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No. 1815 : March 10, 1918

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By

F. E. Giesecke and S. P. Finch

BUREAU OF ECONOMIC GEOLOGY AND TECHNOLOGY
J. A. Udden, Director
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F. E. Giesecke, Head of the Division

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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

Sam Houston

Cultivated mind is the guardian genius of democracy. . . . It is the only dictator that freemen acknowledge and the only security that freemen desire.

Mirabeau B. Lamar

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PHYSICAL PROPERTIES OF DENSE CONCRETE AS DETERMINED BY THE RELATIVE QUANTITY OF CEMENT

ACKNOWLEDGMENT

This investigation was undertaken as a part of the work of the Engineering Division of the Bureau of Economic Geology and Technology of the University of Texas and was conducted by Prof. F. E. Giesecke and Prof. S. P. Finch, assisted by Mr. E. F. Ries. Mr. J. P. Nash, Testing Engineer for the Bureau of Economic Geology and Technology, also gave much assistance, being in charge of the work of making and testing the specimens of Series II and III. Mr. G. A. Parkinson acted as laboratory assistant and displayed great care in making the specimens to be tested. Miss Nellie Jefferson, laboratory assistant, prepared the diagrams for this bulletin.

The authors are much indebted to Mr. H. R. Thomas, C. E., 1912, University of Texas and M. S., 1914, University of Illinois, for valuable suggestions in regard to the best type of compression moulds and for making the University of Illinois compressometer to be used in the elasticity tests.

INTRODUCTION

Object of the investigation. It has long been the custom in the use of concrete to arbitrarily specify the proportions of cement, fine, and coarse aggregate, as 1 cement, 2 sand, 4 stone, choosing the proportions which the results of tests and standard practice seemed to indicate would give the necessary strength or other properties desired. Prompted by the belief that it was much better and more economical to proportion the fine and coarse aggregate so as to produce a dense concrete and to incorporate the amount of cement necessary to obtain the physical properties desired, this investigation was undertaken so that these properties might be known for different percentages of cement.

Scope of investigation. The attempt was made to determine the variation in the compressive strength, modulus of elasticity, tensile strength, modulus of rupture, bond strength, perviousness, and resistance to abrasion, for concrete approximating as closely as possible a maximum density mix and containing varying percentages of cement.

Tests were made on both broken stone and gravel concrete with six different percentages of cement varying from about 4% cement by weight, or 1.61 sacks of cement per cubic yard of concrete, up to about 28% cement, or 11.55 sacks of cement per cubic yard.

History of the investigation, the three series of tests. All of the tests, as outlined above, were begun in the spring of 1916 and extended throughout the summer of that year with the exception of the test for modulus of rupture, which was not included in the original plan. To make the results more complete, it was later decided to add this test, including compressive tests also, which would serve to "tie in" these new tests with the earlier ones of 1916. As the results of the bond tests seemed somewhat erratic, it was thought best to have these tests duplicated and extended, making additional bond tests in order that corroborative data might be obtained. More tension tests were also included.

A new set of experiments was accordingly begun in the spring of 1917 in which were made the four kinds of tests just mentioned. It was the intention to use the machine mixer as in the tests of 1916, and keep the materials and method of mixing, etc. as much alike as possible to those of the preceding tests. However, after a few batches of this concrete had been made up, it was noticed that the fine material of the mix stuck in considerable quantity to the mixer and that the concrete therefore did not have the proportions intended. It was accordingly decided to mix the materials by hand and at the same time to use a somewhat wetter consistency than had been used in the former set of tests.

All of the results of the several sets of tests are reported in this bulletin. They are grouped under three different series:

Series I includes the tests of 1916. The concrete is machine mixed and due to the fact that some of the finer material remained in the mixer, it is of proportions somewhat different from those intended and recorded, the fine aggregate being less than indicated by the mechanical analysis curves and the cement falling short of the amount reported by probably 10% to 12%.

Series II includes the machine mixed concrete of 1917, alike in all particulars to that of Series I. Only tests on the gravel concrete fall in this series. Although there are but few specimens in this group, it was thought best to report the results obtained; for, by comparison with those of Series I, they would at least help to indicate the variation which might be expected in separate batches of the same kind of concrete and would give additional values for determining final averages.

Series III includes all of the tests of 1917 which were hand mixed and in which larger percentages of water were used than in the preceding series.

In all of the concrete, essentially the same materials, coarse aggregate, fine aggregate, and cement, were used.

MATERIALS AND PROPORTIONS

Cement. The cement used in the tests of Series I was a blend of four brands of cement on the local market: Alamo, El Toro, Lone Star, and Trinity. One sack of each kind was placed in a Smith concrete mixer of four cubic feet capacity and thoroughly mixed. This was then stored in a large can with cover. A second batch was mixed in the same way and the can, which had a capacity of about eight cubic feet, was thus filled. When this amount of cement was used up, enough to fill the can was again prepared. In the mean time, the cement, in sacks, was stored in the dry air of the laboratory until mixed to form the blend.

During the progress of the work in making up the specimens of Series I, the cement was tested as follows:

A sample was taken from the first two bags of each brand used and the standard tests made. A complete set of tests was also made of the first batch of blended cement. Thereafter, during the making of the compressive specimens, only strength tests were made of the blend as new quantities of cement were mixed. As the cement used in making the bond, tension, permeability, and abrasion specimens was taken from later shipments, two or three months after the cement for the compressive specimens had been used, tests were made of the new cement similar to those already outlined, i. e., complete tests of each brand and of the blend, and for each subsequent blend, strength tests only. The results of the tests on the cement used in this series are given in Tables 1 and 2:

TABLE 1

RESULTS OF TESTS OF CEMENT USED IN MAKING COMPRESSIVE TESTS, SERIES I

Kind of Test		Kind of Cement				
		No. 1	No. 2	No. 3	No. 4	Blend
Ultimate Tensile Strength in Lbs. per Square Inch	Neat, 7 Days	778	658	686	715	714
	28 Days	797	740	662	733	768
	1:3 Mortar, 7 Days	272	205	255	230	261
	28 Days	350	297	328	312	302
Specific Gravity		3.11	3.17	3.12		3.15
Fineness, % on 100		1.59	2.35	5.63	1.95	2.77
% on 200		21.64	19.03	19.51	23.00	20.51
Soundness, Normal		O. K.	O. K.	O. K.	O. K.	O. K.
Accelerated		O. K.	O. K.	O. K.	O. K.	O. K.
Time of set, Initial		2h-25m	2h-25m	1h-15m	1h-55m	3h-30m
Final		4h- 5m	4h-10m	2h-40m	2h-50m	5h-35m
Normal Consistency		21½%	22%	22½%	22½%	22%

(Each value of strength test of single brand the average of three briquettes. Each value of strength test of blended cement the average of nine briquettes made from three separate mixes of the cement, three briquettes from each mix.)

TABLE 2

RESULTS OF TESTS OF CEMENT USED IN MAKING ALL OF THE TESTS EXCEPT THE COMPRESSIVE TESTS, SERIES I.

Kind of Test		Kind of Cement				
		No. 1	No. 2	No. 3	No. 4	Blend
Ultimate Tensile Strength in Lbs. per Square Inch	Neat, 7 Days	658	642	598	646	572
	28 Days	837	690	785	677	778
	1:3 Mortar, 7 Days	218	217	257	232	262
	28 Days	283	292	347	295	319
Specific Gravity		3.11	3.12	3.14	3.12	3.14
Fineness, % on 100 sieve		2.1	5.4	1.24	3.4	2.9
% on 200 sieve		23.1	23.6		23.2	22.1
Soundness, Normal		O. K.			O. K.	O. K.
Accelerated		O. K.	O. K.	O. K.	O. K.	O. K.
Time of set, Initial		1h-10m	1h- 0m	1h-15m	0h-40m	1h-20m
Final		3h-30m	2h-15m	3h- 5m	2h-10m	2h-50m
Normal Consistency		23½%	23½%	24%	25%	23½%

(Each value of strength test of single brand the average of three briquettes. Each value of strength test of blended cement the average of six briquettes made from two separate mixes of the cement, three briquettes from each mix.)

It is well to note that the results given in Table 1 are determined from tests which were made in March and April, while those in Table 2 are from tests made on the new shipments in August by a different operator. In general, the tests agree as closely as could be expected. Due probably to the difference in the time of year, the normal consistency results of Table 2 are higher and the times of set shorter than those of Table 1.

The cement used in Series II and III was a blend of the four brands of cement already named. Enough of these cements was mixed at the time the new series were begun to make all of the specimens, the blend of cement being kept stored in a closed box lined with paper during the progress of the tests. The results of the tests on this cement are not included.

Sand. The sand was obtained from the bed of the Colorado River near Austin. It was a clean sharp sand with an average specific gravity of 2.64, composed of about 50% quartz and flint, the remainder being limestone with some feldspar. This material was screened into the various sizes needed as described later, the coarser sand being separated from the bank run gravel, while the fine sand was sifted from material gathered from the top of sand beds especially chosen for the fineness of the material.

Broken Stone. The broken stone came from Comal County near New Braunfels, Texas. It was fairly hard limestone with an average specific gravity of 2.60 and an ultimate crushing strength of 6,000 pounds per square inch. It consisted of material passing through a 1¼ sieve and held on a sieve of ¼ mesh. This was screened into the various sizes needed as described later.

Gravel. The gravel was obtained from the bed of the Colorado River near Austin. It was a smooth water worn gravel with an average specific gravity of 2.62, consisting of quartz, flint, and gneiss together with a large percentage of lime stone and containing many flat pieces. This material was screened into the various sizes needed as shown later.

Proportioning the material. The attempt was made to proportion the dry material in such a manner that the resulting mechanical analysis curves for the combination of cement, sand

and coarse aggregate should be as near as practicable to the maximum density curves as determined by Fuller's tests.

It was planned to have mixtures of this kind containing varying percentages of cement approximating 2, 4, 6, 8, 10, and 12 sacks of cement respectively per cubic yard of concrete for both gravel and broken stone.

To illustrate the method of determining the ratio of the cement to be used to the total dry material by weight, the percentage of cement for the "four sack" concrete of Series I will be calculated. Assuming concrete to weigh 150 pounds per cubic foot and a sack of cement to weigh 94 pounds, the approximate percentage of cement (neglecting the presence of the water) equals $\frac{4\text{x}94}{27\text{x}150}$ equals 9.28%. The exact number of sacks of cement per cubic yard was determined later for each mix by weighing the total amount of material used, including the water, and finding the weight of each specimen of the concrete immediately after it was placed in the mould. The total weight of cement divided by the total weight of dry material and water and multiplied by the average weight of a specimen gives the weight of cement per specimen. This divided by 94 and by the volume of the specimen in cubic yards gives the number of sacks of cement per cubic yard of concrete. The actual number of sacks for each mix in Series I determined in this way, was 4% to 6% lower than the number used as shown above in computing the percentage of cement, except for the "2 sack" gravel and broken stone concrete, in which, by mistake, 4.16% of cement was used instead of 4.64%, which resulted in a concrete with 1.66 and 1.63 sacks per cubic yard respectively; except for the "6 sack" concrete of both kinds in which 14.4% of cement was used instead of 13.92%, giving a gravel concrete of 5.96 and a broken stone concrete of 5.9 sacks per cu. yd.; and except for the "8 sack" gravel concrete, where 20.3% of cement was used in place of 18 6%, giving 8.45 sacks per cubic yard.

In Series III, the difference between the assumed number of sacks of cement per cubic yard and the actual number differed for the richer mixes by as much as 10% to 12%. This was probably due to the larger percentages of water used in this series.

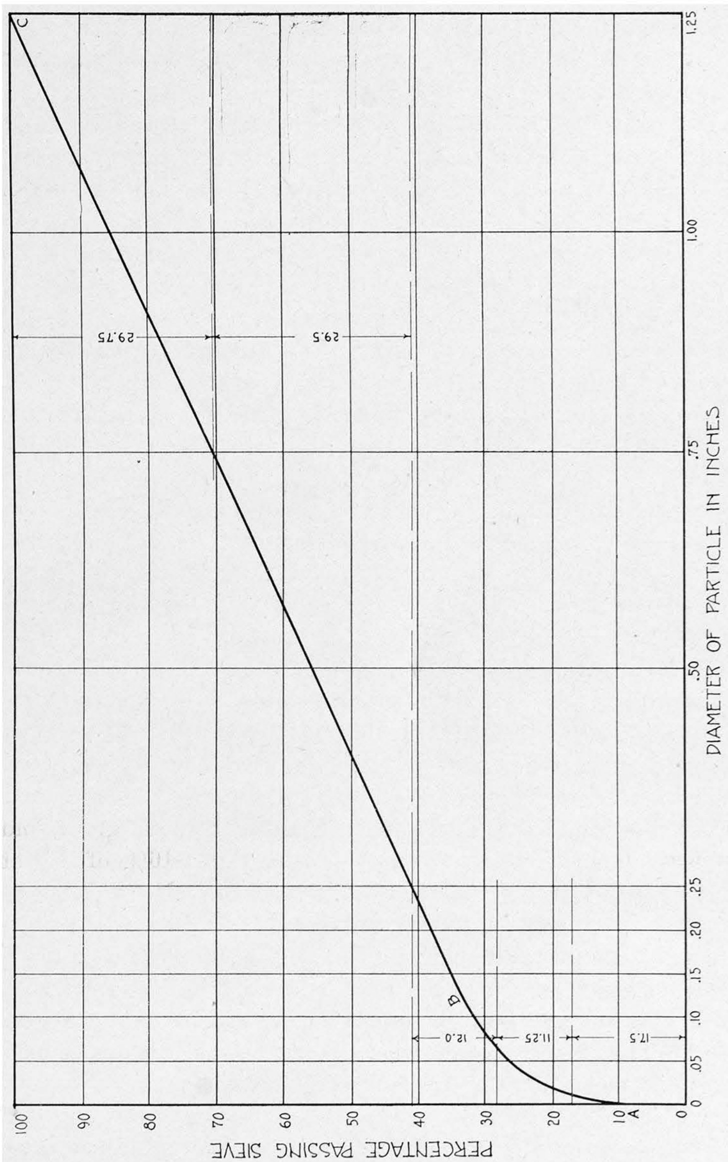


Fig. 1. Fuller's Curve for Sand and Gravel,

The method of determining the proper proportions of the sand and coarse aggregate can be shown by explaining in detail what was done to find out the percentages of these different materials to be used for the gravel concrete.

