	903	823	848	863
79-47	68.0	64.4	20.5	452	800	851	747	719	827
79-48	69.8	66.2	20.5	498	854	854	834	778	827
79-49	68.0	67.1	20.5	583	853	924	745	796	876
79-50	69.8	59.0	20.5	427	899	944	943	823	900
Average	68.9	65.2	20.5	423	792	906	835	771	850

TABLE VIIa.—*Tensile strength of typical Portland cement used in mortar tests*—Cont'd.

Register No.	Temperature (° F.).		Water (per cent).	Tensile strength (pounds per square inch).					
	Water.	Air.		1 day.	7 days.	28 days.	90 days.	180 days.	360 days.
79-51	69.8	62.0	20.5	494	819	851	827	825	859
79-52	69.8	68.0	20.5	510	852	762	837	776	862
79-53	69.8	66.2	20.5	509	624	723	765	833	841
79-54	69.8	72.5	20.5	514	867	731	780	832	857
79-55	69.8	68.0	20.5	537	848	733	812	786	879
79-56	71.6	64.2	20.5	536	835	804	657	846	866
79-57	71.6	64.2	20.5	488	757	803	888	841	847
79-58	69.8	65.4	20.5	465	672	728	815	874	852
Average	70.3	66.7	20.5	507	784	767	798	827	858
133-3	63.0	67.1	20.5	383	708	867	837	789	863
133-5	68.0	78.8	20.5	425	684	784	769	844	880
133-17	68.9	67.1	20.5	491	748	787	826	882	722
133-21	69.8	78.8	20.5	437	725	815	715	960	697
133-23	69.8	64.0	20.5	329	764	749	677	769	877
133-28	68.0	66.2	20.5	476	768	772	862	853	843
133-40	71.6	71.6	20.5	487	780	798	834	804	861
Average	68.4	70.5	20.5	433	740	796	789	843	820
135-4	78.8	82.4	....	467	740	690	960	858	....
135-14	78.8	77.0	20.5	377	652	816	971	830	....
135-20	77.9	74.3	....	480	794	819	886	870	....
135-23	78.8	72.5	20.5	418	788	831	862	823	723
Average	78.6	76.5	20.5	436	744	789	920	845	....

Compressive strength.—The results of the compression tests are given in Table VII*b*, each value being the average of three tests. The foregoing remarks with regard to storage apply equally well to the samples used in the compression tests. The variation in strength of the compressive-test pieces with age is shown in fig 7 (p. 39), each of the separate averages being represented by an individual curve. These curves are less uniform than those shown in fig. 3 (p. 26).

TABLE VII*b*.—*Compressive strength of typical Portland cement used in mortar tests.*

Register No.	Temperature (° F.).		Water (per cent).	Compressive strength (pounds per square inch).					
	Water.	Air.		1 day.	7 days.	28 days.	90 days.	180 days.	360 days.
79-1	69.0	68.7	21.5	2,946	8,284	10,068	11,409	12,792	14,664
79-2	74.8	66.2	21.5	2,479	8,671	10,033	10,716	12,774	16,286
79-3	69.8	67.6	21.5	1,896	7,696	11,475	11,793	12,658	13,184
79-4	71.6	55.0	21.5	2,635	8,607	10,539	11,129	14,392	14,098
79-5	70.0	64.4	21.5	3,048	7,103	9,714	11,861	13,073	12,422
79-6	69.6	60.3	21.5	2,915	6,767	8,300	11,462	12,671	14,113
79-7	70.5	54.3	21.5	3,001	7,561	9,724	12,730	12,000	12,982
79-8	71.6	68.2	21.5	4,203	7,071	10,813	12,489	12,473	11,583
79-9	71.2	68.0	21.5	2,367	6,778	11,245	11,143	11,917	11,333
79-10	70.7	52.0	20.5	2,344	7,233	9,892	13,308	14,289	14,418
Average	70.9	62.5	21.4	2,783	7,577	10,280	11,804	12,904	13,508
79-11	73.4	57.2	20.5	2,586	7,717	9,132	11,842	14,065	12,583
79-12	68.0	60.8	20.5	3,044	6,895	8,284	11,220	13,229	13,014
79-13	68.0	73.4	20.5	2,855	7,648	8,699	12,738	11,838	13,218
79-14	70.7	69.0	20.5	3,075	6,688	10,761	12,008	13,933	14,007
79-15	69.8	70.0	20.5	3,093	7,240	10,573	12,684	13,342	12,326
79-16	70.7	70.0	20.5	3,216	7,036	10,232	12,448	13,515	14,743
79-17	70.2	69.8	20.5	3,351	7,467	9,570	11,246	9,893	14,243
79-18	68.0	66.2	20.5	3,726	7,428	9,640	13,890	10,288	12,045
79-19	69.8	66.2	20.5	3,885	8,838	9,870	12,090	12,101	11,841
79-20	69.8	72.0	20.5	3,848	8,000	9,111	10,963	14,494	13,251
Average	69.8	67.5	20.5	3,268	7,496	9,587	12,113	12,670	13,127

TABLE VII*b*.—*Compressive strength of typical Portland cement used in mortar tests*—Cont'd.

Register No.	Temperature (° F.).		Water (per cent).	Compressive strength (pounds per square inch).					
	Water.	Air.		1 day.	7 days.	28 days.	90 days.	180 days.	360 days.
79-21	69.8	68.0	20.5	4,277	8,568	9,008	10,675	11,188	12,969
79-22	70.7	64.4	20.5	3,954	7,684	11,229	11,488	11,164	12,664
79-23	73.4	71.6	20.5	3,988	8,006	10,595	10,516	11,881	14,169
79-24	70.7	62.6	20.5	2,794	7,675	10,235	12,421	13,534	10,914
79-25	68.9	69.8	20.5	3,850	7,533	9,463	10,364	11,342	16,546
79-26	70.7	69.0	20.5	3,721	8,089	10,228	11,253	14,071	12,113
79-27	70.7	66.2	20.5	3,010	7,300	9,667	13,174	13,117	13,116
79-28	69.8	63.0	20.5	3,148	6,542	11,091	13,388	13,693	11,204
Average	70.6	66.4	20.5	3,593	7,675	10,190	11,660	12,499	12,962
79-34	70.7	60.8	20.5	2,888	6,301	10,189	12,969	13,474	12,415
79-35	70.0	70.0	20.5	3,679	7,383	11,871	13,204	13,546	11,124
79-36	68.0	70.7	20.5	3,546	7,103	10,435	10,820	11,472	11,980
79-37	69.8	70.0	20.5	3,188	7,846	9,957	10,875	11,688	12,906
79-38	68.0	68.0	20.5	3,276	7,333	8,501	11,159	13,863	13,654
79-39	69.8	67.1	20.5	2,312	8,247	10,379	12,532	14,362	12,947
79-40	71.6	71.6	20.5	4,617	7,102	10,228	10,674	12,188	14,084
Average	69.7	68.3	20.5	3,358	7,331	10,223	11,748	12,942	12,725
79-41	68.0	64.4	20.5	....	5,859	10,157	....	....	....
79-42	68.0	68.0	20.5	1,800	7,729	11,036	11,112	13,216	13,856
79-43	64.4	64.4	20.5	2,598	8,046	10,439	10,468	14,706	15,667
79-44	68.0	64.4	20.5	2,707	6,669	10,721	11,425	12,955	14,725
79-45	68.0	64.4	20.5	2,726	7,388	9,925	10,596	8,507	14,392
79-46	68.0	64.4	20.5	2,634	7,061	11,179	10,623	11,148	14,441
79-47	69.8	62.6	20.5	3,474	7,738	10,732	12,863	8,150	13,992
79-48	68.8	62.6	20.5	2,963	7,963	11,425	12,221	10,458	13,377
79-49	68.0	67.1	20.5	3,321	7,480	11,037	13,331	13,056	14,098
79-50	69.8	60.0	20.5	2,637	7,913	10,464	11,957	11,609	13,322
Average	68.1	64.2	20.5	2,762	7,385	10,712	11,622	11,534	14,208
79-51	69.8	69.8	20.5	4,224	3,800	9,960	11,606	12,469	14,414
79-52	68.9	69.2	20.5	3,258	7,677	12,096	13,304	11,794	13,837
79-53	69.8	68.0	20.5	4,798	8,456	10,391	12,389	12,488	13,483
79-54	69.8	65.3	20.5	2,962	8,425	10,621	13,640	11,318	14,203
79-55	69.8	68.0	20.5	3,929	7,835	11,278	12,942	13,129	14,266
79-56	71.6	67.1	20.5	4,868	8,678	9,889	10,935	10,916	14,424
79-57	69.8	64.2	20.5	2,552	8,446	11,046	10,985	11,326	14,393
Average	69.9	67.2	20.5	3,799	8,268	10,754	12,257	11,920	14,146
133-3	63.5	74.0	20.5	5,157	8,018	8,875	10,788	10,707	14,579
133-5	67.1	68.0	20.5	4,505	8,299	8,609	12,204	13,118	14,457
133-17	68.9	77.0	20.5	5,188	7,844	8,174	11,381	13,033	15,645
133-21	69.8	73.4	20.5	4,374	7,471	9,843	11,818	11,423	13,343
133-23	68.9	68.0	20.5	3,445	8,372	11,869	13,286	11,410	14,576
133-28	68.9	74.3	20.5	4,998	6,591	8,104	11,617	10,023	14,147
133-40	71.6	69.8	20.5	4,192	7,240	9,585	12,996	10,444	14,814
Average	68.4	72.1	20.5	4,551	7,691	9,293	12,013	11,451	14,509
135-1	68.0	64.4	20.5	2,549	7,043	9,484	10,464	14,235	13,026
135-5	78.8	80.6	....	4,443	7,250	9,051	11,691	11,806	....
135-14	78.8	75.2	....	4,967	8,305	10,333	10,185	12,976	....
135-20	77.9	74.3	....	4,925	8,296	8,626	12,096	12,716	....
135-23	78.8	72.5	20.5	4,312	6,625	11,553	11,196	12,716	....
135-24	78.8	71.6	11.5	5,062	7,675	9,282	11,767	12,847	....
135-25	78.8	71.6	10.0	5,062	7,667	9,282	....	11,848	....
135-26	78.8	71.6	11.0	5,062	7,667	9,282	11,767	....	....
Average	77.3	72.7	14.7	4,548	7,566	9,612	11,309	12,738	....

Transverse strength.—The results of the transverse tests are given in Table VII*c*, each value being the average of three tests. The values in the table are the moduli of rupture computed from the breaking load at the center by means of the formula $s=\frac{Mc}{I}$. The results given in this table are shown graphically in fig. 8. These

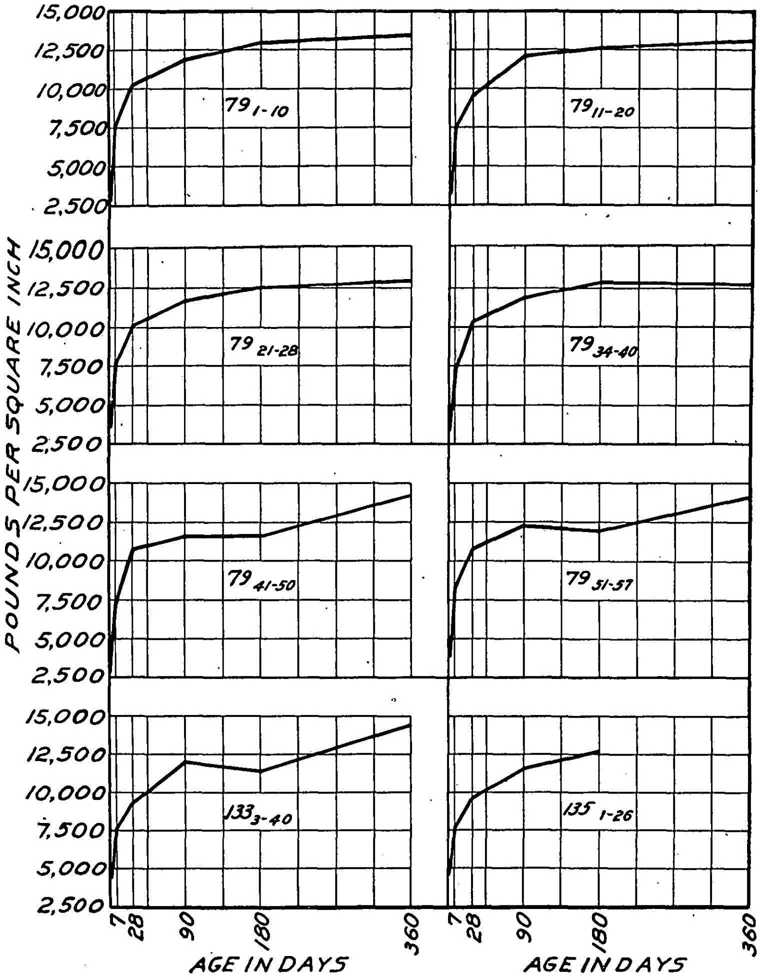


FIG. 7.—Curves showing variation of compressive strength with age of typical Portland cement.

curves seem to indicate that the strength increases to 90 days, remains practically constant to 180 days, and then decreases slightly to 360 days. When the first transverse test pieces were made the cement had been stored about a year, and a period of about five months had elapsed between the molding of the first and the last test pieces.

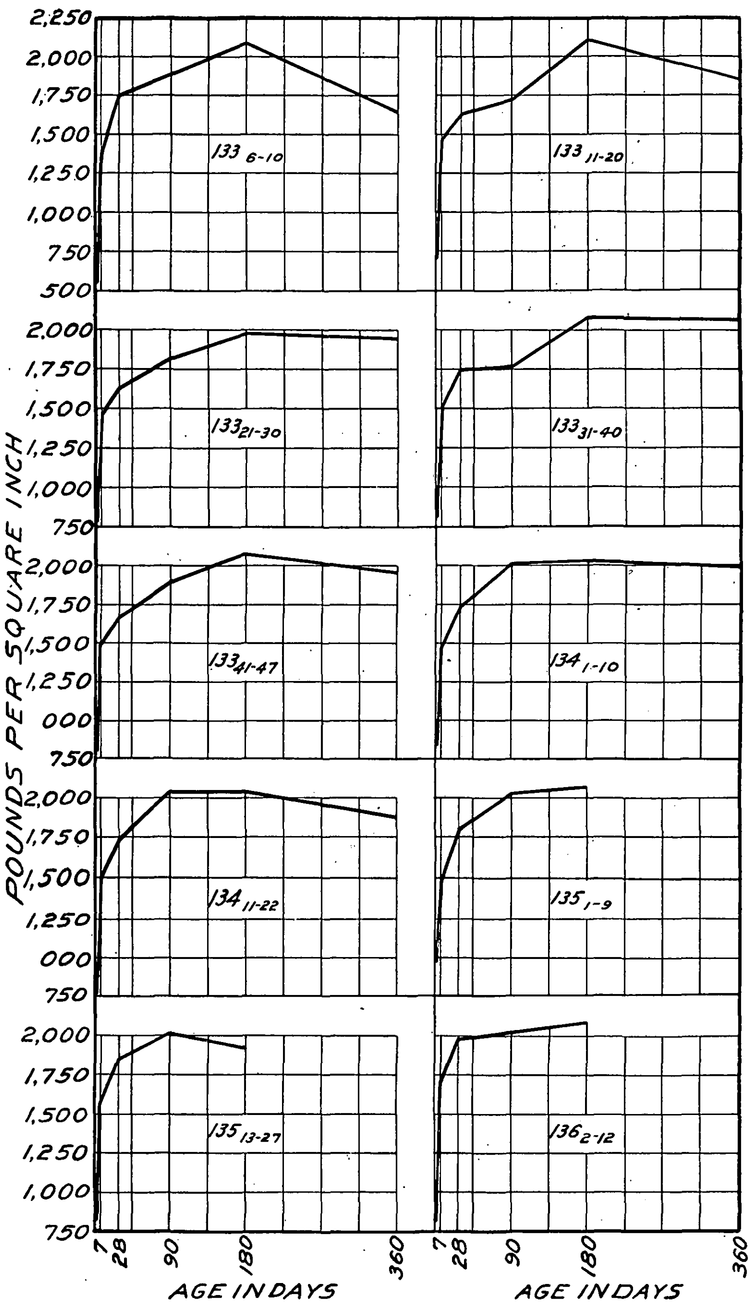
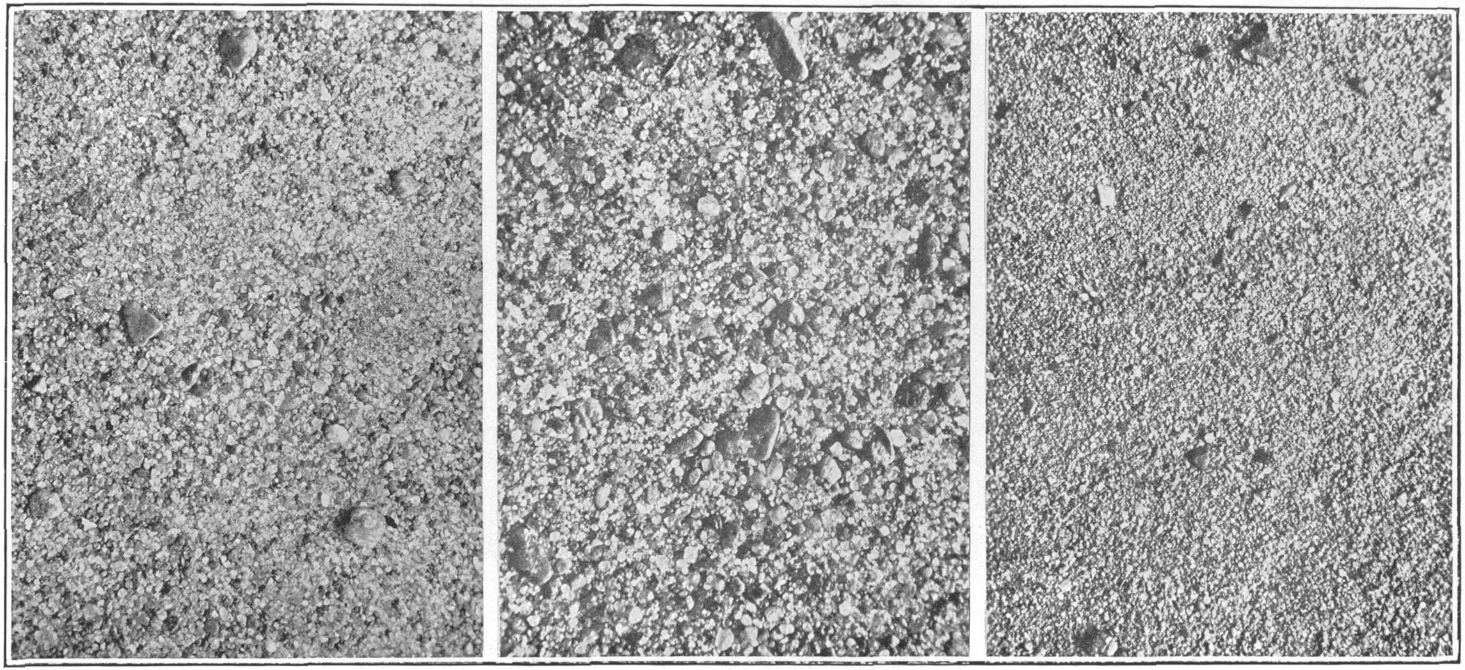


FIG. 8.—Curves showing variation of transverse strength with age of typical Portland cement.



A B C

A. MISSOURI RIVER SAND, KANSAS CITY, MO. (SAMPLE 1).
B. KAW RIVER SAND, ARMOURDALE, KANS. (SAMPLE 2).
C. SCIOTO RIVER SAND, COLUMBUS, OHIO (SAMPLE 3).

TABLE VII*c*.—*Transverse strength of typical Portland cement used in mortar tests.*

Register No.	Temperature (° F.).		Water (per cent).	Transverse strength (pounds per square inch).					
	Water.	Air.		1 day.	7 days.	28 days.	90 days.	180 days.	360 days.
183-6	71.6	64.2	20.5	540	1,332	1,782	1,836	2,160	1,566
133-7	69.8	64.2	20.5	540	1,368	1,800	2,070	2,124	1,530
133-8	69.8	65.4	20.5	630	1,386	1,602	1,908	1,890	1,338
133-9	69.8	68.0	20.5	774	1,422	1,764	1,746	2,088	1,620
133-11	63.0	70.7	20.5	738	1,332	1,728	1,512	2,160	1,944
133-12	63.0	67.1	20.5	792	1,548	1.494	1,512	2,106	1,908
133-13	63.5	74.0	20.5	738	1,386	1,440	1,872	2,016	1,962
133-14	66.2	78.8	20.5	792	1,512	1,692	1,710	2,106	1,944
133-15	68.0	78.8	20.5	756	1,602	1,746	1,818	2,142	1,890
133-16	67.1	68.0	20.5	756	1,620	1,386	1,908	2,070	1,926
Average	67.2	69.9	20.5	705	1,451	1,638	1,780	2,086	1,763
133-18	68.9	67.1	20.5	882	1,422	1,710	1,440	2,070	1,656
133-19	68.9	77.0	20.5	738	1,332	1,638	1,818	2,142	1,764
133-20	69.8	78.8	20.5	1,026	1,440	1,764	1,872	2,106	1,620
133-22	69.8	73.4	20.5	882	1,512	1,602	1,710	2,070	1,638
133-24	69.8	64.0	20.5	810	1,566	1,908	1,854	1,764	1,890
133-25	68.0	68.7	20.5	828	1,440	1,710	1,782	1,584	1,908
133-26	68.9	68.0	20.5	828	1,386	1,440	1,962	2,106	2,016
133-27	68.0	66.2	20.5	846	1,476	1,530	1,854	2,124	2,106
133-29	68.9	74.3	20.5	1,008	1,584	1,512	1,764	2,052	2,034
133-30	69.8	69.8	20.5	972	1,188	1,674	1,710	2,106	2,034
Average	69.1	70.7	20.5	882	1,435	1,650	1,777	2,012	1,867
133-31	68.0	77.0	20.5	792	1,566	1,836	1,764	2,070	2,088
133-32	71.6	80.6	20.5	972	1,494	1,710	1,638	....	2,016
133-34	69.8	71.6	20.5	918	1,386	1,764	1,962	2,124	2,088
133-35	71.6	68.0	20.5	900	1,530	1,458	1,692	2,214	2,088
133-36	70.7	64.4	20.5	918	1,584	1,890	1,692	2,106	2,111
133-37	69.8	64.2	20.5	774	1,404	1,440	1,854	1,998	2,021
132-38	68.9	65.3	20.5	828	1,458	1,926	1,926	2,106	1,993
133-39	71.6	71.6	20.5	972	1,548	1,836	1,656	1,962	1,967
133-41	71.6	69.8	20.5	954	1,710	1,818	1,962	1,998	1,661
133-42	69.8	68.9	20.5	846	1,386	1,548	1,800	2,106	2,070
Average	70.3	70.1	20.5	889	1,498	1,724	1,795	2,076	2,010
133-43	70.7	71.6	20.5	864	1,368	1,746	1,836	2,160	2,070
133-44	70.7	74.3	20.5	864	1,458	1,692	1,836	2,214	1,818
133-47	70.7	77.0	20.5	846	1,404	1,602	1,980	2,178	1,944
134-1	72.4	78.8	20.5	828	1,494	1,638	1,854	1,962	1,980
134-2	77.0	78.8	20.5	972	1,440	1,440	1,944	2,160	2,025
134-3	74.3	80.0	20.5	810	1,656	1,674	1,944	2,106	1,926
134-4	76.1	74.8	20.5	954	1,278	1,890	2,124	2,124	1,944
134-5	75.2	72.5	20.5	918	1,548	1,728	2,142	1,908	1,957
134-6	75.2	70.7	20.5	846	1,422	1,746	1,962	1,854	1,920
134-8	76.1	77.0	20.5	936	1,476	1,782	2,016	2,016	2,052
Average	73.8	75.5	20.5	884	1,454	1,695	1,964	2,074	1,964
134-9	75.2	80.6	20.5	1,044	1,278	1,674	1,908	2,106	1,944
134-10	75.2	78.8	20.5	990	1,476	1,818	2,252	2,016	2,088
134-11	74.3	71.6	20.5	954	1,530	1,836	2,034	1,872	1,836
134-13	75.2	76.1	20.5	756	1,494	1,800	1,926	2,168	1,692
134-14	77.0	80.6	20.5	990	1,332	1,656	2,142	2,052	1,975
134-15	77.0	80.6	20.5	954	1,386	1,800	1,998	2,034	1,805
134-16	77.0	75.2	20.5	738	1,494	1,422	1,998	2,088	1,800
134-17	77.0	75.2	20.5	810	1,548	1,962	2,106	2,016	1,854
134-18	77.0	70.7	20.5	900	1,512	1,728	2,016	2,142	1,751
134-19	78.8	82.4	20.5	918	1,566	1,728	2,034	2,106	1,859
Average	76.4	77.1	20.5	905	1,461	1,742	2,041	2,060	1,865
134-20	75.2	73.4	20.5	1,008	1,530	1,890	2,034	1,962	2,147
134-21	77.0	77.0	20.5	414	1,674	1,584	2,016	2,034	2,003
134-22	78.8	73.4	20.5	900	1,566	1,746	2,088	1,962	1,823
135-1	78.8	82.4	20.5	1,008	1,620	1,854	2,052	1,962	1,908
135-3	78.8	80.6	20.5	1,008	1,242	1,854	2,016	2,088	2,003
135-4	78.8	82.4	20.5	1,296	1,476	1,602	2,016	2,106	....
135-5	78.8	80.6	20.5	1,008	1,620	1,818	2,052	2,150	....
135-6	79.5	77.0	20.5	990	1,476	1,674	2,016	2,124	....
Average	77.2	78.4	20.5	954	1,823	1,753	2,036	2,047	1,977
135-7	78.8	78.8	20.5	936	1,476	1,602	2,070	2,034	....
135-8	78.8	80.6	20.5	846	1,494	1,998	1,980	2,052	....
135-13	80.6	80.6	20.5	918	1,440	1,638	2,052	1,926	....
135-14	80.6	84.2	20.5	972	1,584	1,854	2,070	1,602	....
135-15	80.6	82.4	20.5	774	1,584	1,782	2,034	1,872	....

TABLE VIIc.—*Transverse strength of typical Portland cement used in mortar tests*—Con.

Register No.	Temperature (° F.).		Water (per cent).	Transverse strength (pounds per square inch).					
	Water.	Air.		1 day.	7 days.	28 days.	90 days.	180 days.	360 days.
135-16	81.4	82.4	20.5	918	1,656	1,818	1,980	1,818	....
135-17	77.0	68.0	20.5	918	1,782	1,854	2,070	2,034	....
135-19	77.0	68.0	20.5	810	1,656	1,962	2,070	2,052	....
Average	79.3	76.9	20.5	886	1,584	1,814	2,041	1,926	....
135-21	79.5	76.1	20.5	1,008	1,458	2,070	2,034	2,016	....
135-22	78.8	75.2	20.5	990	1,170	1,962	1,980	1,980	....
135-27	78.8	84.2	8.9	828	1,476	1,674	1,998	1,890	....
136-2	80.6	82.4	20.5	576	1,692	1,908	2,088	2,052	....
136-3	78.8	80.6	20.5	900	1,584	1,998	2,070	2,160	....
136-4	77.9	76.1	20.5	972	1,314	1,980	2,034	2,142	....
136-9	78.8	68.9	20.5	936	1,764	1,962	2,052	1,998	....
136-11	77.0	68.0	20.5	1,116	1,746	2,034	2,124	2,142	....
136-12	76.1	71.6	20.5	954	1,854	1,962	2,016	2,070	....
Average	77.3	75.9	20.5	920	1,562	1,950	2,046	2,050	....

Lapse of time between first and last molding.—The tension- and compression-test pieces of typical Portland cement were made at about the same time, the first mix being exhausted before the transverse molds arrived at the laboratories. While the transverse-test pieces were being made, the second, third, and fourth mixes were used, and part of these, as well as a portion of the fifth mixture, were used in molding the transverse-test pieces. As far as can be seen from the results, there was no appreciable difference in the qualities of the cements in the different mixtures.

SANDS AND SAND MORTARS.

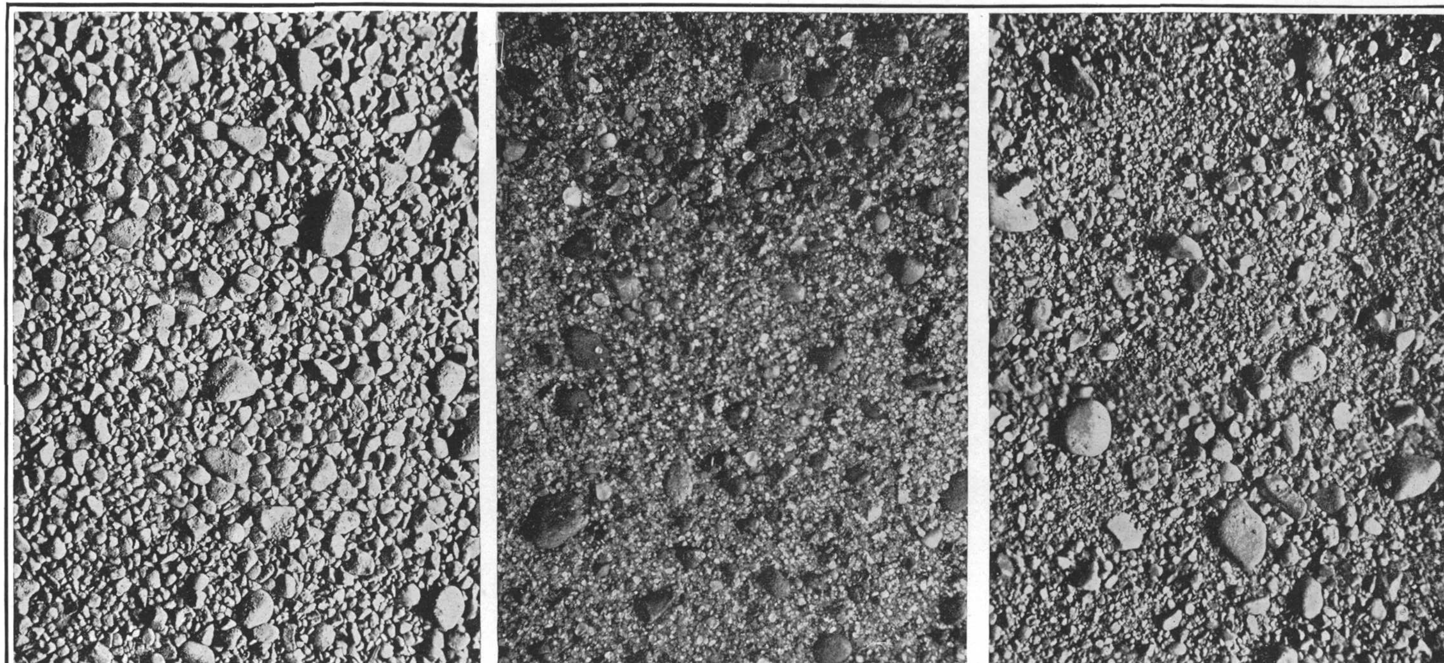
ACKNOWLEDGMENT OF DONATIONS.

In the investigations reported in this bulletin 22 sands were used. They were generously donated by the following firms and companies :

American Sand and Gravel Company, Chicago, Ill.
Buckeye Dredging Company, Columbus, Ohio.
William P. Carmichael, Attica, Ind.
Fleming & Co., Cincinnati, Ohio.
C. H. Little & Co., Detroit, Mich.
Miami Sand and Gravel Company, Loveland, Ohio.
Mound City Gravel and Cement Company, Moselle, Mo.
Ohio and Michigan Gravel and Sand Company, Chilson, Mich.
Stewart Peck Sand Company, Kansas City, Mo.
Toledo Stone and Glass Sand Company, Toledo, Ohio.
Union Sand and Material Company, St. Louis, Mo.
R. J. Ware & Sons, Cincinnati, Ohio.

METHOD OF COLLECTION.

In almost every case, in order to insure the collection of a typical sample of any sand, a special representative of the laboratories visited the deposit and personally supervised its collection and shipment.



A *B* *C*

A. BANK SAND, SYMMES, OHIO (SAMPLE 4).
B. OHIO RIVER SAND, CINCINNATI, OHIO (SAMPLE 5).
C. BANK SAND, ST. CHARLES, ILL. (SAMPLE 6).

Samples were shipped in double sacks, the inner of which was a close-textured grain bag, and the outer a coarse bag of burlap. This precaution was taken in order to eliminate as far as possible the possibility of losing any part of the fine material. A complete description of each sample of sand is given in the following pages; also illustrations from photographs. All the sands were subjected to the usual physical tests and were mixed with typical Portland cement to make mortar test pieces.

DESCRIPTIONS OF SANDS.

Register No. Sd. 1.—A recent river sand, designated Sd. 1, was pumped from the Missouri River channel at Kansas City, Mo., and discharged upon scows, in which it was transported to Kansas City. An endeavor was made to procure the sand in its original condition, so as to determine the proportion of silt and its consequent effect on mortars in which the sand was used; but this was found practically impossible, as a large amount of the silt was washed away in pumping, and when received at the laboratories the determination showed only 0.2 per cent of silt. While this does not indicate the amount of silt present in the original sand, it does show the condition of the sand marketed. It is reported to be used for all purposes except that it is unsuited for finishing work because of a tendency to check or peel off.

An examination of the granularmetric analysis curve (fig. 10, p. 48) proves this material to be one of the "finest" sands received at the laboratories. The physical properties of this and other sands and screenings are shown in Table VIII (p. 59). The percentage of voids is 32.5; the weight per cubic foot is 109.3 pounds; and the yield in 1:3 mortar is 1.18. The results of the strength tests of mortars made by the use of one part of typical Portland cement to 3 parts, to 4 parts, and to 3 parts sifted to 30–40 size of this and 21 other sands are given in Table IX (p. 62). Pl. I, *A*, illustrates this sand, showing the material in its actual size, great care having been taken to procure a photograph that would represent as nearly as possible the grading and the relative proportion of fine and coarse material.

Register No. Sd. 2.—Another recent river sand, designated Sd. 2, was obtained from the channel of Kansas (Kaw) River, at Armourdale (a part of Kansas City, Kans.), by means of a dredge and pump, and discharged into a scow.

The granularmetric analysis curve (fig. 11, p. 50) indicates that about 70 per cent passes the No. 20 sieve and about 15 per cent passes the No. 40 sieve. The percentage of voids is 34.9; the weight per cubic foot is 107.7 pounds; there is only a trace of silt, and the yield in 1:3 mortar is 1.12. The results of the strength tests of mortars made from this sand are given in Table IX (p. 62). This sand is illustrated in Pl. I, *B*.

Register No. Sd. 3.—A river sand designated Sd. 3 was obtained from Scioto River at Columbus, Ohio, by means of an endless-chain device with elevator buckets. The material was dumped upon scows and transferred to cars by means of a traveling crane.

The granularmetric analysis curve is shown in fig. 12 (p. 52), and the appearance in Pl. I, *C*. The percentage of voids is 36.1; the weight per cubic foot is 103.3 pounds; the amount of silt is 4.2 per cent, and the yield in 1:3 mortar is 1.09. The results of the strength tests of mortars made from this sand are given in Table IX (p. 62).

Register No. Sd. 4.—Sand designated Sd. 4 was obtained from a gravel bank of glacial origin located at Symmes, Ohio. The material, consisting of sand, gravel, and bowlders, was excavated from a bank about 600 feet long by means of a steam shovel. After excavation it was passed through a crusher, following which it was screened and washed.

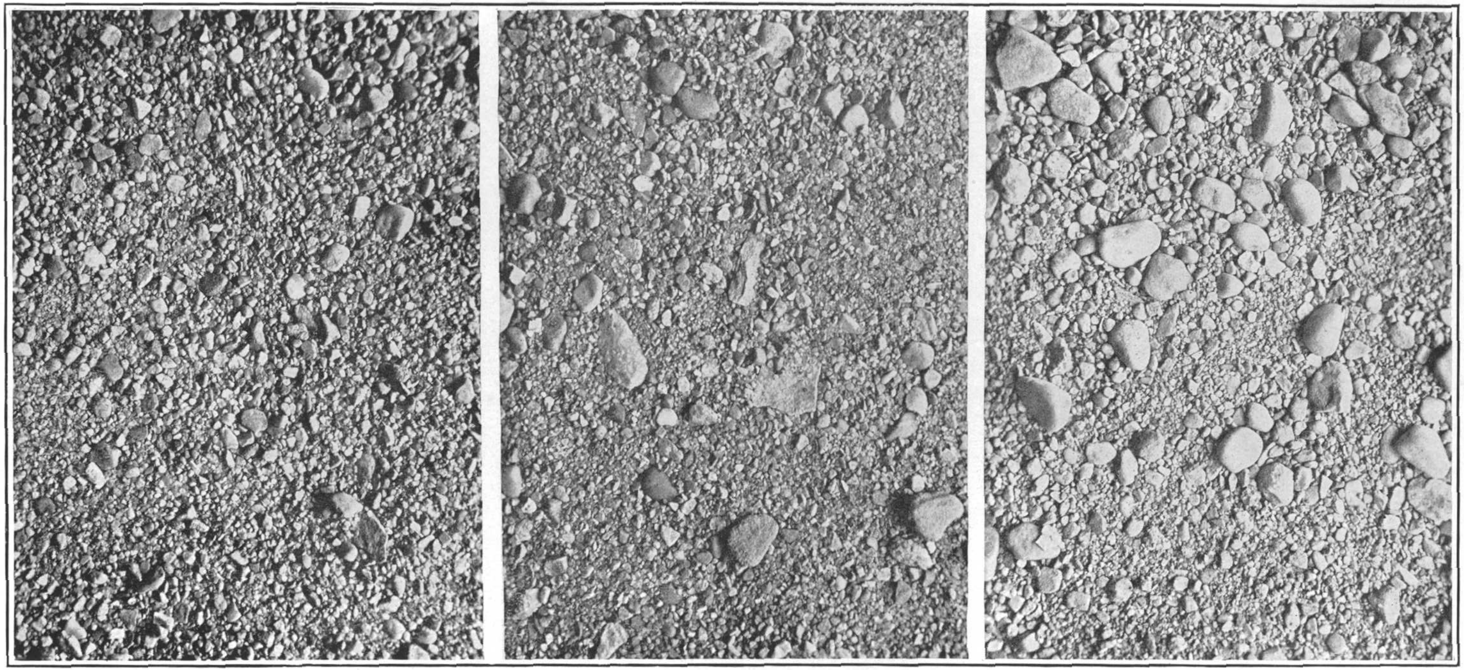
An inspection of the granularmetric analysis curve (fig. 13, p. 54), indicates that this is next to the coarsest and most uniformly graded of the 22 sands herein described. Only 32 per cent passed the No. 20 sieve. The appearance is shown in Pl. II, *A*. The percentage of voids is 28; the weight per cubic foot is 116.4 pounds; the amount of silt is 1.4 per cent, and the yield in 1:3 mortar is 1.14. The results of the strength tests of mortars made from this sand are given in Table IX (p. 62).

Register No. Sd. 5.—A river sand designated Sd. 5 consisted of a mixture of sand and gravel excavated from the Ohio River shore near Cincinnati by means of a centrifugal pump. The material was discharged into barges, from which it was loaded into wagons for distribution throughout the city. The bank that was worked extended for a distance of 500 feet along the Ohio River shore. After being taken from the river the sand was passed through a ¼-inch screen and washed.

The grading of this sand is somewhat irregular, as shown by the granularmetric analysis curve in fig. 11 (p. 50) and the appearance in Pl. II, *B*. The percentage of voids is 34.6; the weight per cubic foot is 104.8 pounds; a trace only of silt is present, and the yield in 1:3 mortar is 1.11. The results of the strength tests of mortars made from this sand are given in Table IX (p. 62).

Register No. Sd. 6.—The sample designated Sd. 6 is a bank sand, a glacial deposit near Fox River, and was excavated by tram and bucket from the sand pit at St. Charles, Ill.

As shown by the granularmetric analysis curve (fig. 11, p. 50), this sand is rather fine, 68 per cent passing the No. 20 sieve. The



A *B* *C*

A. BANK SAND, FOX RIVER, CARPENTERVILLE, ILL. (SAMPLE 7).
B. BANK SAND, FOX RIVER, ALGONQUIN, ILL. (SAMPLE 8).
C. BANK SAND, DESPLAINES RIVER, LIBERTYVILLE, ILL. (SAMPLE 9).

percentage of voids is 31.6; the weight per cubic foot is 113.5 pounds; the amount of silt is 0.53 per cent; and the yield in 1:3 mortar is 1.14. The results of tests of mortars made from this sand are given in Table IX (p. 62) and the appearance is shown in Pl. II, *C*.