A plot of the Fuller "practical" curve for sand and gravel was first made, taking 1¼″ as the maximum size of the material. This curve is a combination of a straight line and an ellipse, $(y-7)^2=\frac{b^2}{a^2}(2ax-x^2)$, beginning at a point of tangency to the Y axis at $y = 7$ and extending to a point of tangency with the straight line where $x =$ one tenth the maximum size of the material, or in this case .125″. This straight line extends to a point where x is the max. size of material which is 1 ¼″. For this material, $b=28.6$, $a=.164$ multiplied by the maximum size of material$=.164 \times 1.25=.205$″.

Fig. 1 shows a plot of this curve for sand and gravel, while Fig. 2 shows the curve for sand and broken stone. The point "A" is the point of tangency with the Y axis. The ellipse extends from A″ to the point of tangency with the straight line, "B-C," at "B."

To secure a combination which would give a curve like the one shown, it was decided to use two classes of coarse aggregate and three classes of fine material in addition to the cement. The coarse aggregate was therefore divided into that which would pass a 1¼″ opening and be held on a screen of ¾″ opening, and that which would pass a ¾″ opening and be held on a screen of ¼″ opening. By referring to the curve, Fig. 1, it can be seen that 29.75% of the first size and 29.5% of the latter size would be needed. The fine material was to be divided into that passing a ¼″ opening and held on a No. 10 sieve with opening .073″, that passing this latter sieve and held on a No. 50 sieve with .011″ opening, and that passing this sieve and including the cement. The percentages of these different sizes needed, as read from the curve, are 12% for the first, 11.25% for the second, and 17.5% for the third.

Enough material of each of the above sizes was prepared by screening through ordinary commercial sieves. As a sieve with .073″ opening was not available, a No. 12 was used.

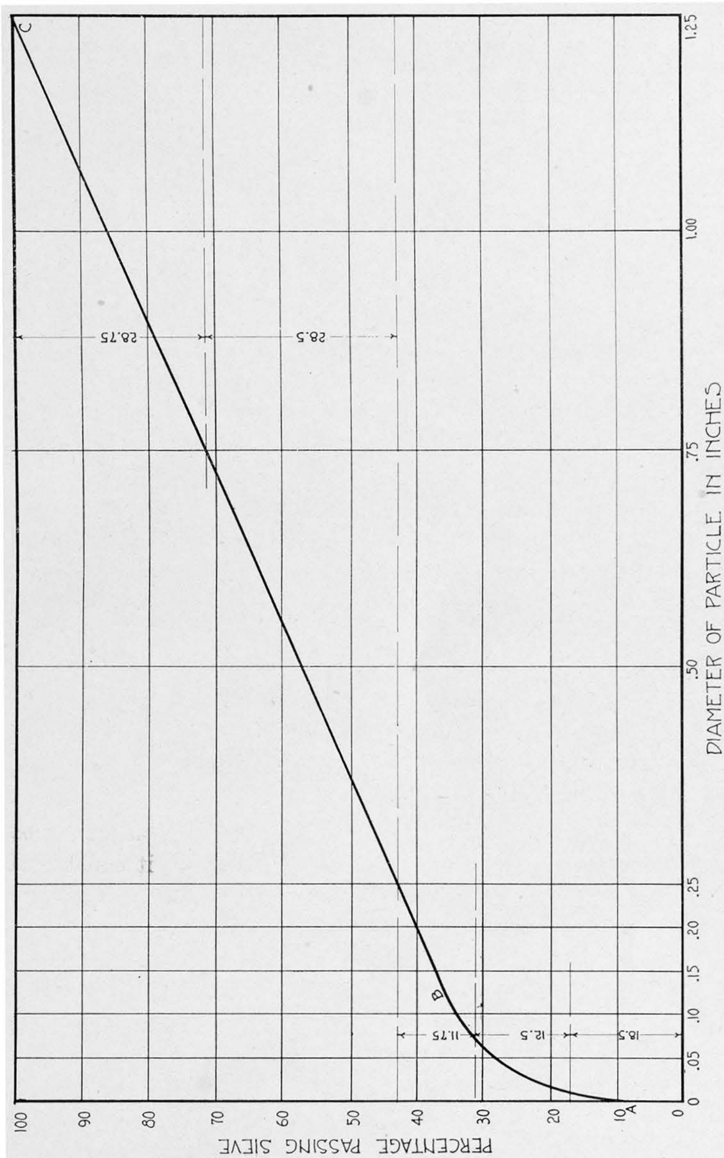


Fig. 2. Fuller's Curve for Sand and Broken Stone.

Below are given the numbers of the sieves used and the approximate size of opening, together with the name to be applied describing each material by giving the sieve through which it passed and the sieve on which it was retained.

No. of Sieve	Size of Opening	Description of Material
1¼	1¼″	1¼-¾
¾	¾″	¾-¼
¼	¼″	¼-12
12	.061″	12-50
50	.011″	50- and below.

The percentages of the different sizes as used in making the "1.66 sack" gravel concrete of Series I are shown in Table 5. The total percentage of material which should pass the number 50 sieve is 17.5%. As it takes 4.16% cement to make this concrete, then 17.5% minus 4.16% or 13.34% of fine sand, i. e. "50-and below," must be used. For making the "11.5 sack" concrete, about 27.9% of cement is needed and so no sand passing a number 50 was used and only .85% of "12-50" sand. as the cement supplied a percentage of fine material practically equal to the part needed of that passing a number 12 sieve, which is 28.75%.

Curves for the material used in the "1.66 sack" and the "11.50 sack" gravel concrete of Series 1, together with the Fuller maximum density curve, are given in Fig. 3. The corresponding curves for the later series are shown in Fig. 4. Fig. 5 shows the same set of curves for the material used in the broken stone concrete of Series I, while Fig. 6 gives those for Series III of this concrete. In the lower right hand corner, the parts of the curves showing the percentages of fine material are plotted to a larger scale than the entire curves. Although the curves of Series I are based on the materials used in only part of that series, they are typical of what was used in the whole. Tables 3 and 4 give the information on which all of these curves are based. These tables were computed by using the mechanical analyses of the materials of each size, together with the percentages of each which were required.

Tables 5 to 8 show the percentages of the materials of the different sizes, together with those of the cement and water, used in all of the series of tests.

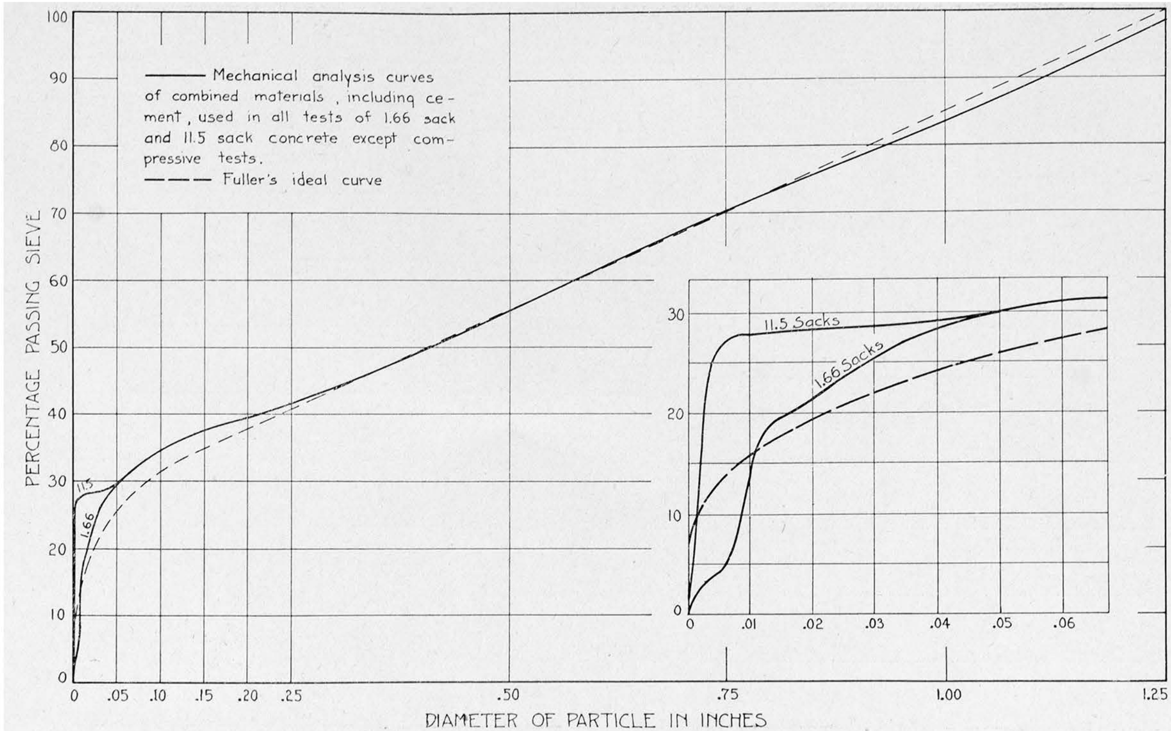


Fig. 3. Mechanical Analysis Curves for Gravel Concrete, Series I.

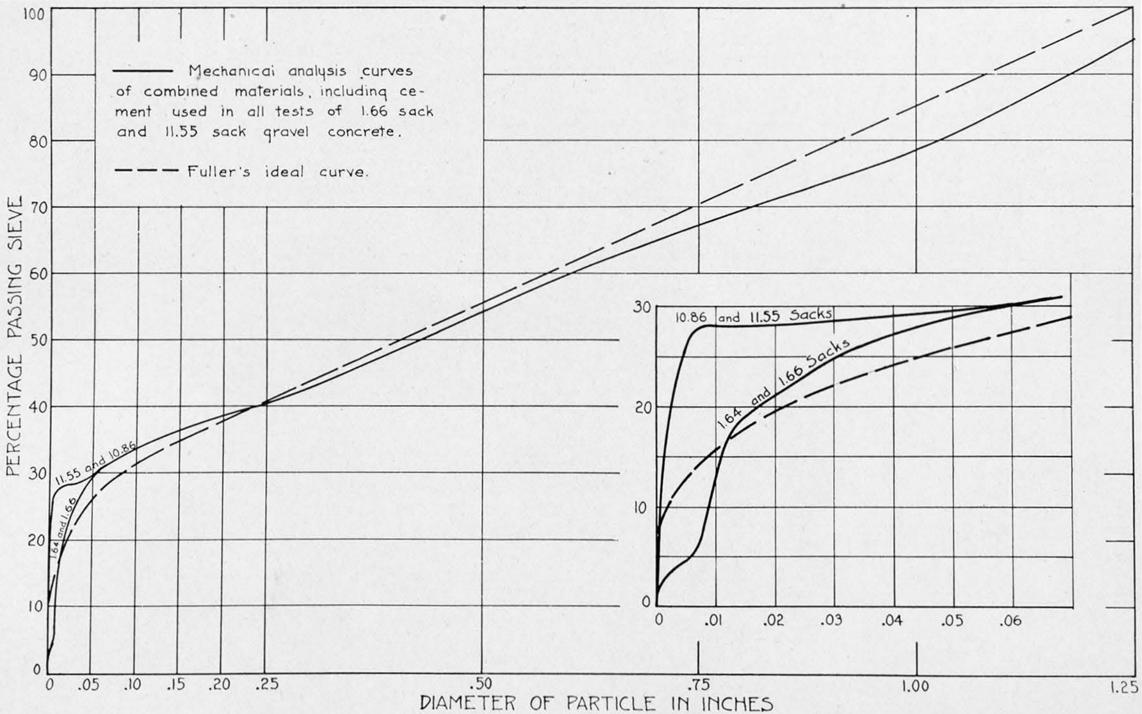


Fig. 4. Mechanical Analysis Curves for Gravel Concrete, Series II and III.

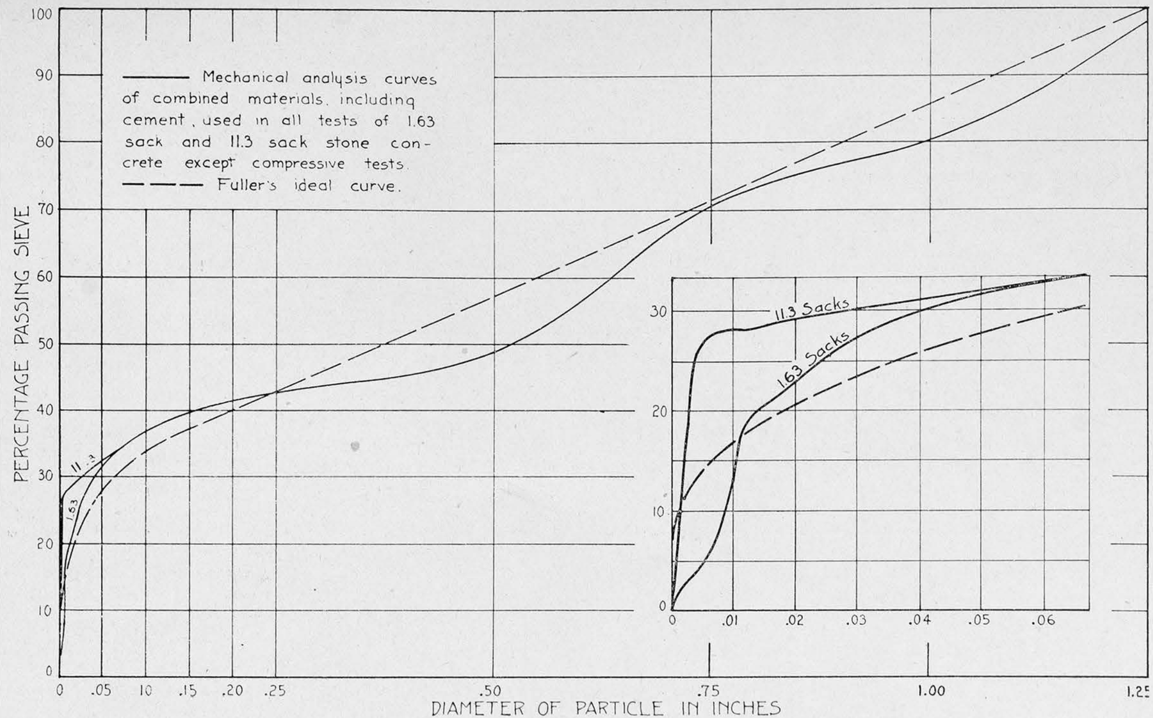


Fig. 5, Mechanical Analysis Curves for Broken Stone Concrete, Series I.

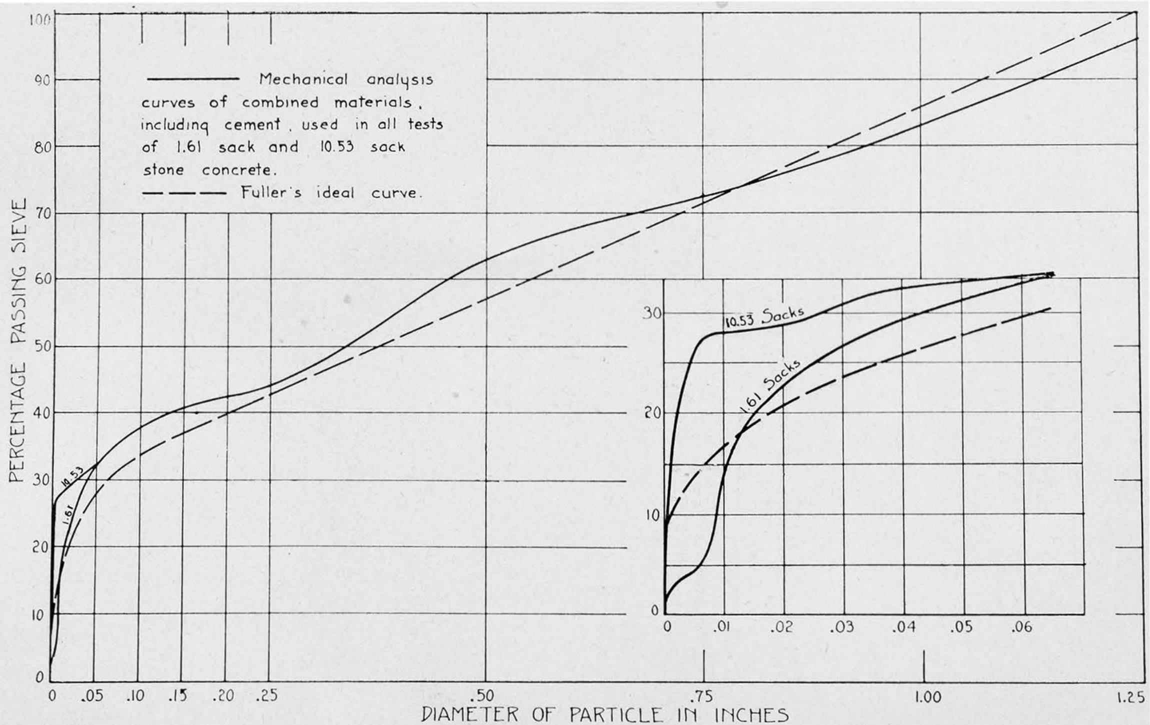


Fig. 6. Mechanical Analysis Curves for Broken Stone Concrete, Series III.

TABLE 3

MECHANICAL ANALYSES OF MATERIAL USED IN GRAVEL CONCRETE

Sieve	Size of opening in inches	Series I		Series II and III	
		Percent passing for 1.66 sacks of cement per cubic yard	Percent passing for 11.50 sacks of cement per cubic yard	Percent passing for 1.64 sacks of cement per cubic yard	Percent passing for 11.55 and 10.86 sacks of cement per cubic yard
1¼	1¼	98.4	93.4	95.1	95.1
1	1	83.5	83.5	78.3	78.3
¾	¾	70.3	70.3	67.3	67.3
½	½	55.3	55.3	54.1	54.1
¼	¼	41.6	41.6	40.2	40.2
⅛	⅛	36.1	36.1	35.0	35.0
10	.065	31.1	31.1	30.6	30.6
20	.0328	26.3	28.5	25.7	28.5
28	.0232	23.0	28.3	22.3	28.3
35	.0164	19.9	28.1	19.6	28.1
48	.0116	17.4	27.9	15.7	27.9
65	.0082	8.5	27.9	7.7	27.9
100	.0058	4.7	27.1	4.8	27.1
200	.0029	3.3	21.8	3.5	21.8

The values given above for Series I represent the results obtained for this series by combining the mechanical analyses of all of the materials, including the cement, used in making all of the tests except the compressive tests. The values given for Series II and III were obtained by combining the mechanical analyses of all the materials, including the cement, used in making all of the tests of these series.

TABLE 4

MECHANICAL ANALYSES OF MATERIAL USED IN BROKEN STONE CONCRETE

Sieve	Size of opening in inches	Series 1		Series III	
		Percent passing for 1.63 sacks of cement per cubic yard	Percent passing for 11.30 sacks of cement per cubic yard	Percent passing for 1.61 sacks of cement per cubic yard	Percent passing for 10.53 sacks of cement per cubic yard
1¼	1¼	97.8	97.8	96.0	96.0
1	1	80.2	80.2	83.1	82.9
¾	¾	70.6	70.6	72.3	72.0
½	½	49.0	49.0	63.2	62.9
¼	¼	43.0	43.0	44.2	43.9
⅛	⅛	38.2	38.2	39.8	39.4
10	.065	33.3	33.3	34.0	33.7
20	.0328	28.3	30.3	28.0	30.4
28	.0232	24.6	29.4	24.1	29.2
35	.0164	21.2	28.6	21.1	28.5
48	.0116	18.3	28.0	16.8	28.0
65	.0082	8.8	27.9	7.9	27.9
100	.0058	4.7	27.1	4.8	27.1
200	.0029	3.3	21.8	3.5	21.8

The values given above for Series I represent the results obtained for this series by combining the mechanical analyses of all the materials, including the cement, used in making all of the tests except the compressive tests. The values given for Series III were obtained by combining the mechanical analyses of all the materials, including the cement, used in making all of the tests of this series.

*TABLE 5

MATERIAL FOR GRAVEL CONCRETE, SERIES I AND II

Sacks of Cement per Cu. Yd. of Concrete	Proportion of each material expressed in percent by weight of total dry material						
	Cement	Sand 50–	Sand 12–50	Sand ¼–12	Gravel ¾–¼	Gravel 1¼–¾	Water
1.66	4.16	13.34	11.25	12.00	29.50	29.75	7.71
3.8	9.28	8.22	11.25	12.00	29.50	29.75	6.73
*5.54	14.40	3.10	11.25	12.00	29.50	29.75	11.57
†5.82	14.40	3.10	11.25	12.00	29.50	29.75	8.20
5.96	14.40	3.10	11.25	12.00	29.50	29.75	6.78
8.45	20.30	0.0	9.95	11.74	28.91	29.10	6.85
9.67	23.20	0.0	5.55	12.00	29.50	29.75	7.19
11.50	27.90	0.0	0.85	12.00	29.50	29.75	7.70

*The "very wet" mixture.
†The "wet" mixture.

TABLE 6

MATERIAL FOR GRAVEL CONCRETE, SERIES III

Sacks of Cement per Cu. Yd. of Concrete	Proportion of each material expressed in percent by weight of total dry material						
	Cement	Sand 50–	Sand 12–50	Sand ¼–12	Gravel ¾–¼	Gravel 1¼–¾	Water
1.64	4.16	13.34	11.25	12.00	29.50	29.75	8.12
3.76	9.28	8.22	11.25	12.00	29.50	29.75	7.77
5.88	14.40	3.10	11.25	12.00	29.50	29.75	7.40
8.20	20.30	0.0	9.95	11.74	28.91	29.10	8.31
9.18	23.20	0.0	5.55	12.00	29.50	29.75	9.20
10.86	27.90	0.0	0.85	12.00	29.50	29.75	10.26

*TABLE 7

MATERIAL FOR BROKEN STONE CONCRETE, SERIES I

Sacks of Cement per Cu. Yd. of Concrete	Proportion of each material expressed in percent by weight of total dry material						
	Cement	Sand 50–	Sand 12–50	Sand ¼–12	Stone ¾–¼	Stone 1¼–¾	Water
1.63	4.16	14.34	12.50	11.75	28.50	28.75	8.85
3.75	9.28	9.22	12.50	11.75	28.50	28.75	7.92
5.90	14.40	4.10	12.50	11.75	28.50	28.75	7.50
7.63	18.60	0.00	12.40	11.75	28.50	28.75	7.60
9.45	23.20	0.00	7.80	11.75	28.50	28.75	8.55
11.30	27.90	0.00	3.10	11.75	28.50	28.75	8.65

*See page 6 for possible variations in proportions.

*TABLE 8
MATERIAL FOR BROKEN STONE CONCRETE, SERIES III

Sacks of Cement per Cu. Yd. of Concrete	Proportion of each material expressed in percent by weight of total dry material						
	Cement	Sand 50-	Sand 12-50	Sand ¼-12	Stone ¾-¼	Stone 1¼-¾	Water
1.61	4.16	14.34	12.50	11.75	28.50	28.75	9.58
3.63	9.28	9.22	12.50	11.75	28.50	28.75	9.10
5.64	14.40	4.10	12.50	11.75	28.50	28.75	9.23
7.38	18.60	0.00	12.40	11.75	28.50	28.75	9.76
9.02	23.20	0.00	7.80	11.75	28.50	28.75	10.45
10.53	27.90	0.00	3.10	11.75	28.50	28.75	11.85

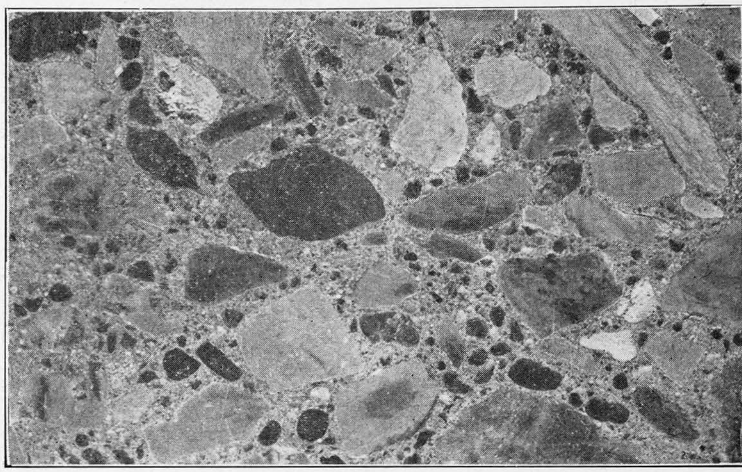
*The percentages of the dry materials are recorded the same as for Series I, although in some cases the actual percentage differed very slightly from the recorded one.