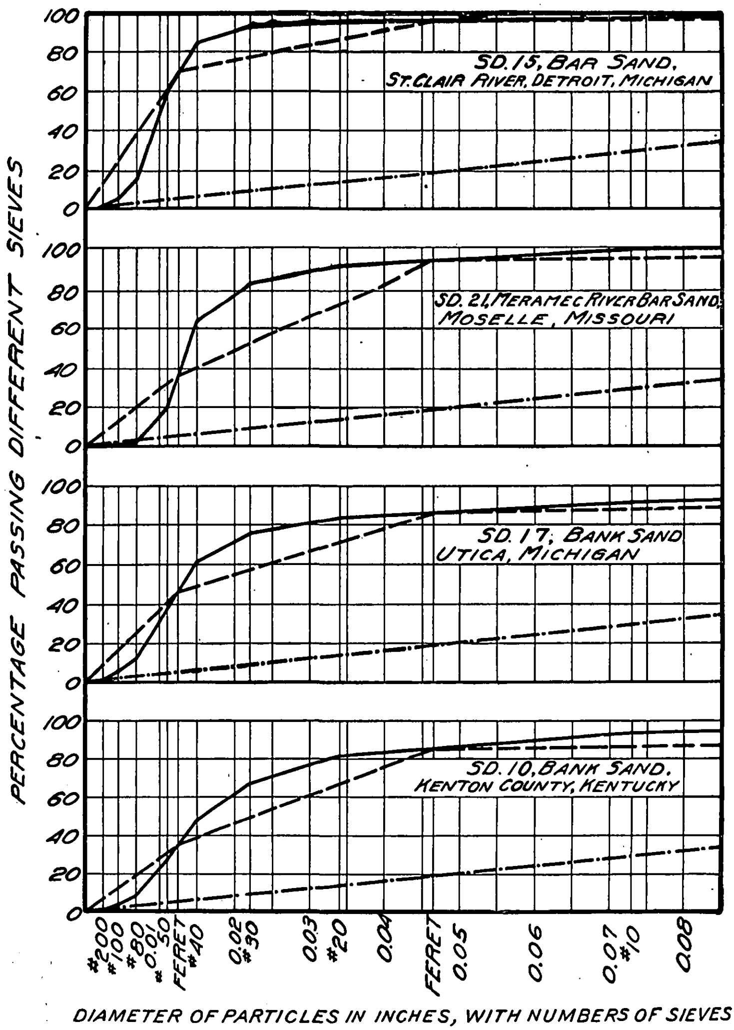


FIG. 9.—Granularmetric analysis curves for sands 15, 21, 17, and 10. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

Register No. Sd. 7.—The sample designated Sd. 7 was obtained by means of a tram and bucket from a glacial deposit of indefinite extent along Fox River at Carpenterville, Ill.

As indicated by the granularmetric analysis curve (fig. 10, p. 48) and the appearance (Pl. III, *A*), this sand contains a large amount of fine material, 77 per cent passing the No. 20 sieve. The percentage of voids is 31.6; the weight per cubic foot is 116 pounds; the amount of silt is 1.2 per cent; and the yield in 1:3 mortar is 1.22. The results of the strength tests of mortars made from this sand are given in Table IX (p. 62).

Register No. Sd. 8.—Material designated Sd. 8 is bank sand from a portion of a glacial deposit along Fox River in the vicinity of Algonquin, Ill., and was excavated by means of tram and bucket.

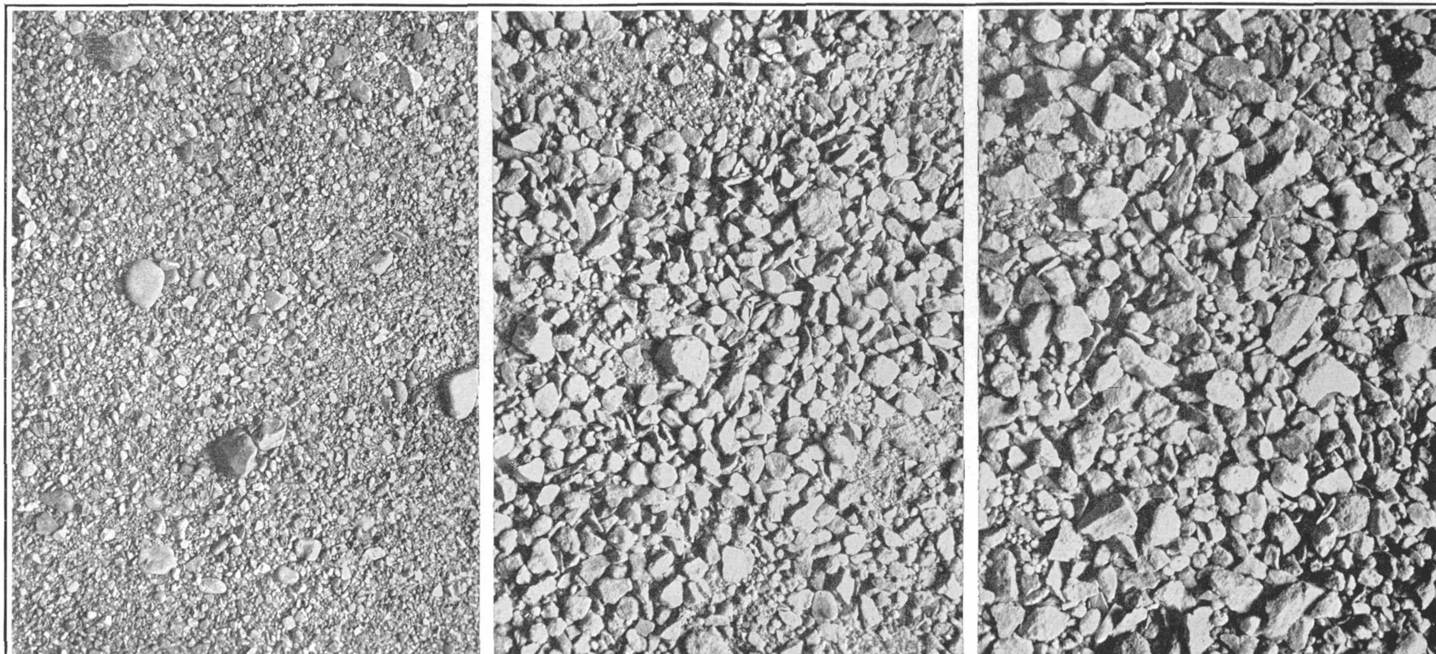
As shown by the granularmetric analysis curve (fig. 13, p. 54) this sand is somewhat coarser than the average, but it is very uniformly graded, and only 46 per cent passed the No. 20 sieve. The percentage of voids is 30.7; the weight per cubic foot is 114.5 pounds; the amount of silt is 1.3 per cent; and the yield in 1:3 mortar is 1.16. The results of the strength tests of mortars made from this sand are given in Table IX (p. 62). This sand is illustrated in Pl. III, *B*. The presence of particles from the smallest up to the ¼-inch size indicates to the eye the uniform grading.

Register No. Sd. 9.—The sample designated Sd. 9 was taken by means of a dredge from a glacial deposit along Desplaines River at Libertyville, Ill.

As indicated by the granularmetric analysis curve for this sand (fig. 12, p. 52), it is very uniformly graded, and only about 50 per cent passes the No. 20 sieve. The percentage of voids is 31.4; the weight per cubic foot is 110.5 pounds; the amount of silt is 2.6 per cent; and the yield in 1:3 mortar is 1.16. The particles of this sand are so soft that they can easily be crushed between the fingers. The uniform grading of this sand indicates that the strength of the mortar should be high; but, evidently owing to the character of the sand, this expectation was not borne out in the tests. This sand is illustrated in Pl. III, *C*. The uniform grading is clearly apparent. The results of the strength tests of mortars made from this sand are given in Table IX (p. 62).

Register No. Sd. 10.—The sample designated Sd. 10 is a mixture of outwash glacial and alluvial deposits from a bank located in Kenton County, Ky. The working was about 600 feet long by 70 feet wide, and the sand was shipped to the vicinity of Cincinnati, Ohio. The face of the bank ahead of the work had a peculiar appearance, on account of the arrangement of the strata. The layer of sand that was excavated was covered by a 4-foot layer of moldy sand and a 10-foot layer of gravel.

As indicated by the granularmetric analysis curve (fig. 9, p. 45), this sand contains a large amount of fine material, 9 per cent passing the No. 80 sieve and about 82 per cent passing the No. 20 sieve. The percentage of voids is 31.6; the weight per cubic foot is 110 pounds; the amount of silt is 2.1 per cent; and the yield in 1:3 mortar is 1.18.



A B C

A. BANK SAND, KENTON COUNTY, KY. (SAMPLE 10).
B. MIXED LIMESTONE SCREENINGS AND SAND, TOLEDO, OHIO (SAMPLE 11).
C. MIXED LIMESTONE SCREENINGS AND SAND, TOLEDO, OHIO (SAMPLE 12).

In the illustration of this sand (Pl. IV, *A*) the small amount of large material and the large amount of smaller particles present can be clearly seen. The results of the strength tests of mortars made from this sand are given in Table IX (p. 62).

Register No. Sd. 11.—Material designated Sd. 11 is a mixture of washed magnesian limestone crusher screenings and a washed glass sand. The limestone is from the Monroe formation (Silurian) and was removed by the open-face method, dynamite being used for blasting and compressed air for drilling. The sand (Sylvania sandstone) is found between two limestone beds in the quarry. The working face is about 2,500 feet long and about 30 feet high. This quarry was operated by an elaborate gravity system. The material was marketed in Detroit, Mich., and in Toledo and Cleveland, Ohio, in three grades, viz, coarse, medium, and fine, sand 11 being the medium grade.

According to the granularmetric analysis curve (fig. 12, p. 52), this mixture of sand and limestone is shown to be very uniformly graded, and 46 per cent passes the No. 20 sieve. The sample is illustrated in Pl. IV, *B*. The amount of voids is 36 per cent; the weight per cubic foot is 110 pounds; the amount of silt is 3.4 per cent; and the yield in 1:3 mortar is 1.13. The results of the strength tests of mortars made from this mixture are given in Table IX (p. 62).

Register No. Sd. 12.—The sample designated Sd. 12 is the finest grade prepared in the manner described for Sd. 11.

As shown by the granularmetric analysis curve (fig. 13, p. 54) and the illustration from photograph (Pl. IV, *C*), this sand is very uniformly graded; and 41 per cent passes the No. 20 sieve. The percentage of voids is 35.5; the weight per cubic foot is 106.5 pounds; the amount of silt is 4.7 per cent; and the yield in 1:3 mortar is 1.12, which is practically the same as that of Sd. 11. The results of the strength tests of mortars made from this mixture are given in Table IX (p. 62).

Register No. Sd. 13.—The sample designated Sd. 13 is a washed sand of glacial origin, containing particles up to one-eighth inch in diameter. It was excavated by means of a steam shovel from a bank 5,000 feet long and 300 feet wide at Chilson, Mich., and was being shipped to Toledo, Ohio.

As indicated by the granularmetric analysis curve (fig. 13, p. 54), this is one of the most uniformly graded sands used in these investigations; and 38 per cent passes the No. 20 sieve. The appearance is shown in Pl. V, *A*. The percentage of voids is 28.9; the weight per cubic foot is 119.5 pounds; the amount of silt is 0.3 per cent; and the yield in 1:3 mortar is 1.21. The results of the tests on mortars made from this mixture are given in Table IX (p. 62).

Register No. Sd. 14.—The sample designated Sd. 14 was removed from the north channel of St. Clair River by means of a centrifugal pump, after which it was screened and loaded in scows for delivery to Detroit.

As indicated by the granularmetric analysis curve (fig. 10) and the illustration from a photograph (Pl. V, B), this sand has a large amount of small grains, 71 per cent passing the No. 20 sieve.

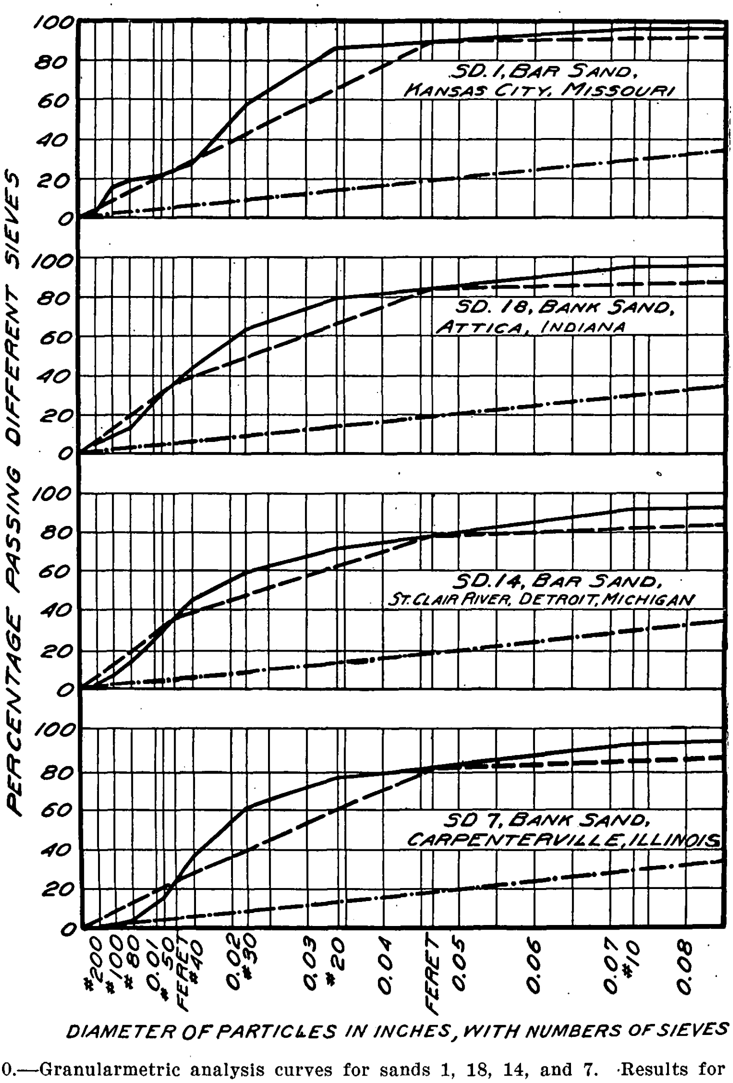
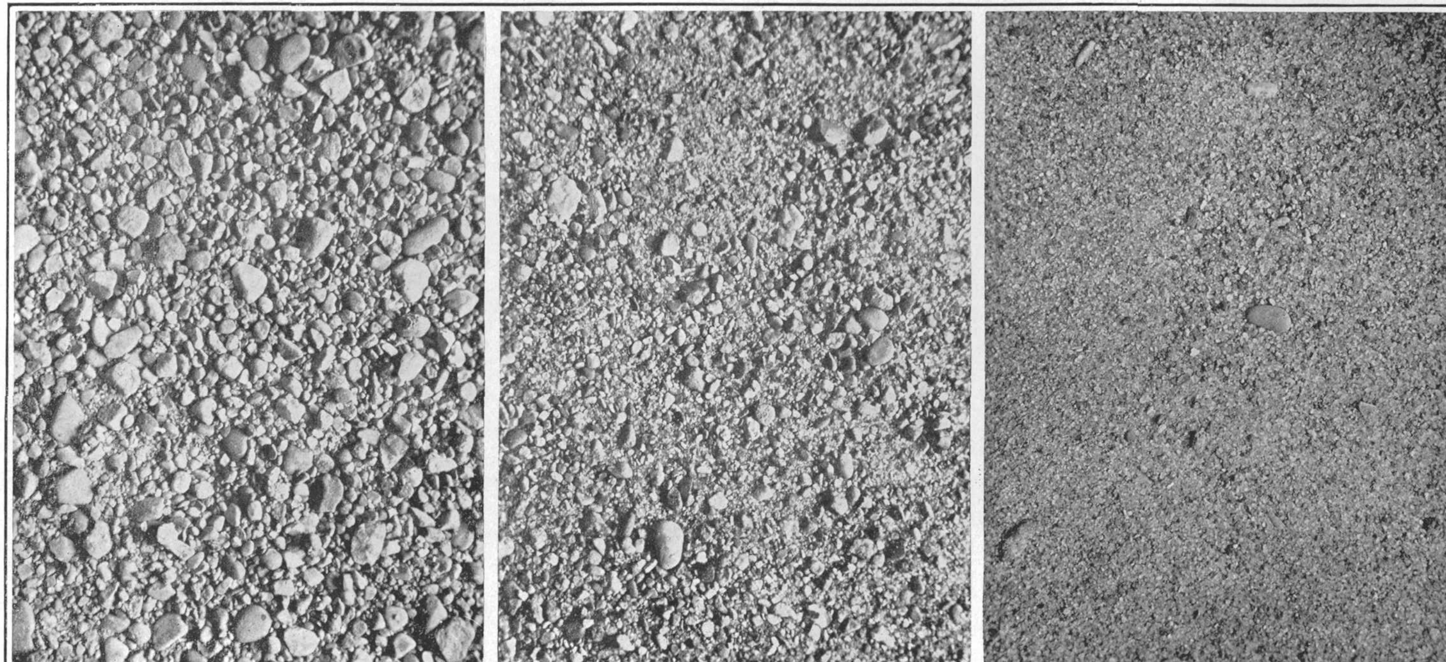


FIG. 10.—Granularmetric analysis curves for sands 1, 18, 14, and 7. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

The percentage of voids is 31.9; the weight per cubic foot is 111 pounds; the amount of silt is 2 per cent; and the yield in 1:3 mortar is 1.19. The results of the strength tests of mortars made from this sand are given in Table IX (p. 62).



A

B

C

A. BANK SAND, CHILSON, MICH. (SAMPLE 13).
B. ST. CLAIR RIVER SAND, DETROIT, MICH. (SAMPLE 14).
C. ST. CLAIR RIVER SAND, DETROIT, MICH. (SAMPLE 15).

Register No. Sd. 15.—The sample designated Sd. 15 is a very fine sand, extensively used as a finishing sand for sidewalks and concrete blocks. It was taken from St. Clair River by means of a centrifugal pump, loaded in scows and transported to Detroit.

According to the granularmetric analysis curve (fig. 9, p. 45) this sand is the finest of the 22 sands herein described, 96 per cent passing the No. 20 sieve and 85 per cent passing the No. 40 sieve. The percentage of voids is 40.5; the weight per cubic foot is 95 pounds; the amount of silt is 2 per cent, and the yield in 1:3 mortar is 1.13. The results of the strength tests of mortars made from this sand are given in Table IX (p. 62). Pl. V, *C* shows that there is only an occasional large particle in the sand, the great mass of the particles being exceedingly small.

Register No. Sd. 16.—The sample designated Sd. 16 was obtained at the beach of St. Clair River near Amherstburg, Ontario, by means of a centrifugal pump, and was dumped into scows and towed to Detroit.

The granularmetric analysis curve of this sand is shown in fig. 13 (p. 54). The percentage of voids is 29.7; the weight per cubic foot is 119.5 pounds; the amount of silt is 0.2 per cent, and the yield in 1:3 mortar is 1.20. The results of the strength tests of mortars made from this sand are given in Table IX (p. 62). The illustration of this sand (Pl. VI, *A*) shows that the material is very uniformly graded, particles of almost all sizes being in sight.

Register No. Sd. 17.—The sample designated Sd. 17 was excavated by pick and shovel from a rather dirty bank of glacial material, at Utica, Mich., and shipped to Detroit.

According to the granularmetric analysis curve (fig. 9, p. 45) this is a very fine sand, 61 per cent passing the No. 40 sieve and 83 per cent passing the No. 20 sieve. The percentage of voids is 34.5; the weight per cubic foot is 105.5 pounds; the amount of silt is 3.4 per cent, and the yield in 1:3 mortar is 1.27. The results of the strength tests on mortars made from this sand are given in Table IX (p. 62). The appearance of the sand is shown in Pl. VI, *B*.

Register No. Sd. 18.—The sample designated Sd. 18 was screened from a gravel of glacial origin at Attica, Ind. It was excavated from the bank by a steam shovel, and was then screened into several sizes and washed.

According to the granularmetric analysis curve (fig. 10) this sand is rather fine, 79 per cent passing the No. 20 sieve, 44 per cent passing the No. 40 sieve, and 14 per cent passing the No. 80 sieve. Its appearance is shown in Pl. VI, *C*. The percentage of voids is 34; the weight per cubic foot is 106.5 pounds; the amount of silt present is 3.9 per cent, and the yield in 1:3 mortar is 1.15. The results of the strength tests of mortars made from this sand are shown in Table IX (p. 62).

Register No. Sd. 19.—A second sample, screened from the same deposit at Attica, Ind., was designated Sd. 19.

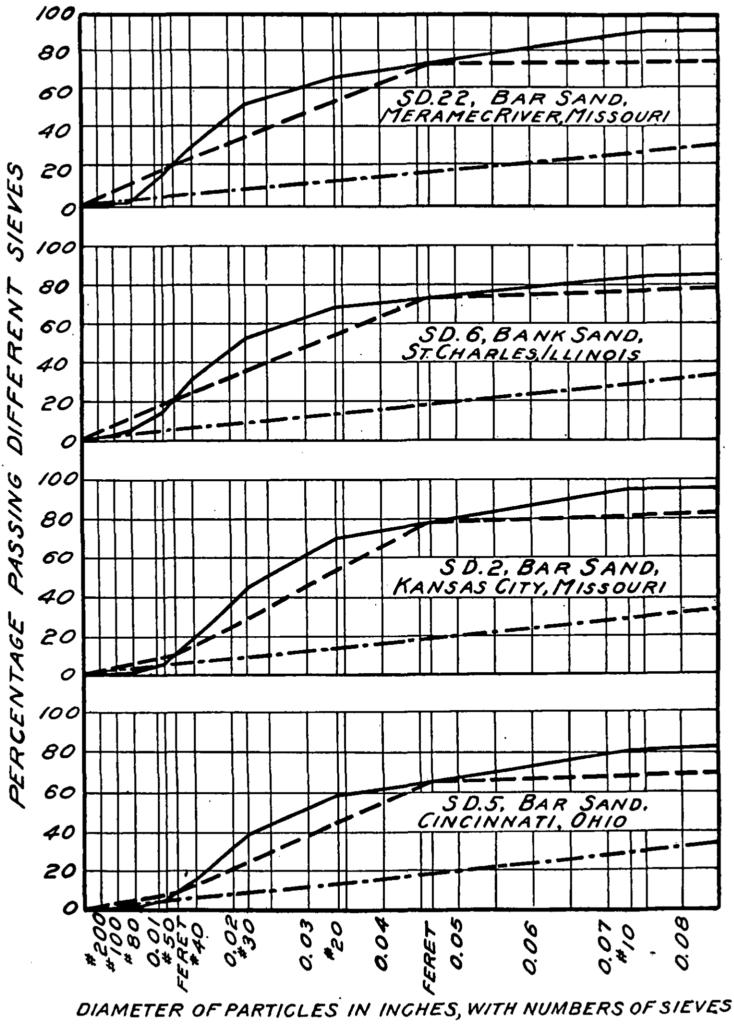
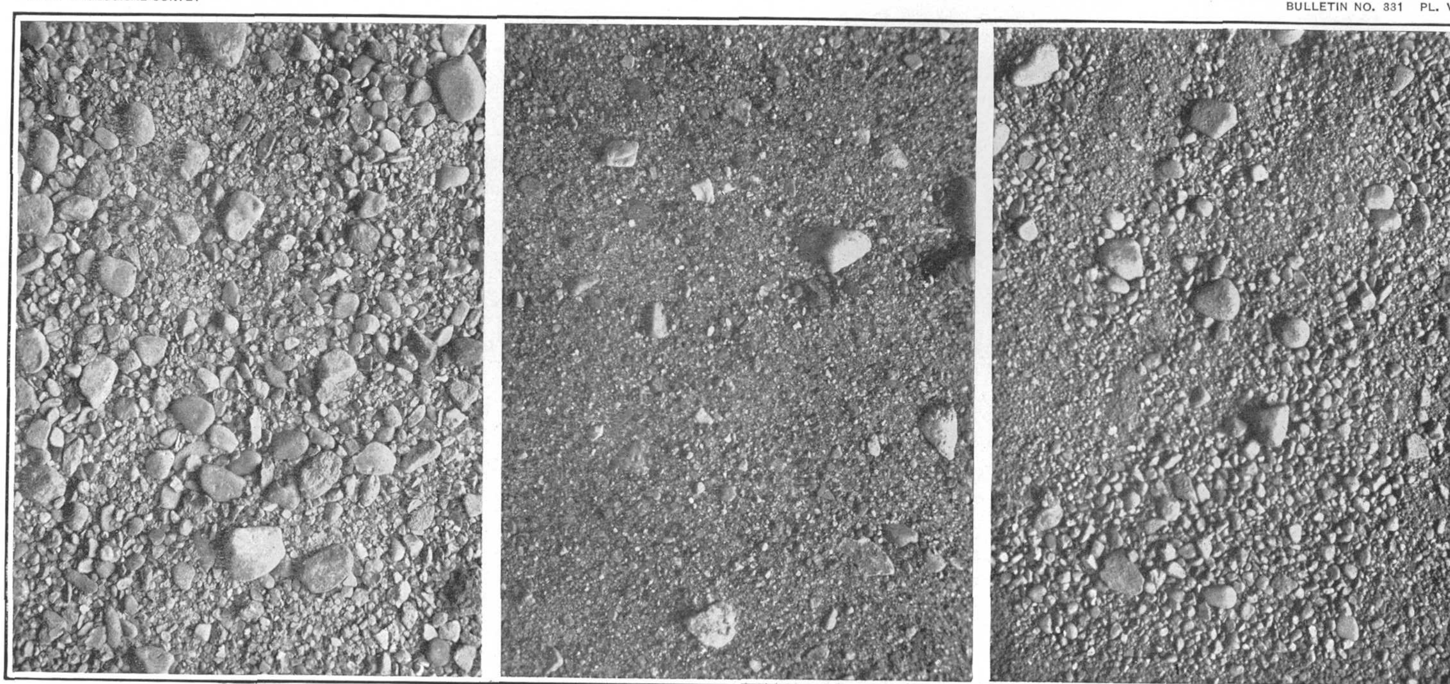


FIG. 11.—Granularmetric analysis curves for sands 22, 6, 2, and 5. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

According to the granularmetric analysis curve (fig. 12, p. 52) this material is very uniformly graded; 45 per cent passes the No. 20 sieve, 29 per cent passes the No. 30 sieve, and 2 per cent passes the No. 80 sieve. The percentage of voids is 26.9, the weight per cubic foot is 119.9 pounds, the amount of silt is 0.7 per cent, and the yield



A *B* *C*

A. ST. CLAIR RIVER SAND, AMHERSTBURG, ONTARIO (SAMPLE 16).
B. BANK SAND, UTICA, MICH. (SAMPLE 17).
C. BANK SAND, ATTICA, IND. (SAMPLE 18).

in 1:3 mortar is 1.19. The results of the strength tests of mortars made from this sand are shown in Table IX (p. 62). This sand is illustrated in Pl. VII, *A*. The comparatively uniform grading is evident, and it can be seen that the sizes range uniformly from the largest down to the smallest.

Register No. Sd. 20.—A third sample, from the same bank as Sd. 18 and Sd. 19, was designated Sd. 20.

According to the granularmetric analysis curve (fig. 12, p. 52) this sand is midway between a fine and a uniformly coarse sand, 50 per cent passing the No. 20 sieve. The percentage of void is 28; the weight per cubic foot is 116.5 pounds; the amount of silt is 1.3 per cent, and the yield in 1:3 mortar is 1.16. The results of the strength tests of mortars made from this sand are shown in Table IX (p. 62), and the sand is illustrated in Pl. VII, *B*.

Register No. Sd. 21.—The sample designated Sd. 21 is a bar sand from Meramec River at Moselle, Mo.

According to the granularmetric analysis curve (fig. 9, p. 45) this is a very fine sand, 82 per cent passing the No. 30 sieve and 2 per cent passing the No. 80 sieve. A large amount of this sand, over 60 per cent, is of approximately one size, between Nos. 30 and 50 sieves. This may be seen in the photograph reproduced in Pl. VII, *C*. The percentage of voids is 40.9; the weight per cubic foot is 89 pounds; a trace only of silt is present, and the yield in 1:3 mortar is 1.05. The results of the strength tests of mortars made from this sand are shown in Table IX (p. 62).

Register No. Sd. 22.—A sand generously donated in large quantities by a St. Louis company is used at the laboratories wherever a standard sand is required in tests not involving the quality of the cement. The selection was influenced (1) by the physical quality of the sand and (2) by the facility with which it could be procured. It is designated Sd. 22 and is a recent river sand, pumped by a suction dredge from the bed of Meramec River at Drake, Mo., about 15 miles from the laboratories. The dredge deposits the material in scows which convey it a few hundred yards to the screens where it is elevated by means of a clam-shell bucket and washed down through a series of screens, which separate the material into 2-inch, 1-inch, ½-inch, coarse, and fine sizes.

The granularmetric analysis curve (fig. 11, p. 50) indicates that it lies midway between the coarse and the fine sands, and that it is uniformly graded; 93 per cent passes the No. 10 sieve, 69 per cent passes the No. 20 sieve, 55 per cent passes the No. 30 sieve, and 17 per cent passes the No. 50 sieve. The percentage of voids is 36.4; the weight per cubic foot 98.8 pounds; there is only a trace of silt, and the yield in 1:3 mortar is 1.11. The results of the strength tests of mortars made from this sand are shown in Table IX (p. 62). This sand is illustrated in Pl. VIII, *A*.

Standard Ottawa sand.—Sand from the St. Peter formation at Ottawa, Ill., sifted to 20–30 size, was designated standard Ottawa sand. That the grains are almost all of the same size can readily be

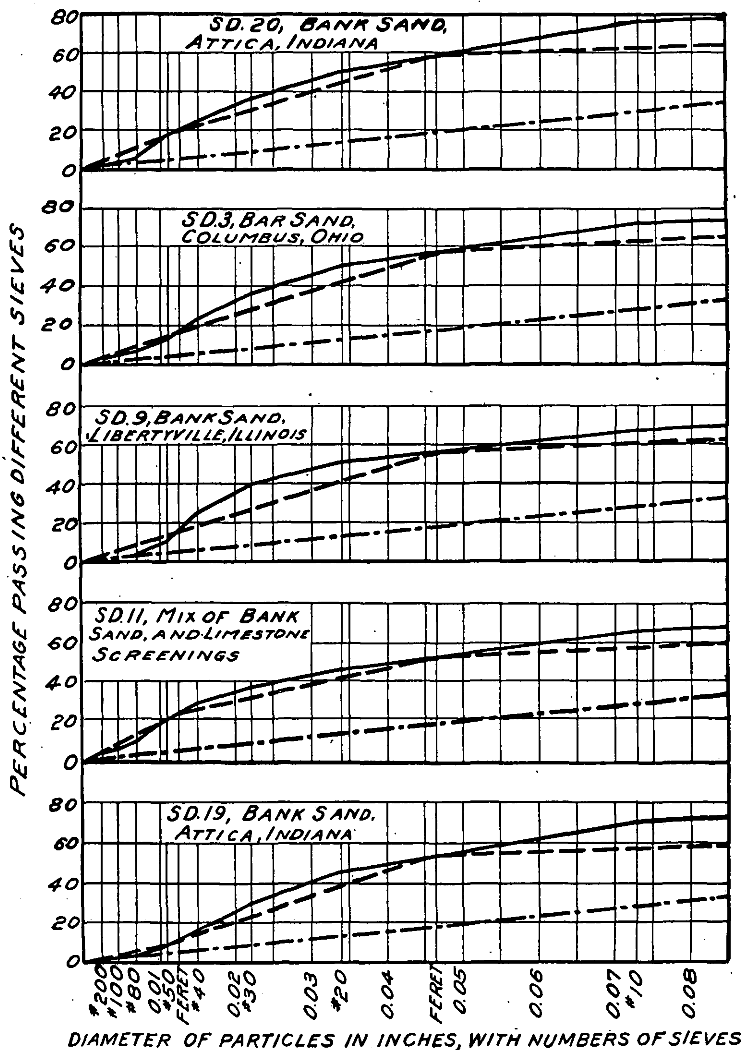
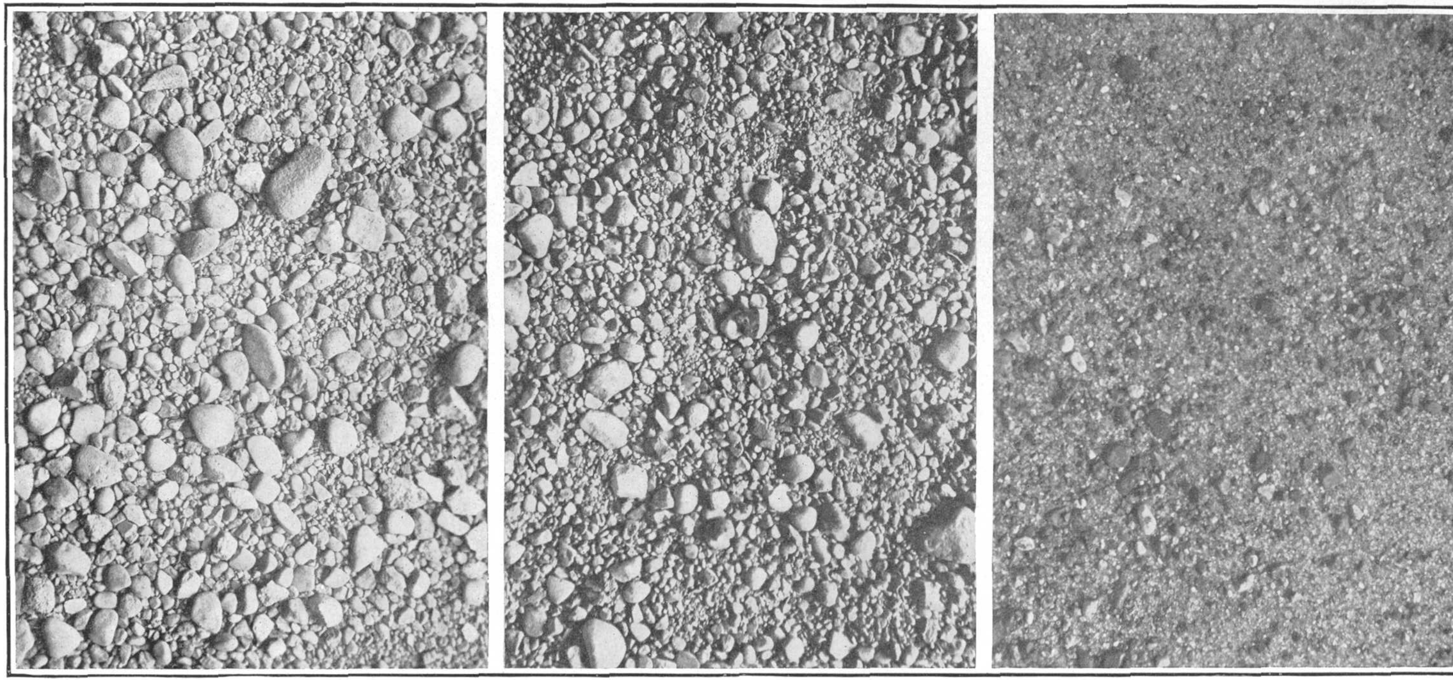


FIG. 12—Granularmetric analysis curves for sands 20, 3, 9, 11, and 19. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

seen by an inspection of Pl. VIII, *B*. This is a standard sand used in investigations of cement so as to give comparable results. The results of some tests of 1:3 mortar made from this sand are given in Tables II (p. 13), IV (p. 29), and VI (p. 32).



A *B* *C*

A. BANK SAND, ATTICA, IND. (SAMPLE 19).
B. BANK SAND, ATTICA, IND. (SAMPLE 20).
C. MERAMEC RIVER SAND, MOSELLE, MO. (SAMPLE 21).

PHYSICAL TESTS OF SANDS.

Method.—When a sample of sand is received at the laboratories it is spread on a concrete floor in a thin layer and turned at frequent intervals for a period varying from a few hours to 2 days, until it is thoroughly air dried. The temperature of the room in which the air drying takes place is maintained at about 70° F.

The sands (all of which have previously passed the ¼-inch screen) are submitted to tests for granularmetric composition, percentage of voids, specific gravity, weight per cubic foot, percentage of moisture, and the percentage and the chemical analysis of silt, which are determined and recorded as explained in Bulletin No. 329. The results of the chemical analyses of the silts are given in Table X (p. 77), and of the other determinations in Table VIII (p. 59).

Granularmetric analyses.—The set of sieves for the granularmetric analyses comprises those with 10, 20, 30, 40, 50, 80, 100, and 200 openings per linear inch. A sample of the air-dried material is placed on the upper of the nest of sieves and shaken for 15 minutes, when the residue on each sieve and the material passing the No. 200 sieve are weighed. The weight of material retained on each sieve and passing the No. 200 sieve is divided by the weight of the original sample to find the percentages retained on each sieve and passing the No. 200 sieve. These percentages are given in Table VIII (p. 59). Granularmetric analysis curves are also drawn for purposes of comparison.

Granularmetric curves.—The granularmetric analysis curves are shown in figs. 9–13, the ordinate at any sieve being the total percentage that passes that sieve, and not, as in Table VIII (p. 59) the percentage retained by the sieve. The percentage passing any sieve is found by adding together the percentages retained on all the smaller sieves and that passing the No. 200 sieve. At the left-hand side of each curve are given the percentages, and at the bottom of each figure the diameters of the particles that pass the different sieves, also the numbers of the standard sieves used in the work. Starting at the top of fig. 9 (p. 45) with the curve of the sand (Sd. 15) having the largest amount of fine material, these curves are arranged in consecutive order, ending at the bottom of fig. 13, with the curve of the sand (Sd. 16) having the largest amount of coarse material.

The granularmetric analysis curves, as determined by the standard sieves previously referred to, are given in full lines. In order to illustrate the difference between this method of analysis and the two-sieve method proposed by M. Feret, the curve representing the analysis by the latter method is plotted in each case in broken lines. The diameters of particles that would pass through the two sieves proposed by Feret are approximately 0.0125 and 0.0465 inch. Therefore, the broken lines are drawn from zero to the point at which the full granularmetric analysis line crosses the ordinate at 0.0125; thence to the point at which the full granularmetric analysis line crosses the ordinate at 0.0465; and thence to 100 per cent at diameter 0.25, the latter being off the diagram. In Feret's method a $\frac{1}{5}$-inch sieve is used, but in the investigations reported in this bulletin, since the $\frac{1}{4}$-inch screen was used, the line is drawn in this way.