To bring out as clearly as possible the sizes and interrelation of the component materials and to make evident the density of the finished concrete, photographs were taken of polished sections made from some of the broken tensile specimens of the "six-sack" and the "twelve-sack" concretes, both gravel and broken stone. From these photographs, which were made to full size, typical portions were selected and used to make the cuts shown on pp. 22 and 23.

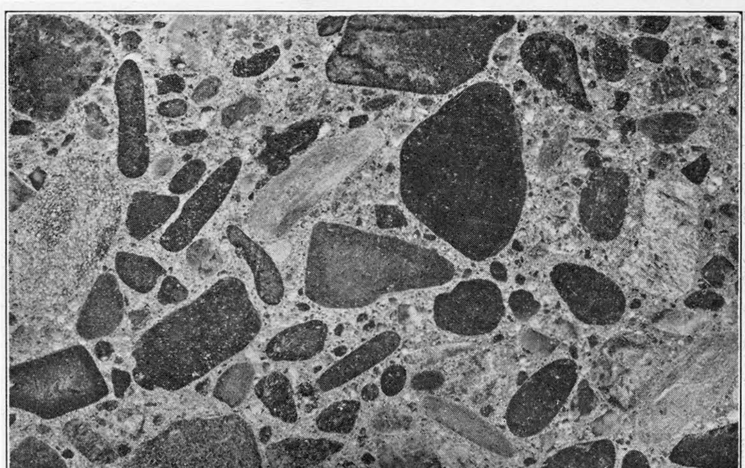
Consistency. For Series I, the consistency adopted after making a trial batch of concrete, was such that the concrete would not flow but could be readily tamped to completely fill the moulds. The amount of water necessary for each mix was determined by noting the appearance of the concrete in the mixer and adding enough water to make the consistency the same as the standard. This, of course, required different percentages of water with the changes in the percentages of cement and fine aggregate. For Series II, the same percentages of water were used as in Series I, but the consistency seemed a trifle dryer.

To find out the effect of using a wetter consistency, parallel tests were run with a "six sack" (actually 5.82 sacks per cubic yard) gravel concrete in Series I in which 8.2% of water was used instead of 6.78%, which was the standard for this mixture. This concrete was wet enough to flow into the moulds and take its place with a little jarring or spading. In Series II, a "very wet" "six sack" mixture was also made up in which 11.57% of water was used.

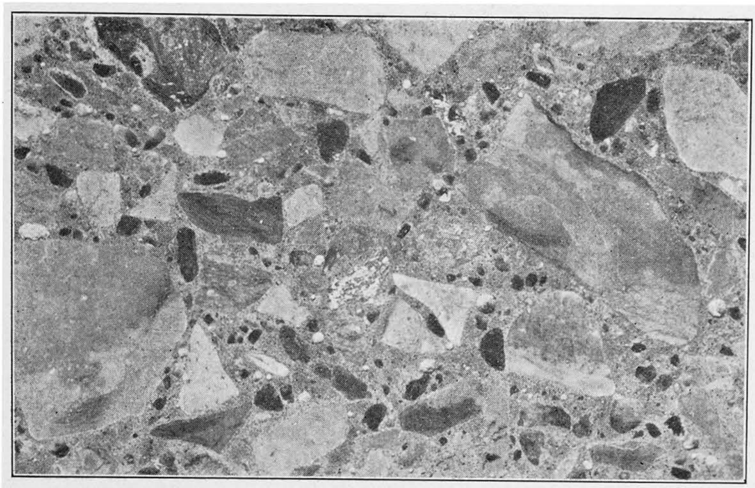
For Series III, a wetter consistency than the standard of Se-



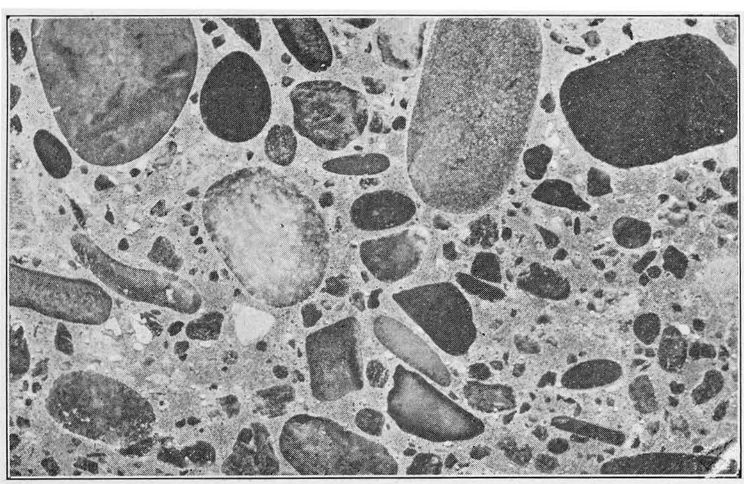
"6 Sack" Broken Stone Concrete.
(Full size)



"6 Sack" Gravel Concrete.
(Full size)



"12 Sack" Broken Stone Concrete.
(Full size)



"12 Sack" Gravel Concrete.
(Full size)

ries I and II was adopted, the concrete being so wet that, as mixed on the floor, it soon flowed and the mass flattened out, the percentages of water being from 1/10 to 1/3 greater than in the preceding tests.

MIXING, MOULDING, STORING

Mixing and moulding. The concrete of Series I and II was machine mixed. The proportions having been determined for the various concretes, the materials were carefully weighed out and placed in the Smith four cubic foot mixer, the interior of which had been previously wet. Water was then added and the mixer allowed to run for five minutes at 19.4 r. p. m., after which the concrete was dumped into a wheel barrow and then placed in the moulds. In Series I, the concrete for each percentage of cement for the tension, bond, permeability, and abrasion tests was made on the same day, the mixing being done in two batches, and part of the specimens for each kind of test being made from one batch and part from the other, except for the permeability test specimen which was made from the first batch. The concrete for the compressive specimens, while mixed in two batches for each percentage of cement, was made at an earlier date. When the tests were made, some samples from each batch were used.

In Series II, the specimens for all of the tests for each percentage of cement were made at one time.

The method of mixing in Series III differed from that in Series I and II, first, in that the materials were hand mixed; second, in that three batches were made up on as many different days, for each percentage of cement, one specimen being made from each batch for each of the different kinds of tests. The materials were thoroughly mixed dry on a cement floor, water was then added and the concrete turned until homogeneous and of uniform consistency. At the time of testing, one specimen from each of the three batches was used.

Storage. After twenty-four hours in air, the specimens were removed from the moulds, except as later specified, and placed under water for eleven days. They were then removed and in most cases some were immediately tested, while the remainder were kept in the dry air of the laboratory for testing at the various ages shown later.

COMPRESSION TESTS

Scope of the investigation. For the tests of Series I, one hundred and forty-four specimens, eight inches in diameter and sixteen inches long, were made of the standard consistency. One-half of these were of broken stone concrete, the other half of gravel. For each different percentage of cement, there were twelve specimens. Three of each kind were broken at ages of 12 days, 28 days, and 3 months, and the remaining three were held for testing at the end of one year. In addition, twelve specimens of "six sack" gravel concrete, the "wet" mixture, were made and tested as outlined above.

For the tests of Series II, twelve specimens were made of gravel concrete, there being two specimens for each different percentage of cement. One of each kind was broken at ages of 28 days and 3 months. In addition, four specimens of "six sack" gravel concrete, two of the "wet" mixture and two of the "very wet" mixture, were made and tested.

For the tests of Series III, twenty-four specimens were made of the gravel concrete and thirty-six of the broken stone concrete. For each different percentage of cement, there were four specimens of gravel and six of broken stone concrete, one-half of which were tested at the age of 28 days, the remainder at the age of 3 months.

Moulds. The moulds used for the compressive specimens were made by cutting an eight inch wrought iron pipe into lengths of sixteen inches and carefully facing the ends. A cut was then taken along a longitudinal section through one wall of each length of pipe and extending from top to bottom. The edges of this cut were planed until they failed to meet by about one-quarter of an inch. Two small angles, one on each side of the opening near the top, and two similar ones near the bottom were riveted to the pipe. Through the outstanding legs of these angles were passed two and one-half inch bolts by which the edges of the pipe could be drawn together. A small bent plate was riveted on the outside near the top of the mould and opposite the part where the cut was made. The mould could be lifted by using this plate and the top angles as handles. A smooth cast iron plate 10″x10″, resting on three short legs, supported the mould.

Mixing, placing, etc. The concrete for each percentage of cement was mixed as already described and placed in the moulds in layers of about two to four inches and thoroughly tamped with a tamper four inches in diameter and weighing 13 pounds.

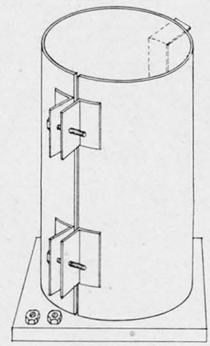


Fig. 7. Mould for Compression Specimen.

The specimens were smoothed off on top and weighed in the moulds which had been previously weighed empty. After setting until the next day, they were removed from the moulds and stored as already described until the time for breaking.

Testing. The specimens of Series I, broken at each period, were selected so that part were taken from the first batch mixed and part from the second batch. In Series II and III one specimen from each batch mixed was broken at the end of each period. Several hours before testing, the top of each specimen was covered with a thin layer of plaster of Paris to give a smooth bearing for applying the load.

A Riehle 400,000# universal machine was used in making the compressive tests. The specimen was carefully centered on the weighing table and a hemispherical compression block placed between it and the movable cross-head. The load was then applied by motor, the cross-head being run down at the rate of

.05″ per minute. The load was continuously applied until rupture in the case of the 12 day and 28 day tests; while in the three months and one year tests, since the compressometer was used to take deformation readings, the load was applied by increments, varying in size with the richness of the mixture, with short time intervals between the applications of the increments. This method was followed up to a point near the rupture of the specimen, when, on the removal of the compressometer, the load was applied continuously to the breaking point.

The concretes containing 6 sacks or more of cement per cubic yard, at ages of 28 days or over, broke suddenly with a loud report, the pieces flying out some distance from the machine. The specimens from the mixes leaner than 6 sacks per cubic yard merely cracked and gradually crushed.

Results. Tables 9 to 11 give the results of the tests on the gravel concrete, while Tables 12 and 13 give those for the broken stone concrete. The values for each series are the averages determined by combining the individual results obtained from testing the specimens of that series.

Figs. 8 and 9 give the curves for the gravel concrete, while Figs. 10 and 11 give those for the broken stone concrete. These curves were determined by first plotting the individual result of the test of each specimen for a given age for all series. The lowest points for a given series were then joined in order with light straight lines. The next lowest points were then connected, and so on. This was done for each series. The heavy curve was obtained by averaging the unit breaking loads determined from the light curves for 1, 2, 3, - - - - - 11 sacks of cement per cubic yard respectively. It accordingly represents average values as determined by combining the results of all the series for a concrete of given coarse aggregate and of a certain age.

Particular attention is called to the values indicated by ✖ ● ◎ in Figs. 8 and 9. The first shows the results of the tests on the "wet" mixture "six sack" gravel concrete of Series I, the second, the same thing for Series II, while the last shows the results for the "very wet" mixture "six sack" concrete of this series.

The curves of Fig. 12 show average values for Series I for the different ages. These are based on the data given in Tables 9 and 12.

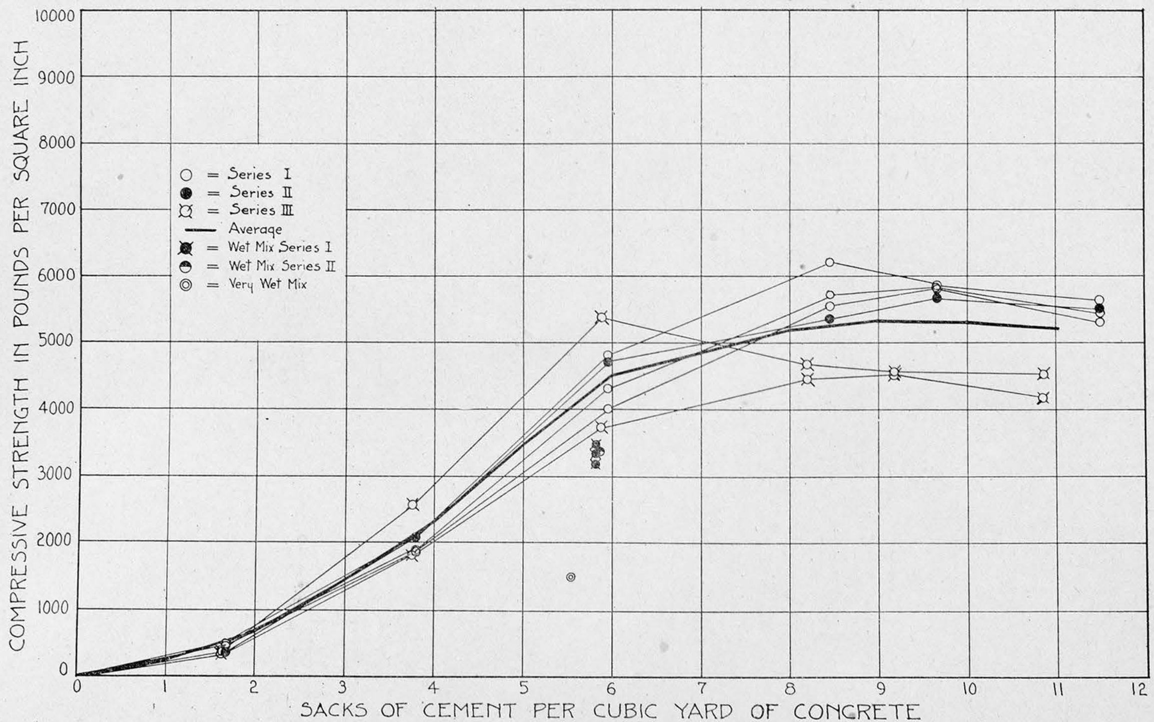


Fig. 8. Ultimate Compressive Strength of Gravel Concrete, Age 28 Days.