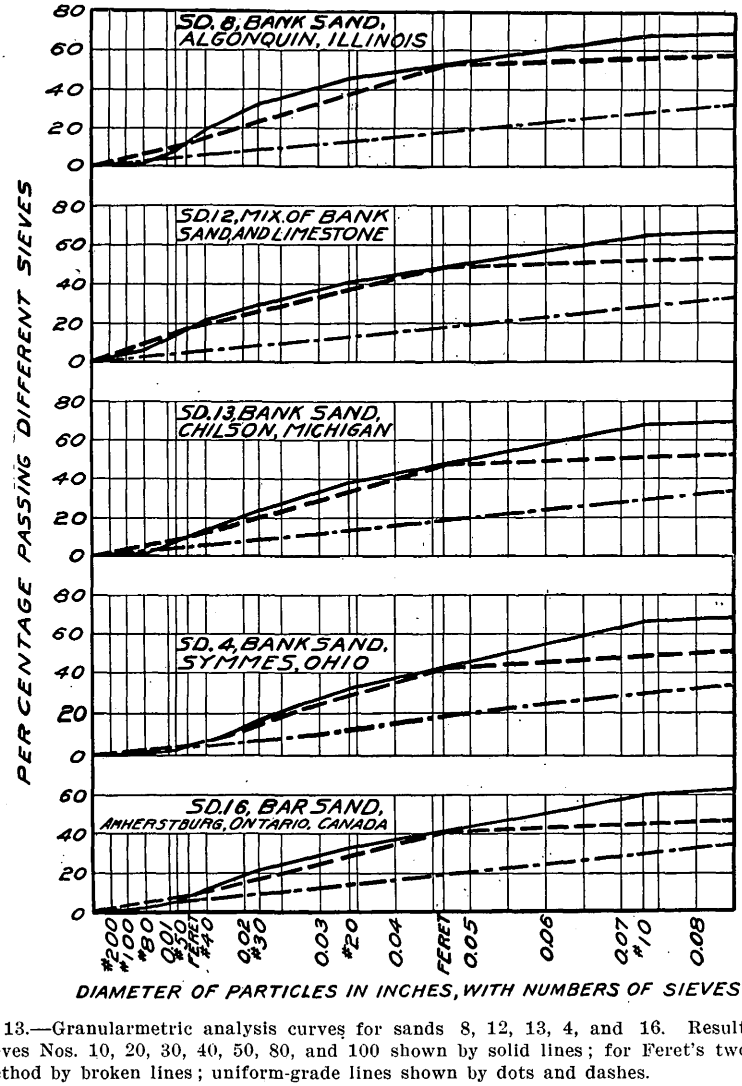
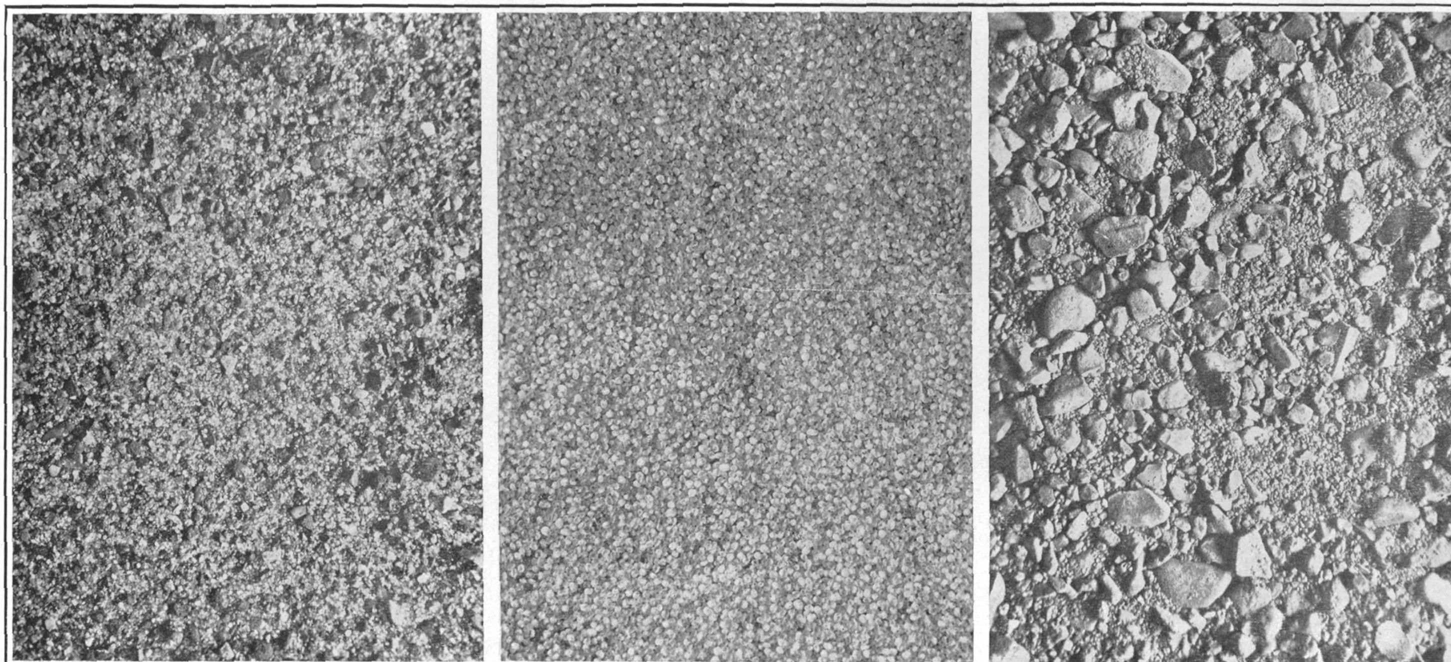


FIG. 13.—Granularmetric analysis curves for sands 8, 12, 13, 4, and 16. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

Below the two curves just described is given the uniform-grade line in dots and dashes. It can be seen that in arranging from the finest to the coarsest sand the curves have been arranged in the order of the size of segment included between the granularmetric analysis curve and the uniform-grade line. In can also be seen that, as the



A *B* *C*

A. MERAMEC RIVER SAND, DRAKE, MO. (SAMPLE 22).
B. STANDARD OTTAWA SAND, OTTAWA, ILL.
C. BAR GRAVEL SCREENINGS, MERAMEC RIVER, DRAKE, MO. (SAMPLE 1).

segment decreases the sand gradually becomes coarser and approaches uniform grading more nearly.

Only that portion of each curve that shows the variation in grading under the No. 10 sieve, and for a short distance beyond it, is drawn in the figures. If the remainder of the curves were drawn there would simply be three straight lines from the line for the No. 10 sieve to 100 per cent at a diameter of 0.25. Instead of this, the lines to the right of the No. 10 ordinate are given the proper inclination and the remainder is omitted.

Comparison between measured and computed voids.—In the determination of the percentage of voids and the weight per cubic foot, three independent determinations were made. After each reading the material was thoroughly air dried for the next test.

On account of the great difficulty experienced in the determination of the percentage of voids, due to the flexibility in compacting the material, and to the contained moisture, great care was required in these determinations. Afterwards, the voids were computed from the specific gravity and weight per cubic foot.

On account of the fact that different methods of placing the material in the weighing cylinder result in different degrees of compactness, a uniform method of handling was adopted. This consists in allowing the material to fall from the same height and to fill the cylinder in a certain length of time.

The computed and measured voids are given in Table VIII (p. 59). The computed percentage of voids for any sand is found by first multiplying the specific gravity by the weight of a cubic foot of water. This gives the product "X" (column 10) in the table, which is the weight of a solid cubic foot of the material. The measured weight per cubic foot, W, is then divided by X to give the part of the space actually occupied by the sand grains (column 11). The difference between this quotient and one, multiplied by 100, gives the computed percentage of voids.

In columns 14 and 15 of the table are given the differences between the measured and computed values. In only two cases, namely, Sd. 7 and Sd. 16, are the measured voids an appreciable amount greater than the computed. Almost invariably the latter is the greater, but in more than two-thirds of the cases the difference is not more than 1 per cent. From the line marked "Average" it can be seen that the computed voids are 0.8 per cent greater than the measured.

Uniformity coefficient.—It is frequently necessary to draw comparisons between sands composed of grains of different sizes. It has been generally established that the strength quality or value of a sand may be indicated by ascertaining whether it lies in the coarse, medium, or fine region, and it is important to determine in some way the degree of coarseness or fineness. One method that suggests itself is to sift the sand through the eight sieves that are used in the series of experiments under description, and then to plot the granularmetric analysis curve as has been done in this report. A direct comparison can then be made between any sands whose granularmetric analyses are known. Feret's two-sieve method for studying properties of sands has been already explained (p. 53). Another method of studying sands is by means of Hazen's uniformity coefficient.

Hazen suggested a factor equal to the ratio of the diameter of one particle (located by the intersection of the 60 per cent abscissa with the granularmetric analysis curve) to the diameter of another particle (located by the intersection of the 10 per cent abscissa with the curve); the size of the latter or smaller particles he terms the "effective size," and, inasmuch as this acts in the capacity of a divisor, its fluctuations affect the uniformity coefficient. When the curves show a general normal alignment through the two points mentioned above, the uniformity coefficient as thus obtained is a fair index of the relative grading of the sand.

The uniformity coefficients of the sand studied in this investigation are arranged progressively in decreasing order in Table XI (p. 62). The voids of each sand are also given for convenience of comparison. This uniformity coefficient does not appear to indicate the quality of a sand any better than the granularmetric analysis curves.

PHYSICAL TESTS OF SAND MORTARS.

Method.—Each of the sands described in the preceding pages was mixed with typical Portland cement to form mortars of different proportions, and these mortars were made into test pieces for the tensile, compressive, and transverse tests. Proportions of 1:3 and 1:4 were used in every case; in many other cases where there was sufficient material of one size this was tested as a 1:3 one-size mortar. For each sand 15 test pieces were made for each kind of stress, and three pieces were tested at each of the five ages, 7, 28, 90, 180, and 360 days.

The results of the strength tests on these mortars, including the register number, the yield at the 1:3 ratio, the register number of the corresponding typical Portland cement test pieces, the temperature (in °F.) of the water and of the air at the time of molding, the percentage of water used for normal consistency, and the breaking strengths (in pounds per square inch) at different ages are given in Table IX (p. 62). In giving the results of tests on 1:3 one-size mortar the size to which the sand was shifted is also shown. Table VIII (p. 59) summarizes data respecting the field origin and nature of each sand; and the average physical properties are given in Table XII (p. 78).

The yield of 1:3 mortar was determined in order to form a general basis as to the volume of mortar derived from a given volume of sand when mixed with cement in proportions of 1:3 by weight. This value is obtained by dividing the volume of mortar by the volume of the sand before mixing.

The results of the strength tests on neat cement test pieces made from the same cement used in the mortars are given in Table VII (p. 36) and are plotted in figs. 6, 7, and 8. The corresponding cement numbers found in the left-hand column of Table VII are also given in Table IX so that the strength of the mortar can be compared with the strength of the neat cement used in the mortar.

Tensile strength.—The results of the tensile tests on 1:3, on 1:4, and on 1:3 one-size sand mortar are given in Table IX*a* (p. 62). The results are arranged in groups of three, and the average of each group is shown in the line marked "Average."

The lack of uniformity in the increase of strength is probably due to physical differences in the sands. In general, the tensile strength of all three proportions seems to decrease with the increase in the voids. An increase in tensile strength is also noticeable as the sands approach uniform grading.

Compressive strength.—The results of the compressive tests are given in Table IX*b* (p. 67). The values in this table are in pounds per square inch and are obtained by dividing the total breaking load by the area of cross section of a 2-inch cube.

Considering these tests in the order of the percentage of voids, as arranged under tensile strength, we see that the strength appears to decrease with the increase of voids. The strength of mortars made from sands which have a small percentage of voids is in every case much greater than that of mortars made from sands having a large percentage of voids. The difference in strengths of the mortars of different proportions is also greater for those sands that have small percentages of voids. This condition is the same as that noticed in the study of tensile strength and indicates that the greatest compresive strength can be obtained by the use of a mortar in which the sand is uniformly graded.

Transverse strength.—The results of the transverse tests are given in Table IX*c* (p. 73). As stated elsewhere (p. 9), the values given in this table are moduli of rupture in pounds per square inch. These tests show the same tendency as in those for tensile and compressive strength. The strength of mortar made from those sands in which the percentages of voids are low, while not so marked as in the tension and compression tests, is greater than that of mortar made from sands in which the percentages of voids are high.

Summary of sand-mortar tests.—In general there is greater uniformity in tests made at the end of 180 days than in those made at the end of the shorter periods. Alterations in environment materially affect the early strength, while the nature of the cement often causes irregularity in the strengths for the earlier periods. This irregularity disappears to a great extent as the test pieces become older, as is well illustrated in Tables III (p. 28), IV (p. 29), V (p. 31), and VI (p. 32), showing the percentage of gain in strength of tensile- and compressive-test pieces of neat cement and 1:3 standard-sand mortar. In that connection (p. 39) it was pointed out that, despite the many different strengths at 7 days and the many different percentages of gain to 28 and 90 days, the strengths at 180 days showed remarkable uniformity. In comparing the strength of mortars it is desirable to use the results of the 180-day tests.

The results of these tests seem to indicate that the nearer the grading curve approaches the uniform-grade line the greater is the strength. It is also apparent that the strength decreases with the increase in the percentage of voids.

Density.—The density of mortar made from each sand was determined in order to ascertain its relation to the other physical properties and to see if there is a relation between the density and the strength of the mortar. The density was determined for only the 1:3 mortar; in subsequent investigations density determinations are to be made for all proportions.

The method of making the density test is as follows: After the sand, cement, and water have been weighed in the required proportions and thoroughly intermixed, 1,000 grams of the mixture are introduced in portions of about 50 grams into a graduated cylinder of 500 cubic centimeters capacity. Each layer is tamped until the water flushes to the surface. The graduated cylinder is weighed before and after the mortar is introduced, the difference being the weight of the mortar. A reading on the top of the mortar is taken after the level of the top becomes stationary, generally within 30 minutes after the mortar is introduced.

The weight of sand and cement used is known from the amount introduced into the cylinder. The absolute volumes of these ingredients are then determined by their respective specific gravities.

Each of these absolute volumes is divided by the recorded volume of the mortar, and these ratios are termed the "elementary volumes" of cement and sand, being designated by "C" for cement and "S" for sand. The sum of the elementary volumes of cement and sand, or, using the suggested notation, "C+S," is termed the "density." In other words, density as applied to mortar signifies the ratio of the absolute volume of sand and cement to the recorded volume of the mortar.

The densities of 1:3 mortar and the relation between the densities and other physical properties of the sands and mortars are given in

Table XII (p. 78). In column 1 are given the register numbers of the sands used in the mortars whose densities are given in column 2. The densities are arranged in order, with the largest value at the top. For purposes of comparison the number of the granular metric analysis curve for each sand is given in column 3. The numbers start with No. 1 for Sd. 15 (at the top of fig. 9, p. 45) and end with No. 22 for Sd. 16 (at the bottom of fig. 13, p. 54). The percentage of voids, weight per cubic foot, and tensile, compressive, and transverse strengths of the corresponding mortars at 180 days are given in columns 4–8. It will be observed that in the upper part of the table, where the values of density are greatest, the percentages of voids are least and the weights per cubic foot and the strengths are greatest, and near the bottom the opposite is true.

TABLE VIII.—*Physical properties of sands 1–22, gravel screenings 1–12, and stone screenings 1–25.*

SANDS.

Register No.	Location.	Source of supply.	Specific gravity.	Weight per cubic foot (pounds).	Absorption (per cent). In 24 hours.	Absorption (per cent). In 48 hours.	Per cent of silt.
1	2	3	4	5	6	7	8
Sd. 1	Kansas City, Mo.	Bar	2.64	109.3	0.36	0.42	0.20
Sd. 2	....do	....do	2.65	107.7	.36	.39	Trace.
Sd. 3	Columbus, Ohio	....do	2.60	103.3	....	....	4.2
Sd. 4	Symmes, Ohio	Bank	2.63	116.4	....	....	1.4
Sd. 5	Cincinnati, Ohio	Bar	2.59	104.8	.93	1.06	Trace.
Sd. 6	St. Charles, Ill	Bank	2.67	113.5	1.48	2.11	.53
Sd. 7	Carpenterville, Ill	....do	2.68	116.0	.95	.96	1.2
Sd. 8	Algonquin, Ill	....do	2.68	114.5	....	1.31	1.3
Sd. 9	Libertyville, Ill	....do	2.60	110.5	.92	1.39	2.6
Sd. 10	Kenton County, Ky	....do	2.62	110.0	1.06	1.41	2.1
Sd. 11	Toledo, Ohio	Mixture of sand and limestone screenings.	2.71	108.3	3.05	3.63	3.4
Sd. 12	....do		2.70	106.5	....	....	4.7
Sd. 13	Chilson, Mich	Bank	2.70	119.5	.61	1.63	.3
Sd. 14	St. Clair River, Mich	Bar	2.64	111.0	2.36	2.61	2.0
Sd. 15	....do	....do	2.63	95.5	....	....	2.2
Sd. 16	....do	....do	2.69	119.5	1.03	1.59	.23
Sd. 17	Utica, Mich	Bank	2.62	105.5	....	1.53	3.4
Sd. 18	Attica, Ind	....do	2.64	106.5	....	....	3.9
Sd. 19	....do	....do	2.65	119.9	.64	1.19	.7
Sd. 20	....do	....do	2.63	116.5	....	....	1.3
Sd. 21	Moselle, Mo	Bar	2.61	89.0	....	....	Trace.
Sd. 22	Drake, Mo	....do	2.60	98.8	....	....	Trace.

GRAVEL SCREENINGS.

Register No.	Location.	Source of supply.	Specific gravity.	Weight per cubic foot (pounds).	Absorption in 24 hours.	Absorption in 48 hours.	Per cent of silt.
Gl. 1	St. Louis, Mo	Bar	2.56	115.0	1.90	1.90	0.15
Gl. 2	Moselle, Mo	....do	2.57	113.5	1.58	1.61	Trace.
Gl. 3	Columbus, Ohio	River bar	2.66	102.6	1.26	1.70	1.37
Gl. 4	Loveland, Ohio	Bank	2.67	117.1	.68	.72	2.7
Gl. 5	Carthage, Ohio	....do	2.67	115.3	1.71	1.80	.04
Gl. 6	Ludlow, Ky	....do	2.72	120.8	.95	1.02	2.85
Gl. 7	Chilson, Mich	....do	2.68	113.4	.63	.71	.15
Gl. 8	....do	....do	2.70	111.5	1.31	1.31	.2
Gl. 9	Amherstburg, Canada	River beach	2.66	117.8	1.57	1.65	.71
Gl. 10	Lorain, Ohio	Lake beach	2.68	118.9	.5	.5	.4
Gl. 11	Attica, Ind	Bank	2.68	122.5	1.08	1.10	.3
Gl. 12	....do	....do	2.67	120.3	1.32	1.36	.5

TABLE VIII.—*Physical properties of sands 1–22, gravel screenings 1–12, and stone screenings 1–25*—Continued.

STONE SCREENINGS.

Register No.	Location.	Source of supply.	Specific gravity.	Weight per cubic foot (pounds).	Absorption (per cent). In 24 hours.	Absorption (per cent). In 48 hours.	Per cent of silt.
1	2	3	4	5	6	7	8
Se. 1	St. Louis, Mo	Limestone	2.70	103.5	0.64	0.67	4.90
Se. 2	do	do	2.70	106.2	.50	.55	5.40
Se. 3	do	do	2.67	103.5	1.28	1.31	2.30
Se. 4	Glencoe, Mo	do	2.65	105.5	.89	.91	.62
Se. 5	Springfield, Mo	do	2.66	95.7	.53	.55	1.00
Se. 6	Joplin, Mo	Chat	2.61	109.5	.75	.76	7.00
Se. 7	do	do	2.63	102.7	1.51	2.36	4.92
Se. 8	do	do	2.61	105.5	1.88	1.90	2.90
Se. 9	do	do	2.62	108.0	2.72	2.73	3.00
Se. 10	do	do	2.62	109.8	.82	1.05	4.73
Se. 11	St. Louis, Mo	Limestone	2.70	95.5	2.65	2.74	10.10
Se. 12	Kansas City, Mo	do	2.64	105.3	1.33	1.54	4.70
Se. 13	St. Joseph, Mo	do	2.71	102.2	1.65	1.79	2.20
Se. 14	Kansas City, Mo	do	2.64	104.3	1.40	1.42	4.00
Se. 15	Hoffman, Mo	Chat	2.84	109.5	1.25	1.28	.47
Se. 16	Bonneterre, Mo	do	2.86	120.0	1.12	1.13	3.72
Se. 17	Graniteville, Mo	Granite	2.70	108.8	.32	.32	1.40
Se. 18	Kankakee, Ill	Limestone	2.70	103.8	2.04	2.11	7.80
Se. 19	McCook, Ill	do	2.78	102.5	1.04	1.06	4.97
Se. 20	Columbus, Ohio	Bowlder	2.69	108.5	2.48	2.52	3.1
Se. 21	Hillsboro, Ohio	Limestone	2.71	97.4	.04	.04	3.12
Se. 22	Greenfield, Ohio	do	2.72	106.3	1.90	2.05	1.07
Se. 23	Casparis, Ohio	do	2.65	99.7	.04	.13	3.5
Se. 24	Sylvania, Ohio	do	2.72	101.1	1.81	1.86	1.1
Se. 25	Sibley, Mich	do	2.70	110.3	......	......	16.3

SANDS.

Register No.	Measured and computed voids. 62.355 × specific gravity = X (pounds).	W/X	Computed voids $100\left(1-\frac{W}{X}\right)$.	Measured voids.	Excess. Computed.	Excess. Measured.	Percentage by weight of 500 grams. Retained on sieve No.— 10.	20.	30.	40.	50.	80.	100.	200.	Passing sieve No. 200.
1	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Sd. 1	164.62	0.664	33.6	32.5	1.1	......	3.2	10.3	29.3	29.8	5.7	2.2	3.4	14.8	0.9
Sd. 2	165.25	.652	34.8	34.9	.....	0.1	5.4	25.4	26.0	25.7	12.8	4.2	.4	.1	......
Sd. 3	162.12	.637	36.3	36.1	.2	......	24.7	23.2	15.0	13.2	9.4	6.6	1.9	1.9	3.3
Sd. 4	163.99	.710	29.0	28.0	1.0	......	33.0	34.9	15.2	8.4	4.4	2.1	.4	.3	.9
Sd. 5	161.49	.649	35.1	34.6	.5	......	18.5	22.7	19.7	23.4	11.4	3.3	.3	.1	......
Sd. 6	166.48	.682	31.8	31.6	.2	......	15.5	15.9	16.0	20.5	17.7	9.1	1.7	1.9	1.2
Sd. 7	167.11	.694	30.6	31.6	.....	1.0	7.4	14.4	17.0	23.3	21.4	12.0	1.9	1.1	.7
Sd. 8	167.11	.685	31.5	30.7	.8	......	30.7	22.2	14.2	13.7	10.7	6.0	.9	.6	.6
Sd. 9	162.12	.682	31.8	31.4	.4	......	31.1	17.3	12.2	15.0	14.4	6.5	1.0	.8	1.3
Sd. 10	163.37	.673	32.7	31.6	1.1	......	6.4	12.0	14.3	18.6	21.5	18.0	4.6	3.0	1.2
Sd. 11	168.98	.641	35.9	36.0	.....	.1	32.4	20.9	9.7	8.1	8.8	10.9	3.3	2.3	3.0
Sd. 12	168.36	.633	36.7	35.5	1.2	......	33.3	24.7	11.8	7.5	7.2	7.3	2.4	2.2	2.8
Sd. 13	168.36	.710	29.0	28.9	.1	......	30.9	30.4	14.4	10.0	6.7	5.2	1.0	.4	.2
Sd. 14	164.62	.668	33.2	31.9	1.3	......	7.4	21.4	12.0	13.3	15.3	15.2	6.7	5.7	2.1
Sd. 15	163.99	.582	41.8	40.5	1.3	......	1.0	1.8	2.0	8.5	25.3	44.7	9.6	4.5	1.2

TABLE VIII.—*Physical properties of sands 1–22, gravel screenings 1–12, and stone screenings 1–25*—Continued.

SANDS—Continued.

Register No.	Measured and computed voids.						Percentage by weight of 500 grams.								
	62.355 × specific gravity = X (pounds).	W/X	Computed voids $100\left(1-\frac{W}{X}\right)$.	Measured voids.	Excess.		Retained on sieve No. —								Passing sieve No. 200.
					Computed.	Measured.	10.	20.	30.	40.	50.	80.	100.	200.	
1	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Sd. 16	167.73	0.713	28.7	29.7	.....	1.0	39.5	27.5	11.6	9.4	6.8	3.0	0.8	0.4	0.3
Sd. 17	163.37	.646	35.4	34.5	.9	......	8.4	7.5	7.8	14.3	24.2	25.4	6.1	3.6	1.8
Sd. 18	164.62	.647	35.3	34.0	1.3	......	4.1	16.3	16.0	19.0	13.8	16.3	4.1	5.0	4.6
Sd. 19	165.25	.726	27.4	26.9	.5	......	27.1	26.9	16.4	14.3	7.2	5.2	.8	.6	.7
Sd. 20	163.99	.710	29.0	28.0	1.0	......	23.3	26.5	13.9	11.7	7.7	11.7	1.9	1.3	1.1
Sd. 21	162.75	.547	45.3	40.9	4.4	......	1.0	7.3	7.6	20.0	43.5	18.0	1.6	.2	.1
Sd. 22	162.12	.609	39.1	36.4	2.7	......	7.33	23.7	14.3	21.6	15.8	15.1	1.7	.5	.1
Average..	164.90	.662	33.8	33.0	1.1	.1	......	......	......	......	......	......	......	......	......

GRAVEL SCREENINGS.

Register No.	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Gl. 1	....	......	28.0	29.0	.....	1.0	61.8	12.6	6.3	7.7	7.5	3.6	0.3	0.0	0.2
Gl. 2	....	......	29.2	31.0	.....	1.8	37.8	14.5	7.8	9.6	13.1	13.3	2.2	0.8	.9
Gl. 3	....	......	38.2	38.6	.....	.4	79.0	5.0	2.6	1.6	1.7	.9	.8	1.7	6.7
Gl. 4	....	......	29.7	30.9	.....	1.2	28.0	11.3	11.5	19.8	15.9	9.0	1.6	1.8	1.1
Gl. 5	....	......	30.7	29.7	1.0	......	39.6	2.3	13.9	12.3	7.5	3.0	.4	.1	.1
Gl. 6	....	......	28.8	27.9	.9	......	46.2	16.1	6.9	7.8	8.1	7.0	2.6	2.2	3.1
Gl. 7	....	......	32.1	32.8	.....	.7	95.5	4.5	.0	.0	.0	.0	.0	.0	.0
Gl. 8	....	......	33.8	34.8	.....	1.0	97.7	1.3	.0	.0	.0	.0	.0	.2	.8
Gl. 9	....	......	29.0	30.7	.....	1.7	99.3	.7	.0	.0	.0	.0	.0	.0	.0
Gl. 10	....	......	28.9	27.9	1.0	......	33.2	16.0	9.3	10.1	14.3	14.7	1.4	.7	.3
Gl. 11	....	......	26.7	25.5	1.2	......	45.3	26.1	13.7	7.1	4.0	2.3	.5	.2	.8
Gl. 12	....	......	27.8	26.5	1.3	......	26.1	23.1	13.1	14.0	9.6	10.5	1.9	1.0	.7
Average..	....	......	......	......	1.1	1.1	......	......	......	......	......	......	......	......	......

STONE SCREENINGS.

Register No.	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Se. 1	....	......	38.5	39.4	.....	0.9	36.8	22.5	12.3	7.8	5.4	5.4	2.7	4.9	2.2
Se. 2	....	......	36.9	37.2	.....	.3	40.5	21.1	10.0	7.7	5.1	4.9	2.1	5.6	3.0
Se. 3	....	......	37.8	37.0	0.8	......	34.6	12.8	9.3	8.7	7.6	6.9	5.0	13.1	2.0
Se. 4	....	......	37.4	36.0	1.4	......	73.9	6.0	5.2	3.0	2.2	2.2	1.5	4.5	1.5
Se. 5	....	......	42.3	41.1	1.2	......	78.4	10.1	3.3	2.1	1.2	1.9	.9	.9	1.2
Se. 6	....	......	32.7	33.1	.....	.4	68.2	10.6	3.4	2.0	1.5	1.7	.8	2.4	9.4
Se. 7	....	......	37.1	36.1	1.0	......	47.1	24.6	10.2	5.2	3.6	2.7	.9	1.9	3.8
Se. 8	....	......	35.2	34.6	.6	......	51.3	21.1	8.4	4.9	3.7	3.8	1.5	2.2	3.1
Se. 9	....	......	33.9	33.0	.9	......	53.6	18.5	7.8	4.8	3.9	4.0	1.5	2.5	3.4
Se. 10	....	......	32.8	31.8	1.0	......	49.8	19.2	8.6	5.9	4.1	2.6	2.1	2.8	4.9
Se. 11	....	......	43.3	42.1	1.2	......	9.9	40.3	13.7	7.9	7.2	7.9	3.6	18.5	1.0
Se. 12	....	......	36.0	35.1	.9	......	31.2	23.6	11.0	7.4	5.2	6.5	1.9	11.3	1.9
Se. 13	....	......	39.5	38.2	1.3	......	38.4	33.8	13.7	4.9	1.8	1.4	1.1	4.5	.4
Se. 14	....	......	36.6	35.8	.8	......	54.9	19.0	7.4	4.3	2.8	2.8	1.4	3.9	3.5
Se. 15	....	......	35.9	37.0	.....	1.1	56.9	35.3	5.3	1.2	.3	.1	.0	.1	.3
Se. 16	....	......	32.7	32.1	.6	......	27.4	34.2	14.5	8.4	5.5	4.4	1.4	1.5	1.6
Se. 17	....	......	......	34.7	.....	......	49.7	22.8	8.7	4.4	4.1	3.2	1.2	2.7	3.2
Se. 18	....	......	38.3	39.0	.....	.7	48.7	17.8	7.7	5.5	3.5	3.6	1.4	3.1	8.7
Se. 19	....	......	40.9	39.3	1.6	......	22.9	37.6	13.5	8.9	4.1	3.1	1.3	3.1	5.5
Se. 20	....	......	......	35.2	.....	......	61.5	7.1	2.4	1.8	1.2	1.7	1.2	4.2	18.9
Se. 21	....	......	42.4	41.0	1.4	......	5.8	14.1	8.5	8.8	10.1	13.6	9.4	14.1	15.3
Se. 22	....	......	37.3	37.5	.....	.2	44.4	21.4	8.5	4.9	3.4	3.0	1.5	3.0	9.9
Se. 23	....	......	39.7	38.2	1.5	......	57.0	13.8	6.6	4.3	3.9	4.0	1.1	3.9	5.4
Se. 24	....	......	40.4	41.8	.....	1.4	87.0	6.8	1.5	.6	.5	.5	.0	.5	2.6
Se. 25	....	......	34.5	33.8	.7	......	46.3	17.0	6.6	4.8	3.1	3.5	1.6	12.2	4.2
Average..	....	......	......	......	1.1	.7	......	......	......	......	......	......	......	......	......

TABLE IXa.—*Tensile strength of the mortars of 22 sands.*

Register No.[a]	Ratio of cement to sand.[b]	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Tensile strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 1	1:3	1.18	79–15	71.0	69.0	8.9	390 400 379	505 460 475	485 455 480	420 415 410	377 347 380
	Average						390	480	473	415	368
	1:4		79–17	71.2	67.6	8.3	308 285 292	370 365 384	380 400 383	312 310 328	333 318 308
	Average						295	373	388	317	320
	1:3 (sifted)		79–26	69.8	68.0	8.9	287 295 310	371 375 360	435 400 425	297 293 340	307 299 212
	Average						297	369	420	310	273
Sd. 2	1:3	1.12	79–15	71.0	69.0	8.9	342 357 330	420 435 450	492 490 490	367 370	316 343 300
	Average						343	435	491	369	320
	1:4		79–17	71.2	67.6	8.3	275 302 312	395 420 419	417 395 377	275 280 300	265 249 242
	Average						296	411	396	285	252
	1:3 (sifted)		79–27	70.7	64.4	8.9	317 310 308	335 350 315	392 400	312 320 300	272 278 271
	Average						312	333	396	311	274
Sd. 3	1:3	1.09	79–28	71.0	59.2	8.9	395 400 380	557 510 500	505 545 495	480 493 512	537 582 575
	Average						392	522	515	495	565
	1:4		79–28	71.0	59.2	8.3	335 350 341	400 435 417	500 542 510	402 415 415	473 432 445
	Average						342	417	517	411	450
	1:3 (sifted)		79–28	71.0	59.2	8.9	212 218 220	354 346 350	380 360 365	400 370 365	410 365 384
	Average						217	350	368	378	386
Sd. 4	1:3	1.14	79–32	70.7	62.6	8.9	533 539 490	595 630 630	743 738 785	717 760 716	783 720 815
	Average						521	618	755	731	773
	1:4		79–32	70.7	62.6	8.3	367 373 380	505 560 560	690 644 645	638 640 632	615 648 658
	Average						373	542	660	637	640
	1:3 (sifted)		79–32	70.7	62.6	8.9	327 320 316	407 405 365	470 503 512	421 426 453	455 470 483
	Average						321	392	495	433	469

[a] For details of field origin of sand samples see pp. 43–52.
[b] In tests marked "sifted" the sand used was sifted through No. 30 and over No. 40 size.

TABLE IXa.—*Tensile strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Tensile strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 5	1:3	1.11	79-29	70.7	70.7	8.9	418	475	580	401	444
							424	511	551	420	410
							388	510	535	440	392
	Average						410	499	555	420	415
	1:4		79-29	70.7	70.7	8.3	325	371	475	311	319
							335	400	485	342	362
							295	362	445	310	334
	Average						318	378	468	321	338
	1:3 (sifted)		79-29	70.7	70.7	8.9	282	332	400	280	308
							277	325	375	300	324
							295	322	405	285	351
	Average						285	326	393	288	328
Sd. 6	1:3	1.14	79-40	69.8	70.0	8.9	500	633	715	638	752
							475	607	690	629	770
							495	625	710	574	741
	Average						490	622	705	614	754
	1:4		79-40	69.8	70.0	8.3	438	530	626	540	660
							420	520	605	500	619
							423	530	580	510	634
	Average						427	527	604	517	638
	1:3 (sifted)		79-40	69.8	70.0	8.9	327	380	440	316	453
							300	385	470	390	421
							306	422	430	324	440
	Average						311	396	447	343	438
Sd. 7	1:3	1.22	79-42	69.8	64.4	8.9	430	507	540	572	628
							420	533	512	655	632
							400	540	505	582	645
	Average						417	527	519	603	635
	1:4		79-42	69.8	64.4	8.3	310	460	410	430	524
							320	455	370	484	522
							280	410	398	473	497
	Average						303	442	393	462	514
	1:3 (sifted)		79-42	69.8	64.4	8.9	285	423	367	414	460
							325	467	392	370	442
							290	420	405	390	449
	Average						300	437	388	391	450
Sd. 8	1:3	1.16	79-43	68.0	68.0	8.9	540	605	730	757	706
							560	645	758	704	678
							535	635	747	700	682
	Average						545	628	745	720	689
	1:4		79-43	68.0	68.0	8.3	420	562	570	570	586
							403	515	565	586	624
							418	522	550	......	639
	Average						414	533	562	578	620
	1:3 (sifted)		79-43	68.0	68.0	8.9	320	420	406	397	427
							310	425	410	412	421
							290	425	425	......	415
	Average						307	423	414	404	421

TABLE IX*a*.—*Tensile strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Tensile strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 9	1:3	1.16	79-45	68.0	64.4	8.9	390	504	481	486	507
							400	470	490	470	532
							412	505	515	492	536
	Average						401	493	495	483	525
	1:4		79-45	68.0	64.4	8.3	325	428	428	422	415
							304	397	437	460	415
							308	410	400	442	413
	Average						312	412	422	441	414
	1:3 (sifted)		79-45	68.0	64.4	8.9	274	385	351	387	452
							291	370	354	365	421
							304	376	352	376	447
	Average						290	377	352	376	440
Sd. 10	1:3	1.18	79-39	71.5	70.0	8.9	392	550	680	486	610
							430	549	640	487	585
							412	541	657	491	592
	Average						411	547	659	488	596
	1:4		79-39	71.5	70.0	8.3	341	460	540	395	428
							325	400	513	396	452
							320	410	517	410	454
	Average						329	423	523	400	445
	1:3 (sifted)		79-39	71.5	70.0	8.9	328	380	473	396	405
							318	390	460	372	368
							300	440	452	349	398
	Average						315	403	462	372	390
Sd. 11	1:3	1.13	79-46	71.6	71.6	8.9	434	600	647	662	727
							429	606	......	725	748
							420	600	655	737	730
	Average						428	602	651	708	735
	1:4		79-46	71.6	71.6	8.3	353	512	505	703	690
							373	514	542	710	670
							350	531	530	708	687
	Average						359	519	526	707	682
	1:3 (sifted)		79-46	71.6	71.6	8.9	334	442	420	650	621
							345	463	460	575	606
							332	463	461	589	588
	Average						337	456	447	605	605
Sd. 12	1:3	1.12	79-47	68.0	64.0	8.9	405	605	610	591	807
							400	605	627	598	811
							415	580	630	614	799
	Average						407	597	622	601	806
	1:4		79-47	68.0	64.4	8.3	342	506	600	640	636
							331	504	585	655	681
							366	534	593	645	656
	Average						346	515	593	647	658
	1:3 (sifted)		79-47	68.0	64.4	8.9	265	320	370	405	512
							267	300	372	435	489
							270	310	370	415	486
	Average						267	310	371	418	496

TABLE IX*a*.—*Tensile strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Tensile strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 13	1:3	1.21	79–50	69.8	59.0	8.9	547 560 522	600 580 575	661 650	631 695 679	796 750 787
	Average	....	....	....	....	....	543	585	655	668	778
	1:4	....	79–50	69.8	59.0	8.3	431 456	520 475 492	548 575 555	547 536 530	673 695 706
	Average	....	....	....	....	....	444	496	559	538	691
Sd. 14	1:3	1.19	79–52	69.8	68.0	8.9	430 415	444 450 437	425 425 450	475 482 494	588 571 578
	Average	....	....	....	....	....	422	444	433	484	579
	1:4	....	79–52	69.8	68.0	8.3	295 315 295	321 324 350	376 355 343	385 376 398	408 410 415
	Average	....	....	....	....	....	302	332	358	386	411
	1:3 (sifted)	....	79–52	69.8	68.0	8.9	319 298 325	332 369 345	348 360 345	379 367 382	387 406 415
	Average	....	....	....	....	....	314	349	351	376	403
Sd. 15	1:3	1.13	79–53	69.8	66.2	8.9	320 300 315	336 343 325	367 380	343 331 319	386 374 370
	Average	....	....	....	....	....	312	335	374	331	377
	1:4	....	79–53	69.8	66.2	8.3	250 255 231	285 276 258	266 271 261	294 317 302	280 325 312
	Average	....	....	....	....	....	245	273	266	304	306
	1:3 (sifted)	....	79–53	69.8	66.2	8.9	269 255 240	313 320 285	330 330 307	315 348 326	335 324 341
	Average	....	....	....	....	....	255	306	322	330	333
Sd. 16	1:3	1.20	79–54	69.2	75.2	8.9	488 461 465	515 530 510	595 573 575	583 611 621	661 648 640
	Average	....	....	....	....	....	471	518	581	605	650
	1:4	....	79–54	69.8	75.2	8.3	446 420 457	440 475 481	535 420 515	540 567 551	521 555 550
	Average	....	....	....	....	....	441	465	490	553	542
	1:3 (sifted)	....	135–20	....	....	....	376 389 380	462 431 496	472 495 522	584 571 562	....
	Average	....	....	....	....	....	382	463	496	572	......

TABLE IXa.—*Tensile strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Tensile strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 17	1:3	1.27	79–56	71.6	64.2	8.9	338 344 348	380 345 357	438 420 450	436 473 489	485 470 468
	Average						343	361	436	466	474
	1:4		79–56	71.6	64.2	8.3	285 292 270	318 317 321	360 345 330	386 375 399	430 406 412
	Average						282	319	345	387	416
	1:3 (sifted)		79–56	71.6	64.2	8.9	308 300 330	333 345 347	383 382 360	341 362 350	389 395 387
	Average						313	342	375	351	390
Sd. 18	1:3	1.15	133–5	68.0	78.8	8.9	351 364 382	450 500 480	496 506 540	575 540 534	542 560 564
	Average						366	477	514	550	555
	1:4		133–5	68.0	78.8	8.3	300 337 320	400 355 405	460 457 497	452 485 477	464 462 456
	Average						319	387	471	471	461
	1:3 (sifted)		133–5	68.0	78.8	8.9	228 255 232	329 310 350	330 377 351	376 330 343	426 397 408
	Average						238	330	353	350	410
Sd. 19	1:3	1.19	133–17	68.9	67.1	8.9	534 515 555	635 647 680	703 663 659	792 780 746	799 781 842
	Average						535	654	675	773	807
	1:4		133–17	68.9	67.1	8.3	492 485 450	515 500 490	530 528	665 615 633	592 700 653
	Average						476	502	529	638	648
	1:3 (sifted)		133–17	68.9	67.1	8.9	265 282 290	317 340 320	376 346 336	426 388 382	383 353 353
	Average						279	326	353	399	363
Sd. 20	1:3	1.16	133–21	69.8	78.8	8.9	455 446 420	548 565 556	624 573	632 673 706	648 760 700
	Average						440	556	598	670	703
	1:4		133–21	69.8	78.8	8.3	384 375 355	498 466 499	571 535 562	610 544 562	566 480 540
	Average						371	488	556	572	529
	1:3 (sifted)		135–23			8.9	337 320 309	347 395 398	332 368 380	423 422 436	571 578 566
	Average						322	380	360	427	572

TABLE IXa.—*Tensile strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Tensile strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 21	1:3	1.05	133-3	63.0	67.1	8.9	285	361	350	405	389
							275	357	336	373	397
							300	350	337	362	383
	Average						287	356	341	380	390
	1:4		133-3	63.0	67.1	8.3	210	256	243	300	275
							203	250	293	308	264
							200	247	260	280	275
	Average						204	251	265	296	271
	1:3 (sifted)		133-3	63.0	67.1	8.9	232	282	283	337	337
							285	282	290	294	320
							260	311	300	280	329
	Average						259	292	291	304	329
Sd. 22	1:3	1.11		68.0	71.0	11.5	285	454	440	462	......
							276	439	438	490	......
							272	432	470	510	......
	Average						277	442	449	487	......
	1:4			68.0	71.0	11.0	188	318	367	414	......
							194	311	368	375	......
							200	323	377	391	......
	Average						194	317	371	393	......
	1:3 (sifted)			68.0	65.0	11.5	225	307	358	375	......
							235	310	365	372	......
							217	315	360	354	......
	Average						226	311	361	367	......