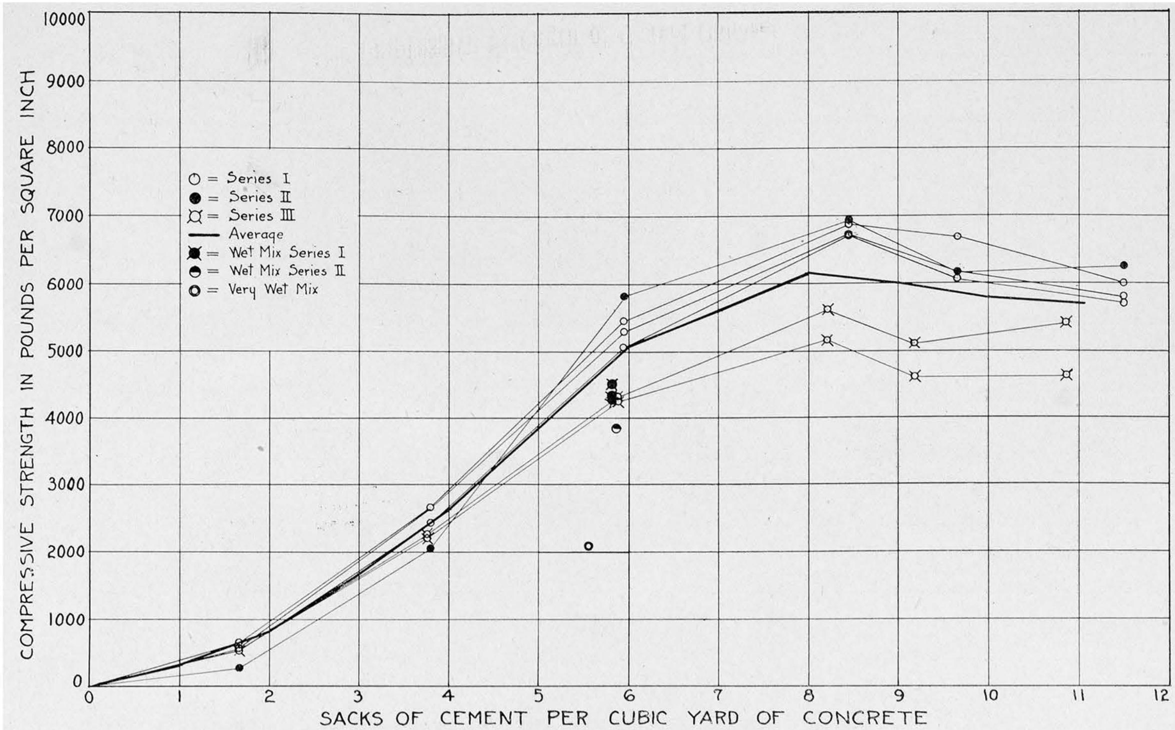


Fig. 9. Ultimate Compressive Strength of Gravel Concrete, Age 3 Months.

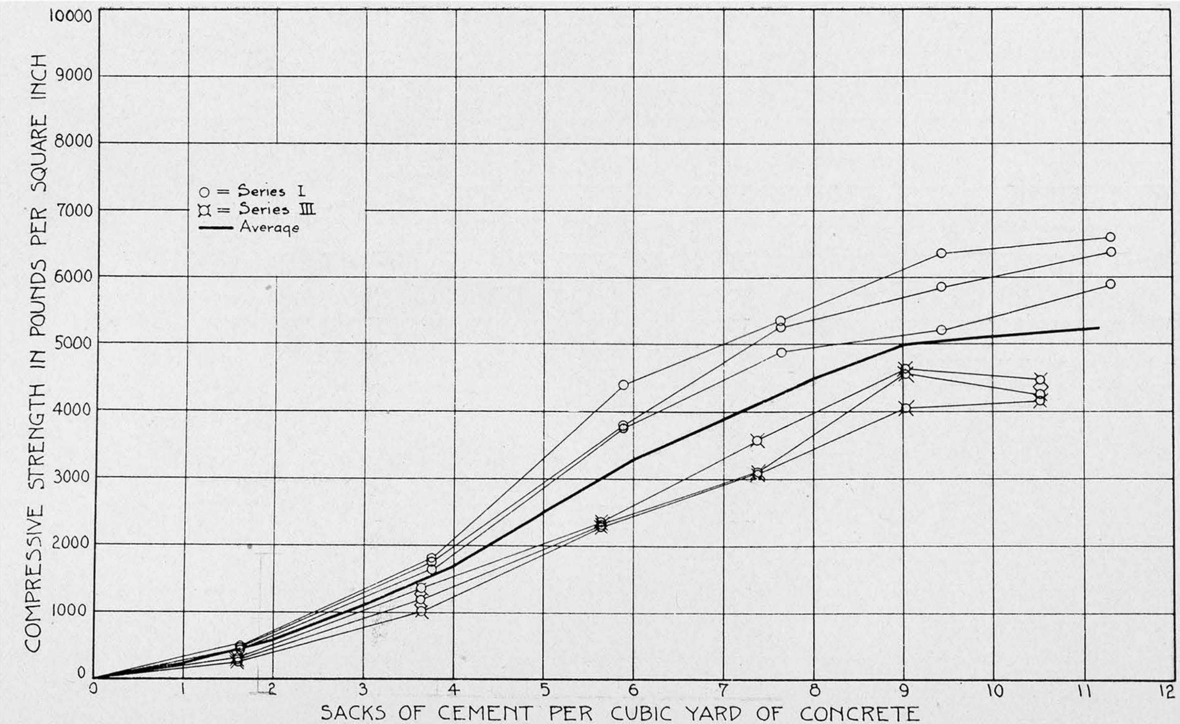


Fig. 10. Ultimate Compressive Strength of Broken Stone Concrete, Age 28 Days.

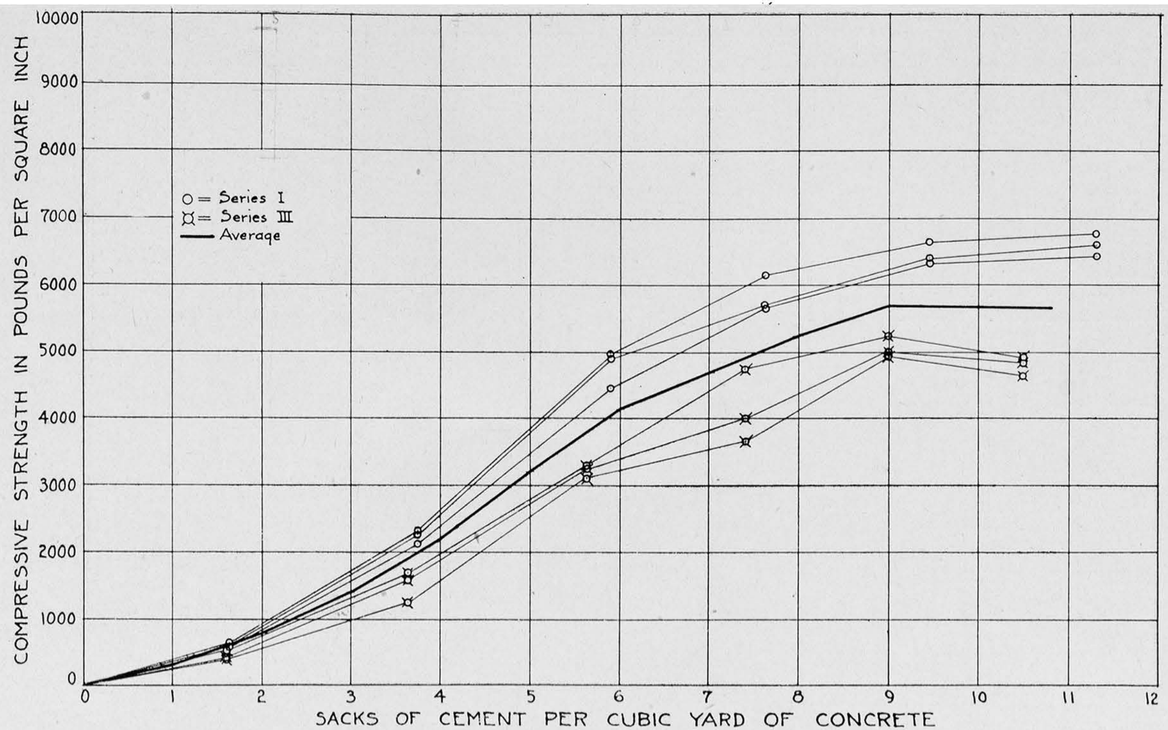


Fig. 11. Ultimate Compressive Strength of Broken Stone Concrete, Age 3 Months.

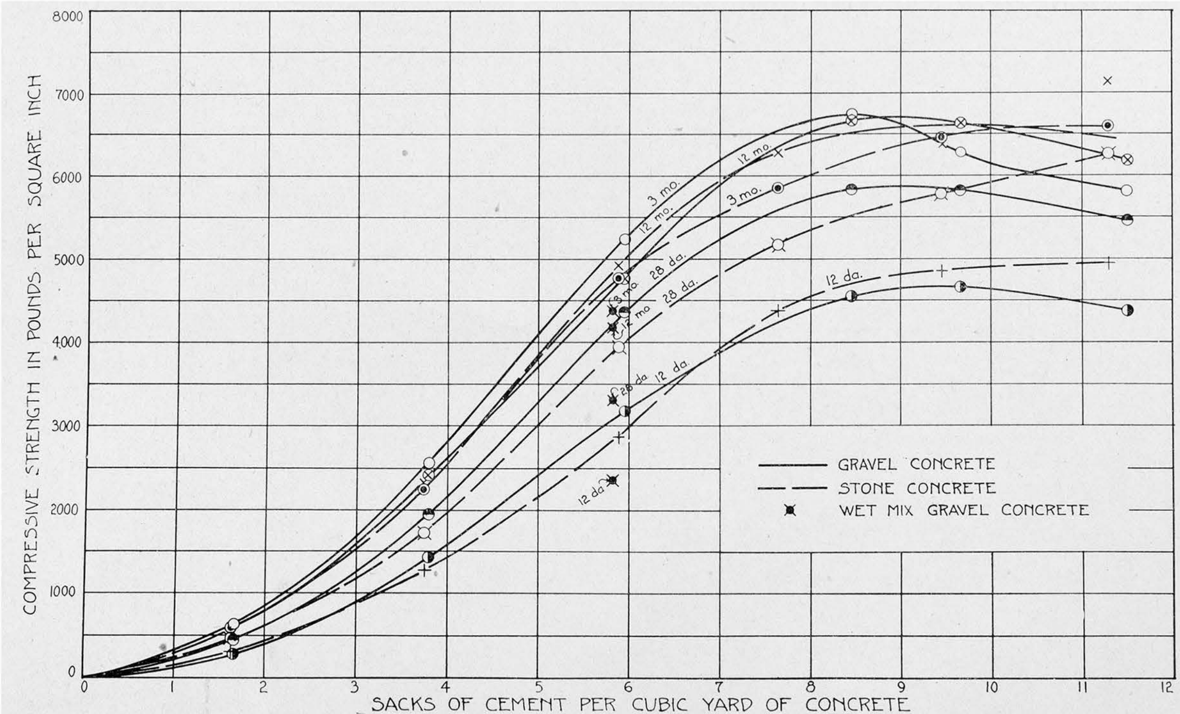


Fig. 12. Ultimate Compressive Strength of Gravel and Broken Stone Concrete at Different Ages, Series I.

TABLE [illegible]

COMPRESSIVE STRENGTH OF GRAVEL CONCRETE, SERIES I
(Each Result the Average of Tests of Three Cylinders 8"x16")

Sacks of cement per cu. yd. of concrete	Weight per cubic foot in pounds				Ultimate unit stress in pounds per square inch			
	Age 12 da.	Age 28 da.	Age 3 mo.	Age 1 yr.	Age 12 da.	Age 28 da.	Age 3 mo.	Age 1 yr.
1.66	149.0	143.5	141.9	141.3	282	445	604	574
3.80	152.0	150.0	147.9	147.5	1418	1948	2565	2401
*5.82	152.0	150.4	148.1	147.9	2347	†3310	4367	4180
5.96	154.5	153.2	152.3	150.9	3185	4379	5237	4778
8.45	155.3	154.5	153.7	152.3	4547	5820	6733	6656
9.67	156.1	154.8	154.0	152.9	4662	5802	6273	6640
11.50	154.9	154.3	153.0	152.2	4377	5447	5803	6180

*The "wet" mixture.
†Age 31 days.