TABLE IXb.—*Compressive strength of the mortars of 22 sands.*

Register No.[a]	Ratio of cement to sand.[b]	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Compressive strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 1	1:3	1.18	79-5	70.0	64.4	8.9	1,200	2,200	3,642	3,630	4,475
							1,250	2,112	3,475	3,570	4,200
							1,147	2,137	3,500	3,830	4,150
	Average						1,199	2,150	3,539	3,677	4,275
	1:4		79-12	68.0	60.8	8.3	932	1,375	2,488	2,850	3,000
							875	1,562	2,313	2,813	2,900
							852	1,412	2,488	2,813	3,200
	Average						886	1,450	2,430	2,825	3,033
	1:3 (sifted)		79-21	69.8	68.0	8.9	1,325	2,077	2,790	2,825	3,425
							1,275	2,187	2,570	3,125	3,500
							1,272	2,192	3,170	2,775	3,350
	Average						1,291	2,152	2,843	2,908	3,425
Sd. 2	1:3	1.12	79-5	70.0	64.4	8.9	1,625	3,212	4,667	5,285	5,800
							1,795	3,700	4,630	5,538	5,725
							1,715	3,367	4,875	5,258	5,650
	Average						1,712	3,426	4,724	5,360	5,725
	1:4		79-13	68.0	73.4	8.3	1,100	2,025	2,745	3,150	3,975
							1,037	2,000	2,500	3,025	3,750
							1,012	2,162	2,500	....	3,600
	Average						1,050	2,062	2,582	3,088	3,775
	1:3 (sifted)		79-22	70.7	64.4	8.9	1,200	1,900	2,100	2,515	3,050
							1,125	1,930	2,545	2,488	2,750
							1,105	1,862	2,500	2,610	2,925
	Average						1,143	1,897	2,382	2,538	2,908

[a] For details of field origin of sand samples see pp. 43-52.

[b] In tests marked "sifted" all sand used was sifted through No. 30 and over No. 40 size.

TABLE IX*b*.—*Compressive strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Compressive strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 3	1:3	1.12	79-23	73.4	71.6	8.9	2,012	3,722	4,608	5,088	6,140
							1,987	3,750	4,850	5,578	6,062
							2,002	3,720	5,113	5,173	6,202
	Average						2,000	3,731	4,857	5,280	6,135
	1:4		79-23	73.4	71.6	8.3	1,167	2,618	3,470	3,778	4,135
							1,092	2,825	3,725	4,043	4,850
							1,225	2,385	3,453	3,780	4,335
	Average						1,161	2,609	3,549	3,867	4,440
	1:3 (sifted)		135-24	78.8	71.6	11.5	....	2,225	3,550	3,300	......
							1,775	2,600	3,400	3,175	......
							1,675	....	3,300	2,475	......
	Average						1,725	2,412	3,417	2,983	......
Sd. 4	1:3	1.12	79-27	70.7	62.6	8.9	3,275	5,220	5,975	5,935	7,825
							3,168	4,838	6,075	6,275	8,100
							3,225	4,975	6,288	....	8,075
	Average						3,223	5,011	6,113	6,105	8,000
	1:4		79-27	70.7	62.6	8.3	1,968	2,908	4,453	....	5,050
							1,838	3,225	4,388	3,930	5,525
							1,750	3,000	4,530	4,335	5,300
	Average						1,852	3,044	4,457	4,133	5,292
	1:3 (sifted)		135-25	78.8	71.6	10.1	....	2,700	4,375	3,713	......
							1,450	2,025	4,600	3,500	......
							1,475	....	....	3,750	......
	Average						1,462	2,362	4,488	3,654	......
Sd. 5	1:3	1.11	79-24	70.7	62.6	8.9	2,250	2,500	4,363	4,925	1,850
							2,300	2,375	4,613	4,750	1,812
							2,057	2,613	4,523	4,580	2,000
	Average						2,202	2,496	4,500	4,752	1,887
	1:4		79-24	70.7	62.6	8.3	1,427	1,920	3,215	3,608	2,048
							1,412	2,000	3,225	3,605	2,088
							1,350	2,188	3,000	3,628	2,253
	Average						1,396	2,036	3,147	3,614	2,130
	1:3 (sifted)		79-24	70.7	62.6	8.9	1,425	1,258	2,100	2,870	1,848
							1,375	1,335	2,225	2,695	2,185
							1,300	1,373	2,250	2,538	2,250
	Average						1,367	1,322	2,192	2,701	2,094
Sd. 6	1:3	1.14	79-40	71.6	71.6	8.9	2,658	3,995	3,050	4,425	4,950
							2,675	4,208	3,490	3,975	4,850
							2,725	4,093	3,168	4,275	5,112
	Average						2,686	4,099	3,236	4,225	4,971
	1:4		79-40	71.6	71.6	8.3	1,790	2,460	2,650	3,100	4,000
							1,658	2,525	2,850	3,325	......
							1,678	2,718	2,722	3,200	3,825
	Average						1,709	2,568	2,741	3,208	3,912
	1:3 (sifted)		79-40	71.6	71.6	8.9	1,163	1,893	1,565	2,175	2,800
							1,220	1,720	1,585	2,300	3,050
							1,275	1,770	1,500	2,325	2,925
	Average						1,219	1,794	1,550	2,267	2,925

TABLE IXb.—*Compressive strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Compressive strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 7	1:3	1.22	79-42	68.0	68.0	8.9	1,600	3,380	5,100	5,650	5,600
							1,575	3,513	4,585	5,650	5,950
							1,500	3,358	5,195	5,900	5,475
	Average						1,558	3,415	4,959	5,733	5,675
	1:4		79-42	68.0	68.0	8.3	1,080	2,200	3,418	3,175	4,175
							1,158	2,038	3,303	3,500	4,400
							1,058	2,388	3,625	3,325	4,375
	Average						1,098	2,209	3,449	3,333	4,317
	1:3 (sifted)		79-42	68.0	68.0	8.9	1,263	2,375	3,238	3,325	4,125
							1,163	2,175	2,975	3,675	4,100
							1,183	2,288	3,093	3,475	4,050
	Average						1,203	2,279	3,102	3,492	4,092
Sd. 8	1:3	1.16	79-43	64.4	64.4	8.9	2,403	5,670	5,825	7,512	7,125
							2,408	5,410	5,950	7,525	8,000
							2,520	5,388	6,225	7,625	7,075
	Average						2,444	5,489	6,000	7,554	7,400
	1:4		79-43	64.4	64.4	8.3	1,633	3,675	4,250	4,902	4,725
							1,690	4,000	4,100	5,608	4,550
							1,760	3,918	3,975	5,068	4,400
	Average						1,694	3,864	4,108	5,193	4,558
	1:3 (sifted)		79-43	64.4	64.4	8.9	1,263	1,743	1,750	2,425	3,175
							1,265	1,600	1,675	2,388	2,950
							1,168	1,738	......	2,638	2,900
	Average						1,232	1,694	1,712	2,484	3,008
Sd. 9	1:3	1.16	79-45	68.0	64.4	8.9	2,230	3,745	5,825	2,950	6,000
							2,000	3,328	5,288	2,815	5,925
							2,038	3,410	......	3,038	5,650
	Average						2,089	3,494	5,557	2,934	5,858
	1:4		79-45	68.0	64.4	8.3	1,460	2,608	3,163	2,650	4,175
							1,375	2,728	3,000	2,262	4,100
							1,423	2,500	3,513	3,022	3,875
	Average						1,419	2,612	3,225	2,645	4,050
	1:3 (sifted)		79-45	68.0	64.4	8.9	900	1,500	1,750	2,288	3,100
							850	1,475	1,875	2,370	2,925
							845	......	......	2,358	3,000
	Average						865	1,488	1,812	2,339	3,008
Sd. 10	1:3	1.18	79-39	69.8	67.1	8.9	1,623	3,120	4,425	4,705	5,975
							1,688	2,840	4,500	4,600	5,775
							1,750	2,648	......	4,612	5,700
	Average						1,687	2,869	4,462	4,639	5,817
	1:4		79-39	69.8	67.1	8.3	1,050	1,895	2,263	2,650	3,800
							1,163	1,945	2,470	2,668	3,900
							1,063	1,792	2,288	2,750	3,675
	Average						1,092	1,877	2,340	2,689	3,792
	1:3 (sifted)		79-39	69.8	67.1	8.9	930	1,408	2,288	2,282	2,175
							933	1,480	2,238	2,462	2,300
							925	1,512	2,413	......	2,050
	Average						929	1,467	2,313	2,372	2,175

TABLE IX*b*.—*Compressive strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Compressive strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 11	1:3		79-46	68.0	64.4	8.9	2,025	5,358	5,863	5,050	5,925
							2,045	5,208	5,650	5,125	5,450
							2,213	5,300	5,563	5,025	5,600
	Average						2,094	5,289	5,692	5,067	5,658
	1:4		79-46	68.0	64.4	8.3	2,113	3,835	4,450	5,000	4,700
							1,988	4,015	4,038	5,200	4,975
							2,000	3,583	4,375	4,550	4,800
	Average						2,034	3,811	4,288	4,917	4,825
	1:3 (sifted)		79-46	68.0	64.4	8.9	1,038	2,335	3,238	2,225	3,200
							1,045	2,198	......	1,875	2,975
							1,045	......	3,128	1,800	3,075
	Average						1,043	2,266	3,183	1,967	3,083
Sd. 12	1:3	1.12	79-47	69.8	62.6	8.9	2,550	4,250	6,438	......	6,600
							2,263	4,240	6,083	6,000	6,800
							2,480	......	6,213	6,250	6,975
	Average						2,431	4,245	6,245	6,125	6,792
	1:4		79-47	69.8	62.6	8.3	1,875	2,750	3,875	3,700	4,450
							1,788	2,973	4,235	3,950	4,225
							2,000	2,795	3,975	3,825	4,225
	Average						1,888	2,839	4,028	3,825	4,300
	1:3 (sifted)		79-47	69.8	62.6	8.9	1,260	1,500	1,975	850	2,750
							1,200	1,550	2,025	1,100	2,812
							1,250	1,525	......	1,100	2,925
	Average						1,237	1,525	2,000	1,017	2,829
Sd. 13	1:3	1.21	79-50	69.8	60.0	8.9	3,200	5,633	5,637	7,500	6,775
							3,138	5,575	6,375	7,000	6,550
							3,188	5,538	5,685	7,050	6,887
	Average						3,175	5,582	5,899	7,183	6,737
	1:4		79-50	69.8	60.0	8.3	2,888	4,348	4,135	5,550	4,125
							3,000	4,708	4,737	5,550	4,375
							2,700	4,250	4,425	5,375	4,425
	Average						2,863	4,435	4,432	5,492	4,308
Sd. 14	1:3	1.19	79-52	68.9	68.2	8.9	1,875	3,188	3,708	4,350	4,000
							1,938	3,138	3,425	3,850	3,800
							......	3,150	3,475	4,025	4,062
	Average						1,906	3,159	3,536	4,075	3,954
	1:4		79-52	68.9	68.2	8.3	1,350	1,900	2,650	2,725	3,200
							1,413	2,088	2,875	2,250	3,300
							1,350	1,830	......	2,375	3,250
	Average						1,371	1,939	2,763	2,450	3,250
	1:3 (sifted)		79-52	68.9	68.2	8.9	1,380	1,988	2,675	3,075	2,900
							1.488	1,895	2,638	3,000	2,900
							1,475	2,025	2,825	2,750	3,000
	Average						1,448	1,969	2,713	2,942	2,933

TABLE IX*b*.—*Compressive strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Compressive strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 15	1:3	1.13	79-53	69.8	68.0	8.9	1,243	1,860	2,012	2,800	2,750
							1,263	1,900	2,000	2,575	2,687
							1,280	1,933	2,087	2,525	2,750
	Average						1,262	1,898	2,033	2,633	2,729
	1:4		79-53	69.8	68.0	8.3	995	1,388	1,500	1,875	1,950
							908	1,345	1,488	1,725	1,925
							958	1,323	1,675	1,900	2,000
	Average						954	1,352	1,554	1,833	1,958
	1:3 (sifted)		79-53	69.8	68.0	8.9	1,150	1,610	2,025	2,200	2,000
							1,108	1,548	2,088	2,050	2,050
							1,070	1,500	1,800	1,950	2,062
	Average						1,109	1,553	1,971	2,067	2,037
Sd. 16	1:3	1.20	79-54	69.8	65.3	8.9	3,025	5,525	5,062	7,225	6,750
							3,375	5,675	5,975	7,150	6,625
							3,285	5,813	5,538	6,950	6,862
	Average						3,228	5,671	5,525	7,108	6,742
	1:4		79-54	69.8	65.3	8.3	2,388	3,525	3,750	4,375	4,787
							2,440	3,675	4,250	4,750	4,675
							2,300	3,838	......	4,725	4,800
	Average						2,376	3,679	4,000	4,617	4,754
	1:3 (sifted)		135-20				2,225	3,225	3,475	3,513	......
							2,200	3,575	2,900	3,025	......
							2,225	3,175	3,375	3,725	......
	Average						2,217	3,325	3,250	3,421	......
Sd. 17	1:3	1.27	79-56	71.6	67.1	8.9	1,940	3,143	4,225	4,700	4,887
							1,850	3,100	3,755	4,475	4,725
							1,933	3,093	3,875	5,050	4,687
	Average						1,908	3,112	3,952	4,742	4,766
	1:4		79-56	71.6	67.1	8.3	1,345	2,385	2,625	3,275	3,425
							1,338	2,263	2,562	3,475	3,500
							1,280	2,368	2,650	3,250	3,612
	Average						1,321	2,339	2,612	3,333	3,512
	1:3 (sifted)		79-56	71.6	67.1	8.9	1,408	2,440	2,610	3,275	3,400
							1,348	2,250	2,600	3,050	3,412
							1,363	2,418	2,538	3,000	3,600
	Average						1,373	2,369	2,583	3,108	3,471
Sd. 18	1:3	1.15	133-5	67.1	68.0	8.9	1,513	3,183	3,950	3,800	4,425
							......	2,888	4,075	3,150	4,550
							1,613	3,188	......	4,050	4,450
	Average						1,563	3,086	4,012	3,667	4,475
	1:4		133-5	67.1	68.0	8.3	1,335	1,988	......	3,225	3,175
							1,380	2,130	2,000	3,000	3,100
							1,275	2,125	2,075	2,975	3,150
	Average						1,330	2,081	2,038	3,067	3,142
	1:3 (sifted)		133-5	67.1	68.0	8.9	1,158	1,500	1,950	2,050	2,725
							1,175	1,638	2,008	2,350	2,650
							1,113	......	2,000	2,300	2,650
	Average						1,149	1,569	1,986	2,233	2,675

TABLE IXb.—*Compressive strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Compressive strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 19	1:3	1.19	133-17	68.9	77.0	8.9	4,475	5,620	6,325	6,525	7,900
							4,128	5,425	5,100	6,575	8,400
							4,138	5,755	5,700	7,050	6,950
	Average						4,247	5,600	5,708	6,719	7,750
	1:4		133-17	68.9	77.0	8.3	2,588	2,825	5,675	5,350	4,950
							2,305	3,110	4,225	4,950	4,200
							2,320	2,750	3,775	5,250	5,250
	Average						2,404	2,895	4,558	5,183	4,800
	1:3 (sifted)		135-26	78.8	71.6	11.0	2,125	2,375	2,550	3,900	......
							1,875	2,400	2,475	3,488	......
							1,875	2,425	......	3,475	......
	Average						1,958	2,400	2,512	3,621	......
Sd. 20	1:3	1.16	133-21	69.8	73.4	8.9	3,443	5,218	5,150	5,800	5,450
							3,565	5,140	4,800	6,500	7,025
							3,703	5,148	5,375	6,300	7,000
	Average						3,570	5,169	5,108	6,200	6,492
	1:4		133-21	69.8	73.4	8.3	2,025	3,200	3,575	4,725	5,200
							2,253	3,258	3,550	5,050	4,800
							2,000	3,013	4,050	5,500	4,550
	Average						2,093	3,157	3,725	5,092	4,850
	1:3 (sifted)		135-23	78.8	72.5	8.9	1,450	2,400	3,650	3,550	......
							1,425	2,300	3,525	3,650	......
							1,500	2,550	3,375	3,375	......
	Average						1,458	2,417	3,517	3,525	......
Sd. 21	1:3	1.05	133-3	63.5	74.0	8.9	1,600	2,353	2,920	2,550	3,300
							1,500	2,145	2,620	3,000	3,375
							1,545	2,250	2,600	3,125	3,325
	Average						1,548	2,249	2,713	2,892	3,333
	1:4		133-3	63.5	74.0	8.3	1,065	1,300	1,762	1,825	2,350
							1,078	1,210	1,945	1,850	2,250
							......	1,203	......	2,250	2,500
	Average						1,071	1,238	1,853	1,975	2,367
	1:3 (sifted)		133-3	63.5	74.0	8.9	1,020	1,663	1,900	2,175	2,525
							1,015	1,660	1,670	2,325	2,562
							1,093	1,583	1,912	2,400	2,650
	Average						1,043	1,635	1,827	2,300	2,579
Sd. 22	1:3	1.11	......	71.0	68.8	11.5	2,375	4,075	5,625	5,125	......
							2,250	4,175	5,650	4,900	......
							2,325	4,050	5,425	4,850	......
	Average						2,317	4,100	5,570	4,958	......
	1:4		......	71.0	68.0	11.0	1,375	2,450	3,625	3,600	......
							1,375	2,350	3,900	3,675	......
							1,325	2,375	3,812	3,550	......
	Average						1,358	2,395	3,780	3,608	......
	1:3 (sifted)		......	68.0	65	11.5	1,425	2,750	3,400	3,550	.....
							1,400	2,700	3,450	3,500	......
							1,425	2,650	3,375	3,675	......
	Average						1,417	2,700	3,408	3,575	......

TABLE IXc.—*Transverse strength of the mortars of 22 sands.*

Register No.[a]	Ratio of cement to sand.[b]	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Transverse strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 1	1:3	1.18	133-36	70.7	64.4	8.9	576	792	972	1,116	1,044
							720	774	864	1,008	1,116
							630	774	756	1,044	1,062
	Average						642	780	864	1,056	1,074
	1:4		133-37	69.8	64.2	8.3	504	648	756	918	792
							468	666	576	918	......
							504	684	594	......	......
	Average						492	666	642	918	792
	1:3 (sifted)		133-38	68.9	65.3	8.9	468	648	648	882	810
							450	612	684	828	828
							504	522	......	864	792
	Average						474	594	666	858	810
Sd. 2	1:3	1.12	133-39	71.6	71.6	8.9	648	846	684	972	1,008
							666	810	666	1,008	1,044
							666	738	702	720	972
	Average						660	798	684	900	1,008
	1:4		133-41	71.6	69.8	8.3	504	......	666	828	468
							414	666	594	756	396
							432	558	612	774	......
	Average						450	612	624	786	432
	1:3 (sifted)		133-42	69.8	68.9	8.9	450	558	576	792	864
							360	504	684	846	864
							324	702	738	702	828
	Average						378	588	666	780	852
Sd. 3	1:3	1.09	136-9	......	......	8.9	720	918	1,116	1,134	......
							720	828	1,224	1,224	......
							684	900	1,224	1,188	......
	Average						708	882	1,188	1,182	......
	1:4		136-8	......	......	8.3	522	630	846	1,116	......
							540	630	936	1,170	......
							522	702	846	1,116	......
	Average						528	654	876	1,134	......
Sd. 4	1:3	1.14	136-10	......	......	8.9	1,152	1,152	1,278	1,206	......
							1,098	1,080	1,368	1,242	......
							1,008	1,116	1,296	1,224	......
	Average						1,086	1,116	1,314	1,224	......
	1:4		136-11	......	......	8.3	756	828	1,098	1,224	......
							684	864	1,152	1,188	......
							630	720	1,044	1,296	......
	Average						690	804	1,098	1,236	......
Sd. 5	1:3	1.11	136-12	......	......	8.9	576	756	990	972	......
							612	738	1,080	1,044	......
							594	756	1,098	936	......
	Average						594	750	1,056	984	......
	1:4		136-13	......	......	8.3	504	558	738	846	......
							450	576	648	864	......
							540	540	684	......	......
	Average						498	558	690	855	......

[a] For details of field origin of sand samples see pp. 43-52.
[b] In tests marked "sifted" all sand used was sifted through No. 30 and over No. 40 size.

TABLE IXc.—*Transverse strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Transverse strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 6	1:3	1.14	134–11	74.3	71.6	8.9	774 936 792	882 864 1,044	1,188 1,152 1,206	1,512 1,566 1,368	1,476 1,458 1,422
	Average						834	930	1,182	1,482	1,452
	1:4		134–12	75.2	74.6	8.3	576 666 576	864 864 756	936 972 864	1,044 1,116 990	1,134 1,152 1,206
	Average						606	828	924	1,050	1,164
	1:3 (sifted)		134–13	75.2	76.1	8.9	576 504 540	486 630 720	828 756 810	630 558 756	738 828 792
	Average						540	612	798	648	786
Sd. 7	1:3	1.22	134–14	77.0	80.6	8.9	648 720 792	990 954	1,098 1,044 1,206	1,098 972 1,044	1,206 1,278 1,260
	Average						720	972	1,116	1,038	1,148
	1:4		134–15	77.0	80.6	8.3	540 342	720 702 738	918 990 882	936 1,026 918	972 918 972
	Average						441	720	930	960	954
	1:3 (sifted)		134–16	77.0	75.2	8.9	486 468 468	576 612	864 1,080 954	846 972 828	918 936 828
	Average						474	594	966	882	894
Sd. 8	1:3	1.16	134–17	77.0	75.2	8.9	576 594 432	1,134 1,206 1,026	1,044 1,170 1,080	1,260 1,296 1,206	1,296 1,296 ......
	Average						534	1,122	1,098	1,254	1,296
	1:4		134–18	77.0	70.7	8.3	468 468 414	1,008 792 810	1,026 1,062 918	1,224 1,116 1,170	954 972 972
	Average						450	870	1,002	1,170	966
	1:3 (sifted)		134–19	78.8	82.4	8.9	486 468 504	648 576 612	720 792 810	756 864 774	630 648 648
	Average						486	612	774	798	642
Sd. 9	1:3	1.16	134–20	75.2	73.4	8.9	684 684 702	720 792 702	918 1,062 972	882 972 846	990 1,008 900
	Average						690	738	984	900	966
	1:4		134–21	77.0	77.0	8.3	648 558 540	612 612 630	792 846 756	864 846 936	738 702 684
	Average						582	618	798	882	708
	1:3 (sifted)		134–22	78.8	73.4	8.9	522 558 576	612 612 648	612 702 828	684 702 684	756 684 756
	Average						552	624	714	690	732

TABLE IXc.—*Transverse strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Transverse strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 11	1:3	1.13	135-4	78.8	82.4	8.9	864	1,152	1,260	1,188	......
							774	1,044	1,332	1,296	......
							738	1,116	1,188	1,332	......
	Average						792	1,104	1,260	1,272	......
	1:4		135-5	78.8	80.6	8.3	558	1,008	1,242	1,314	......
							522	1,008	1,026	1,368	......
							......	918	1,188	1,314	......
	Average						540	978	1,152	1,332	......
Sd. 12	1:3	1.12	135-6	79.5	77.0	8.9	648	954	1,368	1,350	......
							900	1,008	1,368	1,404	......
							810	882	1,224	1,386	......
	Average						786	948	1,320	1,380	......
	1:4		135-7	78.8	78.8	8.3	612	900	1,134	864	......
							558	918	1,098	1,008	......
							594	954	1,008	936	......
	Average						588	924	1,080	936	......
Sd. 13	1:3	1.21	135-8	78.8	80.6	8.9	792	900	1,206	1,224	......
							864	918	1,080	1,368	......
							864	864	1,098	1,350	......
	Average						840	894	1,128	1,314	......
	1:4		135-9	78.8	77.0	8.3	666	......	1,206	1,152	......
							558	1,008	1,440	1,224	......
							558	918	1,332	1,242	......
	Average						594	963	1,326	1,206	......
	1:3 (sifted)		135-14	80.6	84.2	8.3	558	900	990	918	......
							612	720	1,116	972	......
							......	936	1,062	936	......
	Average						585	852	1,056	942	......
Sd. 14	1:3	1.19	135-27	78.8	84.2	8.9	720	702	1,206	1,062	......
							666	720	1,062	1,080	......
							......	792	1,116	990	......
	Average						693	738	1,128	1,044	......
	1:4		135-16	81.4	82.4	8.3	594	666	972	900	......
							576	702	918	936	......
							630	612	918	846	......
	Average						600	660	936	894	......
	1:3 (sifted)		135-15	80.6	82.4	8.9	648	756	1,026	1,044	......
							756	720	918	1,008	......
							666	756	900	1,026	......
	Average						690	744	948	1,026	......
Sd. 15	1:3	1.13	135-18	80.6	84.2	8.9	396	576	954	738	......
							504	558	864	702	......
							486	630	900	936	......
	Average						462	588	906	792	......
	1:4		135-19	77.0	68.0	8.3	360	468	396	756	......
							324	504	486	756	......
							288	450	360	720	......
	Average						324	474	414	744	......
	1:3 (sifted)		135-17	77.0	68.0	8.9	522	630	594	540	......
							486	594	486	684	......
							450	612	612	612	......
	Average						486	612	564	612	......

TABLE IXc.—*Transverse strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (° F.). Water.	Temperature (° F.). Air.	Water (per cent).	Transverse strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 16..	1:3	1.20	135-22	78.8	75.2	8.9	846	1,080	1,044	972	......
							882	1,152	1,206	1,008	......
							846	1,134	1,242	972	......
	Average	......	......	......	......	......	858	1,122	1,164	984	......
	1:4	......	135-21	79.5	76.1	8.3	702	1,044	864	1,044	......
							774	954	1,080	1,026	......
							864	972	1,152	1,062	......
	Average	......	......	......	......	......	780	990	1,032	1,044	......
	1:3 (sifted)	......	135-20	77.0	73.4	8.3	774	954	756	864	......
							576	864	1,008	936	......
							828	864	1,044	882	......
	Average	......	......	......	......	......	726	894	936	894	......
Sd. 17..	1:3	1.27	136-4	77.9	76.1	8.9	522	882	810	990	......
							450	828	828	972	......
							432	864	936	1,044	......
	Average	......	......	......	......	......	468	858	858	1,002	......
	1:4	......	136-3	78.8	80.6	8.3	468	756	828	972	......
							432	648	828	972	......
							396	720	792	954	......
	Average	......	......	......	......	......	432	708	816	966	......
	1:3 (sifted)	......	136-2	80.6	82.4	8.9	468	612	756	828	......
							360	666	720	900	......
							378	594	756	1,026	......
	Average	......	......	......	......	......	402	624	744	918	......
Sd. 22..	1:3	1.11	......	71	68	11.5	594	882	1,044	972	......
							571	936	1,008	1,080	......
							594	855	1,017	922	......
	Average	......	......	......	......	......	586	891	1,023	1,008	......
	1:4	......	......	71	68	11.0	396	612	810	846	......
							396	666	864	846	......
							398	630	882	900	......
	Average	......	......	......	......	......	397	636	852	864	......
	1:3 (sifted)	......	......	65	68	11.5	396	630	882	774	......
							414	648	954	810	......
							423	621	864	882	......
	Average	......	......	......	......	......	411	623	900	822	......

TABLE X.—*Chemical analyses of silt contained in 17 sands, in 11 gravel screenings, and in 24 stone screenings*

[Values expressed in percentages.]

SILT CONTAINED IN SANDS.[a]

Register No.[b]	Silica (SiO_2).	Alumina (Al_2O_3).	Ferric oxide (Fe_2O_3).	Manganese oxide (MnO).	Lime (CaO).	Magnesia (MgO).	Sulphuric anhydride (SO_3).	Alkalies.		Water at 100° C.	Ignition loss.	
								Na_2O.	K_2O.		Total.	Carbon in organic matter.
Sd. 1	69.78	9.92	3.12	0.31	4.92	2.18	0.16	0.72	1.51	0.74	70.6	0.67
Sd. 3	46.46	10.06	5.14	.17	12.28	5.52	.09	.03	1.60	.55	18.23	2.00
Sd. 4	30.90	5.80	4.17	.11	18.06	11.36	.10	.37	.82	.50	28.04	.26
Sd. 6	27.98	8.90	1.36	.33	19.88	11.30	.22	1.04	.63	.66	27.90	.73
Sd. 7	31.18	6.20	4.84	.18	18.28	10.82	.17	.70	1.62	.57	25.83	.71
Sd. 8	31.63	5.99	3.81	.20	17.83	10.96	.33	1.65	.90	.14	56.75	.55
Sd. 9	28.94	14.69	1.27	.28	16.64	9.97	.10	.32	1.76	.79	25.51	.81
Sd. 10	37.40	6.77	7.99	.59	13.82	7.90	.10	1.76	1.52	.61	21.70	.53
Sd. 11	7.18	1.58	.68	.54	27.79	18.74	.89	.27	.71	.04	....	.37
Sd. 12	5.54	1.59	.47	.11	28.56	18.43	.10	.86	.44	.08	43.94	.23
Sd. 13	39.52	10.59	2.87	1.30	17.06	4.66	.17	.86	1.36	.14	21.46	1.46
Sd. 14	57.30	8.03	.71	.18	12.53	4.58	.09	.87	.41	.25	15.27	.81
Sd. 16	47.78	5.87	3.27	.47	15.76	4.96	.14	1.04	1.06	.25	19.79	.96
Sd. 17	57.92	12.68	5.18	.20	7.60	3.04	.03	.03	2.19	.69	10.31	.58
Sd. 18	42.76	8.63	8.22	.74	12.50	7.02	.12	.19	1.30	.73	17.99	......
Sd. 19	41.74	7.10	7.60	.61	14.58	6.15	.13	.71	1.73	.76	19.04	.42
Sd. 20	42.40	8.12	8.00	.50	12.78	6.82	.16	.86	1.68	.74	18.16	......

SILT CONTAINED IN GRAVEL SCREENINGS.[c]

Register No.	Silica	Alumina	Ferric oxide	Manganese oxide	Lime	Magnesia	Sulphuric anhydride	Na_2O	K_2O	Water at 100° C.	Total	Carbon in organic matter
Gl. 1	51.90	9.10	2.04	0.30	11.56	1.96	0.17	1.51	0.94	1.61	18.95	{ 4.09 4.11
Gl. 3	24.80	8.88	.96	.33	23.70	8.96	.04	.58	1.22	.51	29.87	1.08
Gl. 4	30.66	11.20	1.38	.74	18.66	9.13	.05	.55	1.53	.38	26.04	.67
Gl. 5	28.78	7.98	3.94	.46	20.68	9.07	.09	.67	1.61	.58	26.20	1.81
Gl. 6	43.90	9.77	3.25	.14	13.30	6.22	.03	.17	2.04	.57	20.57	.77
Gl. 7	29.24	6.16	3.08	.71	23.16	8.14	.17	.46	.90	.49	27.59	1.15
Gl. 8	27.30	8.75	1.61	.82	22.24	7.85	.35	.83	1.12	.42	28.58	2.11
Gl. 9	28.04	5.24	3.86	.22	25.28	6.02	.14	.41	.78	.51	29.59	1.67
Gl. 10	53.56	17.74	1.46	.37	8.36	3.42	.22	.59	1.91	.52	12.22	.88
Gl. 11	39.40	11.37	3.86	.40	15.32	6.43	.09	.20	2.15	.52	20.44	1.11
Gl. 12	41.68	12.02	4.09	.66	14.20	6.20	.06	.53	1.98	.63	18.09	......

SILT CONTAINED IN STONE SCREENINGS.[d]

Register No.	Silica	Alumina	Ferric oxide	Manganese oxide	Lime	Magnesia	Sulphuric anhydride	Na_2O	K_2O	Water at 100° C.	Total	Carbon in organic matter
Se. 1[e]	22.56	2.66	2.97	......	35.53	3.86	1.85	......	......	......	28.60	0.29
Se. 2	19.89	8.40	.62	......	36.88	1.81	.56	......	......	......	34.04	......
Se. 3	7.20	1.95	.56	0.37	47.50	1.42	.12	0.44	0.20	0.70	39.62	.34
Se. 4	6.05	.22	1.36	......	47.60	3.70	1.01	......	......	......	43.30	......
Se. 5	13.40	2.60	.71	.50	45.48	.47	.19	.24	.40	.29	36.01	.21
Se. 7[f]	50.02	7.60	.81	.51	10.14	5.71	.14	.30	.65	.36	16.33	.84
Se. 8[g]	44.40	3.91	3.82	......	22.53	1.82	3.52	......	......	......	17.82	.27
Se. 9[h]	47.58	.69	1.97	.37	20.00	4.23	.12	.14	.40	.11	19.57	.30
Se. 10[i]	45.64	.98	2.27	.87	16.52	5.73	.12	.07	.23	.13	17.83	.19
Se. 11	20.84	6.51	1.71	.50	28.49	8.71	.99	.87	.42	.47	30.45	.31
Se. 12	7.16	3.40	2.70	1.24	46.08	1.28	.12	.17	.15	.38	37.66	.17
Se. 13	24.92	8.79	4.41	1.34	31.13	.17	.07	.46	1.26	.58	24.48	.20
Se. 14	9.02	3.10	3.42	1.10	45.00	.14	.14	.58	.06	.31	36.51	.16
Se. 15	25.72	8.96	3.50	.74	18.29	8.36	3.74	.42	5.17	.33	24.89	1.11
Se. 16	12.08	6.92	4.12	1.34	24.33	12.98	1.07	.54	1.47	......	32.38	.25
Se. 17	65.90	16.94	2.72	.14	2.46	.52	.15	4.70	2.99	.66	3.08	.27
Se. 18	25.52	7.11	1.36	.22	18.58	13.92	.16	1.86	1.12	.51	29.91	.20
Se. 19[j]	15.68	4.61	.91	.45	22.21	17.05	.24	.03	1.67	.12	....	.11
Se. 20[k]	14.28	3.31	2.05	.26	28.00	13.41	.22	.07	.88	.04	....	.60
Se. 21	16.33	6.19	1.73	.40	26.24	13.04	.20	.10	.30	.19	....	.26
Se. 22	7.66	1.43	1.86	.31	28.00	17.99	.08	.08	.35	.25	....	.33
Se. 23	17.14	4.04	4.04	.43	35.80	4.21	.46	.16	.49	.35	....	.34
Se. 24	10.18	3.01	.40	.36	29.18	14.53	.03	.36	1.11	.18	....	.51
Se. 25	13.12	2.70	1.94	.48	39.22	4.87	.15	.32	.50	.20	....	.51

[a] Not enough silt present in sands 2, 21, and 22 for analysis, and no chemical analysis was made of silt in sands 5 and 15.

[b] For details of field origin of samples see pp. 43–52 as to sands, pp. 80–86 as to gravels, and pp. 93–106 as to stone screenings.

[c] Not enough silt present in gravel 2 for analysis.

[d] No chemical analysis of silt in Se. 6 was made, as only a trace was present.

[e] Undetermined, 1.87.

[f] FeS_2, 3.65; ZnS, 3.79.

[g] Undetermined, 2.18.

[h] FeS_2, 1.57; ZnS, 3.20.

[i] FeS_2, 0.28; ZnS, 9.29.

[j] CO_2, 36.21.

[k] CO_2, 36.75.

TABLE XI.—*Uniformity coefficients of 22 sands and of 12 gravel screenings.*[a]

SANDS.

Register No.	Uniformity coefficient.	Voids.	Density.	Register No.	Uniformity coefficient.	Voids.	Density.
Sd. 12	7.576	33.5	0.738	Sd. 18	4.200	34.0	0.735
Sd. 11	6.382	36.0	.730	Sd. 4	3.969	28.0	.808
Sd. 20	5.625	28.0	.794	Sd. 6	2.978	31.6	.766
Sd. 1	5.465	32.5	.742	Sd. 10	2.785	31.6	.743
Sd. 3	5.436	36.1	.752	Sd. 5	2.733	34.6	.752
Sd. 16	5.105	29.7	.760	Sd. 22	2.700	36.4	.709
Sd. 8	4.957	30.7	.763	Sd. 17	2.552	34.5	.704
Sd. 9	4.909	31.4	.769	Sd. 7	2.333	31.6	.730
Sd. 13	4.879	28.9	.754	Sd. 2	2.322	34.9	.756
Sd. 19	4.450	26.9	.789	Sd. 21	1.706	40.9	.700
Sd. 14	4.273	31.9	.732	Sd. 15	1.692	40.5	.676

GRAVEL SCREENINGS.

Gl. 3	19.78	38.6	....	Gl. 12	5.26	26.5	0.782
Gl. 6	13.07	27.9	0.772	Gl. 5	4.96	29.7	.756
Gl. 2	9.00	31.0	.763	Gl. 4	3.35	22.1	....
Gl. 1	8.78	29.0	.771	Gl. 9	2.08	33.2	.804
Gl. 11	5.74	25.5	.796	Gl. 8	1.99	34.8	.741
Gl. 10	5.50	23.0	.783	Gl. 7	1.80	32.3	.783

[a] For details of field origin of sand samples see pp. 43–52; of gravel samples, pp. 80–86.

TABLE XII.—*Average physical properties of 22 sands, of 12 gravel screenings, and of 25 stone screenings, and their mortars.*[a]

SANDS AND THEIR MORTARS.

Register No.	Density.	Granulometric curve.	Measured voids (per cent).	Weight per cubic foot (pounds).	Strength of 1:3 mortar at 180 days (pounds per square inch). Tensile.	Compressive.	Transverse.
1	2	3	4	5	6	7	8
Sd. 4	0.808	21	28.0	116.4	731	6,105	1,224
Sd. 20	.794	13	28.0	116.5	670	6,200	....
Sd. 19	.789	17	26.9	119.9	773	6,719	....
Sd. 9	.769	15	31.4	110.5	483	2,934	900
Sd. 6	.766	10	31.6	113.5	614	4,225	1,482
Sd. 8	.763	18	30.7	114.5	720	7,554	1,254
Sd. 16	.760	22	29.7	119.5	605	7,108	984
Sd. 2	.756	11	34.9	107.7	369	5,360	900
Sd. 13	.754	20	28.9	119.5	668	7,183	1,314
Sd. 3	.752	14	36.1	103.3	495	5,280	1,182
Sd. 5	.752	12	34.6	104.8	420	4,752	984
Sd. 10	.743	4	31.6	110.0	488	4,639	....
Sd. 1	.742	5	32.5	109.3	415	3,677	1,056
Sd. 12	.738	19	35.5	106.5	601	6,125	1,380
Sd. 18	.735	6	34.0	106.5	550	3,667	....
Sd. 14	.732	7	31.9	111.0	484	4,075	1,044
Sd. 7	.730	8	31.6	116.0	603	5,733	1,038
Sd. 11	.730	16	36.0	108.3	708	5,067	1,272
Sd. 22	.709	9	36.4	98.8	487	4,958	1,008
Sd. 17	.704	3	34.5	105.5	466	4,742	1,002
Sd. 21	.700	2	40.9	89.0	380	2,892	....
Sd. 15	.676	1	40.5	95.5	331	2,633	792

[a] For details of field origin of sand samples see pp. 43–52; of gravel samples, pp. 80–86; of stone screenings, pp. 93–106.

TABLE XII.—*Average physical properties of 22 sands, of 12 gravel screenings, and of 25 stone screenings, and their mortars*—Continued.

GRAVEL SCREENINGS AND THEIR MORTARS.

Register No.	Density.	Granu-larmetric curve.	Measured voids (per cent).	Weight per cubic foot (pounds).	Strength of 1:3 mortar at 180 days (pounds per square inch).		
					Tensile.	Compres-sive.	Trans-verse.
1	2	3	4	5	6	7	8
Gl. 11	0.796	7	25.5	122.5	737	7,825	....
Gl. 9	.791	11	30.7	117.8	654	8,567	....
Gl. 12	.782	2	26.5	120.3	733	6,892	....
Gl. 7	.774	12	32.8	113.4	690	6,325	....
Gl. 6	.772	6	27.9	120.8	617	6,397	....
Gl. 1	.771	8	29.0	115.0	601	7,460	....
Gl. 2	.763	4	31.0	113.5	626	8,074	....
Gl. 4	.759	1	30.9	117.1	703	5,570	....
Gl. 5	.756	5	29.7	115.3	647	6,873	....
Gl. 10	.749	3	27.9	118.9	546	5,433	....
Gl. 8	.741	10	34.8	111.5	476	6,825	....
Gl. 3	....	9	38.6	102.6	426	4,654	....

STONE SCREENINGS AND THEIR MORTARS.

Register No.	Density.	Granu-larmetric curve.	Measured voids (per cent).	Weight per cubic foot (pounds).	Tensile.	Compres-sive.	Trans-verse.
Se. 8	0.774	16	34.6	105.5	793	6,307	1,374
Se. 10	.763	13	31.8	109.8	767	7,394	1,218
Se. 6	.760	21	33.1	109.5	750	8,048	1,326
Se. 14	.757	19	35.8	104.3	664	6,042	1,338
Se. 7	.756	14	36.1	102.7	677	5,279	1,206
Se. 4	.755	22	36.0	105.5	939	8,644	1,602
Se. 19	.753	3	39.3	102.5	790	5,459	1,560
Se. 25	.752	11	33.8	110.3	656	6,417	....
Se. 9	.752	17	33.0	108.0	816	5,982	1,494
Se. 18	.746	12	39.0	103.8	623	6,221	1,380
Se. 5	.745	24	41.1	95.7	761	4,954	1,248
Se. 13	.743	9	38.2	102.2	807	5,394	1,356
Se. 1	.740	7	39.4	103.5	707	5,263	....
Se. 16	.740	6	32.1	120.0	767	4,972	....
Se. 23	.737	20	38.2	99.7	545	4,362	....
Se. 3	.733	4	37.0	103.5	809	6,500	1,410
Se. 12	.733	5	35.1	105.3	717	6,193	1,446
Se. 15	.726	23	37.0	109.5	660	4,681	....
Se. 2	.721	8	27.2	106.2	768	5,251	1,332
Se. 22	.719	10	37.5	106.3	924	7,382	....
Se. 11	.709	2	42.1	95.5	543	3,757	918
Se. 24	.666	25	41.8	101.1	715	3,692	....
Se. 21	.655	1	41.0	97.4	683	3,948	....
Se. 17	....	15	34.7	108.8	575	5,313	1,014
Se. 20	....	18	35.2	108.5	505	4,998	....

GRAVEL-SCREENINGS MORTARS.

ACKNOWLEDGMENT OF DONATIONS.

The 12 samples of gravel used in the investigations of gravel-screenings mortars reported in this bulletin were generously donated by the following firms and companies:

Buckeye Dredging Company, Columbus, Ohio.
Carey Construction Company, Cleveland, Ohio.
Wm. P. Carmichael, Attica, Ind.
Fleming & Co., Cincinnati, Ohio.
C. H. Little & Co., Detroit, Mich.
Loveland Sand and Gravel Company, Loveland, Ohio.
Moores-Cooney Company, Cincinnati, Ohio.
Mound City Gravel Company, St. Louis, Mo.
New Union Sand Company, St. Louis, Mo.
Ohio and Michigan Gravel and Sand Company, Toledo, Ohio.

METHOD OF COLLECTION.

The methods of collection and shipment were the same as those used with the samples of sand (p. 42).

The material in almost every sample represented the run of bank or bar, many samples having pebbles as large as 2 inches. For the purpose of making mortar only the material that passed a ¼-inch screen was used. A complete description of each sample of gravel, together with illustrations from photographs of the screenings (actual size), is given in the following pages. All the screenings were subjected to the usual physical determinations and were mixed with typical Portland cement to make mortar test pieces.

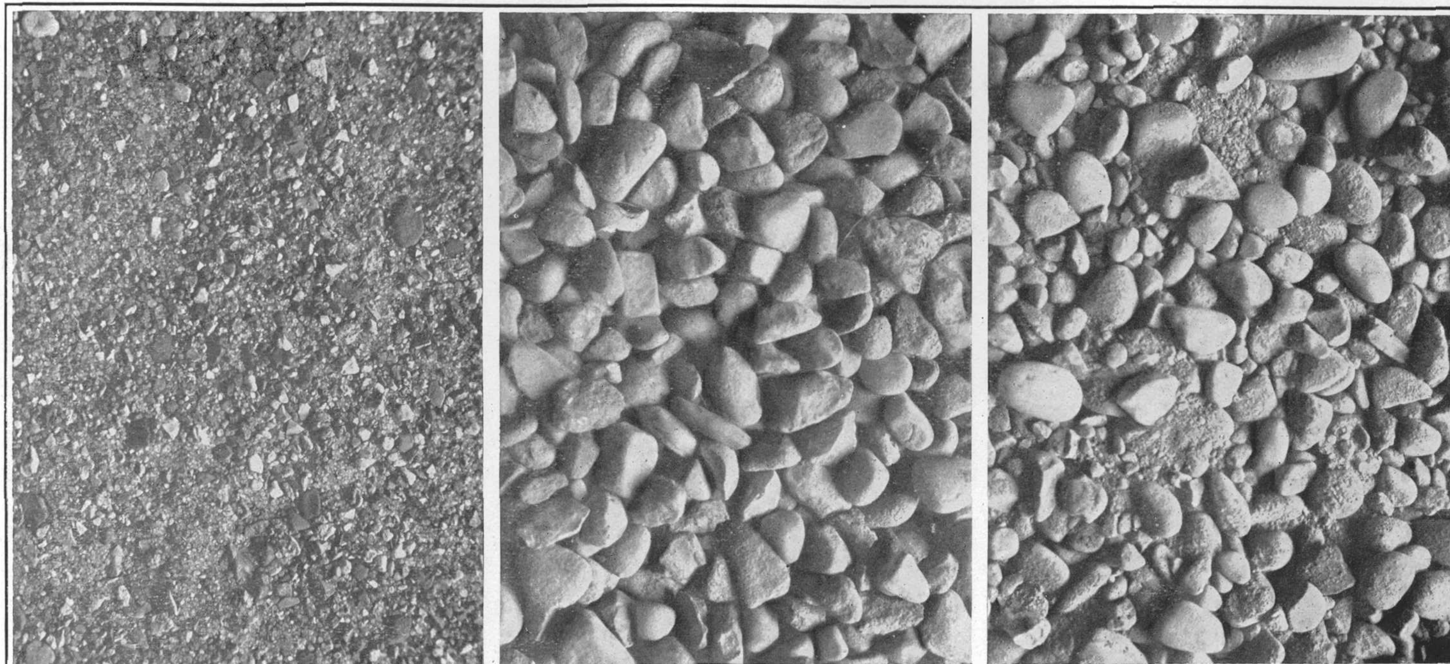
DESCRIPTIONS OF GRAVEL SCREENINGS.

Register No. Gl. 1.—A sample obtained from a recent deposit of river gravel at the Morsches Spur Bar in Meramec River was designated Gl. 1. A dipper dredge was operated over a space 1,200 feet long by 75 feet wide, transferring the material to scows or cars for delivery to St. Louis and other points. In handling the material by the dredge no attempt was made to wash out the silt.

Only 42 per cent of the sample received at the laboratories passed the ¼-inch screen, and no portion of these screenings passed the No. 80 sieve. As shown by the granularmetric analysis curve (fig. 15, p. 83), and the illustration (Pl. VIII, *C*, p. 54), the screenings are very uniformly graded. There is practically no fine material (smaller than the No. 80 sieve). The percentage of voids is 29; the weight per cubic foot is 113.5 pounds; the amount of silt is 0.15 per cent, and the yield in 1:3 mortar is 1.16. The results of the strength tests on mortars made from these and 11 other gravel screenings are given in Table XIII (p. 89).

Register No. Gl. 2.—The sample designated Gl. 2 is a recent river gravel obtained from the Meramec River bar at Moselle, Mo. A clam-shell dredge operated over a space 4,000 feet long and 2,000 feet wide raises the material from the bottom of the river. The gravel is generally shipped to St. Louis, Mo.

About 58 per cent of the samples received at the laboratories passed the ¼-inch screen. As shown by the granularmetric analysis curve (fig. 14), these screenings are not far from uniform in grading and contain but a small portion of fine material, only 3 per cent passing the No. 80 sieve. The material is illustrated in Pl. IX, *A*. The percentage of voids is 31; the weight per cubic foot is 113.5 pounds; the amount of silt is 0.39 per cent, and the yield in 1:3 mortar is 1.14. The results of the strength tests of mortars made from these gravel screenings are shown in Table XIII.



A *B* *C*

A. BAR GRAVEL SCREENINGS, MERAMEC RIVER, MOSELLE, MO. (SAMPLE 2).
B. BAR GRAVEL SCREENINGS, SCIOTO RIVER, COLUMBUS, OHIO (SAMPLE 3).
C. BANK GRAVEL SCREENINGS, LOVELAND, OHIO (SAMPLE 4).

Register No. Gl. 3.—The sample designated Gl. 3 is a mixture of limestone and granite, and the gravel is removed from a 500-foot bar in Scioto River, Columbus, Ohio, by means of an endless chain. It is dumped on scows, hauled to a suitable point, and placed in cars by a bucket and crane for shipment.

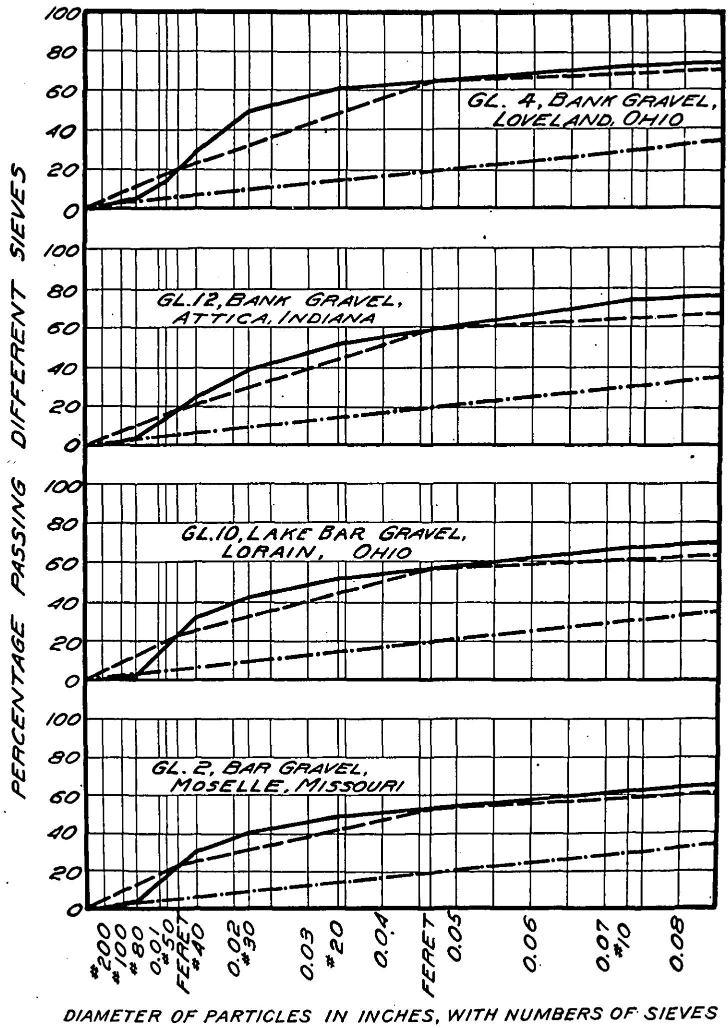


FIG. 14.—Granularmetric analysis curves for gravels 4, 12, 10, and 2. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

As received at the laboratories, this material was supposed to range from 1½- to ¼-inch material. On analysis it was discovered that 12 per cent of the material would pass the ¼-inch screen, and this portion was used in the mortar tests. As shown by the granularmetric analysis curve (fig. 16, p. 85), these screenings are very uniformly graded, although 10 per cent passes the No. 80 sieve. The illustration (Pl. IX, *B*) also shows the uniformity in grading. The percentage of voids is 38.6; the weight per cubic foot is 102.6 pounds; and the amount of silt is 1.4 per cent. The results of the strength tests of mortars made from this gravel are shown in Table XIII (p. 89).

Register No. Gl. 4.—The sample designated Gl. 4 was obtained at Loveland, Ohio, from a gravel bank about 1,200 feet long and 60 feet wide, which was part of a glacial deposit. The material is excavated by a steam shovel and shipped to Cincinnati.

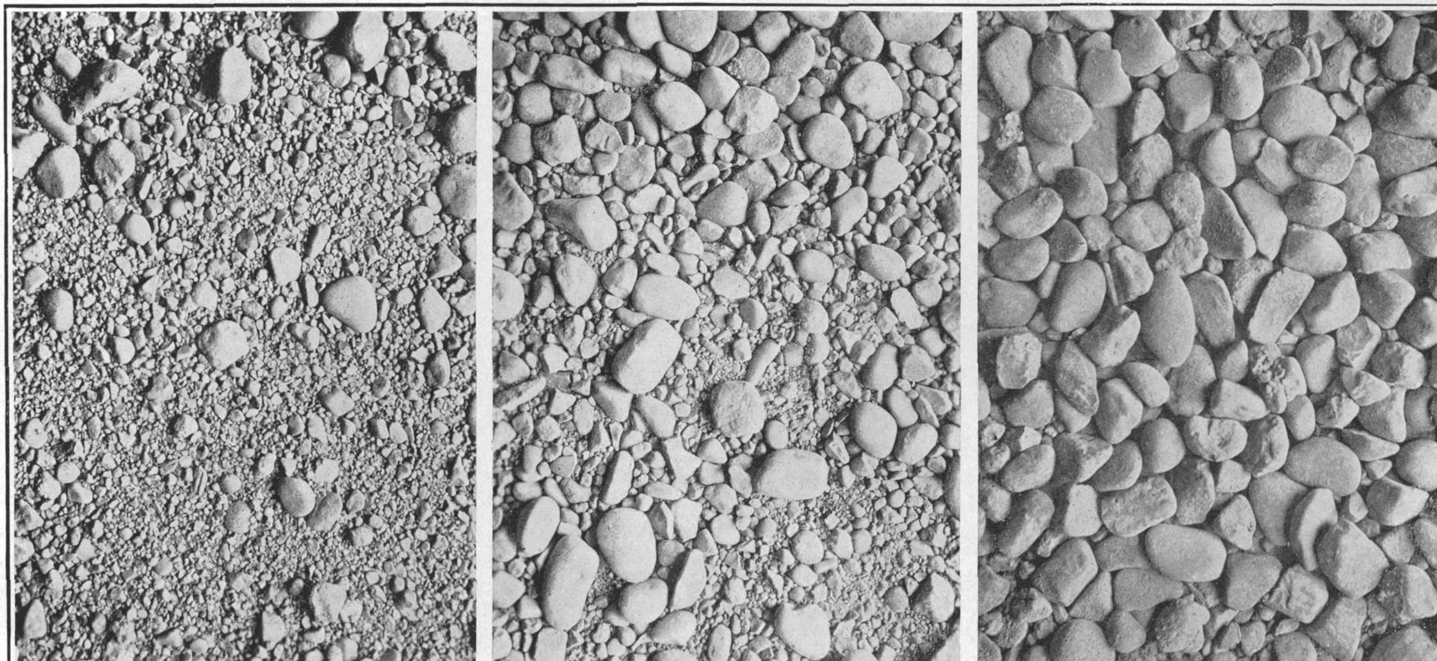
The gravel received at the laboratories was that portion which passed a 1-inch screen, and about one-third of this passed the ¼-inch screen. The granularmetric analysis curve (fig. 14, p. 81) shows that about 40 per cent of the ¼-inch screenings of this material passed the No. 20 sieve, and 5 per cent passed the No. 80 sieve. The percentage of voids is 30; the weight per cubic foot is 117.1 pounds; the amount of silt is 2.67 per cent, and the yield in 1:3 mortar is 1.15. The results of the strength tests of mortars made from this gravel are shown in Table XIII. The screenings are illustrated in Pl. IX, *C*.

Register No. Gl. 5.—The sample designated Gl. 5 is obtained from a deposit of river alluvium and glacial material spread over about 10 acres near Carthage, Ohio. This material was excavated by pick and shovel, and shipped to Cincinnati and vicinity. It contains but a small proportion of coarse particles, and it is generally passed over a ¼-inch screen and the screenings used as sand.

Of the sample received at the laboratories 81 per cent passed the ¼-inch screen. As shown by the granularmetric analysis curve (fig. 15), only 2 per cent of this material passed the No. 50 sieve, and the remainder of the grading followed the general direction of the uniform-grade line. The percentage of voids is 29.7; the weight per cubic foot is 115.3 pounds; the amount of silt is 0.4 per cent, and the yield in 1:3 mortar is 1.15. The results of the strength tests of mortars made from these screenings are shown in Table XIII (p. 89). This sample is illustrated in Pl. X, *A*. The uniform grading of the material and the absence of anything resembling dust or very fine grains are evident.

Register No. Gl. 6.—Sample designated Gl. 6 was obtained from an alluvial and glacial deposit at Ludlow, Ky., the area worked being 600 feet long and 70 feet wide. The gravel is a mixture of natural, ungraded bank gravel and sand, with particles as large as 1¼ inches.

The sample received at the laboratories all passed the ¼-inch screen, and, as shown by the granularmetric analysis curve (fig. 15), 31 per cent passed the No. 30 sieve. The percentage of voids is 27.9; the weight per cubic foot is 120.8 pounds; the amount of silt



A *B* *C*

A. BANK GRAVEL SCREENINGS, CARTHAGE, OHIO (SAMPLE 5).
B. BANK GRAVEL SCREENINGS, LUDLOW, KY. (SAMPLE 6).
C. BANK GRAVEL SCREENINGS, CHILSON, MICH. (SAMPLE 7).

is 2.85 per cent, and the yield in 1:3 mortar is 1.22. The results of the strength tests of mortar made from these screenings are shown in Table XIII. This sample is illustrated in Pl. X, *B*.

Register No. Gl. 7.—One sample, designated Gl. 7, was obtained from a glacial deposit at Chilson, Mich., and was excavated by steam shovel from a pit 530 feet long and 30 feet wide. The run-of-bank

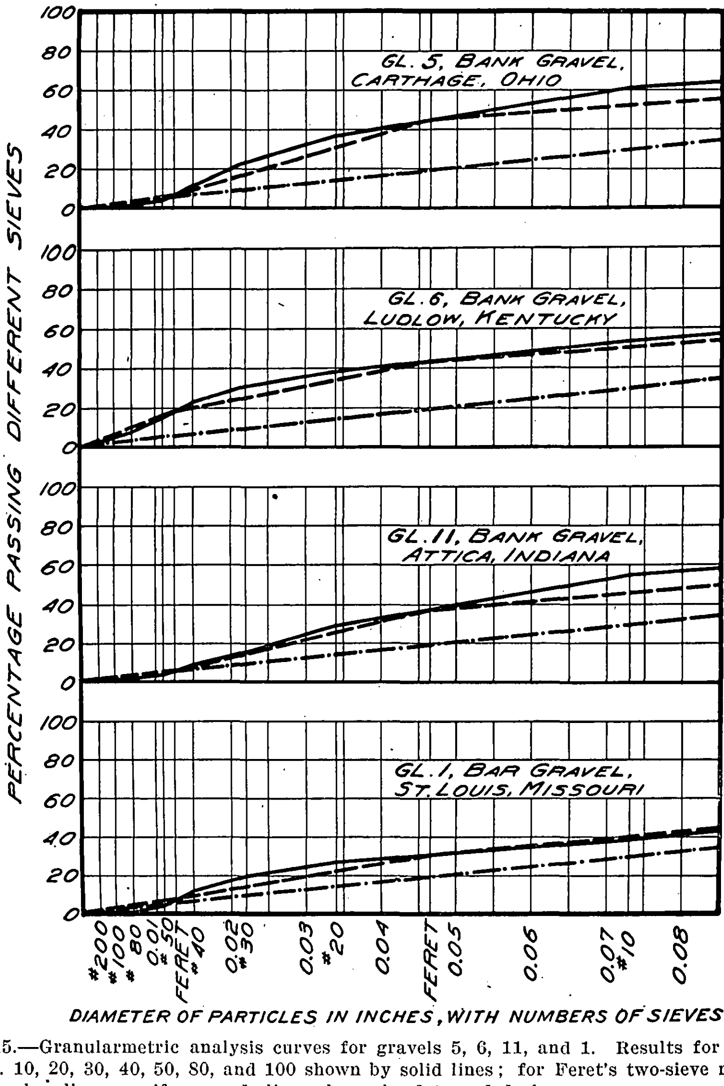


FIG. 15.—Granularmetric analysis curves for gravels 5, 6, 11, and 1. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

gravel could not be procured, inasmuch as all the material was sized by a series of screens. The sample shipped to the laboratories was designated as a No. 2 washed gravel, and comprised particles between three-eighths and 1¼ inches. The graded material is used in the vicinity of Toledo, Ohio.

The commercial sizing of the gravel is not perfect; of the sample received at the laboratories about 22 per cent passed the $\frac{1}{4}$-inch screen, and scarcely any of it passed the No. 10 sieve. The screenings give a very peculiar granularmetric analysis curve (fig. 16), starting at about 0 at the No. 10 sieve and going to 100 at the $\frac{1}{4}$-inch screen. They are practically one-size material between the $\frac{1}{4}$-inch and the No. 10. The percentage of voids is 32.8; the weight per cubic foot is 115.2 pounds; the amount of silt is 0.2 per cent, and the yield in 1:3 mortar is 1.10. The results of the strength tests of mortars made from these screenings are shown in Table XIII. These screenings are illustrated in Pl. X, *C*. It is very evident from the photograph that this material is not uniformly graded, and also that there are practically no very fine grains.

Register No. Gl. 8.—The sample designated Gl. 8 is another grade of the material just described (Gl. 7). Commercially, it is regarded as a $\frac{1}{8}$-inch to $\frac{3}{8}$-inch size, and the granularmetric analysis at the laboratories (fig. 16) shows that this is very nearly the case.

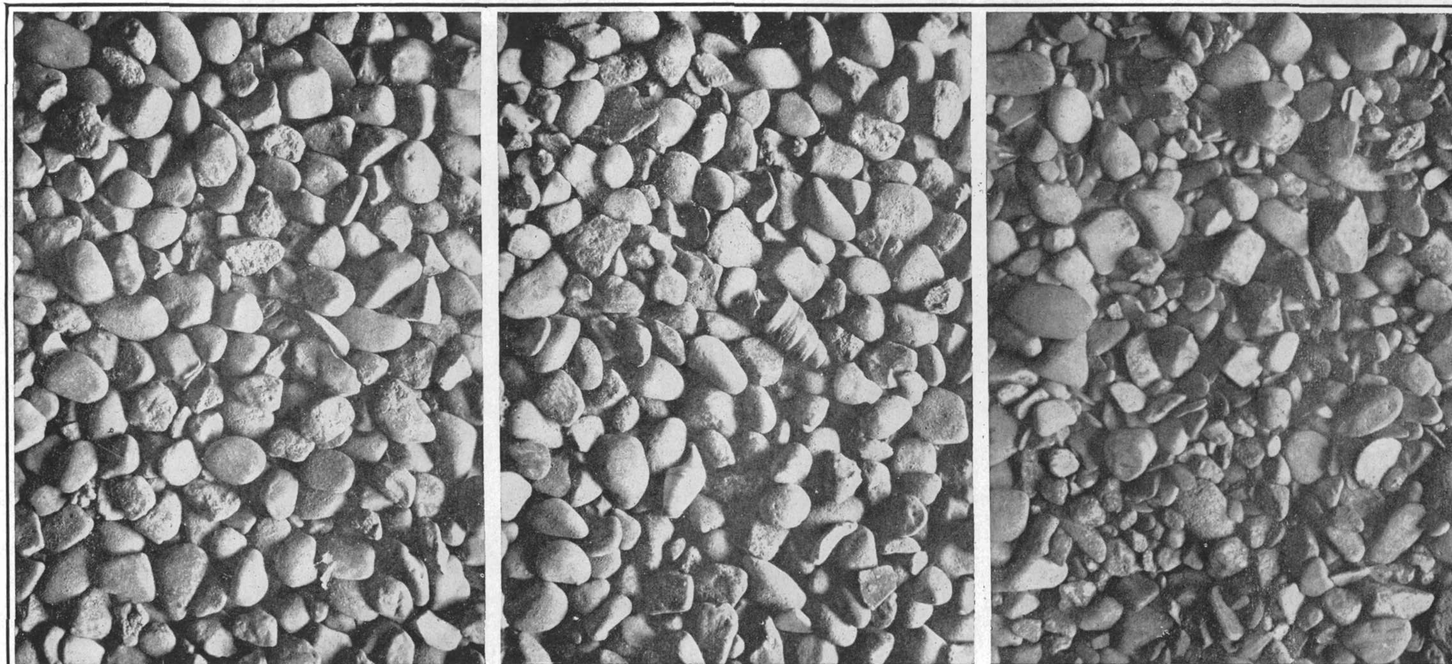
Of the sample received 48 per cent was retained on the $\frac{1}{4}$-inch screen and 98 per cent on the No. 10 sieve. This material is therefore practically a one-size material. The percentage of voids is 34.8; the weight per cubic foot is 111.5 pounds; and the amount of silt is 0.2 per cent; the yield of 1:3 mortar was not determined. The results of the strength tests of mortars are shown in Table XIII. The material is illustrated in Pl. XI, *A*.

Register No. Gl. 9.—The sample designated Gl. 9 was obtained from the shore of St. Clair River near Amherstburg, Ontario. It was pumped into scows by means of a centrifugal pump and taken to Detroit, Mich. The sample shipped to the laboratories consisted of screenings of approximately one size sifted out of the material excavated.

The granularmetric analysis (fig. 16) shows that practically all the material was retained by the No. 10 sieve. The percentage of voids is 30.7; the weight per cubic foot is 117.8 pounds; the amount of silt is 0.7 per cent, and the yield in 1:3 mortar is 1.10. The results of strength tests of mortars made from this material are shown in Table XIII. The appearance of the material may be seen in Pl. XI, *B*.

Register No. Gl. 10.—The sample designated Gl. 10 was obtained from a "wash" on the shore of Lake Erie, near Lorain, Ohio. The extent of the deposit is indefinite. The material was handled by pick and shovel and shipped to Cleveland. In commercial form this product ranges from 3-inch pebbles down to the finest sands.

Of the sample shipped to the laboratories 62 per cent passed the $\frac{1}{4}$-inch screen. As indicated by the granularmetric analysis curve (fig. 14, p. 81), about 50 per cent of the screenings lie between the



A *B* *C*

A. BANK GRAVEL SCREENINGS, CHILSON, MICH. (SAMPLE 8).
B. ST. CLAIR RIVER GRAVEL SCREENINGS, AMHERSTBURG, ONTARIO (SAMPLE 9).
C. LAKE ERIE GRAVEL SCREENINGS, LORAIN, OHIO (SAMPLE 10).

No. 20 and the No. 80 sieves. The gravel is illustrated in Pl. XI, *C*. The percentage of voids is 27.9; the weight per cubic foot is 118.9 pounds; the amount of silt is 0.4 per cent, and the yield in 1:3 mortar is 1.19. The results of the strength tests on mortars made from these screenings are shown in Table XIII.

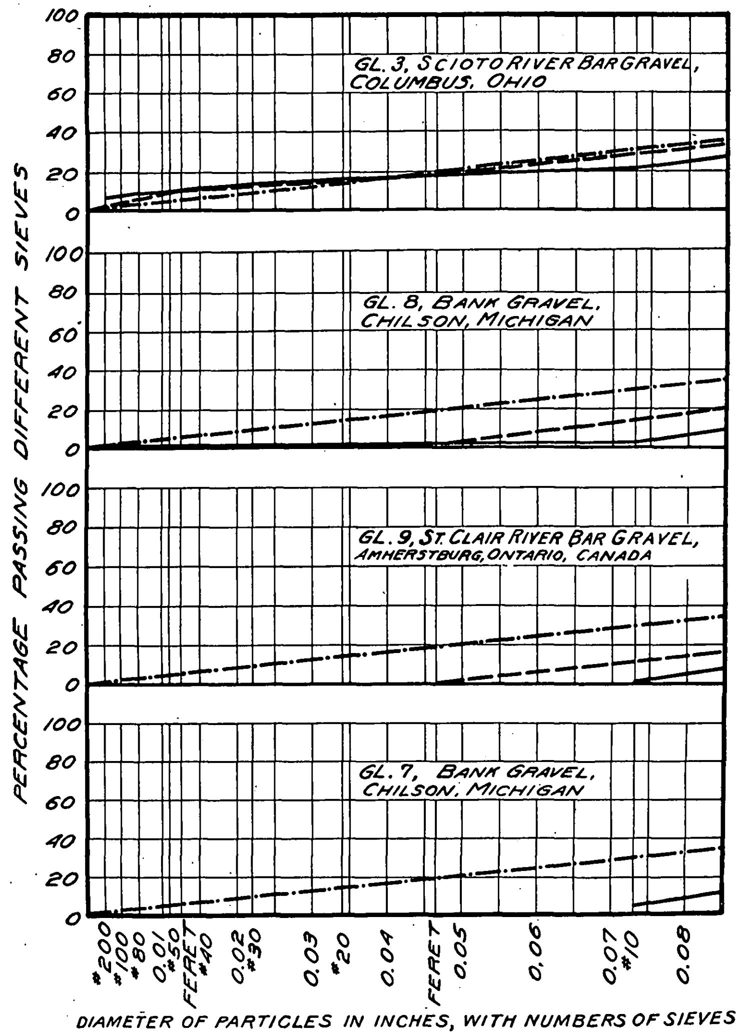


FIG. 16.—Granularmetric analysis curves for gravels 3, 8, 9, and 7. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

Register No. Gl. 11.—Sample designated Gl. 11 was obtained at Attica, Ind., from the deposit described under "Sd. 18" (p. 49). Of the sample shipped to the laboratories, 40 per cent passed the ¼-inch screen, and only 28 per cent passed the No. 20 sieve (fig. 15, p. 83). The percentage of voids is 25.5; the weight per cubic foot is

122.5 pounds; the amount of silt is 0.3 per cent; and the yield in 1:3 mortar is 1.20. The results of the strength tests of mortars made from these screenings are shown in Table XIII. The uniform grading of the particles is apparent at a glance (Pl. XII, *A*).

Register No. Gl. 12.—A second sample from Attica, Ind., designated Gl. 12, is a bank gravel from the same locality as Gl. 11. Of the sample shipped to the laboratories 86 per cent passed the ¼-inch screen, and 50 per cent passed the No. 20 sieve (fig. 14, p. 81). The percentage of voids is 26.5; the weight per cubic foot is 120.3 pounds; the amount of silt is 0.5 per cent, and the yield in 1:3 mortar is 1.18. The results of the strength tests of mortars made from these screenings are shown in Table XIII. The illustration of this material (Pl. XII, *B*) shows the comparatively uniform grading of the particles. There is a small amount of very fine material present and a rather large amount of large grains.

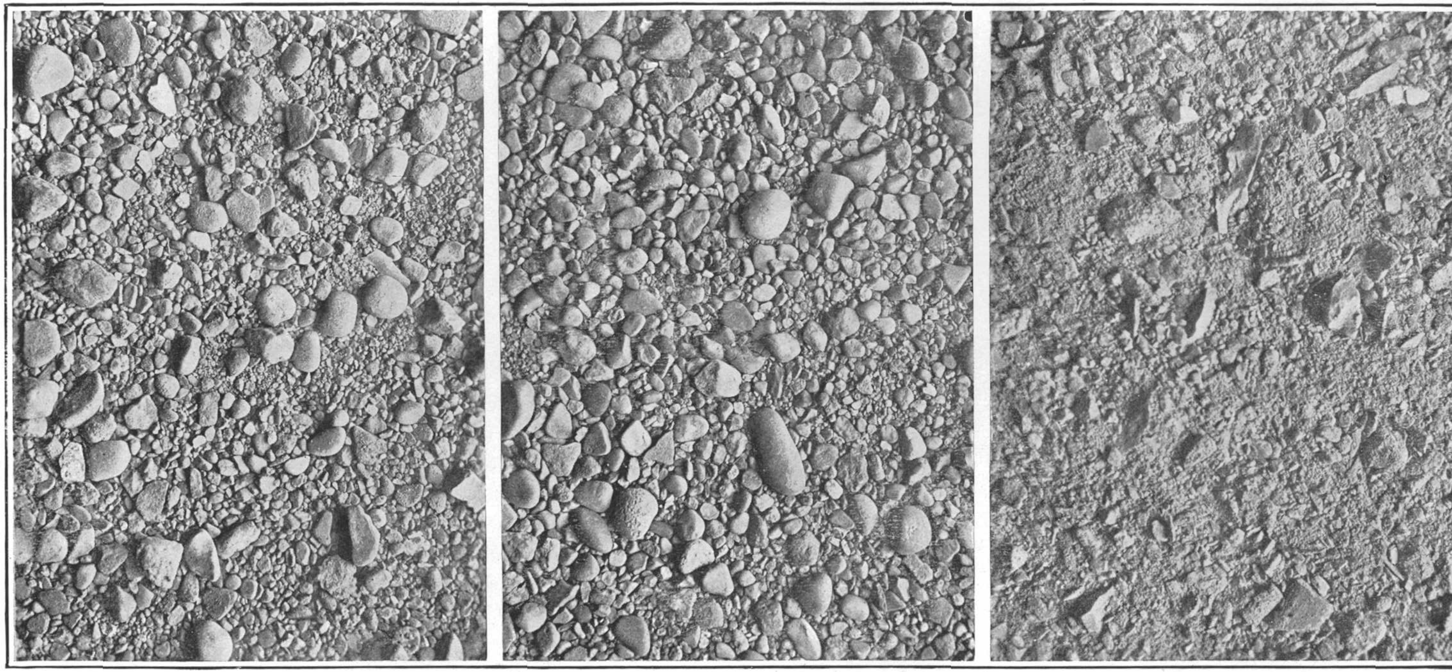
PHYSICAL TESTS OF GRAVEL SCREENINGS.

Method.—When a sample of gravel is received at the laboratories it is spread on a concrete floor and turned at intervals until thoroughly air dried. It is then passed over a ¼-inch screen to separate the coarser material. Great care is taken so that no part of the fine material shall be lost. The percentage of the original shipment that passes the ¼-inch screen is recorded. The screenings are used in the mortar tests and the residue above the ¼-inch size is discarded.

The screenings (all of which have passed the ¼-inch screen) are submitted to tests for granularmetric composition, percentage of voids, specific gravity, weight per cubic foot, and percentage of moisture. These results are given in Table VIII (p. 59). The percentage and chemical composition of silt are given in Table X (p. 77).

Granularmetric analysis.—The set of sieves for the granularmetric analysis consists of Nos. 10, 20, 30, 40, 50, 80, 100, and 200. It was found that great care had to be taken in order to get a representative sample of each lot, on account of the tendency of the fine material to work to the bottom of the mass.

Granularmetric curves.—The granularmetric analysis curves are shown in figs. 14, 15, and 16, the ordinate at any sieve being the total percentage that passes that sieve. These curves are arranged in the order of the segment included between the granularmetric analysis curve, shown in full line, and the uniform-grade line, shown by dots and dashes. The sample which departs farthest from the uniform grading is Gl. 4 (at the top of fig. 14, p. 81), and the curves gradually approach the uniform-grade line until Gl. 3 (at the top of fig. 16, p. 85) is reached. This sample drops slightly below the uniform-grade line at the No. 10 sieve, and is slightly above it at the other



A *B* *C*

A. BANK GRAVEL SCREENINGS, ATTICA, IND. (SAMPLE 11).
B. BANK GRAVEL SCREENINGS, ATTICA, IND. (SAMPLE 12).
C. LIMESTONE SCREENINGS, ST. LOUIS, MO. (SAMPLE 1).

sieves, but very nearly coincides throughout the entire length. The three samples following Gl. 3 in fig. 16 are rather coarse and contain practically no material under the No. 10 sieve. The granularmetric analysis curves for these samples consist practically of a short line starting at 0 at the No. 10 sieve and inclining toward 100 at the ¼-inch screen. In these charts the mechanical analysis curves by means of Feret's two-sieve method are shown in broken lines.

Comparison between measured and computed voids.—In the determination of the percentage of voids and weight per cubic foot, three independent determinations were made.

In order to afford a basis of comparison between the measured voids and the computed voids the latter were computed by means of the specific gravity and the weight per cubic foot, as explained under "Physical tests of sands" (p. 55). The measured and computed voids and the differences between them are given in Table VIII (p. 59). In columns 14 and 15 are also given the differences between the values, the difference in each case being marked under the method giving the higher value. The averages of the differences are shown in the line marked "Average." The difference between them is zero, showing that in this case the results by each method were of equal value.

Uniformity coefficient.—The uniformity coefficients of the gravel screenings studied in these investigations are arranged progressively in decreasing order in Table XI (p. 78). For convenience of comparison the percentage of voids and the density for each sample are also given in the table.

PHYSICAL TESTS OF GRAVEL-SCREENINGS MORTARS.

Method.—Each of the gravel screenings described in the preceding pages was mixed with typical Portland cement to form mortar of different proportions, and this mortar was made into test pieces for tensile and compressive tests. Proportions of 1:3 and 1:4 are used in every case.

Since it was found impossible to obtain sufficient material of one size, no one-size mortar test pieces were made. Test pieces were made of each sample of gravel screenings for each kind of stress, and three pieces were tested at each of the five ages—7, 28, 90, 180, and 360 days.

The results of the strength tests on these mortars, including the register number, the yield at the 1:3 ratio, the register number of the corresponding typical Portland cement test pieces, the temperature of the water and of the air at the time of molding, the percentage of water used for normal consistency, and the breaking strength (in pounds per square inch) at different ages are given in Table XIII (p. 89). Table VIII summarizes data respecting the field origin and nature of each sample of gravel, and the average physical properties are given in Table XII (p. 78).

The results of the strength tests on neat-cement test pieces made from the same cement used in the mortar are given in Table VII (p. 36) and are plotted in figs. 6 (p. 35), 7 (p. 39), and 8 (p. 40). The corresponding typical Portland cement numbers are given in Table XIII, so that the strength of the mortar may be compared with the strength of the neat cement used in the mortar.

Tensile strength.—The results of the tensile tests are given in Table XIII*a* (p. 89). The results are arranged in groups of three, in the same way as for the sand mortars, and the average of each group is shown in the line marked "Average." The results given in the table are the total breaking loads on 1-inch briquets.

The lack of uniformity in the increase in strength is probably due to physical differences in the gravel screenings. In general, the tensile strength of both mortars seems to decrease with the increase in the percentage of voids.

Compressive strength.—The results of the compressive tests are given in Table XIIIb (p. 91). The values in this table are in pounds per square inch, and are obtained by dividing the total breaking load by the area of the cross section of the 2-inch cube. Considering these tests in the order of the percentage of voids, it can be seen that the strength appears to decrease with the increase in the percentage of voids.

Summary of gravel-mortar tests.—A great deal of irregularity can be expected in the testing of gravel-screenings mortar test pieces. This is due to the fact that the operator finds it difficult to obtain a thoroughly uniform mass, especially when the material is composed of coarse grains of approximately one size. In the latter case it invariably happens that the cement and gravel screenings occur in the test pieces in streaks. In many cases the cement accumulates at one side of the neck of the briquet, and the active section is reduced so that the briquet gives eccentric results when tested.

Density.—The density of mortar made from each sample of gravel screenings was determined in order to ascertain its relation to the other physical properties and to see if the strength of the mortar can be approximately foretold by the density.

The density of 1:3 mortar and the relation between the density and other physical properties of the screenings and mortars are given in Table XII (p. 79). In column 1 are given the register numbers of the gravel screenings used in the mortars whose densities are given in column 2. The densities are arranged in order, with the largest value at the top. For purposes of comparison, the number of the granularmetric analysis curve for each gravel is given in column 3. These numbers start with No. 1 for Gl. 4 (at the top of fig. 14, p. 81) and end with No. 12 for Gl. 7 (at the bottom of fig. 16, p. 85). The percentage of voids, weight per cubic foot, and tensile and compressive strengths of the corresponding mortars at 180 days are given in columns 4-8.

TABLE XIIIa.—*Tensile strength of the mortars of 12 gravel screenings.*

Register No.[a]	Ratio of cement to gravel.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Tensile strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days
Gl. 1...	1:3	1.16	79-1	66.2	67.6	9.1	308	565	540	595	525
							326	550	580	632	491
							330	535	590	575	502
	Average	....	....	....	....	....	321	550	570	601	506
	1:4	....	79-6	65.8	64.1	8.4	395	509	438	509	418
							416	492	493	508	407
							380	467	490	520	400
	Average	....	....	....	....	....	397	489	474	512	408
Gl. 2...	1:3	1.14	79-2	63.5	59.0	9.1	365	528	600	595	460
							380	503	643	652	485
							353	566	611	630	522
	Average	....	....	....	....	....	366	532	618	626	489
	1:4	....	79-7	66.2	66.5	8.4	371	485	522	485	492
							390	452	475	530	476
							400	456	481	500	480
	Average	....	....	....	....	....	387	464	493	505	483
Gl. 3...	1:3	....	79-36	68.0	68.9	8.9	311	457	459	432	510
							317	469	477	420	504
							350	440	470	425	482
	Average	....	....	....	....	....	326	455	469	426	499
	1:4	....	79-36	[illegible]3.0	68.9	8.3	338	388	452	363	465
							310	412	430	365	450
							305	380	440	369	427
	Average	....	....	....	....	....	318	393	441	366	447
Gl. 4...	1:3	1.15	79-33	69.8	63.0	8.9	457	612	700	697	733
							435	590	750	712	698
							432	580	767	700	709
	Average	....	....	....	....	....	441	594	739	703	713
	1:4	....	79-33	69.8	63.0	8.3	422	545	610	620	692
							410	542	650	652	652
							430	485	627	......	658
	Average	....	....	....	....	....	421	524	629	636	667
Gl. 5...	1:3	1.15	79-30	70.7	72.5	8.9	592	600	730	623	665
							539	605	710	627	735
							537	626	755	690	722
	Average	....	....	....	....	....	556	610	732	647	707
	1:4	....	79-30	70.7	72.5	8.3	445	547	670	600	638
							458	530	660	594	654
							420	531	615	578	656
	Average	....	....	....	....	....	441	536	648	591	649
Gl. 6...	1:3	1.22	79-38	69.8	68.0	8.9	455	560	640	577	642
							480	600	630	654	682
							442	610	600	620	646
	Average	....	....	....	....	....	459	590	623	617	657
	1:4	....	79-38	69.8	68.0	8.3	394	478	500	510	586
							399	502	540	575	572
							385	510	......	591	590
	Average	....	....	....	....	....	393	497	520	559	583

[a] For details of field origin of samples of gravel screenings see pp. 80-86.