TABLE 10

COMPRESSIVE STRENGTH OF GRAVEL CONCRETE, SERIES II

(Each Result from the Test of One Cylinder 8"x16")

Sacks of cement per cu. yd. of concrete	Ultimate unit stress in pounds per square inch	
	Age 28 days	Age 3 mo.
1.66	384	289
3.80	2060	2037
*5.54	1490	2060
†5.86 (5.82)	3332	3809
5.93 (5.96)	4710	5785
8.45	5350	6880
9.67	5660	6120
11.55(11.50)	5500	6210

*The "very wet" mixture.
†The "wet" mixture.

TABLE 11

COMPRESSIVE STRENGTH OF GRAVEL CONCRETE, SERIES III

(Each Result the Average of Tests of Two Cylinders 8"x16")

Sacks of cement per cu. yd. of concrete	Ultimate unit stress in pounds per square inch	
	Age 28 days	Age 3 mo.
1.64	354	*541
3.76	2180	2216
5.88	4535	4257
8.20	4550	5357
9.18	4533	4810
10.86	4330	4985

*One specimen

TABLE 12

COMPRESSIVE STRENGTH OF BROKEN STONE CONCRETE, SERIES I
(Each Result the Average of Tests of Three Cylinders 8"x16")

Sacks of cement per cu. yd. of concrete	Weight per cubic foot in pounds				Ultimate unit stress in pounds per square inch			
	Age 12 da.	Age 28 da.	Age 3 mo.	Age 1 yr.	Age 12 da.	Age 28 da.	Age 3 mo.	Age 1 yr.
1.63	147.7	141.7			284	461	598	590
3.75	151.7	149.2	146.9	145.7	1278	1718	2227	2310
5.90	153.9	151.9	150.4	148.9	2871	3965	4772	4905
7.63	154.2	152.2	151.2	150.2	4397	5153	5843	6272
9.45	153.2	152.0	150.9	149.8	4858	5787	6450	6360
11.30	153.3	152.9	151.6	150.9	4950	6263	6597	7103

TABLE 13

COMPRESSIVE STRENGTH OF BROKEN STONE CONCRETE, SERIES III

(Each Result the Average of Tests of Three Cylinders 8"x16")

Sacks of cement per cu. yd. of concrete	Ultimate unit stress in pounds per square inch		Sacks of cement per cu. yd. of concrete	Ultimate unit stress in pounds per square inch	
	Age 28 days	Age 3 mo.		Age 28 days	Age 3 mo.
1.61	279	449	7.38	3237	4123
3.63	1174	1499	9.02	4388	5050
5.64	2297	3192	10.53	4286	4777

ELASTICITY TESTS

Scope of the investigation. In Series I, a test was made on three of the compression specimens of each kind at the age of three months and two of each kind (in some cases three) at the age of one year. All of the one year specimens used and two of the three months specimens for each percentage of cement were tested so as to determine the modulus of elasticity, while in the case of the third three months specimen, the load was applied and removed several times and the permanent set obtained, as well as the stress-strain relation for both loading and unloading.

No tests for the modulus of elasticity were made on the specimens of Series II.

In Series III, two of the compression specimens of each kind were tested at the age of three months. In those cases where results of the two tests did not agree closely, a third specimen was tested.

Testing. A wire wound dial compressometer was used to measure the deformation taking place in the test of these specimens. This apparatus is shown in the sketch, Fig. 13. It consists of two yokes attached to the specimen by four pointed thumb screws, two in each yoke, and placed ten inches apart by two removable spacing bars. On one side the yokes are maintained a constant distance apart by a bar connected at the top and bottom by ball and socket joints closely held by small springs, while on the other side the movement is measured by means of a pointer moving over a dial fastened to the upper yoke and graduated to read to two ten thousandths of an inch. This pointer is connected to a small cylinder, free to turn, around

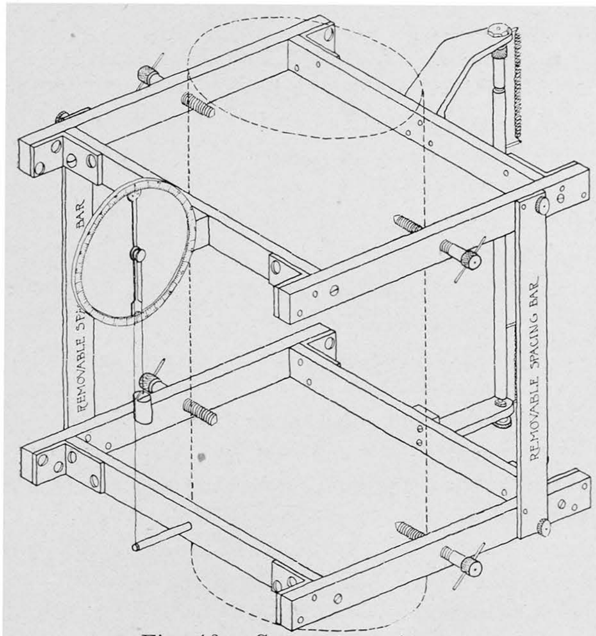


Fig. 13. Compressometer.

which passes a fine wire, one end of which is attached to the lower yoke, a small weight being connected to the other end. As the two yokes are in effect pivoted on the side where the constant distance bar is, the other side, to which is attached the dial, moves twice the distance that the two screw points move, provided these have been correctly placed half way between the bar and dial. This movement is transmitted by the wire to the cylinder which is made to turn and the amount of shortening is thus determined, readings of actual deformation as close as one ten thousandth of an inch being obtained.

The apparatus was carefully attached to the specimen to be tested about midway between the top and bottom, the screw points being centered as near as could be done by eye. The specimen was then placed on the machine, the spacing bars removed, and the pointer set to read zero. The load was applied by increments of from 5000 to 20,000 pounds, depending on the estimated ultimate strength of the concrete. As soon as the load set on the beam of the testing machine had been reached, a dial reading was taken. After an intermission of about one-half minute, a second increment was applied and so on up to the point at which it was thought best to remove the compressometer. It was not considered safe to take readings up to rupture as in testing many of the richer mixes, the concrete, in breaking, popped out with great violence.

Tests similar to the ones just outlined were made on the one year specimens and on two of each set of three specimens tested at the age of three months. The third three months specimen of Series I was tested in a slightly different manner, as shown by the following:

The load was applied in increments similar to those already mentioned up to a point equal to about one third of the maximum load to be expected, then the load was released by decrements, compressometer readings being taken at the same load points as when the load was being increased. This was done to see to what extent the specimen returned to its original length at the different loads and to find out the permanent set. A second series of readings was made in the same way extending to a point approximately equal to a load two thirds of the maximum and the load taken off as before. The load was then applied with the usual increments, with approximately one half minute intervals of rest, up to the point at which the compressometer was removed.

Results. To obtain the values of the modulus of elasticity, a curve for each mix was plotted based on the average unit deformations and their corresponding loads for the specimens tested without the load being repeated. Curves for gravel are shown in Fig. 14, and those for broken stone in Fig. 15. Fig 15a shows the same curves grouped to make comparison easier. These are based on the data of Series I, the three months test, and are typical of the curves for the one year test of this series and of the three months test of Series III. From stress-strain curves like these, the secant modulus of elasticity for a load equal to about one third of the total load could be obtained by using the deformation between the point located by the first load increment and the one third load point. The former was chosen rather than the origin; for in nearly every case, there seemed

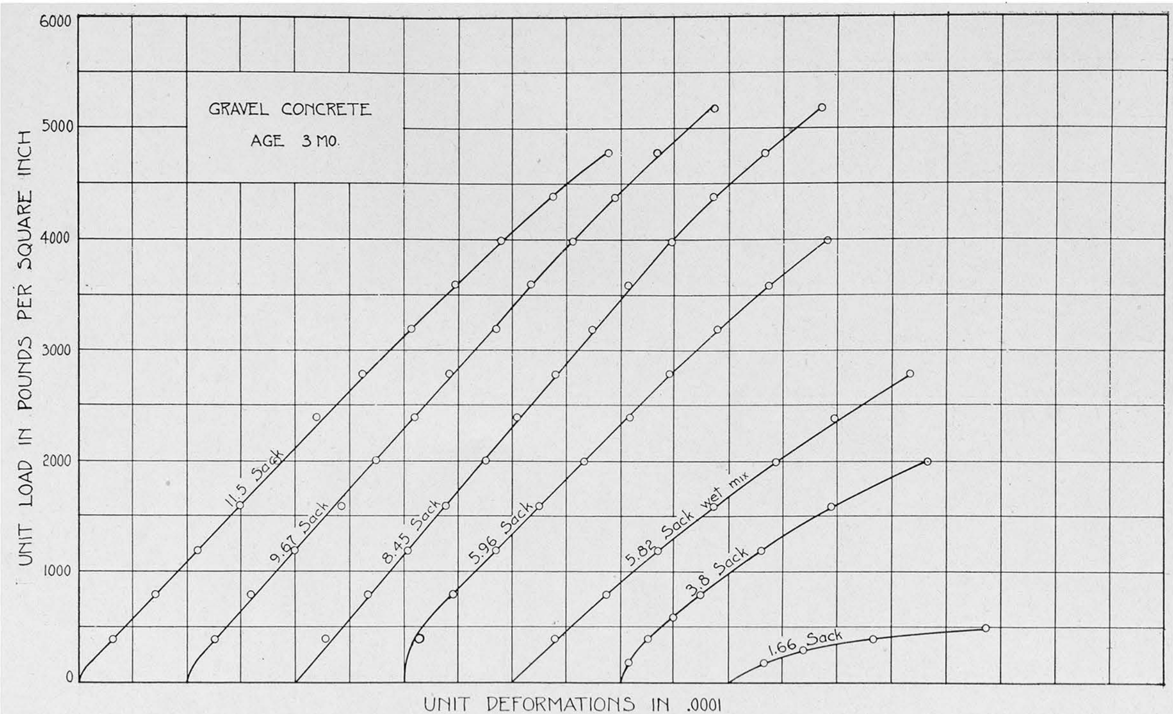


Fig. 14. Average Stress-strain Curves for Gravel Concrete, Age 3 Months, Series I.

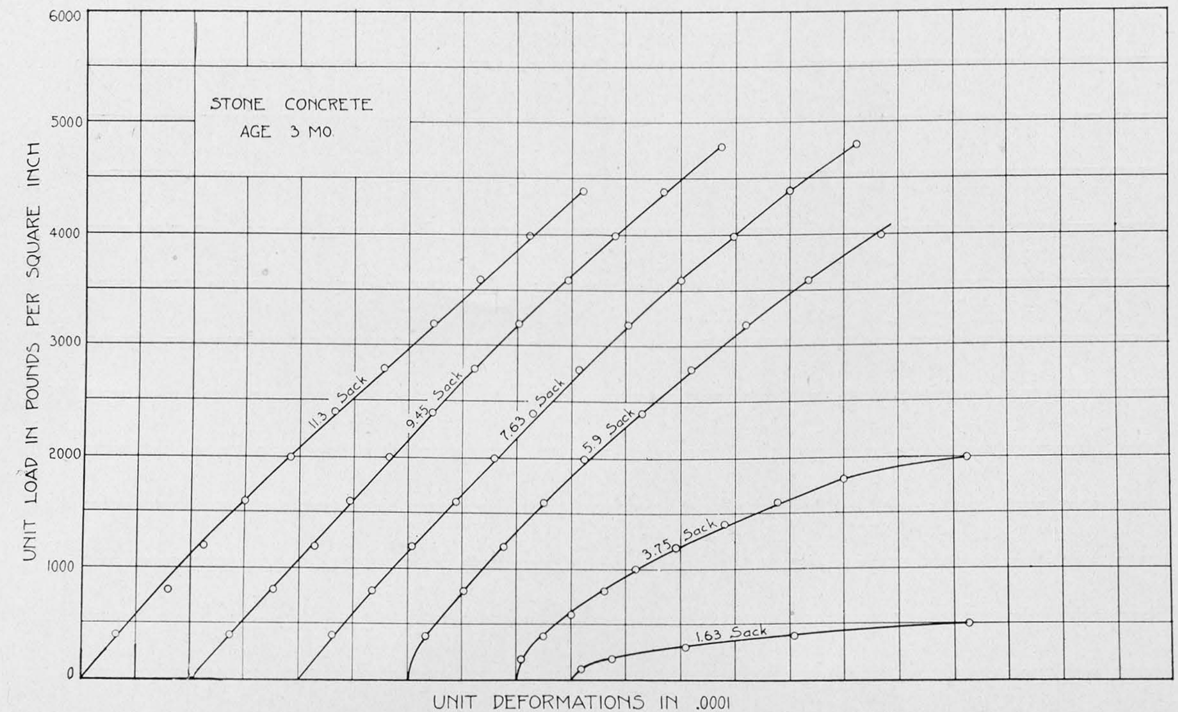


Fig. 15. Average Stress-strain Curves for Broken Stone Concrete, Age 3 Months, Series I,