TABLE XIIIa.—*Tensile strength of the mortars of 12 gravel screenings*—Continued.

Register No.	Ratio of cement to gravel.	Yield.	Cement No.	Temperature (°F.).		Water (per cent.)	Tensile strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Gl. 7	1:3	1.10	79-49	68.0	67.1	8.9	563	590	635	718	697
							600	625	670	663	726
							620	590	650	......	724
	Average						594	602	652	690	716
	1:4		79-40	68.0	67.1	8.3	399	380	486	505	545
							410	420	460	602	535
							370	423	......	......	560
	Average						393	408	473	553	547
Gl. 8	1:3		79-51	69.8	62.0	8.9	420	488	555	563	505
							475	502	585	438	511
							......	......	......	426	502
	Average						448	495	570	476	506
	1:4		79-51	69.8	62.0	8.3	208	290	415	422	465
							255	320	450	403	475
							200	......	......	437	432
	Average						221	305	433	421	457
Gl. 9	1:3	1.10	79-55	68.9	68.0	8.9	529	545	600	663	704
							480	586	605	630	710
							490	585	560	670	682
	Average						500	572	589	654	699
	1:4		79-55	68.9	68.0	8.3	513	476	540	546	556
							490	495	490	560	570
							486	520	......	561	547
	Average						496	497	515	556	558
Gl. 10	1:3	1.19	79-57	7.16	6.42	8.9	336	465	......	526	593
							340	470	550	585	586
							315	475	568	527	616
	Average						330	470	559	546	598
	1:4		79-57	7.16	64.2	8.3	227	352	447	458	510
							250	363	437	482	501
							251	378	399	491	487
	Average						243	364	428	477	499
Gl. 11	1:3	1.20	133-23	69.8	64.0	8.9	492	625	730	745	768
							500	615	765	730	758
							455	640	......	740	793
	Average						482	627	748	737	773
	1:4		133-23	69.8	64.0	8.3	392	484	540	575	626
							415	475	500	510	612
							......	447	535	570	630
	Average						403	469	525	552	623
Gl. 12	1:3	1.18	133-28	68.0	66.2	8.9	485	600	690	710	812
							490	587	641	764	798
							487	615	......	726	824
	Average						487	601	666	733	811
	1:4		133-28	68.0	66.2	8.3	398	530	569	665	604
							360	545	527	645	628
							388	531	545	594	660
	Average						382	535	547	635	631

TABLE XIII*b*.—*Compressive strength of the mortars of 12 gravel screenings.*

Register No.[a]	Ratio of cement to gravel.	Yield.	Cement No.	Temperature (°F.)		Water (per cent).	Compressive strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Gl. 1	1:3	1.16	79-1	69.0	68.7	9.1	3425	5216	6525	1608	8185
							3362	5737	6555	7408	7340
							3237	5650,	7325	7363	7920
	Average						3341	5532	6802	7466	7185
	1:4		79-9	71.2	68.0	8.4	1362	2912	3930	4908	4000
							1735	3300	3750	5163	3663
							1592	3085	4075	4900	4075
	Average						1563	3099	3918	4990	3913
Gl. 2	1:3	1.14	79-2	74.8	66.2	9.1	4400	6270	7683	7513	9660
							4507	6107	7468	8360	9200
							4435	5902	7000	8350	8940
	Average						4447	6093	7384	8074	9267
	1:4		79-10	70.7	52.0	8.4	1845	3375	4530	5023	5300
							1852	3550	4708	5263	4925
							2000	3517	5000	4750	4975
	Average						1899	3481	4746	5012	5067
Gl. 3	1:3		79-36	68.0	70.7	8.9	1925	3400	3763	4725	4825
							1913	3075	3553	4725	4750
							1958	3250	4193	4512	4650
	Average						1932	3242	3970	4654	4742
	1:4		79-36	68.0	70.7	8.3	1460	2518	2848	3438	3875
							1450	2500	3163	3400	4175
							1358	2830	2920	3012	4075
	Average						1423	2616	2977	3233	4042
Gl. 4	1:3	1.15	79-28	70.7	64.4	8.9	2,455	3,975	5,890	5,612	7,425
							2.350	3,725	6,025	5,800	7,050
							2,388	3,987	6,380	5,300	7,100
	Average						2,398	3,896	6,098	5,570	7,192
	1:4		79-28	70.7	64.4	8.3	1,488	2,500	4,675	4,500	4,675
							1,368	2,942	4,688	4,800	4,600
							1,463	2,787	4,403	5,025	4,450
	Average						1,440	2,743	4,589	4,775	4,575
Gl. 5	1:3	1.15	79-25	68.9	69.8	8.9	2,957	4,515	5,975	7,163	7,450
							3,375	4,713	6,050	6,583	7,850
							3,250	4,425	6,138	......	7,700
	Average						3,194	4,551	6,054	6,873	7,667
	1:4		79-25	68.9	69.8	8.3	2,300	3,520	4,325	5,970	5,250
							2,250	3,473	4,050	5,515	5,800
							2,337	3,268	4,163	5,760	5,850
	Average						2,296	3,420	4,179	5,748	5,633
Gl. 6	1:3	1.22	79-38	68.0	68.0	8.9	3,025	4,040	7,250	6,463	7,175
							3,133	4,415	5,815	6,375	6,725
							3,160	4,258	7,013	6,352	7,175
	Average						3,106	4,238	7,026	6,397	7,025
	1:4		79-38	68.0	68.0	8.3	2,320	3,988	4.875	......	6,500
							2,500	3,833	5,110	5,705	6,550
							2,558	3,800	5,115	6,038	6,725
	Average						2,459	3,874	5,033	5,871	6,592
Gl. 7	1:3	1.10	79-49	69.8	68.0	8.9	3,825	4,438	7,295	5,700	6,425
							3,875	4,220	6,970	......	6,162
							......	......	......	6,950	6,550
	Average						3,850	4,329	7,133	6,325	6,379
	1:4		79-40	69.8	68.0	8.3	1,533	3,523	3,557	1,875	4,325
							1,475	3,338	......	......	4,250
							......	3,000	3,975	1,500	4,450
	Average						1,504	3,287	3,766	1,687	4,342

[a] For details of field origin of samples of gravel screenings, see pp. 80–86.

TABLE XIII*b*.—*Compressive strength of the mortars of 12 gravel screenings*—Continued.

Register No.	Ratio of cement to gravel.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Compressive strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Gl. 8	1:3	......	79–51	69.8	69.8	8.9	2,688	2,650	3,250	6,550	5,375
							2.225	2,388	3,162	7,100	5,050
							2,538	......	......	......	4,100
	Average	......	......	......	......	......	2,484	2,519	3,206	6,825	4,842
	1:4	......	79–51	69.8	69.8	8.3	763	1,310	3,725	2,050	2,125
							638	1,500	3,800	2,100	2,175
							663	......	......	......	2,525
	Average	......	......	......	......	......	688	1,405	3,762	2,075	2,275
Gl. 9	1:3	1.10	79–55	69.8	68.0	8.9	4,595	5,550	6,288	8,200	8,900
							4,475	5,000	6,438	8,725	9,062
							4,538	5,488	5,810	8,775	9,400
	Average	......	......	......	......	......	4,536	5,346	6,179	8,567	9,121
	1:4	......	79–55	69.8	68.0	8.3	4,175	5,145	......	6,600	7,375
							4,025	5,163	5,695	6,375	7,625
							3,950	5,345	5,863	6,050	7,300
	Average	......	......	......	......	......	4,050	5,218	5,779	6,342	7,433
Gl. 10	1:3	1.19	79–57	69.8	64.2	8.9	2,318	4,050	4,570	5,300	4,950
							2,288	4,388	4,763	5,475	5,125
							......	4,000	4,325	5,525	4,937
	Average	......	......	......	......	......	2,303	4,146	4,553	5,433	5,004
	1:4	......	79–57	69.8	64.2	8.3	1,370	1,888	2,608	3,225	3,037
							1,450	1,775	2,532	3,350	3,075
							1,413	......	2,680	3,250	3,075
	Average	......	......	......	......	......	1,411	1,832	2,607	3,275	3,062
Gl. 11	1:3	1.20	133–23	68.9	68.0	8.9	4,630	6,365	6,225	9,000	8,675
							4,638	6,238	6,375	7,300	8,975
							......	6,200	6,600	7,175	8,800
	Average	......	......	......	......	......	4,634	6,268	6,400	7,825	8,817
	1:4	......	133–23	68.9	68.0	8.3	2,595	3,938	......	4,450	4,975
							2,363	3,688	4,425	4,400	4,325
							2,550	3,775	3,925	4,750	4,300
	Average	......	......	......	......	......	2,503	3,800	4,175	4,533	4,533
Gl. 12	1:3	1.18	133–28	68.9	74.3	8.9	3,623	5,225	5,550	7,050	8,050
							3,575	5,200	4,925	6,850	7,425
							3,573	......	5,275	6,775	8,225
	Average	......	......	......	......	......	3,590	5,212	5,250	6,892	7,900
	1:4	......	133–28	68.9	74.3	8.3	2,790	4,050	4,550	4,950	6,050
							2,675	3,775	4,650	5,250	6,250
							2,685	3,700	......	4,725	6,150
	Average	......	......	......	......	......	2,717	3,842	4,600	4,975	6,150

STONE-SCREENINGS MORTARS.

ACKNOWLEDGMENT OF DONATIONS.

In the investigations reported in this bulletin, 25 samples of stone screenings were used. They were generously donated by the following firms and companies:

Bambrick-Bates Construction Company, St. Louis, Mo.
Buckeye Dredging Company, Columbus, Ohio.
Bull Frog Mining Company, Joplin, Mo.
Casparis Stone Company, Casparis, Ohio.
Chicago Crushed Stone Company, Chicago, Ill.

Fruin-Bambrick Company, St. Louis, Mo.
Glencoe Lime and Cement Company, St. Louis, Mo.
Granby Zinc and Mining Company, Joplin, Mo.
Hillsboro Stone Company, Hillsboro, Ohio.
Horton Stone and Milling Company, Springfield, Mo.
McLaughlin-Mateer Company, Kankakee, Ill.
McTernan & Halpin Construction Company, Kansas City, Mo.
Ozark Red Granite Company, Graniteville, Mo.
Perkinson Brothers, St. Louis, Mo.
Rucker Stone Company, Greenfield, Ohio.
St. Joseph Lead Company, Bonne Terre, Mo.
St. Joseph Street Construction Company, St. Louis, Mo.
Samuels & Holmes, Kansas City, Mo.
Sibley Quarry Company, Sibley, Mich.
Toledo Stone and Glass Sand Company, Sylvania, Ohio.

METHOD OF COLLECTION.

These samples were collected and shipped to the laboratories in the manner described for sands (p. 42). All the screenings were subjected to the usual physical determinations and were mixed with cement to make mortar test pieces. A complete description of each sample of stone screenings, together with illustrations from photographs (actual size) and the detailed results of tests, is given in the following pages.

DESCRIPTIONS OF STONE SCREENINGS.

Register No. Se. 1.—The sample designated Se. 1 was obtained from a quarry at St. Louis, Mo. This stone is geologically known as the St. Louis limestone, of the Mississippian series. It was blasted with black powder for dimension stones, and with dynamite for crusher stone, and is worked and handled by means of steam drills and derricks. The quarry covers a space 400 by 200 feet to a depth of 225 feet. The sample here described was taken from the deepest bed in the quarry, and is a very fine-grained, dense rock. The upper beds in the same quarry vary in texture from coarse to medium.

Of the crusher run, as received at the laboratories, 40 per cent passed the ¼-inch screen, and of this portion 40 per cent passed the No. 20 sieve and 10 per cent the No. 80 sieve (fig. 18, p. 96). The percentage of voids is 39.4; the weight per cubic foot is 103.5 pounds; the amount of silt is 4.9 per cent, and the yield in 1:3 mortar is 1.04 The results of the strength tests of mortars made from these screenings are shown in Table XIV (pp. 109–124). An illustration of the screenings is shown in Pl. XII, *C* (p. 86).

Register No. Se. 2.—A sample obtained from the upper bed of the formation in the quarry from which sample Se. 1 was taken was designated Se. 2.

Of the entire run as received at the laboratories 43 per cent passed the $\frac{1}{4}$-inch screen, and of this portion 40 per cent passed the No. 20 sieve and 10 per cent the No. 80 sieve (fig. 18, p. 96). The percentage of voids is 37.2; the weight per cubic foot is 106.2 pounds; the amount of silt is 5.4 per cent, and the yield in 1:3 mortar is 1.1. The results of the strength tests of mortars made from these screen-

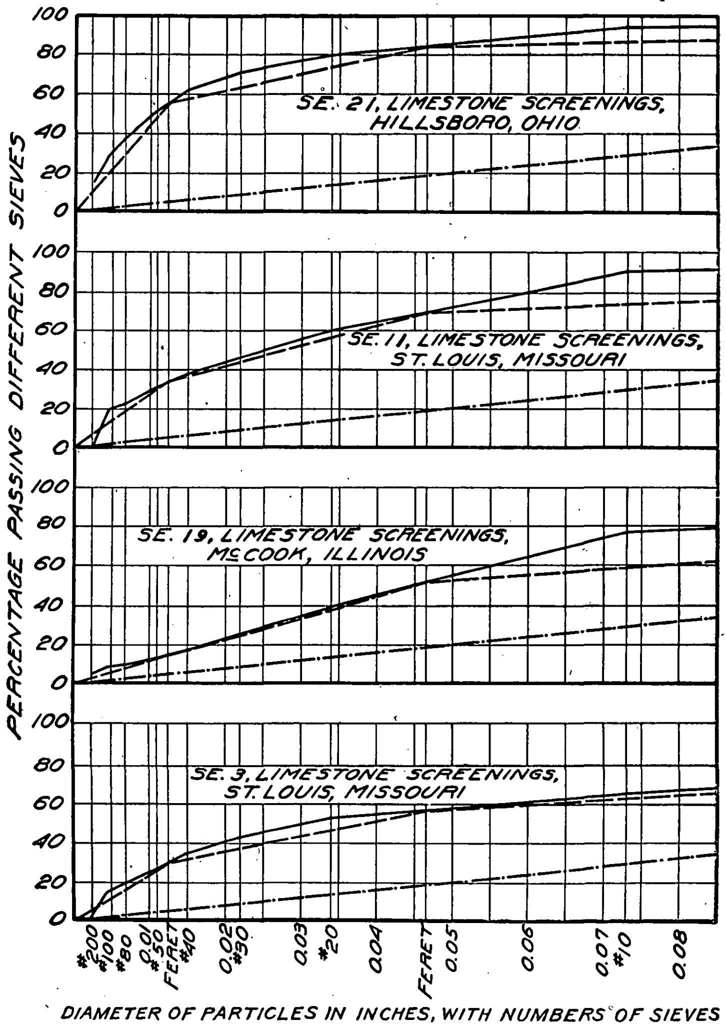
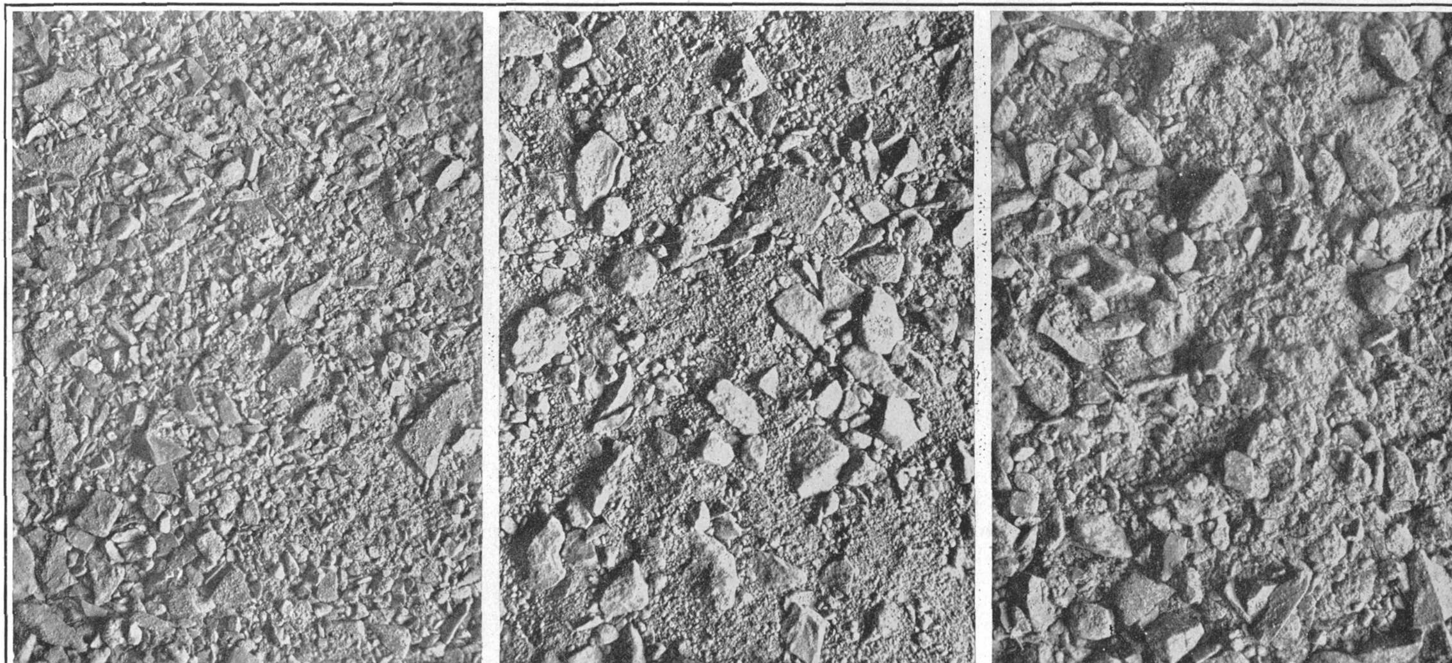


FIG. 17.—Granularmetric analysis curves for stone screenings 21, 11, 19, and 3. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

ings are shown in Table XIV. The appearance is shown in Pl. XIII, *A*.

Register No. Se. 3.—The sample designated Se. 3 was obtained from another quarry at St. Louis. This sample came from the middle bed of the St. Louis limestone, and was blasted out with dynamite and



A *B* *C*

A. LIMESTONE SCREENINGS, ST. LOUIS, MO. (SAMPLE 2).
B. LIMESTONE SCREENINGS, ST. LOUIS, MO. (SAMPLE 3).
C. LIMESTONE SCREENINGS, GLENCOE, MO. (SAMPLE 4).

black powder. The equipment of the quarry embraces compressed-air and steam drills, hoisting machinery, and two large crushers.

Of the crusher-run material as received at the laboratories 23 per cent passed the ¼-inch screen, the large percentage that remained on the ¼-inch screen being about three-eighths inch in size. About 55 per cent passed the No. 20 sieve, and about 15 per cent passed the No. 100 sieve (fig. 17). The percentage of voids is 37; the weight per cubic foot is 103.5 pounds; the amount of silt is 2.3 per cent, and the yield in 1:3 mortar is 1.9. The results of the strength tests of mortars made from these screenings are shown in Table XIV (p. 109). The appearance is shown in Pl. XIII, *B*.

Register No. Se. 4.—A sample from a quarry at Glencoe, St. Louis County, Mo., was designated Se. 4. The outcrop of this rock, an Ordovician limestone, was in the form of a bluff 1,500 feet long and 50 feet high. The stone was excavated by means of black powder and dynamite, and compressed air was largely used in the work.

Of the crusher-run material as received at the laboratories 13½ per cent passed the ¼-inch screen. As may be seen by the granularmetric analysis curve (fig. 22, p. 105) and the illustration (Pl. XIII, *C*), the screenings that passed the ¼-inch screen were almost uniformly graded. The granularmetric analysis curve, shown by solid line in the figure, almost coincides with the uniform-grade line, shown by dots and dashes. Only 20 per cent of this material passed the ¼-inch screen, and only about 5 per cent passed the No. 100 sieve. The percentage of voids is 36; the weight per cubic foot is 105.5 pounds; the amount of silt is 0.6 per cent, and the yield in 1:3 mortar is 1.08. The results of the strength tests of mortars made from these screenings are shown in Table XIV (pp. 109–124).

Register No. Se. 5.—Sample designated Se. 5 was collected at a limestone quarry in Springfield, Mo. The dimensions of the quarry, which is geologically in the Boone formation, were about 200 by 100 by 20 feet. The rock was quarried by means of a steam drill and the use of black powder and dynamite. Both the dimension and crusher-run stones find a ready market in Springfield, Mo., for building purposes.

Of the entire run as received at the laboratories 33 per cent passed the ¼-inch screen. According to the granularmetric analysis curve (fig. 22, p. 105), these screenings are very uniformly graded. About 20 per cent passed the No. 10 sieve and about 12 per cent passed the No. 20 sieve. The percentage of voids is 41.1; the weight per cubic foot is 95.7 pounds; the amount of silt is 1 per cent, and the yield in 1:3 mortar is 1.02. The results of the strength tests of mortars made from these screenings are shown in Table XIV. An illustration of this sample is shown in Pl. XIV, *A*.

Register No. Se. 6.—The sample designated Se. 6 was obtained from a lead mine just west of Joplin, Mo., where a number of lead-bearing veins occur in limestone of the Boone formation. The vein stuff or gangue exists principally in the form of chert, and in the process of separating the galena this chert is crushed into small

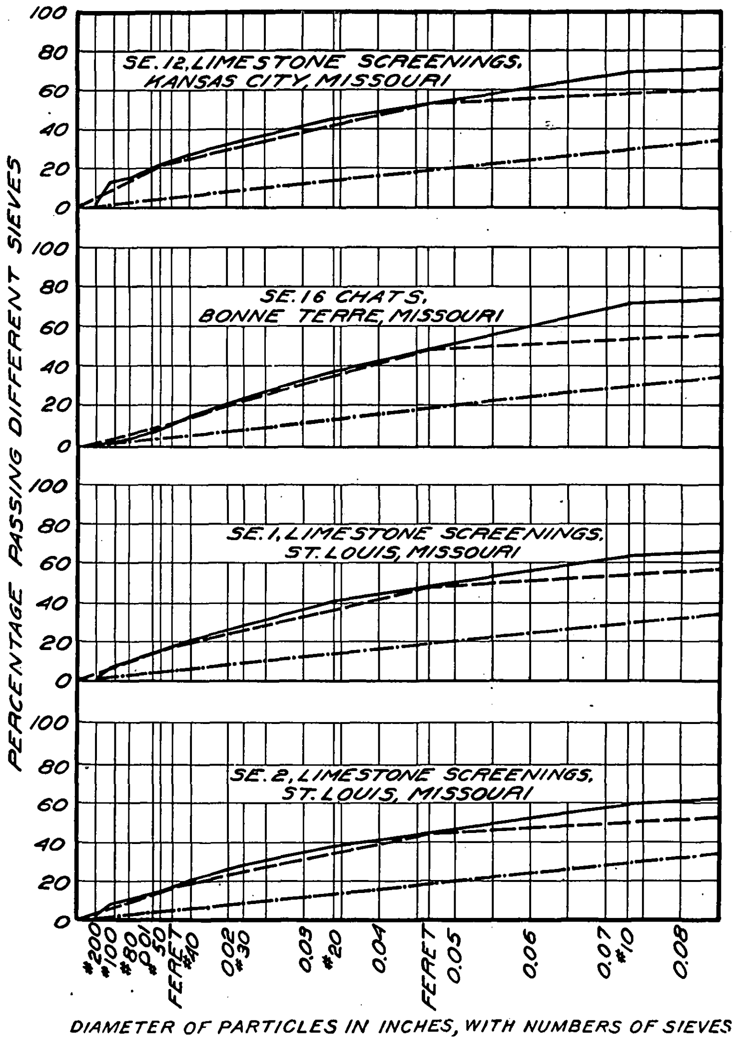
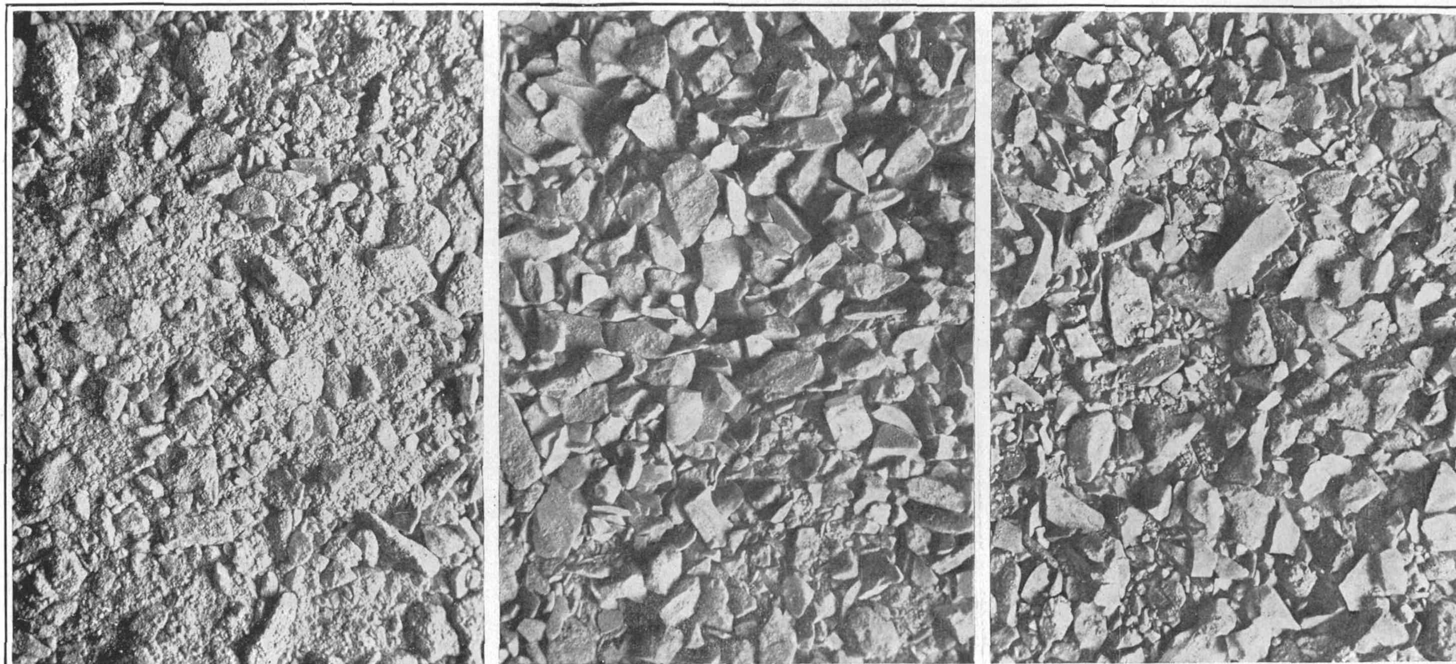


FIG. 18.—Granularmetric analysis curves for stone screenings 12, 16, 1, and 2. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

particles and wasted as lead tailings or chats. The larger of these particles are used as ballast and as an ingredient of concrete; the screenings are used to some extent for mortar.

All the material received at the laboratories passed the ¼-inch screen. According to the granularmetric analysis curve (fig. 22, p.



A *B* *C*

A. LIMESTONE SCREENINGS, SPRINGFIELD, MO. (SAMPLE 5).
B. CHATS, JOPLIN, MO. (SAMPLE 6).
C. CHATS, JOPLIN, MO. (SAMPLE 7).

105), the material is very uniformly graded down to the No. 10 sieve, but below this there is too large an amount of fine material, more than 10 per cent passing the No. 100 sieve. In a general way this may be seen in the illustration (Pl. XIV, *B*). The percentage of voids is 33.1; the weight per cubic foot is 109.5 pounds; the amount of silt is 7 per cent, and the yield in 1:3 mortar is 1.11. The results of the strength tests of mortars made from these chats are given in Table XIV.

Register No. Se. 7.—A second sample from Joplin, Mo., designated Se. 7, was obtained from about the same locality and in the same way as Se. 6, described above, but from a different mine.

Like Se. 6, the entire run of crusher passed the ¼-inch screen; but this was found to be somewhat finer than Se. 6, 53 per cent passing the No. 10 sieve, and about 6 per cent passed the No. 80 sieve. The percentages of voids is 36.1; the weight per cubic foot is 102.7 pounds; the amount of silt is 4.9 per cent; and the yield in 1:3 mortar is 1.07. The results of the tests on mortar made from this material are given in Table XIV (pp. 109–124). The granularmetric analysis curve is shown in fig. 20 (p. 100) and an illustration from photograph in Pl. XIV, *C*.

Register No. Se. 8.—The material designated Se. 8 is a sample of the chats taken from a mine just west of Joplin, Mo.

Of the crusher-run material received at the laboratories, a very small portion was retained on the ¼-inch screen, 82 per cent passing through. From the granularmetric analysis curve shown (fig. 20, p. 100), it is seen that the material is not far from uniform grading. It contains a very small amount of fine material, 7 per cent passing the No. 80 sieve. The percentage of voids is 34.6; the weight per cubic foot is 105.5 pounds; the amount of silt is 2.9 per cent, and the yield in 1:3 mortar is 1.03. The results of the strength test of mortars made from this material are given in Table XIV (pp. 109–124).

An illustration of these chats is shown in Pl. XV, *A*, from which the comparatively uniform grading of this material is at once evident, and there does not appear to be a preponderance of either large or very fine particles.

Register No. Se. 9.—A sample of chats from a lead mine near Joplin, Mo., procured in about the same way as Se. 6 (p. 96), was designated Se. 9.

The greater portion of the entire run of crusher received at the laboratories passed the ¼-inch screen. These screenings show a comparatively uniform grading, as shown by the granularmetric analysis curve (fig. 21, p. 102). The percentage of voids is 33; the weight per cubic foot is 108 pounds; the amount of silt is 3 per cent; and the yield in 1:3 mortar is 1.12. The results of the strength tests of mortars made from these chats are given in Table XIV (p. 109). This sample is illustrated in Pl. XV, *B*.

Register No. Se. 10.—A fifth sample collected in the Joplin district was designated Se. 10. It is similar to the chats previously described, and is a by-product of a lead mine.

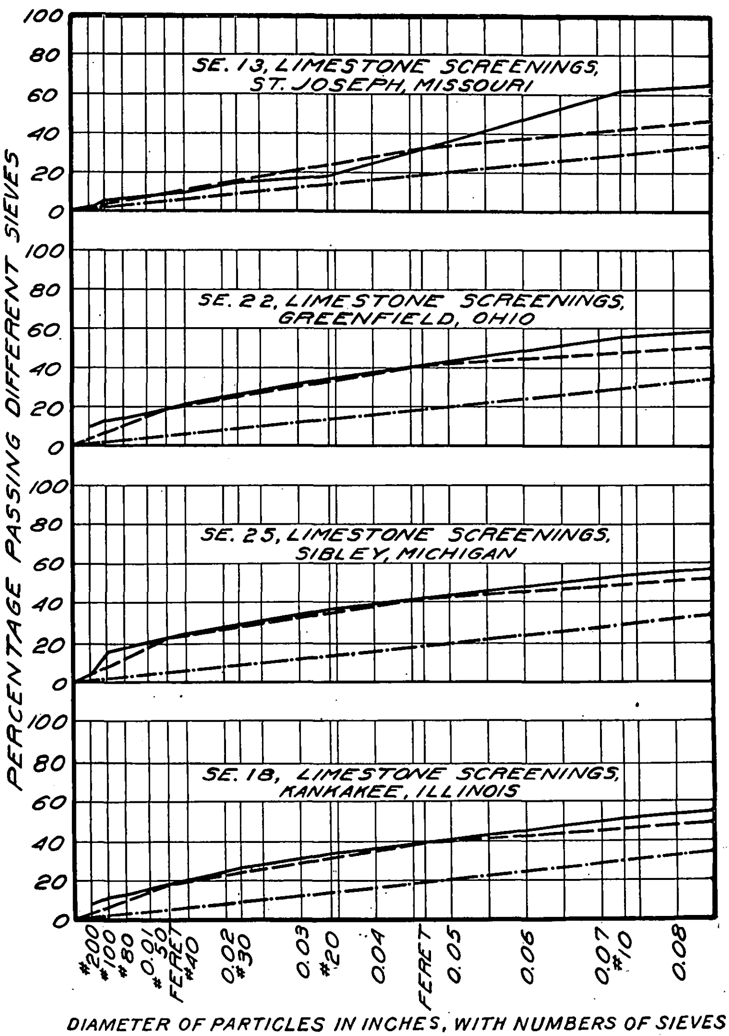
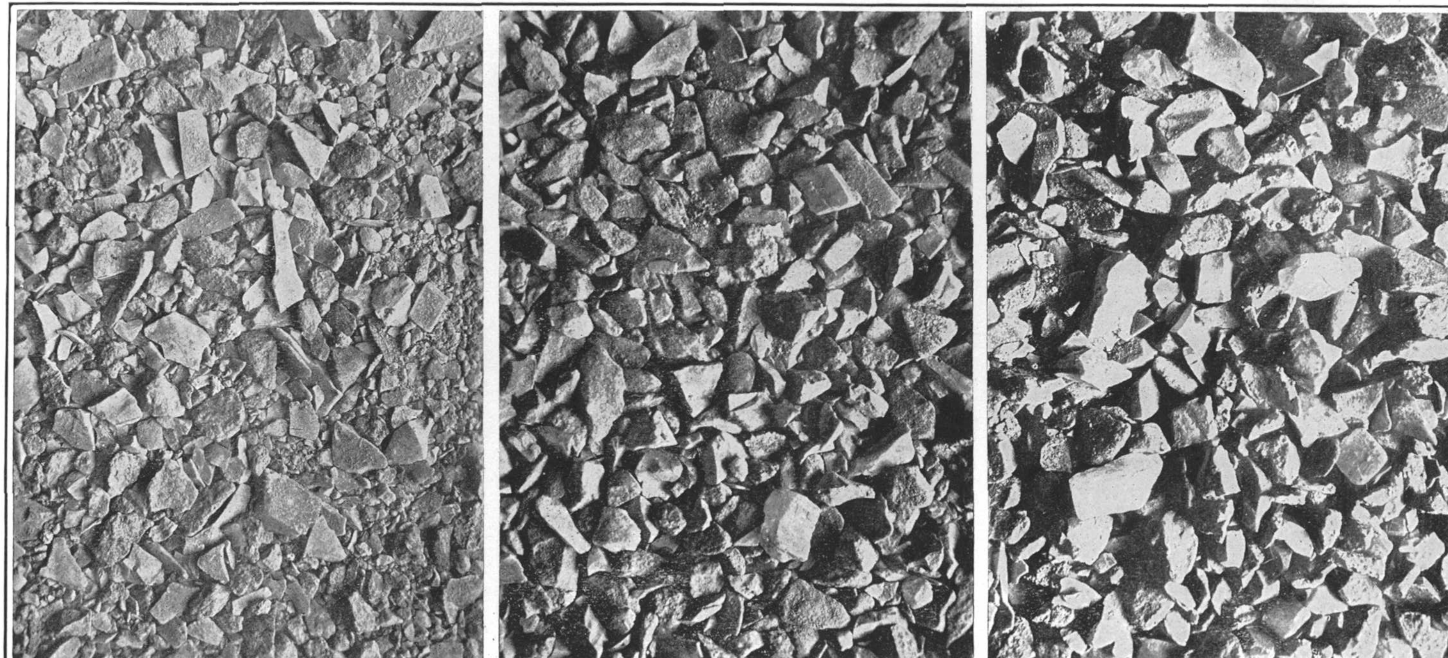


FIG. 19.—Granuarmetric analysis curves for stone screenings 13, 22, 25, and 18. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

Almost all the crusher-run material received at the laboratories passed the ¼-inch screen; about 35 per cent of these screenings passed the No. 20 sieve, and 10 per cent passed the No. 80 sieve. The granularmetric analysis curve is shown in fig. 20 (p. 100) and an illustration from photograph in Pl. XV, *C*. The percentage of voids is



A *B* *C*

A. CHATS, JOPLIN, MO. (SAMPLE 8).
B. CHATS, JOPLIN, MO. (SAMPLE 9).
C. CHATS, JOPLIN, MO. (SAMPLE 10).

31.8; the weight per cubic foot is 109.8 pounds; the amount of silt is 4.7 per cent, and the yield in 1:3 mortar is 1.11. The results of the strength tests of mortars made from this material are given in Table XIV.

Register No. Se. 11.—The sample designated Se. 11 was obtained from a quarry recently opened in the upper central portion of the St. Louis limestone, near St. Louis, Mo. The material was being taken by wagons to St. Louis.

Of the crusher-run material received at the laboratories 50 per cent passed the ¼-inch screen. The grading of the screenings is not at all uniform, as shown by the granularmetric analysis curve (fig. 17, p. 94). Ninety per cent of the material passed the No. 10 sieve; 60 per cent passed the No. 20 sieve, and over 20 per cent passed the No. 100 sieve. The percentage of voids is 42; the weight per cubic foot is 95.5 pounds; the amount of silt is 10.1 per cent, and the yield in 1:3 mortar is 1.12. The results of the strength tests of mortars made from this material are given in Table XIV (p. 109). This sample is illustrated in Pl. XVI, *A*. The dirty appearance of the stone indicates the large percentage of silt.

Register No. Se. 12.—Sample designated Se. 12 was quarried in the vicinity of Kansas City, Mo., from limestone of the Pennsylvanian series. The material was excavated by means of steam drills and the use of powder and dynamite, and shipped to Kansas City. This stone is rather soft, and the large amount of dust and small grains resulting from the crushing is shown by the granularmetric analysis curve (fig. 18, p. 96) and by the illustration (Pl. XVI, *B*).

Register No. Se. 13.—The sample designated Se. 13 is a Pennsylvanian (Bethany) limestone, obtained from a quarry in Buchanan County, Mo. The crusher-run material was obtained by the usual methods of steam drilling, blasting, and crushing, and the output was shipped to the vicinity of St. Joseph, Mo.

Of the entire run of crusher received at the laboratories 29 per cent passed the ¼-inch screen. The granularmetric analysis (fig. 19) shows that the material approaches uniform grading. There are many medium and coarse grains and very little fine material in the screenings. The amount of voids is 38.2 per cent; the weight per cubic foot is 102.2 pounds; the amount of silt is 2.2 per cent, and the yield in 1:3 mortar is 1.04. The results of the strength tests of mortars made from these screenings are given in Table XIV. This sample is illustrated in Pl. XVI, *C*. The irregular grading and the comparatively large amount of coarse and medium grains are evident.

Register No. Se. 14.—The sample designated Se. 14 is limestone of Pennsylvanian age obtained from a quarry in Jackson County, Mo. The usual methods were used in quarrying the stone, which was shipped to Kansas City.

Of the entire run of crusher received at these laboratories, 29 per cent passed the ¼-inch screen, and these screenings were found to be very uniformly graded, as shown by the granularmetric analysis curve (fig. 21, p. 102). The percentage of voids is 35.8; the weight per cubic foot is 104.3 pounds; the amount of silt is 4.0 per cent,

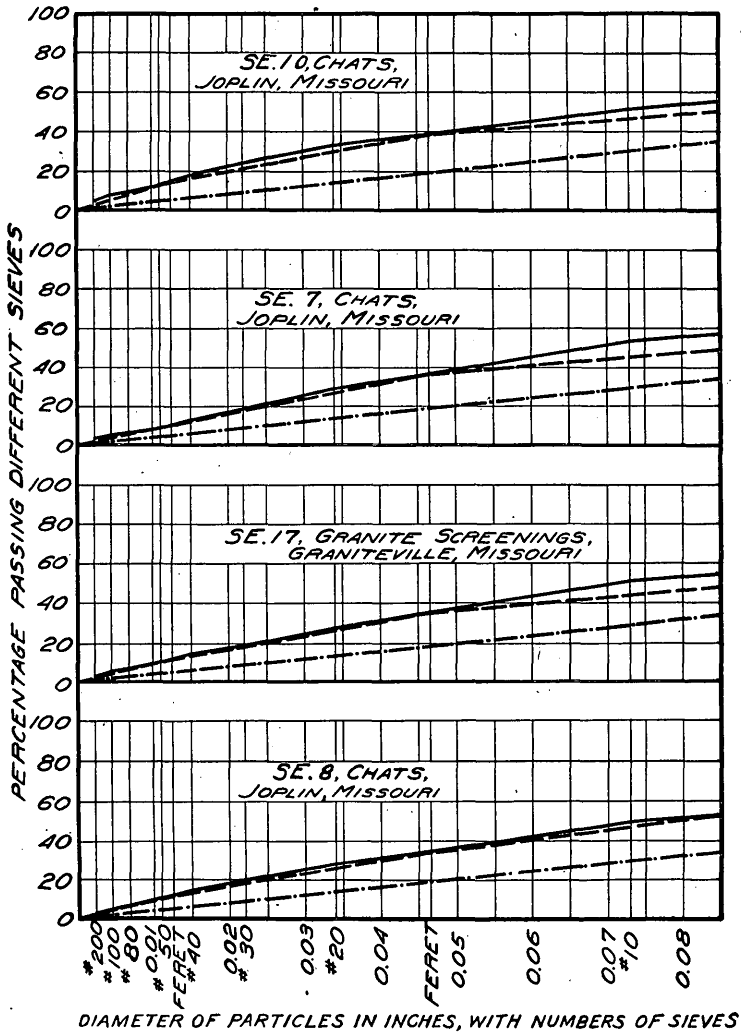
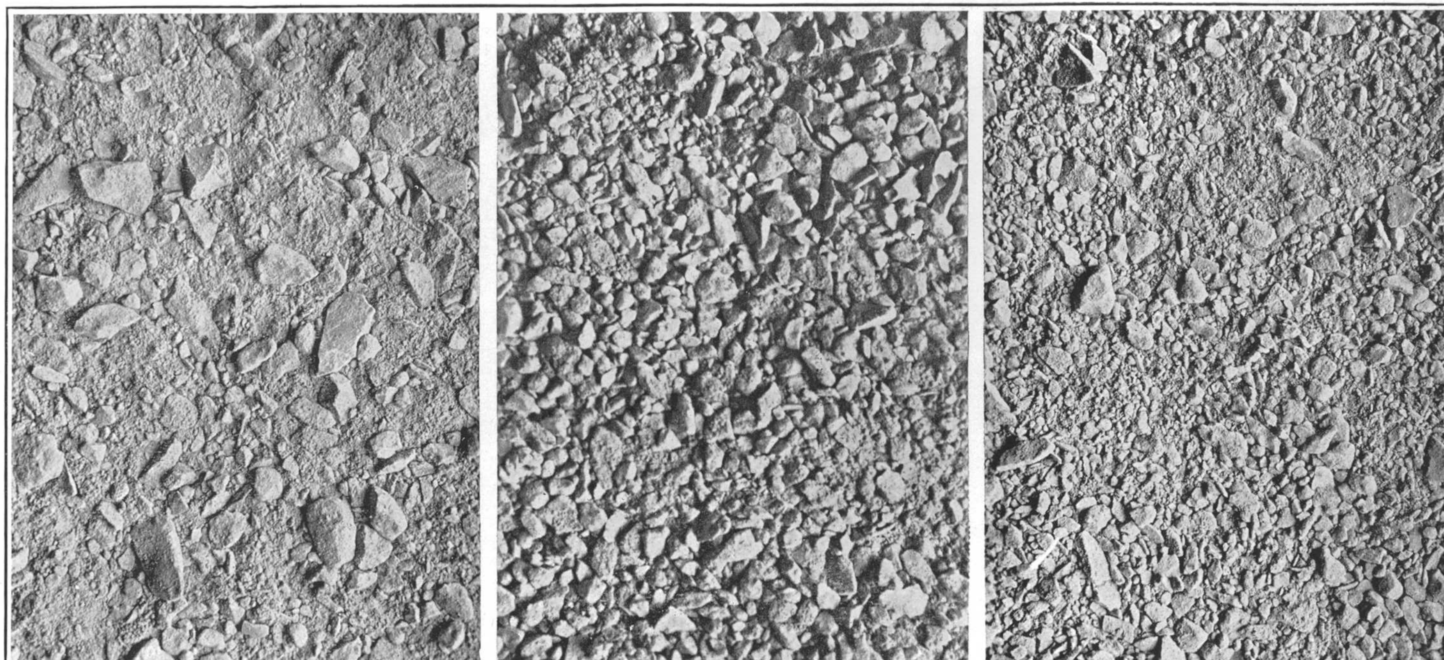


FIG. 20.—Granularmetric analysis curves for stone screenings 10, 7, 17, and 8. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

and the yield in 1:3 mortar is 1.07. The results of the strength tests of mortars made from this material are given in Table XIV (pp. 109–124). The illustration of this material (Pl. XVII, *A*) indicates the uniform grading of particles, from the smallest up to the ¼-inch size, all being plainly visible.



A *B* *C*

A. LIMESTONE SCREENINGS, ST. LOUIS, MO. (SAMPLE 11).
B. LIMESTONE SCREENINGS, KANSAS CITY, MO. (SAMPLE 12).
C. LIMESTONE SCREENINGS, ST. JOSEPH, MO. (SAMPLE 13).

Register No. Se. 15.—Sample designated Se. 15 is obtained from a mine at Hoffman, Mo. Galena is associated with this limestone, and the chats are the calcareous by-product noticeably free from chert. The material is thoroughly washed before marketing in order to eliminate the fine dust.

The entire run of crusher received at these laboratories passed the ¼-inch screen. The granularmetric analysis curve (fig. 22, p. 105) and the illustration (Pl. XVII, *B*) show the absence of any fine grains, there being practically nothing finer than the No. 30, but the curve approaches the uniform-grade line. The percentage of voids is 37; the weight per cubic foot is 109.5 pounds; the amount of silt is 0.5 per cent, and the yield in 1:3 mortar is 1.12. The results of the strength tests of mortars made from this material are given in Table XIV (pp. 109–124).

Register No. Se. 16.—Sample Se. 16 was a by-product from a lead mine in the vicinity of Bonneterre, Mo. It is similar to Se. 15, except that the grading is somewhat different.

The granularmetric analysis curves are shown in fig. 18 (p. 96) and the illustration from photograph in Pl. XVII, *C*. The entire run of crusher, as received at the laboratories, passed the ¼-inch screen, and about 70 per cent of these screenings passed the No. 10 sieve. The percentage of voids is 32.1; the weight per cubic foot is 120 pounds; the amount of silt is 3.7 per cent, and the yield in 1:3 mortar is 1.05. The results of the strength tests of mortars made from this material are given in Table XIV (pp. 109–124).

Register No. Se. 17.—The sample designated Se. 17 was obtained from a quarry at Graniteville, Mo. It is a red granite of very close texture, and geologically is of pre-Cambrian age. The excavated rock is cut partly into dimension stones for building purposes, or Belgian blocks for paving. The resulting spalls are passed through a crusher and then through the 1-inch, ½-inch, and ¼-inch screens, each size being conducted to its own bin by a spout. The screenings are shipped to St. Louis or other cities in the Southwest.

Of the entire run of crusher, as received at the laboratories, 44 per cent passed the ¼-inch screen, showing that the three spouts mentioned above do not furnish equal quantities of the three sizes. According to the granularmetric analysis curve (fig. 20, p. 100) the screenings were uniformly graded; this may also be seen in the illustration from photograph (Pl. XVIII, *A*). The percentage of voids is 34.7; the weight per cubic foot is 108.8 pounds; the amount of silt is 1.4 per cent; and the yield in 1:3 mortar is 1.13. The results of the strength tests of mortars made from this material are given in Table XIV (pp. 109–124).

Register No. Se. 18.—Sample Se. 18 was obtained from a quarry in a bed of fossiliferous "Niagara" limestone near Kankakee, Ill.

The limestone in this region varies perceptibly in texture, that obtained in this quarry being probably the hardest and closest to be found. The stratum was 5 feet 6 inches thick, over a length of 1,800 feet, and contains a ¼-inch layer of soft argillaceous stone. The rock was excavated by means of steam drills and the use of black powder

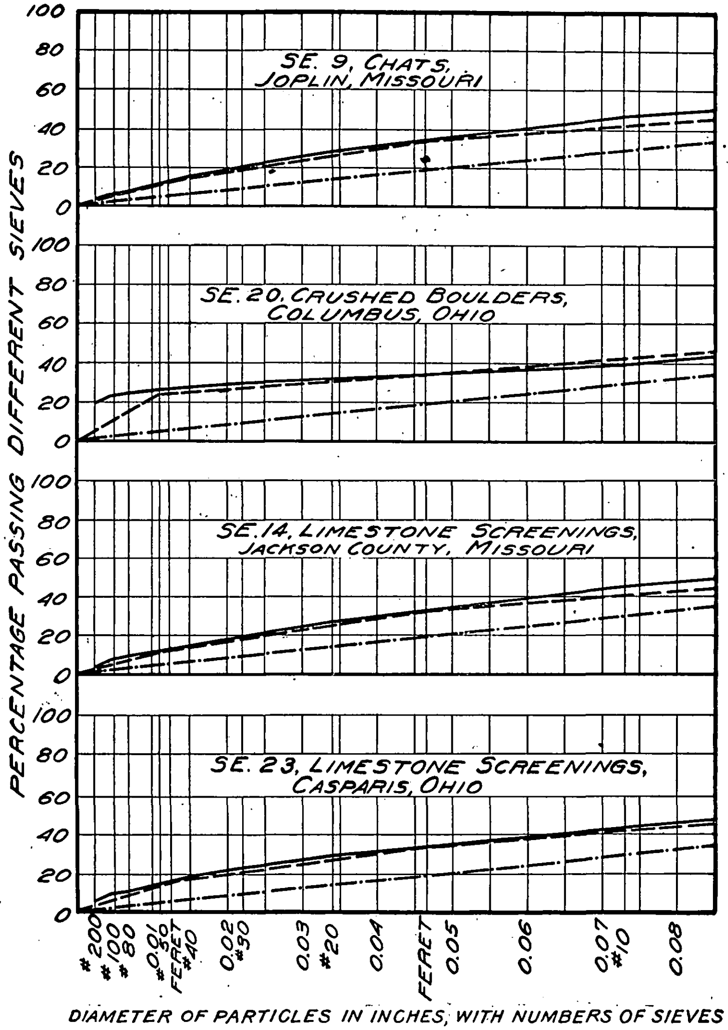
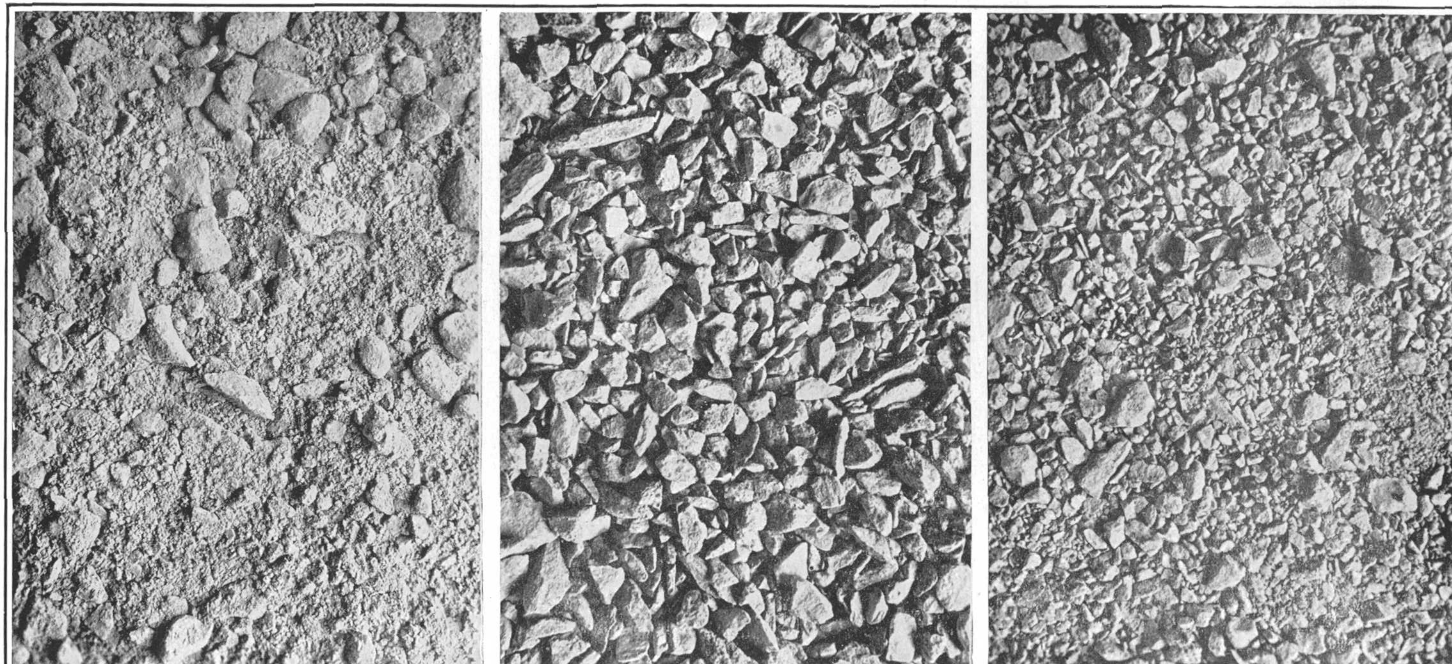


FIG. 21.—Granularmetric analysis curves for stone screenings 9, 20, 14, and 23. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

in blasting. The entire output is passed through a crusher and is not sorted by sieves; it was being shipped to Chicago and Milwaukee.

Of the entire run of crusher, as received at the laboratories, 49 per cent passed the ¼-inch screen. As shown in fig. 19 (p. 98) and the illustration from photograph (Pl. XVIII, *B*), this material is very uniformly graded; but it contains a large amount of fine material,



A *B* *C*

A. LIMESTONE SCREENINGS, JACKSON COUNTY, MO. (SAMPLE 14).
B. CHATS, HOFFMAN, MO. (SAMPLE 15).
C. CHATS, BONNETERRE, MO. (SAMPLE 16).

over 10 per cent passing the No. 100 sieve and 9 per cent passing the No. 200 sieve. The percentage of voids is 39.0; the weight per cubic foot is 103.8 pounds; the amount of silt is 7.48 per cent, and the yield in 1:3 mortar is 1.06. The results of the strength tests of mortars are given in Table XIV (pp. 109–124).

Register No. Se. 19.—The sample designated Se. 19 was obtained from a quarry situated in dolomitic beds of the "Niagara" formation at McCook, Ill. The material was excavated by means of compressed-air drills and the use of black powder in blasting. Part of the material is formed into dimension and paving stones; the remainder is passed through a crusher.

Of the entire run of crusher, as received at the laboratories, 39 per cent passed the ¼-inch screen, and of these screenings 75 per cent passed the No. 10 sieve and 10 per cent passed the No. 100 sieve. The granularmetric analysis curve is shown in fig. 17 (p. 94). The percentage of voids is 39.3; the weight per cubic foot is 102.5 pounds; the amount of silt is 5.0 per cent, and the yield in 1:3 mortar is 1.06. The results of the strength tests of mortars made from this material are given in Table XIV. This sample is illustrated in Pl. XVIII, *C*.

Register No. Se. 20.—Sample Se. 20 was obtained by dredging a strip of the Scioto River bed about 500 feet long at Columbus. The material, as raised by an endless-chain device and dumped into scows, is a mixture of bowlders, gravel, and sand. The bowlders are passed through a crusher and then again mixed with the gravel and sand.

Of the entire run of crusher, as received at the laboratories, 17 per cent passed the ¼-inch screen. As indicated by the granularmetric analysis curve (fig. 21) only about 40 per cent passed the No. 10 sieve, 22 per cent the No. 100, and 20 per cent the No. 200. The percentage of voids is 35.2; the weight per cubic foot is 108.5 pounds; the amount of silt is 3.1 per cent, and the yield in 1:3 mortar is 1.21. The results of the strength tests of mortars made from this material are given in Table XIV (p. 109). The illustration of this material (Pl. XIX, *A*) does not truly represent the grading, as all the fine material has settled to the bottom and does not appear on the surface. The large amount of coarse material in this mixture is readily apparent.

Register No. Sec. 21.—Sample Se. 21 is from a quarry near Hillsboro, Ohio, and the stone is of Silurian age. The rock was handled by means of compressed-air drills, powder, and dynamite. Two sizes are prepared for commercial purposes. The coarser size passes the 1½-inch screen and is retained on the ¼-inch screen. The smaller size passes the ¼-inch screen.

Of the screenings, as received at the laboratories, the entire amount passed the ¼-inch screen. According to the granularmetric analysis curve (fig. 17, p. 94) 72 per cent passed the No. 30 sieve and 30 per cent the No. 100 sieve. The percentage of voids is 41; the weight per cubic foot is 97.4 pounds; the amount of silt is 3.1 per cent, and the yield in 1:3 mortar is 1.14. The results of the strength tests of mortars made from this material are given in Table XIV (pp. 109–124).

From the illustration of these screenings (Pl. XIX, *B*) the very small amount of coarse material and the exceedingly large amount of fine material is readily apparent.

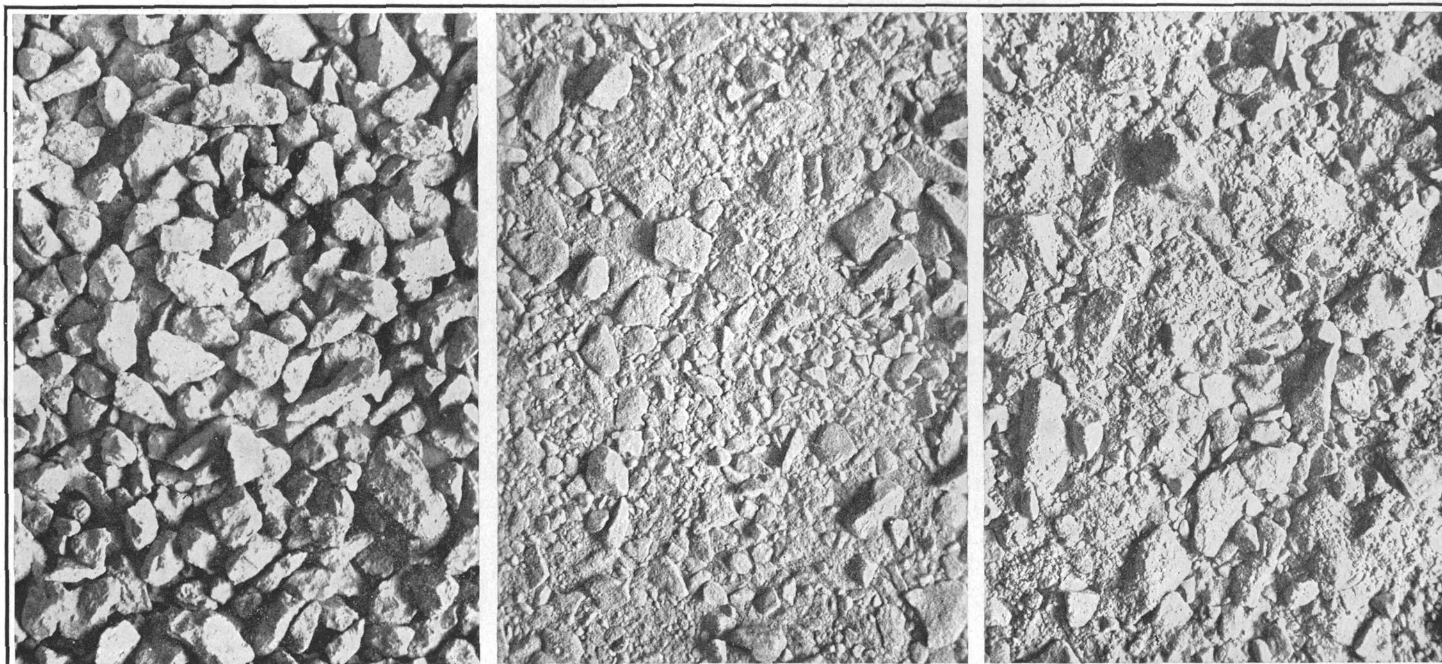
Register No. Se. 22.—Sample Se. 22 belongs to the Monroe formation, found in the vicinity of Greenfield, Ohio, which was being quarried and shipped to Cincinnati. The quarry has a length of about 500 feet, and the rock was blasted by means of black powder and an explosive known to the trade as "rack-a-rock." The ¼-inch screenings removed from the crusher-run material are used for mortar purposes, and the material above one-fourth inch and below 2 inches is used for concrete.

Of the ¼-inch screenings, received at the laboratories, about 15 per cent passed the No. 100 sieve and 10 per cent passed the No. 200 sieve. According to the granularmetric analysis curve (fig. 19, p. 98) the screenings, aside from the large amount of fine material, are uniformly graded. The percentage of voids is 37.5; the weight per cubic foot is 106.3 pounds; the amount of silt is 1.1 per cent, and the yield in 1:3 mortar is 1.14. The results of the strength tests of mortars made from these screenings are given in Table XIV (p. 109). The comparatively large amount of fine material and the presence of grains of all sizes, from the smallest up to the ¼-inch size, is readily apparent from the illustration (Pl. XIX, *C*).

Register No. Se. 23.—Sample Se. 23 is a Devonian limestone obtained from a quarry at Casparis, Ohio. It is very much foliated, and is practically the blanket side of the quarry, which is 8,000 feet long by 65 feet high. The material is obtained by means of air drills and dynamite, and is marketed in Illinois, Indiana, and Ohio. The crushed stone is passed over ¼-inch screens and the material that passes these screens is sold as screenings.

All the particles of this sample as received at the laboratories passed the ¼-inch screen. They are very uniformly graded, as shown by the granularmetric analysis curve (fig. 21, p. 102). The percentage of voids is 38.2; the weight per cubic foot is 99.7 pounds; the amount of silt is 3.5 per cent, and the yield in 1:3 mortar is 1.06. The results of the strength tests of mortars made from these screenings are given in Table XIV (p. 109). The appearance is shown in Pl. XX, *A*.

Register No. Se. 24.—Material designated Se. 24 is a dolomitic limestone in the Monroe formation (Silurian) from a quarry at Silica, about 4 miles from Sylvania, Lucas County, Ohio. The stone is quarried from an open face by means of dynamite, and the material is



A *B* *C*

A. GRANITE SCREENINGS, GRANITEVILLE, MO. (SAMPLE 17).
B. LIMESTONE SCREENINGS, KANKAKEE, ILL. (SAMPLE 18).
C. LIMESTONE SCREENINGS, McCOOK, ILL. (SAMPLE 19).

handled automatically, crushed, and passed through 1-, 2-, and 3-inch screens. On this account no crusher-run material was available. After screening, the material is washed. This company has a most elaborate plant for storing and handling the various products, the conveying and handling machinery being similar to that used in the handling of coal.

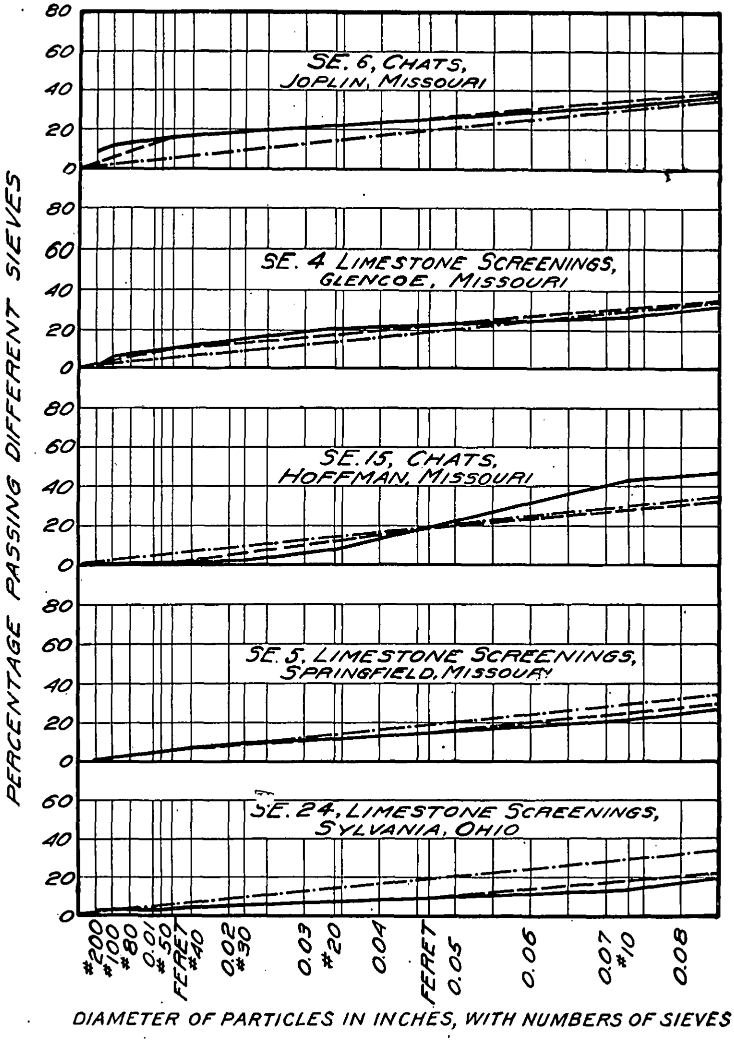


FIG. 22.—Granularmetric analysis curves for stone screenings 6, 4, 15, 5, and 24. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

According to the granularmetric analysis curve (fig. 22) this material is rather uniformly graded. This is also illustrated in Pl. XX, *B*. The percentage of voids is 41.8; the weight per cubic foot is 101 pounds; the amount of silt is 1.1 per cent, and the yield in 1:3

mortar is 1.12. The results of the strength tests of mortars made from this material are given in Table XIV (pp. 109–124).

Register No. Se. 25.—A sample from Sibley, Mich., was designated Se. 25.

According to the granularmetric analysis curve for this material (fig. 19, p. 98) it is very uniformly graded, and about 16 per cent passes the No. 100 sieve. The percentage of voids is 33.8; the weight per cubic foot is 110.3 pounds; the amount of silt is 16.3 per cent. The results of the strength tests of mortars made from this material are given in Table XIV (p. 109). The sample is illustrated in Pl. XX, *C*.

PHYSICAL TESTS OF STONE SCREENINGS.

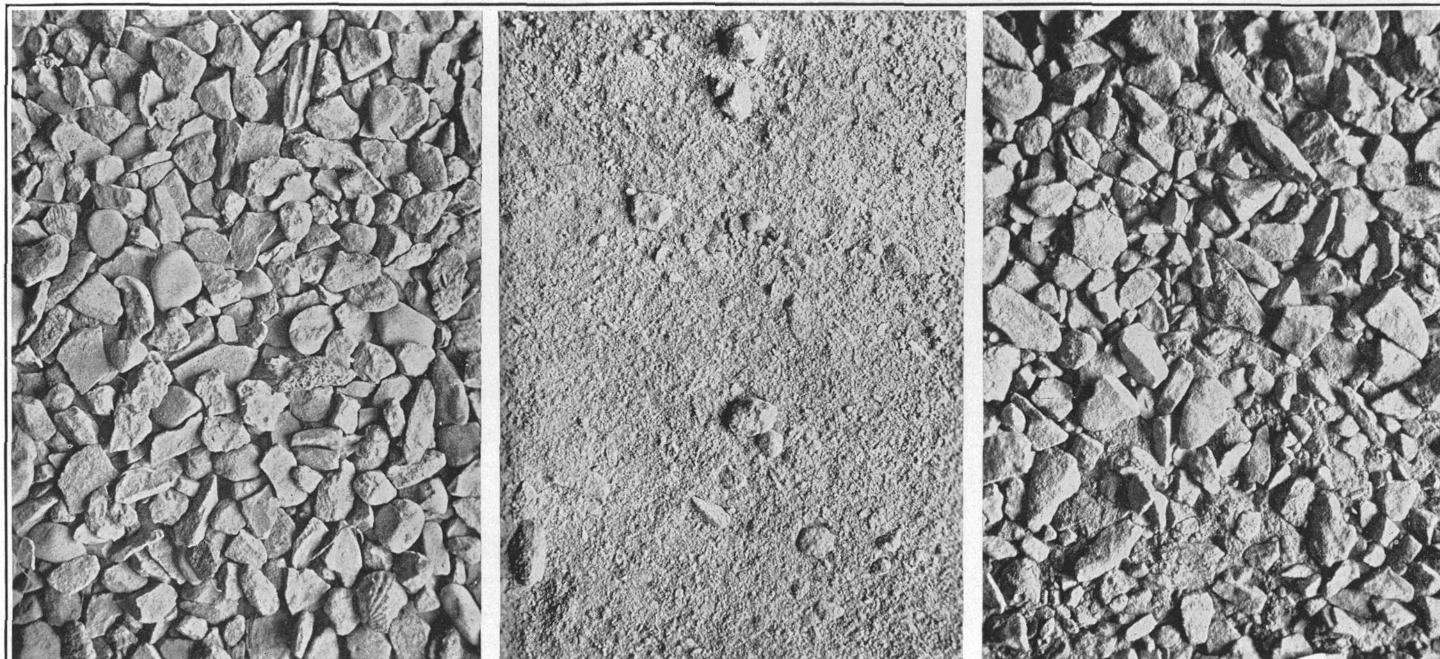
Method.—When a sample of broken stone is received at the laboratories it is spread on a concrete floor, and turned at frequent intervals, so that it will thoroughly dry. It is then passed over a $\frac{1}{4}$-inch screen, and the material that passes the screen is used in the mortar tests. The material retained on the $\frac{1}{4}$-inch screen is discarded. The portion to be used is tested for granularmetric composition, percentage of voids, specific gravity, weight per cubic foot, and percentage of moisture. The results of these determinations are given in Table VIII (p. 59). The percentage and chemical analysis of silt are given in Table X (p. 77).

Granularmetric analysis.—The set of sieves for the granularmetric analysis comprises those with 10, 20, 30, 40, 50, 80, 100, and 200 openings per linear inch.

Granularmetric curves.—The granularmetric analysis curves are shown in figs. 17–22, the ordinate at any sieve being the total percentage that passes that sieve, and not, as in Table VIII (p. 59), the percentage retained by the sieve. Starting with the curve of the screenings having the largest amount of fine material (Se. 21), at the top of fig. 17 (p. 94), these curves are arranged in consecutive order, ending with the curve of the screenings having the largest amount of coarse material (Se. 24), at the bottom of fig. 22 (p. 105).

The granularmetric analysis curves, as determined by the standard sieves previously referred to, are given in solid lines. In order to illustrate the difference between this method of analysis and the two-sieve method proposed by M. Feret, the curve representing the analysis by the latter method is plotted on the same chart in broken lines. Below the two curves just described is given the uniform-grade line in dots and dashes. From the finest to the coarsest screenings the curves have been arranged in the order of the size of the segment included between the granularmetric analysis curve and the uniform-grade line.

Comparison between measured and computed voids.—In order to determine the accuracy of the method of void determination used at



A *B* *C*

A. SCREENINGS FROM CRUSHED BOWLDERS, COLUMBUS, OHIO (SAMPLE 20).
B. LIMESTONE SCREENINGS, HILLSBORO, OHIO (SAMPLE 21).
C. LIMESTONE SCREENINGS, GREENFIELD, OHIO (SAMPLE 22).

the laboratories, the percentage of voids was computed from the specific gravity and the weight per cubic foot of each sample as explained under "Physical tests of sands" (p. 55). The results of these calculations, together with the measured voids, are given in Table VIII (p. 59) for facility of comparison. In columns 14 and 15 are given the differences between the results obtained by the two methods, the difference in each case being given under the method that gives the larger value. The averages of these differences are shown beneath, and it can be seen that the difference between these averages is small, as in the case of sands and gravel screenings.

PHYSICAL TESTS OF STONE-SCREENINGS MORTARS.

Method.—Each of the stone screenings described in the preceding pages was mixed with typical Portland cement to form mortars of different proportions, and these mortars were made into test pieces for tensile, compressive, and transverse tests. Proportions of 1:3 and 1:4 were used in every case, and in addition, wherever there was sufficient material of one size, test pieces were made of 1:3 one-size mortar. With each sample of stone screenings test pieces were made for each kind of stress, and three pieces were tested at each of the five ages, 7, 28, 90, 180, and 360 days.

The results of the strength tests on these mortars, including the register number, the yield at the 1:3 ratio, the register number of the corresponding typical Portland cement test pieces, the temperature of the water and of the air at the time of molding, the percentage of water used for normal consistency, and the breaking strength in pounds per square inch at different ages are given in Table XIV (p. 109). In giving the results of tests on 1:3 one-size mortar the size to which the screenings were sifted is also shown. Table VIII (p. 59) summarizes data respecting the field origin and nature of each sample of stone screenings used, and the average physical properties are given in Table XII (p. 79).

The results of strength tests on neat-cement test pieces made from the same cement used in the mortars are given in Table VII (p. 36). The corresponding cement numbers are given in Table XIV, so that the strength of the mortar can be compared with the strength of the neat cement used in the mortar.

Tensile strength.—The results of the tensile tests on 1:3, on 1:4, and on 1:3 one-size stone-screenings mortar are given in Table XIV*a* (p. 109). The results are arranged in groups of three, and the average of each group is shown in the line marked "Average."

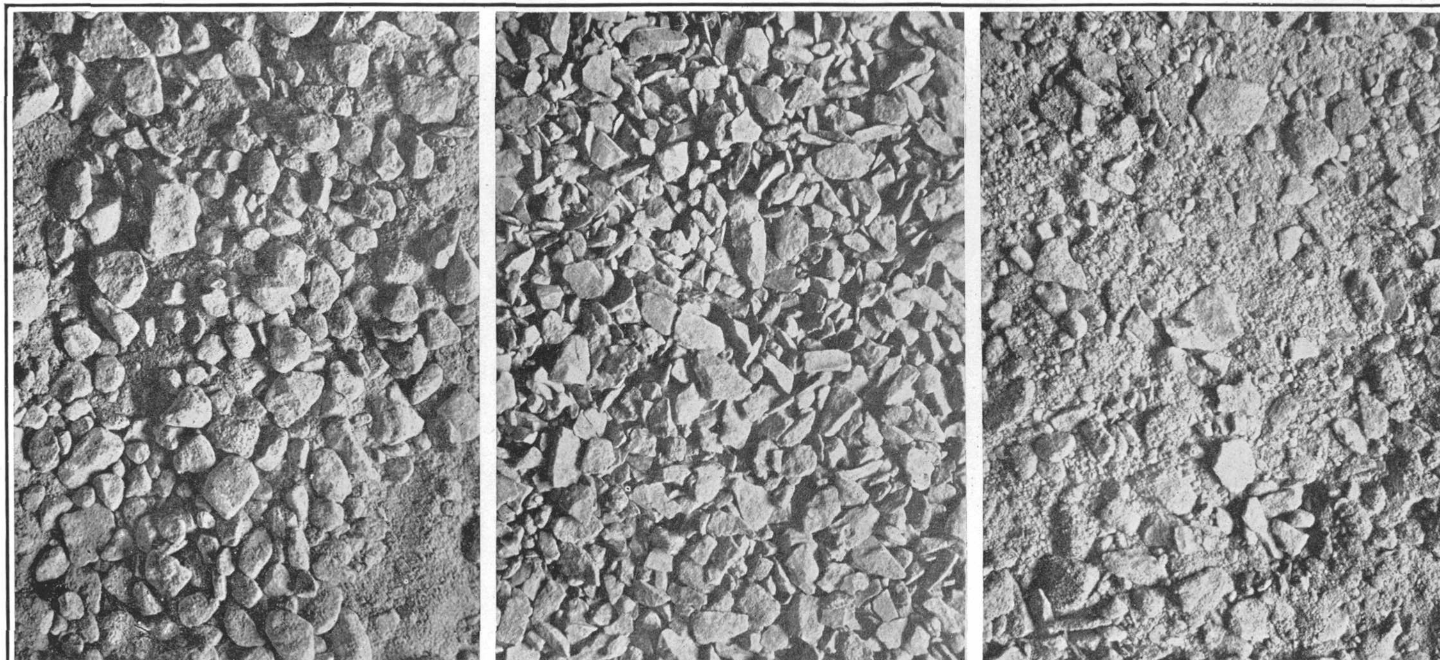
As a general rule the strength of those screenings that are nearest to uniform grading is greater than that of the finer screenings that are farther removed from the uniform grading. In addition, the strength of mortars made from those samples having lesser voids is greater than the strength of mortars made from those in which the voids are greater.

Compressive strength.—The results of the compressive tests on 1:3, on 1:4, and on 1:3 one-size stone-screenings mortar are given in Table XIV*b* (p. 115). The values in this table are in pounds per square inch and are obtained by dividing the total breaking load by the area of cross section of a 2-inch cube.

As in the case of tensile strength, there is a slight indication that the strength of stone-screenings mortar is greater for a sample for which the granularmetric analysis curve is close to the uniform grade line than for one for which the granularmetric analysis curve is farther removed from that line. In addition, the strength appears to increase with the decrease of voids.

Transverse strength.—The results of the transverse tests on 1:3, on 1:4, and on 1:3 one-size stone-screenings mortar are given in Table XIV*c* (p. 121). The values given in this table are moduli of rupture in pounds per square inch. At the time of writing not all of the 360-day transverse test pieces have been tested, and it is, therefore, impossible at this time to complete the tables giving the results of the tests. This is due to the fact that the transverse molds did not arrive until some time after the other test pieces had been made. A study of the table shows that the transverse strength gradually increases up to 90 days in almost every case. Beyond this the strength does not vary much to 360 days, in some cases increasing and in some cases decreasing slightly.

Summary of stone-screenings mortar tests.—In general, more confidence can be attached to the tests of the older test pieces than to those of the earlier test pieces. In the case of homogeneous materials the results of tests of different mortars at the same age should be somewhat uniform or should follow some general law, such as that observed in the case of sands where the position of the granularmetric analysis curve was seen to indicate the comparative strength of the mortars. In the investigations on stone screenings, however, since the stones were obtained in many different places, the results of the tests on test pieces of the same age are not consistent. It can not be said that any definite law can be given by means of which the strength of stone mortar can be approximately foretold by the mechanical conditions, since the strength of the stone from which the screenings are derived has much to do with the strength of the mortar. Almost the same difficulty was found with stone-screenings mortars as with gravel-screenings mortars (p. 88); that is, the tendency of the cement to concentrate at one or more parts of the sections. This was noticed principally where the material was composed of large



A *B* *C*

A. LIMESTONE SCREENINGS, CASPARIS, OHIO (SAMPLE 23).
B. LIMESTONE SCREENINGS, SYLVANIA, OHIO (SAMPLE 24).
C. LIMESTONE SCREENINGS, SIBLEY, MICH. (SAMPLE 25).

grains. The results of the tests of pieces in which this took place were very discordant.

The solid stone, obtained from the same quarry and the same bed from which the crushed stone is collected, is being tested for its physical properties. The results of these tests (which are to appear in another bulletin discussing the constituent materials of concrete) may afford a basis for the comparison of the relative value of mortars made from stone screenings.

Density.—The density of mortar made from each sample of stone screenings was determined in order to ascertain its relation to the other physical properties, and to see if the strength of mortar can be approximately foretold by the density. The density of 1:3 stone-screenings mortar and the relation between the density and other physical properties of stone and mortar are given in Table XII (p. 79). In column 1 are given the register numbers of the stone screenings used in the mortars whose densities are given in column 2. The densities are ranged consecutively, with the largest value at the top. For purposes of comparison the number of the granularmetric analysis curve for each sample of stone screenings is given in column 3. The numbers start with No. 1 for Se. 21 (at the top of fig. 17, p. 94) and end with No. 25 for Se. 24 (at the bottom of fig. 22, p. 105). The percentage of voids, weight per cubic foot, and the tensile, compressive, and transverse strengths of the corresponding mortars at 180 days are given in columns 4–8. It can be seen that in the upper part of the table, where the values of density are greatest, the percentages of voids as a rule are least and the weights per cubic foot and the strengths are greatest, and at the bottom of the table the opposite is true.

TABLE XIV*a*.—*Tensile strength of the mortars of 25 stone screenings.*

Register No.[a]	Ratio of cement to screenings.[b]	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Tensile strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Se. 1	1:3	1.04	79-1	66.2	67.6	9.1	362 342 325	663 645 710	760 840 830	698 728 696	678 800 805
	Average						343	673	810	707	761
	1:4		79-6	65.8	64.1	8.4	375 425 390	546 557 561	618 547 600	662 637 645	637 620 628
	Average						397	555	588	648	628
	1:3 (sifted)		79-11	74.0	70.0	8.9	400 390 365	458 445 440	444 425 480	550 512 497	467 482 464
	Average						385	448	450	520	471

[a] For details of field origin of samples of stone screenings see pp. 93–106.
[b] In tests marked "sifted" the stone screenings used were sifted through No. 10 and over No. 20 size.