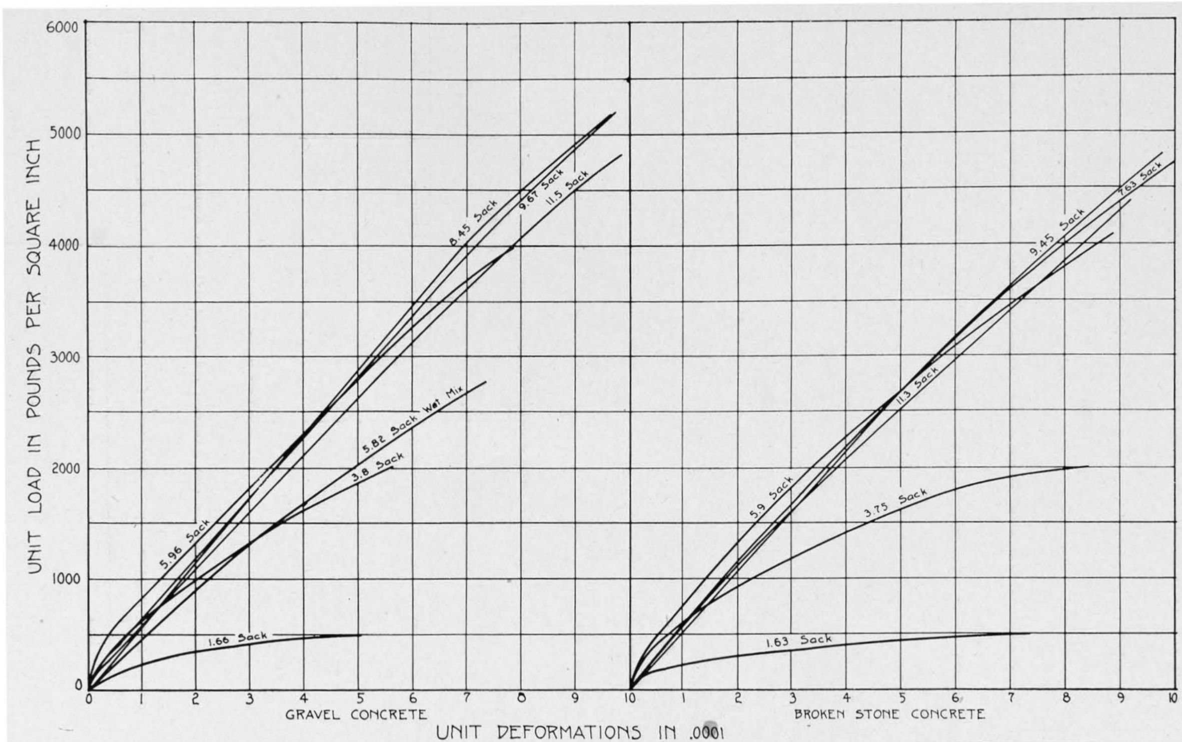


Fig. 15a. Average Stress-strain Curves for Gravel and Broken Stone Concrete, Age 3 Months, Series I.

to be some initial error in the compressometer reading, as can be seen by referring to many of the curves.

Tables 14, 15, 16, 17 give for each mix the ultimate unit stress obtained by averaging the results from testing the specimens used in finding the modulus of elasticity, and the modulus of elasticity determined from the average curve described above. The variation of the modulus with sacks of cement per cubic yard of concrete is shown for the gravel concrete in Fig. 16, while in Fig. 17 is shown this variation for broken stone concrete. The curves drawn in light lines were obtained by plotting the data given in the several tables. The heavy line curves were obtained from these light line curves by averaging the moduli determined from them for 1, 2, 3 - - - - 11 sacks of cement per cubic yard respectively.

The data taken for determining the permanent set for some of the specimens may be considered almost too erratic to warrant presentation here. However, in Figs. 18 and 19 are given the curves based on this test of the third three months specimen of each kind for Series I.

TABLE 14

MODULUS OF ELASTICITY OF GRAVEL CONCRETE, SERIES I
(Each Result the Average of Tests of Two Specimens)

Sacks of cement per cu. yd. of concrete	Age 3 months		Age 1 year	
	Modulus of elasticity in pounds per square inch	Ultimate unit compressive stress in pounds per square inch	Modulus of elasticity in pounds per square inch	Ultimate unit compressive stress in pounds per square inch
1.66	2,800,000	617	1,300,000	585
3.80	4,400,000	2640	†4,400,000	2400
*5.82	4,200,000	4400	4,100,000	4350
5.96	†5,400,000	5235		
8.45	5,800,000	6760	5,700,000	6650
9.67	5,600,000	6390	5,700,000	6650
11.50	5,400,000	5920	†5,200,000	6180

*The "wet" mixture.
†Three specimens.

TABLE 15

MODULUS OF ELASTICITY OF GRAVEL CONCRETE, SERIES III
(Each Result the Average of Tests of Two Specimens)
Age Three Months

Sacks of cement per cu. yd. of concrete	Modulus of Elasticity in pounds per square inch	Ultimate unit compressive stress in pounds per sq. in.
1.64	1,700,000	495 (approx.)
3.76	3,900,000	2215
5.88	5,100,000	4260
8.20	5,000,000	5360
9.18	4,900,000	4810
10.86	5,000,000	4985

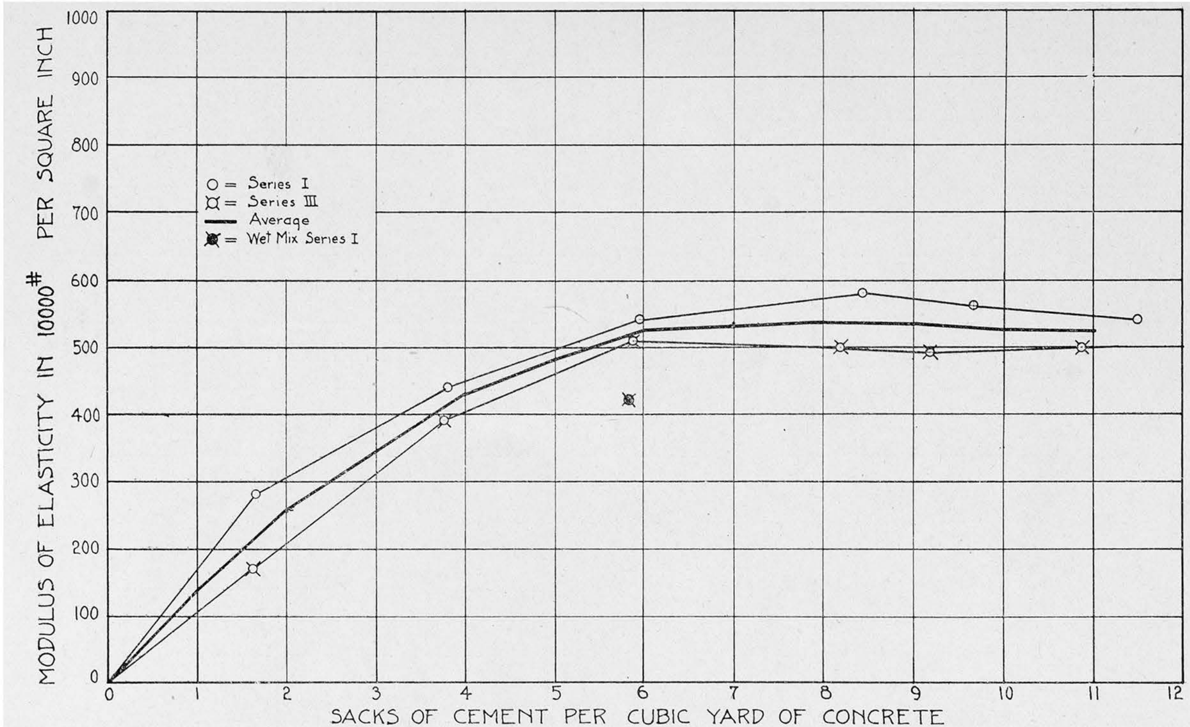


Fig. 16. Modulus of Elasticity of Gravel Concrete, Age 3 Months.

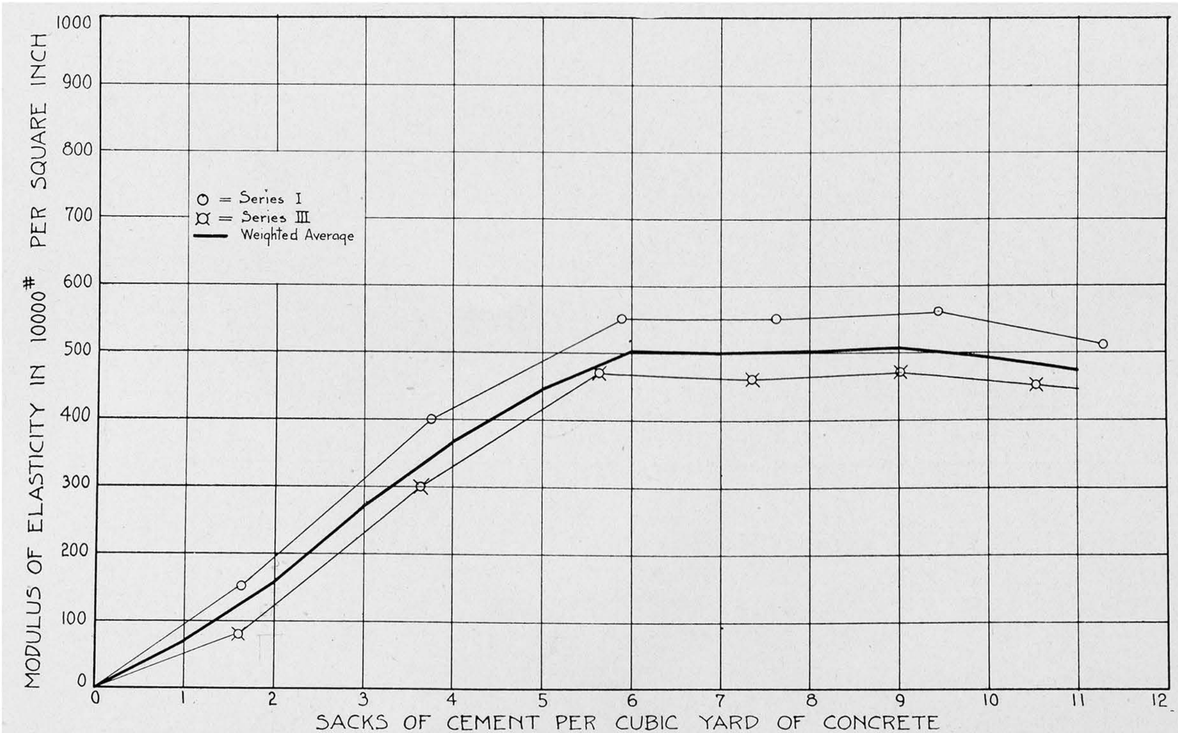


Fig. 17. Modulus of Elasticity of Broken Stone Concrete, Age 3 Months.

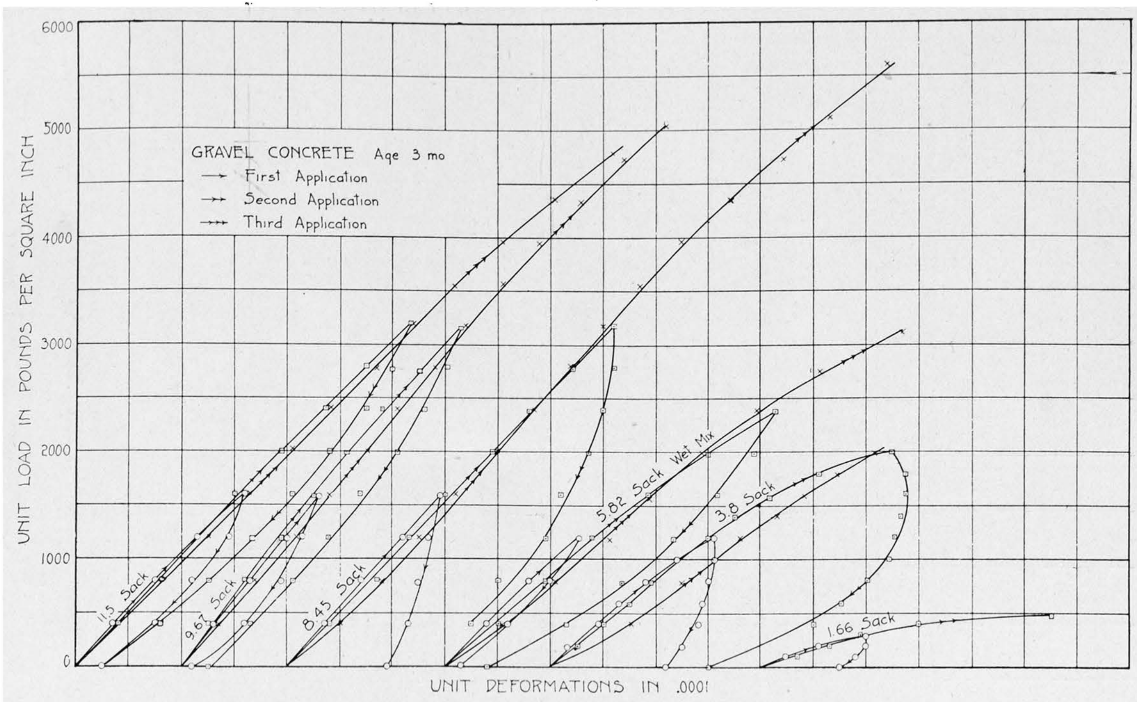


Fig. 18. Stress-strain Curves for Repeated Loads, Gravel Concrete, Series I.