TABLE XIV*a*.—*Tensile strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Tensile strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Se. 2	1:3	1.10	79-1	66.2	67.9	9.1	285	540	664	790	610
							261	541	600	721	686
							298	600	620	792	702
	Average						281	560	628	768	666
	1:4		79-6	65.8	64.1	8.4	370	411	550	676	586
							384	420	590	661	579
							380	474	600	715	606
	Average						378	435	580	684	590
	1:3 (sifted)		79-11	74.0	70.0	8.9	345	473	592	669	563
							365	475	530	600	547
							341	509	600	687	529
	Average						350	486	574	652	546
Se. 3	1:3	1.09	79-2	63.5	59.0	9.1	366	691	748	828	724
							375	606	757	793	733
							375	730	755	805	789
	Average						372	676	753	809	749
	1:4		79-7	66.2	66.5	8.4	455	555	700	756	642
							435	558	672	717	664
							465	595	690	730	672
	Average						452	569	687	734	659
	1:3 (sifted)		79-11	74.0	70.0	8.9	345	392	630	642	497
							360	379	660	612	468
							329	424	600	655	490
	Average						345	398	630	636	485
Se. 4	1:3	1.08	79-2	63.5	59.0	9.1	510	630	919	970	772
							550	680	973	936	830
							560	610	963	910	796
	Average						540	640	952	939	799
	1:4		79-7	66.2	66.5	8.4	414	516	714	845	756
							452	552	790	830	765
							428	529	777	800	769
	Average						431	532	760	825	763
	1:3 (sifted)		79-12	71.6	68.0	8.9	335	477	570	570	456
							303	447	540	547	502
							400	477	570	......	511
	Average						346	467	560	559	490
Se. 5	1:3	1.02	79-3	66.9	53.2	9.1	360	620	690	762	736
							345	613	625	740	771
							325	580	670	780	728
	Average						343	604	662	761	745
	1:4		79-8	65.8	66.2	8.4	400	495	660	670	602
							365	490	550	671	614
							370	496	555	......	592
	Average						378	494	588	670	603
	1:3 (sifted)		133-14	78.8	77.0	8.3	369	493	506	445	575
							379	490	473	446	556
	Average						374	492	490	445	566

TABLE XIV*a*.—*Tensile strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Tensile strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Se. 6	1:3	1.11	79-3	66.9	53.2	9.1	377	600	725	745	637
							400	645	790	756	664
							388	660	800	750	700
	Average						388	635	772	750	667
	1:4		79-8	65.8	66.2	8.4	413	580	790	692	715
							439	567	743	700	705
							385	591	725	......	724
	Average						412	579	753	696	715
	1:3 (sifted)		79-12	71.6	68.0	8.9	352	490	500	630	495
							335	470	590	620	506
							350	495	542	......	478
	Average						346	485	543	625	493
Se. 7	1:3	1.07	79-3	66.9	53.2	9.1	370	616	660	650	655
							382	585	652	690	586
							336	600	718	690	649
	Average						363	600	677	677	630
	1:4		79-8	65.8	66.2	8.4	392	425	592	595	533
							357	430	520	627	532
							350	460	558	......	527
	Average						366	438	557	611	531
	1:3 (sifted)		79-12	71.6	68.0	8.9	330	350	400	......	374
							335	330	370	452	358
							325	325	365	433	380
	Average						330	335	378	442	371
Se. 8	1:3	1.03	79-4	68.0	59.3	9.1	515	684	785	795	756
							517	633	790	780	790
							547	683	728	805	784
	Average						526	667	768	793	777
	1:4		79-9	63.6	51.4	8.4	412	594	660	760	623
							409	599	697	720	618
							400	570	678	750	611
	Average						407	588	678	743	617
	1:3 (sifted)		79-13	70.5	68.0	8.9	365	420	575	472	415
							340	400	555	474	411
							330	395	540	452	452
	Average						345	405	557	466	426
Se. 9	1:3	1.12	79-4	68.0	59.3	9.1	518	630	730	787	722
							526	694	792	835	720
							550	637	799	826	738
	Average						531	654	774	816	727
	1:4		79-9	63.6	51.4	8.4	386	550	648	775	602
							418	511	586	700	620
							403	510	660	771	618
	Average						402	524	631	749	613
	1:3 (sifted)		79-13	70.5	68.0	8.9	270	395	410	489	387
							290	347	365	440	346
							280	390	410	......	352
	Average						280	377	395	464	362

TABLE XIV*a*.—*Tensile strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Tensile strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Se. 10..	1:3	1.11	79-4	68.0	59.3	9.1	485	629	805	770	720
							470	645	735	776	687
							510	659	780	756	712
	Average						488	644	773	767	706
	1:4		79-9	63.6	51.4	8.4	333	440	605	682	584
							289	490	637	660	592
							293	475	560	655	575
	Average						305	468	601	666	584
	1:3 (sifted)		79-13	70.5	68.0	8.9	280	312	413	472	395
							250	309	362	473	379
							268	339	383	498	402
	Average						266	320	386	481	392
Se. 11..	1:3	1.12	79-5	66.2	56.1	9.1	355	451	492	530	645
							335	433	510	560	667
							340	455	524	540	642
	Average						343	446	509	543	651
	1:4		79-10	59.8	69.4	8.3	215	323	410	442	416
							225	320	420	470	435
							245	301	418	492	420
	Average						228	315	416	468	424
	1:3 (sifted)		79-14	71.6	68.0	8.9	365	468	473	580	563
							380	448	455	565	532
							345	438	500	635	546
	Average						363	451	476	593	547
Se. 12..	1:3	1.13	79-5	66.2	56.1	9.1	400	657	744	745	608
							375	623	742	727	620
							390	617	715	678	613
	Average						388	632	734	717	613
	1:4		79-10	59.8	69.4	8.3	415	565	635	673	678
							420	600	657	672	645
							440	590	623	678	683
	Average						425	585	638	674	699
	1:3 (sifted)		79-14	71.6	68.0	8.9	430	565	703	701	675
							410	550	630	711	684
							425	522	660	697	705
	Average						422	546	664	703	688
Se. 13..	1:3	1.04	79-5	66.2	56.1	9.1	462	642	719	810	678
							463	682	768	771	705
							450	625	768	840	691
	Average						458	650	752	807	691
	1:4		79-10	59.8	69.4	8.3	415	550	675	673	615
							400	575	610	702	633
							445	560	600	692	642
	Average						420	562	628	689	630
	1:3 (sifted)		79-14	71.6	68.0	8.9	390	505	645	703	633
							377	470	600	683	623
							400	560	615	724	608
	Average						389	512	620	703	621

TABLE XIV*a*.—*Tensile strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Tensile strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Se. 14	1:3	1.07	79-16	71.6	59.7	8.9	488	622	728	666	579
							495	678	775	645	689
							520	620	730	680	600
	Average						501	640	744	664	623
	1:4		79-18	69.0	68.9	8.3	453	565	695	555	632
							410	550	640	560	695
							449	574	710	591	696
	Average						437	563	682	569	674
	1:3 (sifted)		79-20	69.8	67.6	8.9	420	500	520	480	621
							405	540	580	440	579
							390	512	555	485	560
	Average						405	517	552	468	587
Se. 15	1:3	1.12	79-21	70.5	54.3	8.9	630	574	620	645	685
							600	589	600	675	692
							595	623	574	......	740
	Average						608	595	598	660	706
	1:4		79-22	71.6	68.2	8.3	300	365	460	565	410
							295	361	450	590	436
							290	332	470	......	492
	Average						295	353	460	578	446
	1:3 (sifted)		79-23	71.2	68.0	8.9	304	427	440	386	490
							300	450	420	395	445
							333	468	458	330	460
	Average						312	448	439	370	465
Se. 16	1:3	1.05	79-21	70.5	54.3	8.9	430	717	787	765	856
							480	745	775	764	870
							473	700	800	771	842
	Average						461	721	787	767	856
	1:4		79-22	71.6	68.2	8.3	380	602	695	704	755
							371	565	730	680	741
							396	570	725	700	739
	Average						382	579	717	695	745
	1:3 (sifted)		79-24	70.7	52.0	8.9	300	447	430	442	357
							320	403	400	425	364
							300	418	450	460	406
	Average						307	423	427	442	376
Se. 17	1:3	1.13	79-16	71.6	59.7	8.9	420	550	615	591	522
							424	530	608	570	561
							382	530	610	535	522
	Average						409	537	611	565	535
	1:4		79-18	69.0	68.9	8.3	371	450	425	448	437
							360	435	450	400	455
							345	447	385	......	437
	Average						359	444	420	424	443
	1:3 (sifted)		135-4	78.8	82.4	8.9	232	330	337	425	487
							260	316	398	376	473
							241	341	380	432	534
	Average						244	329	372	411	498

TABLE XIV*a*.—*Tensile strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.).		Water. (per cent).	Tensile strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Se. 18	1:3	1.06	79–25	71.6	73.4	8.9	370	527	640	650	740
							394	530	664	618	712
							381	545	620	600	708
	Average						382	534	641	623	720
	1:4		79–25	71.6	73.4	8.3	323	418	550	530	650
							320	425	555	560	628
							340	458	552	545	......
	Average						328	434	552	546	639
	1:3 (sifted)		79–25	71.6	73.4	8.9	455	634	725	752	640
							448	610	709	750	631
							440	643	675	730	......
	Average						448	629	703	744	635
Se. 19	1:3	1.06	79–19	74.8	66.2	8.9	455	636	750	750	838
							510	656	695	820	742
							500	681	747	800	843
	Average						488	658	731	790	808
	1:4		79–19	74.8	66.2	8.3	400	580	690	715	815
							405	600	682	693	890
							375	580	710	660	823
	Average						393	587	694	689	843
	1:3 (sifted)		79–20	69.8	67.6	8.9	456	670	785	804	771
							445	673	725	805	810
							465	640	735	795	792
	Average						455	661	748	801	791
Se. 20	1:3	1.21	79–35	70.0	70.4	8.9	355	485	574	536	610
							345	492	558	495	562
							347	476	547	485	556
	Average						349	484	560	505	576
	1:4		79–35	70.0	70.4	8.3	300	400	527	476	510
							322	440	483	464	474
							326	410	521	......	......
	Average						316	417	510	470	492
Se. 21	1:3	1.14	79–31	70.7	70.0	8.9	420	535	630	705	661
							400	524	600	660	637
							437	554	640	......	668
	Average						419	538	623	683	655
	1:4		79–31	70.7	70.0	8.3	350	460	548	570	627
							345	460	570	540	620
							355	455	560	560	592
	Average						350	458	559	557	613
	1:3 (sifted)		79–31	70.7	70.0	8.9	410	515	621	635	748
							425	525	657	650	764
							430	535	665	681	750
	Average						422	525	648	655	754
Se. 22	1:3	1.14	79–34	69.8	69.8	8.9	528	603	800	850	902
							503	645	853	924	936
							497	610	845	998	942
	Average						509	619	833	924	927
	1:4		79–34	69.8	69.8	8.3	428	560	685	770	770
							442	530	720	760	782
							470	527	768	746	796
	Average						447	539	724	758	783

TABLE XIV*a*.—*Tensile strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Tensile strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Se. 23	1:3	1.06	79-37	68.0	68.4	8.9	345	485	542	541	560
							339	497	550	545	587
							360	481	556	551	571
	Average						348	488	549	545	573
	1:4		79-37	68.0	68.4	8.3	320	438	500	504	450
							308	431	495	520	481
							312	400	525	500	......
	Average						313	423	507	508	465
Se. 24	1:3	1.12	79-48	69.8	66.2	8.9	385	435	525	650	701
							373	467	......	......	738
							383	423	500	780	753
	Average						380	442	512	715	731
	1:4		79.48	69.8	66.2	8.3	331	372	415	487	578
							334	350	445	495	439
							333	360	......	485	456
	Average						333	361	430	489	491
Se. 25	1:3		133-40	71.6	71.6	8.9	438	570	583	690	691
							412	529	650	640	718
							406	560	591	639	731
	Average						419	553	608	656	713
	1:4		133-40	71.6	71.6	8.3	388	500	600	655	651
							390	475	540	720	690
							360	502	615	722	674
	Average						379	492	585	699	672
	1:3 (sifted)		133.40	71.6	71.6	8.9	277	426	507	630	545
							287	383	550	625	545
							245	385	500	650	602
	Average						270	398	519	635	564

TABLE XIV*b*.—*Compressive strength of the mortars of 25 stone screenings.*

Register No.[a]	Ratio of cement to screenings.[b]	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Compressive strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Se. 1	1:3	1.04	79-1	69.0	68.7	8.9	2,375	3,580	4,740	5,453	6,000
							2,650	3,950	4,795	5,073	5,662
							2,637	3,620	5,038	....	5,327
	Average						2,554	3,717	4,858	5,263	5,663
	1:4		79-8	71.6	68.2	8.3	1,862	2,337	3,435	3,563	4,875
							1,987	2,262	3,475	3,758	4,250
							2,000	2,100	3,400	3,788	4,750
	Average						1,949	2,233	3,437	3,703	4,625
	1:3 (sifted)		79-15	69.8	70.0	8.9	1,175	1,617	1,715	2,150	2,750
							1,152	1,540	1,500	2,355	2,400
							1,287	1,467	1,670	2,213	2,575
	Average						1,205	1,541	1,628	2,239	2,575

[a] For details of field origin of samples of stone screenings see pp. 93-106.

[b] In tests marked "sifted" the stone screenings used were through No. 10 and over No. 20 size.

TABLE XIV*b*.—*Compressive strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Compressive strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Se. 2	1:3	1.10	79-1	69.0	68.7	8.9	2,500	3,410	4,135	5,190	5,467
							2,352	3,375	4,500	5,508	5,380
							2,545	3,162	4,595	5,055	5,525
	Average						2,466	3,316	4,410	5,251	5,457
	1:4		133-7	71.6	68.2	8.3	1,512	2,575	3,312	4,070	4,640
							1,572	2,625	3,570	4,370	5,125
							1,676	2,750	3,717	4,320	4,800
	Average						1,587	2,650	3,533	4,253	4,855
	1:3 (sifted)		79-16	70.7	70.0	8.9	1,500	2,025	2,460	2,950	2,775
							1,570	2,037	2,098	......	2,500
							1,455	1,982	2,650	2,888	2,625
	Average						1,508	2,015	2,403	2,919	2,633
Se. 3	1:3	1.09	79-2	74.8	66.2	8.9	2,750	4,712	5,435	6,688	5,900
							3,025	4,512	5,525	6,193	5,877
							3,037	4,825	5,775	6,618	6,270
	Average						2,937	4,683	5,578	6,500	6,016
	1:4		79-9	71.2	68.0	8.3	2,185	3,550	4,338	5,193	5,278
							2,212	3,687	4,338	5,020	5,082
							2,335	3,630	4,475	4,875	4,958
	Average						2,244	3,622	4,384	5,029	5,106
	1:3 (sifted)		79-16	70.7	70.0	8.9	1,362	1,870	1,765	2,250	2,900
							1,210	1,945	1,985	2,413	2,550
							1,365	2,080	1,750	2,338	2,825
	Average						1,312	1,965	1,833	2,334	2,758
Se. 4	1:3	1.08	79-3	74.8	66.2	8.9	3,225	5,632	......	8,328	7,855
							3,625	5,362	6,450	8,800	7,375
							3,375	5,925	6,235	8,805	8,185
	Average						3,408	5,639	6,342	8,644	7,805
	1:4		79-9	71.2	68.0	8.3	1,612	3,450	3,463	4,175	4,538
							1,660	3,257	2,812	3,908	5,125
							1,760	3,612	3,078	4,193	5,040
	Average						1,677	3,439	3,118	4,092	4,901
Se. 5	1:3	1.02	79-3	69.8	67.6	8.9	2,450	3,927	4,213	4,915	6,590
							2,250	3,570	4,450	4,993	6,155
							2,525	4,362	4,438	......	5,840
	Average						2,408	3,953	4,367	4,954	6,195
	1:4		79-10	70.7	52.0	8.3	1,362	1,705	2,048	2,475	4,400
							1,487	1,837	2,000	......	4,250
							1,262	1,985	1,975	2,500	4,225
	Average						1,370	1,842	2,008	2,488	4,292
Se. 6	1:3	1.11	79-3	69.8	67.6	8.9	3,725	5,250	7,200	8,160	8,875
							3,525	5,025	7,133	8,445	8,837
							3,462	5,517	6,925	7,538	8,859
	Average						3,571	5,264	7,086	8,048	8,859
	1:4		79-10	70.7	52.0	8.3	1,700	3,137	4,900	5,313	5,375
							1,662	3,000	4,500	5,143	5,400
							1,555	2,775	4,500	5,570	5,500
	Average						1,639	2,971	4,633	5,342	5,524

TABLE XIV*b*.—*Compressive strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Compressive strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Se. 7	1:3	1.07	79-4	69.8	67.6	8.9	1,875	2,787	4,358	5,328	5,488
							1,735	3,062	4,520	5,508	5,580
							1,830	2,545	4,420	5,000	5,137
	Average						1,813	2,798	4,433	5,279	5,402
	1:4		79-11	73.4	57.2	8.3	925	1,662	2,250	2,265	3,175
							937	1,652	2,320	2,318	3,300
							850	1,630	2,338	2,475	3,100
	Average						904	1,648	2,303	2,353	3,192
	1:3 (sifted)		79-16	70.7	70.0	8.9	882	1,162	....	1,413	1,600
							950	1,042	1,145	....	1,375
							950	1,135	1,250	1,525	1,650
	Average						927	1,113	1,197	1,469	1,542
Se. 8	1:3	1.03	79-4	71.6	55.0	8.9	2,775	4,275	5,625	5,945	5,575
							2,797	3,875	5,500	6,500	5,763
							2,950	4,475	5,417	6,475	5,375
	Average						2,841	4,208	5,514	6,307	5,571
	1:4		79-11	73.4	57.2	8.3	1,392	2,800	3,250	4,685	6,050
							1,305	2,855	3,500	4,700	5,725
							1,450	2,597	3,325	4,450	5,900
	Average						1,382	2,751	3,358	4,612	5,892
Se. 9	1:3	1.12	79-4	71.6	55.0	8.9	2,375	4,075	5,325	6,113	5,560
							2,380	4,137	5,250	5,850	5,525
							2,400	4,350	5,212	....	5,500
	Average						2,385	4,187	5,262	5,982	5,528
	1:4		79-11	73.4	57.2	8.3	1,312	2,700	3,500	4,198	4,600
							1,435	2,520	3,465	4,300	4,500
							1,450	2,517	3,738	3,768	4,675
	Average						1,399	2,579	3,568	4,089	4,592
	1:3 (sifted)		79-17	70.2	69.8	8.9	750	1,075	1,225	1,310	1,350
							862	1,037	1,350	1,250	1,225
							837	1,130	1,338	1,375	1,550
	Average						816	1,081	1,304	1,312	1,375
Se. 10	1:3	1.11	79-4	71.6	55.0	8.9	2,750	3,737	4,582	....	6,852
							2,520	3,450	4,670	7,513	6,887
							2,260	3,450	4,900	7,275	6,677
	Average						2,510	3,546	4,717	7,394	6,805
	1:4		79-12	68.0	60.8	8.3	795	2,007	2,330	2,783	3,100
							750	2,090	2,475	3,220	3,500
							746	1,960	2,250	3,025	3,175
	Average						764	2,019	2,352	3,009	3,258
	1:3 (sifted)		79-17	70.2	69.8	8.9	937	1,000	1,850	1,675	1,475
							905	1,112	1,925	1,500	1,400
							840	1,000	1,888	1,580	1,250
	Average						894	1,037	1,888	1,585	1,375
Se. 11	1:3	1.12	79-5	70.0	64.4	8.9	1,000	2,000	3,155	3,613	4,850
							1,120	2,155	2,925	3,963	4,825
							1,127	2,000	2,925	3,695	5,050
	Average						1,082	2,052	3,002	3,757	4,908
	1:4		79-12	68.0	60.8	8.3	945	1,540	2,338	2,595	3,725
							985	1,662	2,225	2,875	4,050
							905	1,440	2,075	2,750	3,675
	Average						945	1,547	2,213	2,740	3,813
	1:3 (sifted)		79-17	70.2	69.8	8.9	1,625	....	3,325	2,588	4,300
							1,712	2,270	3,513	2,713	4,250
							1,500	2,075	3,513	2,560	4,325
	Average						1,612	2,171	3,450	2,620	4,292

TABLE XIV*b*.—*Compressive strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Compressive strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Se. 12	1:3	1.13	79-6	69.6	60.3	8.9	2,512	4,525	5,175	6,168	6,400
							3,000	4,470	5,362	6,208	7,225
							2,812	4,500	5,332	6,203	6,550
	Average						2,775	4,498	5,290	6,193	6,725
	1:4		79-13	68.0	73.4	8.3	1,675	3,000	3,950	4,175	6,050
							1,580	2,825	3,650	4,100	5,700
							1,590	2,962	3,643	......	5,650
	Average						1,615	2,929	3,748	4,138	5,800
	1:3 (sifted)		79-18	68.0	66.2	8.9	1,305	1,585	1,930	1,633	1,950
							1,350	1,460	2,000	1,775	1,875
							1,375	1,482	2,085	1,775	2,025
	Average						1,377	1,509	2,008	1,728	1,950
Se. 13	1:3	1.04	79-6	69.6	60.3	8.9	2,700	4,550	5,025	5,533	6,150
							2,500	4,250	5,250	5,000	5,700
							2,450	4,426	5,015	5,650	5,675
	Average						2,550	4,409	5,097	5,394	5,842
	1:4		79-13	68.0	73.4	8.3	1,237	2,275	3,475	3,350	3,725
							1,205	2,200	3,138	3,050	4,050
							1,260	2,187	3,000	......	3,925
	Average						1,234	2,221	3,204	6,200	3,900
	1:3 (sifted)		79-18	68.0	66.2	8.9	1,537	2,055	......	2,975	3,475
							1,462	2,067	2,558	3,105	3,800
							1,505	2,277	2,788	2,950	3,650
	Average						1,501	2,133	2,673	3,010	3,642
Se. 14	1:3	1.07	79-6	69.6	60.3	8.9	2,900	4,750	5,730	6,125	7,075
							3,000	4,550	5,610	5,950	7,175
							2,725	4,550	5,825	6,050	6,600
	Average						2,875	4,617	5,722	6,042	6,950
	1:4		79-14	70.7	69.0	8.3	2,042	2,880	4,045	4,688	4,250
							2,080	2,257	......	4.380	4,600
							2,030	2,905	4,138	4,660	4,475
	Average						2,051	2,681	4,092	4,576	4,442
	1:3 (sifted)		79-18	68.0	66.2	8.9	1,875	2,277	......	3,250	3,625
							1,777	2,250	2,588	3,075	3,475
							1,805	2,200	2,550	3,313	3,600
	Average						1,819	2,242	2,569	3,213	3,567
Se. 15	1:3	1.12	79-7	70.5	54.3	8.9	1,712	2,800	5,500	......	5,480
							1,762	3,087	5,435	4,675	5,675
							1,766	3,225	5,225	4,688	5,800
	Average						1,747	3,037	5,387	4,681	5,652
	1:4		79-14	70.7	69.0	8.3	960	1,025	1,438	1,803	1,075
							875	947	1,400	1,873	1,200
							912	890	1,000	1,725	1,375
	Average						916	954	1,279	1,800	1,217
	1:3 (sifted)		79-19	69.8	66.2	8.9	1,200	2,200	2,625	2,733	2,925
							1,050	2,037	2,520	......	2,800
							1,177	2,025	......	2,788	2,650
	Average						1,142	2,087	2,572	2,760	2,792

TABLE XIV*b*.—*Compressive strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Compressive strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Se. 16	1:3	1.05	79-7	70.5	54.3	8.9	1,767 1,588 2,026	3,500 3,462 3,750	5,363 5,483 5,000	4,930 5,235 4,750	6,875 6,537 7,010
	Average						1,805	3,571	5,282	4,972	6,807
	1:4		79-15	69.8	70.0	8.3	1,290 1,437 1,362	2,052 2,290 2,262	2,963 3,148	3,650 3,750 3,525	4,725 5,000 4,675
	Average						1,363	2,201	3,056	3,642	4,800
	1:3 (sifted)		79-19	69.8	66.2	8.9	1,300 1,287 1,350	2,165 2,237 2,275	2,400 2,280	1,388 1,305 1,390	2,800 2,975 2,900
	Average						1,312	2,226	2,340	1,392	2,892
Se. 17	1:3	1.13	79-7	70.5	54.3	8.9	2,187 2,075 2,400	4,125 3,745 4,200	4,478 4,425 4,633	5,310 5,515 5,113	6,925 7,100 6,300
	Average						2,221	4,023	4,512	5,313	6,775
	1:4		79-14	70.7	69.0	8.3	987 1,112 1,055	2,200 2,000 2,272	3,320 2,975 3,050	3,853 3,618 3,778	3,275 3,825 3,050
	Average						1,051	2,157	3,115	3,750	3,383
	1:3 (sifted)		135-5	78.8	80.6	8.9	2,140 2,025 1,912	2,750 3,000	3,350 3,475 3,375	3,250 2,925 2,875	4,025 3,875 4,050
	Average						2,026	2,875	3,400	3,017	3,983
Se. 18	1:3	1.06	79-20	69.8	72.0	8.9	2,425 2,275 2,262	3,362 3,037 3,132	5,015 4,760 4,663	6,443 6,208 6,013	6,900 6,225 6,500
	Average						2,321	3,177	4,813	6,221	6,542
	1:4		79-20	69.8	72.0	8.3	1,512 1,600 1,525	2,500 2,567 2,287	3,250 3,275	4,275 4,163 4,025	4,475 4,800 4,350
	Average						1,546	2,451	3,262	4,154	4,542
	1:3 (sifted)		79-20	69.8	72.0	8.9	2,350 2,250 2,150	3,195 3,455 3,452	4,010 4,250 4,325	4,775 4,900 5,225	4,400 4,500 4,625
	Average						2,250	3,367	4,195	4,967	4,508
Se. 19	1:3	1.06	79-8	71.6	68.2	8.9	2,345 2,335 2,200	3,785 4,000 3,500	4,857 4,960 5,067	5,665 5,000 5,713	7,075 6,050 7,150
	Average						2,293	3,762	4,961	5,459	6,758
	1:4		79-15	69.8	70.0	8.3	1,637 1,712 1,762	2,675 2,500 2,697	3,560 3,575 3,695	4,800 4,538	6,150 5,675 5,700
	Average						1,704	2,624	3,610	4,669	5,842
	1:3 (sifted)		79-19	69.8	66.2	8.9	1,750 1,780 1,525	2,517 2,845 2,605	4,038 3,890 3,625	3,375 3,510 3,675	4,250 4,475 4,225
	Average						1,685	2,656	3,851	3,520	4,317
Se. 20	1:3	1.21	79-35	70.0	70.0	8.9	2,668 2,585 2,505	4,165 4,135 3,937	5,408 5,155 5,488	5,100 4,875 5,020	6,125 6,550 6,450
	Average						2,586	4,079	5,350	4,998	6,375
	1:4		79-35	70.0	70.0	8.3	2,000 1,913 1,925	3,440 3,382 3,810	4,288 4,370	3,612 3,631 3,975	5,375 5,400 5,375
	Average						1,946	3,377	4,329	3,719	5,383

TABLE XIV*b*.—*Compressive strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Compressive strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Se. 21	1:3	1.14	79-26	70.7	69.0	8.9	1,637	2,525	3,470	3,887	5,305
							1,732	2,400	3,725	4,119	5,270
							1,537	2,250	3,250	3,837	4,850
	Average						1,635	2,392	3,482	3,948	5,142
	1:4		79-26	70.7	69.0	8.3	1,177	1,880	2,675	3,350	4,125
							1,250	1,908	2,578	3,425	4,100
							1,137	1,725	2,733	3,412	4,150
	Average						1,188	1,838	2,662	3,396	4,125
	1:3 (sifted)		79-26	70.7	69.0	8.9	1,387	2,420	3,378	3,650	4,375
							1,375	2,573	3,250	4,137	4,550
							1,440	2,250	3,378	3,575	4,750
	Average						1,401	2,414	3,335	3,787	4,558
Se. 22	1:3	1.14	79-34	69.8	69.8	8.9	2,683	4,682	6,163	7,550	8,675
							2,500	4,650	6,375	7,222	8,600
							2,520	4,682	6,263	7,375	8,225
	Average						2,568	4,671	6,267	7,382	8,500
	1:4		79-34	69.8	69.8	8.3	2,013	3,050	4,763	4,800	6,050
							1,900	3,300	4,600	4,700	5,950
							1,955	3,325	4,575	4,750	5,425
	Average						1,956	3,225	4,646	4,750	5,808
Se. 23	1:3	1.06	79-37	69.8	70.0	8.9	1,543	2,925	3,763	4,225	5,800
							1,595	2,868	3,765	4,512	5,675
							1,550	2,835	3,763	4,350	5,475
	Average						1,563	2,876	3,764	4,362	5,650
	1:4		79-37	69.8	70.0	8.3	1,405	2,298	2,978	2,862	4,400
							1,383	2,392	3,280	3,112	4,150
							1,353	2,375	3,033	3,025	4,100
	Average						1,380	2,355	3,097	2,910	4,217
Se. 24	1:3	1.12	79-48	68.8	62.6	8.9	1,838	2,900	3,080	3,950	4,750
							1,835	2,588	2,943	3,450	4,675
							......	......	......	3,675	5,150
	Average						1,836	2,744	3,011	3,692	4,858
	1:4		79-48	68.8	62.6	8.3	963	1,700	2,268	2,525	2,500
							925	1,925	2,128	2,750	1,625
							978	......	......	2,950	1,750
	Average						955	1,812	2,198	2,742	1,958
Se. 25	1:3		133-40	71.6	69.8	8.9	3,270	4,150	5,350	6,600	6,800
							3,390	4,255	4,650	6,375	6,825
							3,348	4,425	4,550	6,275	6,450
	Average						3,346	4,277	4,850	6,417	6,692
	1:4		133-40	71.6	69.8	8.3	3,005	3,092	......	5,175	4,950
							2,825	3,112	4,125	4,550	4,350
							2,853	3,132	4,575	4,900	4,550
	Average						2,894	3,112	4,350	4,875	4,617
	1:3 (sifted)		133-40	71.6	69.8	8.9	1,763	2,085	2,750	2,800	2,800
							1,885	1,950	2,650	2,625	2,850
							1,783	2,125	2,975	2,725	2,750
	Average						1,810	2,053	2,792	2,717	2,800

TABLE XIV*c*.—*Transverse strength of the mortars of 25 stone screenings.*

Register No.[a]	Ratio of cement to screenings.[b]	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Transverse strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Se. 2	1:3	1.04	133-6	71.6	64.2	9.1	648	1,134	1,530	1,188	1,404
							702	1,080	1,350	1,224	1,404
							738	1,098	1,440	1,584	1,422
	Average						696	1,104	1,440	1,332	1,410
	1:4		133-7	69.8	64.2	8.4	504	900	1,224		
							504	738	1,170		
							522				1,152
	Average						510	819	1,197		1,152
Se. 3	1:3	1.10	133-8	69.8	65.4	9.1	756	1,170	1,458	1,368	1,584
							756	1,224	1,350	1,530	1,620
							828	1,116	1,584	1,332	1,548
	Average						780	1,170	1,464	1,410	1,584
	1:4		133-9	69.8	68.0	8.4	648	1,044	1,188	1,296	1,422
							666	990	990	1,260	1,422
							720	1,080	1,080	1,242	1,440
	Average						678	1,038	1,086	1,266	1,428
	1:3 (sifted)		135-13	80.6	80.6	8.7	792	828	918	1,224	972
							576	612	918	1,152	918
							702	720	1,008	1,044	954
	Average						690	720	948	1,140	948
Se. 4	1:3	1.09	133-10	69.8	66.2	9.1	864	1,206	1,530	1,584	1,476
							720	1,098	1,350	1,620	1,422
							900	990	1,260	1,602	1,386
	Average						828	1,098	1,380	1,602	1,428
	1:4		133-11	63.0	70.7	8.4	522	720	1,188	1,206	1,476
							594	828	1,206	1,152	1,512
								900	1,080	1,314	1,566
	Average						558	816	1,158	1,224	1,518
Se. 5	1:3	1.08	133-12	63.0	67.1	9.1	648	1,116	1,242	1,170	1,404
							540	1,116	1,116	1,332	1,350
							702	954	1,152	1,242	1,368
	Average						630	1,062	1,170	1,248	1,374
	1:4		133-13	63.5	74.0	8.4	612	540	864	882	936
							486	756	936	972	882
							504	684	954	846	900
	Average						534	660	918	900	906
	1:3 (sifted)		133-14	66.2	78.8	8.3	468	540	936	1,026	972
							504	630	864	972	
							522			900	1,044
	Average						498	585	900	966	1,008
Se. 6	1:3	1.02	133-15	68.0	78.8	9.1	450	1,080	1,152	1,368	1,440
							486	972	1,278	1,368	1,512
								1,116	1,116	1,242	1,440
	Average						468	1,056	1,182	1,326	1,464
	1:4		133-16	67.1	68.0	8.4	738	864	1,224	1,116	1,332
							936	936	1,080	1,296	1,260
							936	1,008	1,350	1,368	1,368
	Average						870	936	1,218	1,260	1,320

[a] For details of field origin of samples of stone screening see pp. 93–106.
[b] In tests marked "sifted" the stone screenings used were sifted through No. 10 and over No. 20 size.

TABLE XIVc.—*Transverse strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Transverse strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Se. 7	1:3	1.11	133-18	68.9	67.1	9.1	612 720 756	756 738 1,008	...... 1,008 1,026	1,224 1,206 1,188	1,026 972 972
	Average	......	......	......	......	......	696	834	1,017	1,206	990
	1:4	......	133-19	68.9	77.0	8.4	396 450 432	720 648 540	936 828	1,062 1,188 1,044	756 864 ......
	Average	......	......	......	......	......	426	636	882	1,098	810
	1:3 (sifted)	......	133-20	69.8	78.8	8.9	342 342 288	594 612 576	684 612 702	828 792 828	738 792 ......
	Average	......	......	......	......	......	324	594	666	816	765
Se. 8	1:3	1.07	133-22	69.8	73.4	9.1	720 702 810	1,152 900 1,170	1,314 1,350	1,404 1,296 1,422	1,314 1,494 ......
	Average	......	......	......	......	......	744	1,074	1,332	1,374	1,404
	1:4	......	133-24	69.8	64.0	8.4	504 558	864 990 900	1,170 1,044 1,260	...... 1,188 1,260	1,332 1,368 ......
	Average	......	......	......	......	......	531	918	1,158	1,224	1,350
	1:3 (sifted)	......	133-25	68.0	68.7	8.9	432 378 432	486 522 702	612 558 720	846 810 738	936 936 ......
	Average	......	......	......	......	......	414	570	630	798	936
Se. 9	1:3	1.03	133-26	68.9	68.0	9.1	774 702 864	1,170 1,080 1,152	1,224 1,278 1,260	1,530 1,458 1,494	1,458 1,548 1,476
	Average	......	......	......	......	......	780	1,134	1,254	1,494	1,494
	1:4	......	133-27	68.0	66.2	8.4	612 630 612	864 846 828	792 1,026 972	1,080 1,152 1,224	1,260 1,278 1,368
	Average	......	......	......	......	......	618	846	930	1,152	1,302
	1:3 (sifted)	......	133-29	68.9	74.3	8.9	486 468 396	756 720 702	810 684 612	1,008 864 918	1,080 ....
	Average	......	......	......	......	......	450	726	702	930	1,080
Se. 10	1:3	1.11	133-30	69.8	69.8	9.1	846 882 756	972 1,116 1,044	1,368 1,296 1,404	1,098 1,260 1,296	1,548 1,512 1,656
	Average	......	......	......	......	......	828	1,044	1,356	1,218	1,572
	1:4	......	133-31	68.0	77.0	8.4	540 522 630	864 936 846	828 1,116 990	990 1,134 1,044	1,260 1,224 ......
	Average	......	......	......	......	......	564	882	978	1,056	1,242
	1:3 (sifted)	......	133-32	71.6	80.6	8.9	504 432 486	630 774 648	612 666 540	....	684 630 702
	Average	......	......	......	......	......	474	684	606	......	672

TABLE XIV*c*.—*Transverse strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Transverse strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Se. 11	1:3	1.12	133-33	76.1	74.3	9.1	522	720	828	990	954
							486	900	864	936	900
							468	774	774	828	......
	Average						492	798	822	918	927
	1:4		133-34	69.8	71.6	8.3	306	540	720	864	918
							324	594	774	828	864
							432	612	864	828	828
	Average						354	582	786	840	870
	1:3 (sifted)		133-35	71.6	68.0	8.9	576	882	1,368	1,404	1,296
							648	936	....	1,296	1,224
							486	774	1,404	1,368	1,224
	Average						570	864	1,386	1,356	1,248
Se. 12	1:3	1.13	133-43	70.7	71.6	9.1	864	1,116	1,368	1,296	1,404
							882	900	1,260	1,620	1,404
							846	1,008	1,296	1,422	1,458
	Average						864	1,008	1,308	1,446	1,422
	1:4		133-44	70.7	74.3	8.3	630	1,206	1,170	1,170	1,224
							630	990	1,242	1,152	1,188
							594	936	1,044	1,170	1,170
	Average						618	1,044	1,152	1,164	1,194
	1:3 (sifted)		133-45	72.5	74.6	8.9	666	882	918	1,170	1,044
							612	846	1,008	990	990
							612	792	972	954	1,008
	Average						630	840	966	1,038	1,014
Se. 13	1:3	1.04	133-46	70.7	72.5	9.1	864	1,098	1,260	1,422	1,458
							954	1,188	1,404	1,350	1,422
							900	1,188	1,440	1,296	1,512
	Average						906	1,158	1,368	1,356	1,464
	1:4		133-47	70.7	77.0	8.3	810	900	1,152	1,170	1,332
							774	828	1,152	1,260	1,296
							720	864	1,296	1,170	1,368
	Average						768	864	1,200	1,200	1,332
	1:3 (sifted)		134-1	72.4	78.8	8.9	684	972	918	1,008	1,170
							594	954	1,008	972	1,206
							666	792	1,080	1,080	1,080
	Average						648	906	1,002	1,020	1,152
Se. 14	1:3	1.07	134-2	77.0	78.8	8.9	1,044	1,008	1,314	1,278	......
							864	....	1,278	1,368	1,350
							936	1,062	1,332	1,368	1,404
	Average						948	1,035	1,308	1,338	1,377
	1:4		134-3	74.3	80.0	8.3	738	792	1,278	1,332	1,314
							720	828	1,098	1,224	1,296
							684	936	1,152	1,296	1,242
	Average						714	852	1,176	1,284	1,284
	1:3 (sifted)		134-4	76.1	74.8	8.9	792	918	810	990	1,116
							864	936	972	936	1,080
							972	......	828	1,080	......
	Average						876	927	870	1,002	1,098

TABLE XIV*c*.—*Transverse strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Transverse strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Se. 17	1:3	1.13	134-5	75.2	72.5	8.9	792 720 612	1,026 990 900	1,152 1,026 1,062	1,098 1,008 936	1,188 1,080 1,134
	Average						708	972	1,080	1,014	1,134
	1:4		134-6	75.2	70.7	8.3	504 540 396	936 954 648	828 918 792	612 576 630	1,332 810 ......
	Average						480	846	846	006	1,071
	1:3 (sifted)		135-4	76.1	77.0	8.9	486 522 486	684 702 738	774 828 918	792 792 828	918 846 900
	Average						498	708	840	804	888
Se. 18	1:3	1.06	134-8	76.1	77.0	8.9	702 774 684	918 774 972	1,224 1,260 1,188	1,368 1,440 1,332	...... 1,440 1,386
	Average						720	888	1,224	1,380	1,413
	1:4		134-9	75.2	80.6	8.3	594 594 612	666 900 900	1,188 1,206 1,134	1,332 1,278	1,332 ....
	Average						600	822	1,176	1,305	1,332
	1:3 (sifted)		134-10	75.2	78.8	8.9	738 738 828	1,062 1,116 1,260	1,224 1,368 1,242	1,278 1,368 1,386	1,440 1,440 1,476
	Average						768	1,146	1,278	1,344	1,452
Se. 19	1:3	1.06	135-1	78.8	82.4	8.9	918 1,026 990	1,260 1,368 1,314	1,530 1,584 1,656	1,368 1,548 1,764	1,674 1,620 ......
	Average						978	1,314	1,590	1,560	1,656
	1:4		135-2	77.0	76.1	8.3	828 846 756	1,278 1,188 1,188	1,350 1,332 1,206	1,332 1,386 1,350	1,134 1,044 1,098
	Average						810	1,218	1,299	1,356	1,098
	1:3 (sifted)		135-3	78.8	80.6	8.9	630 540 522	864 846 864	1,062 1,044 936	1,116 1,080 990	1,026 1,116 1,152
	Average						564	858	1,014	1,062	1,098

INDEX.

CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 331.]

The publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists can be had on application.

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3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they can be had at prices slightly above cost.
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The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hyrographic progress reports; Q, Fuels; R, Structural materials. This paper is the third in Series R, the complete list of which follows (B=Bulletin):

SERIES R, STRUCTURAL MATERIALS.

B 324. The San Francisco earthquake and fire of April 18, 1906, and their effects on structures and structural materials; reports by G. K. Gilbert, R. L. Humphrey, J. S. Sewell, and Frank Soulé, with preface by J. A. Holmes. 1907. 170 pp., 57 pls.

B 329. Organization, equipment, and operation of the structural-materials testing laboratories at St. Louis, Mo., by R. L. Humphrey. 1908. 85 pp., 25 pls.

B 331. Portland-cement mortars and their constituent materials; results of tests made at the structural-materials testing laboratories, Forest Park, St. Louis, Mo., 1905-1907, by R. L. Humphrey. 1908. 130 pp., 20 pls.

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FEBRUARY, 1908.

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