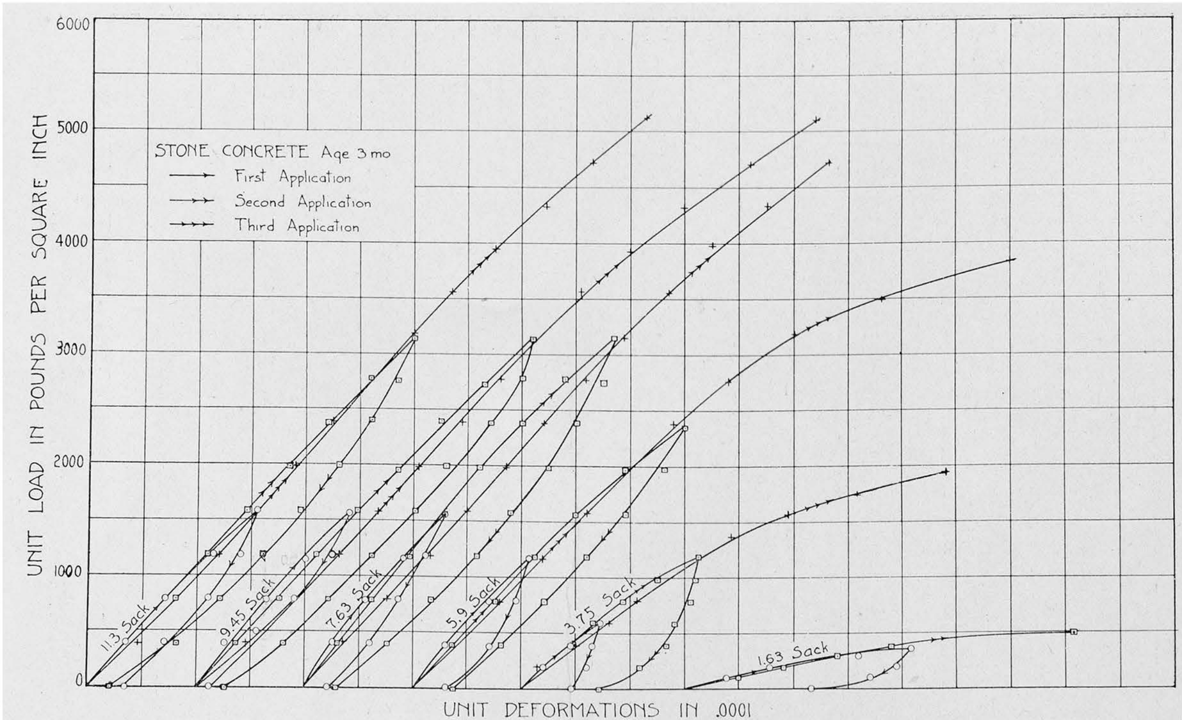


Fig. 19. Stress-strain Curves for Repeated Loads, Broken Stone Concrete, Series I.

TABLE 16

MODULUS OF ELASTICITY OF BROKEN STONE CONCRETE, SERIES I

(Each Result the Average of Tests of Two Specimens)

Sacks of cement per cu. yd. of concrete	Age 3 months		Age 1 year	
	Modulus of elasticity in pounds per square inch	Ultimate unit compressive stress in pounds per square inch	Modulus of elasticity in pounds per square inch	Ultimate unit compressive stress in pounds per square inch
1.63	1,500,000	602	*1,000,000	590
3.75	4,000,000	2215	3,600,000	2345
5.9	5,500,000	4930	4,900,000	4965
7.63	5,500,000	5690	5,200,000	6040
9.45	5,600,000	6515	*4,900,000	6365
11.3	5,100,000	6510	5,400,000	6970

*Three specimens.

TABLE 17

MODULUS OF ELASTICITY OF BROKEN STONE CONCRETE, SERIES III

(Each Result the Average of Tests of Three Specimens Except as Specified)

Age Three Months

Sacks of cement per cu. yd. of concrete	Modulus of Elasticity in pounds per square inch	Ultimate unit compressive stress in pounds per sq. in.
*1.61	800,000	412
3.63	3,000,000	1500
5.64	4,700,000	3190
7.38	4,600,000	4125
9.02	4,700,000	5050
10.53	4,500,000	4775

*Two specimens.

TENSION TESTS

Scope of the investigation. For the tests of Series I, one hundred and eight specimens of standard consistency were made of such shape that they could be broken in tension. One half of these were of gravel concrete, the other half of broken stone. For each different percentage of cement, there were nine specimens. Three of each kind were broken at ages of 12 days, 28 days, and 3 months. In addition, nine specimens of "six sack" gravel concrete, the "wet" mixture, were made and tested.

For the tests of Series II, eighteen specimens were made of the gravel concrete, there being three specimens for each different percentage of cement. One of each kind was broken at ages of 12 days, 28 days, and 3 months. In addition, six specimens of "six sack" gravel concrete, three of the "wet" mixture and three of the "very wet" mixture, were made and tested.

For the tests of Series III, thirty six specimens were made of the gravel concrete and fifty four of the broken stone concrete. For each different percentage of cement, there were six specimens of gravel and nine specimens of broken stone concrete, one third of which were tested at the age of 12 days, one third at the age of 28 days, and the remainder after 3 months.

Moulds. For making the tension specimens, special moulds were made similar in general outline to those used for making standard cement briquettes, but large enough to give a breaking

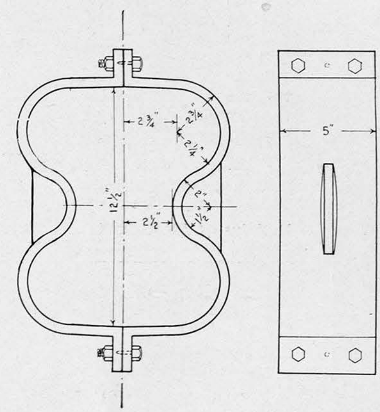


Fig. 20. Mould for Tension Specimen.

section of twenty five square inches. Fig. 20 shows the dimensions of these moulds. They were made of cast iron and finished smooth inside and on top and bottom edges. The pins shown in sketch enable one to quickly fit the two parts together, while the bolts hold them in place.

Mixing, placing, etc. The moulds, well oiled, were placed on greased galvanized iron plates. The concrete for each percentage of cement was mixed as already described and carefully tamped into place in layers of about two inches. After one day in air, the moulds were removed and the specimens were stored until broken as in the previous tests.

Testing. The specimens of Series I, broken at each period, were selected so that part were taken from the first batch mixed and part from the second batch. In Series II and III, one specimen from each batch mixed was broken at the end of each period.

The 100,000# Olsen machine and special holders were used to break the specimens.

The apparatus used in making the tension test is shown in

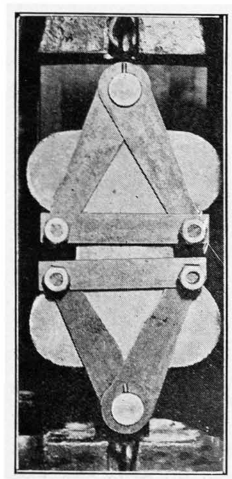


Fig. 21. Apparatus for Testing Tensile Specimens.

Fig. 21. This differed somewhat from that used in some of the earlier tests but worked on the same general principle. It was made up of two holders so constructed as to grasp the enlarged parts of the briquettes. One was fastened to the fixed cross-head of the machine and the other to the movable cross-head. The holder consisted of a roller about 1 ½″ in diameter and 6″ long, from which was suspended by two eye bolts the grip used to clamp the specimen. This grip was made of a cylindrical piece of steel 1½″ in diameter, from each end of which were suspended two flat steel hangers with bolts and spacing bars as shown in figure. These were free to turn in one plane about the points of support and could be spread to a position such that, together with the eye bolts, they took a shape similar to that of the letter "Y" (inverted for upper cross-head). Through the extreme ends of these flat pieces constituting the legs of the "Y" and parallel to the longitudinal axis of the cylinder to which they were fastened, passed two ⅞″ bolts, one on each side, connecting the four hangers in sets of two and

serving to transmit the pull to the specimen to be tested. These two bolts were held the proper distance apart by two spacing bars. When the test was to be made, the roller was placed on the fixed cross-head (for upper holder) and connected by the eye bolts, which were passed through the opening in the cross-head, to the cylindrical piece from which the hangers were suspended. This cylinder was set so that its axis was at right angles to the axis of the roller. This arrangement, together with the connection made by the two eye bolts, permitted the apparatus to adjust itself to any inaccuracy in centering, etc.

Each specimen was carefully centered and the load applied continuously by motor causing the cross-head to move down at the rate of about .05 of an inch per minute. This was equivalent to applying the load at the rate of 40 pounds to 48 pounds per square inch per minute. The specimens broke at or very near the center, giving a breaking area equal to or but little larger than that of the least section. Tests were made at the end of 12 days, 28 days, and 3 months.

Results. Tables 18 to 20 give the results of the tests on the gravel concrete, while Tables 21 and 22 give those for the broken stone concrete. The values given in these tables are represented graphically in the curves of Figs. 22 to 27. The method of plotting these curves and determining the average curve for each aggregate at a given age was the same as that used in plotting the results of the compressive tests.

Particular attention is called to the values indicated by ✖ of Figs. 22 to 24, and by ● and ◉ of these figures. The first shows the results of the "six sack" "wet" mix of Series I, the second, those of the "wet" mix of Series II, and the third, those of the "very wet" mix of this series.

The curves of Fig. 28 show average values for Series I for the different ages. These are based on the data given in Tables 18 and 21.

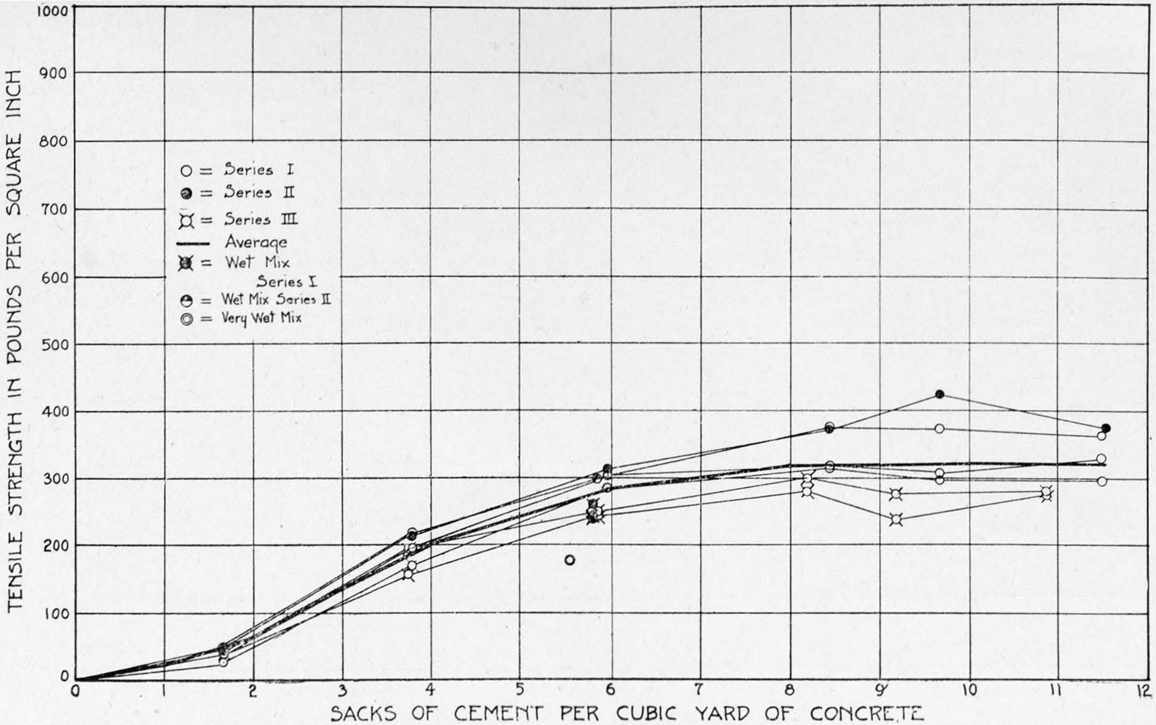


Fig. 22. Ultimate Tensile Strength of Gravel Concrete, Age 12 Days.

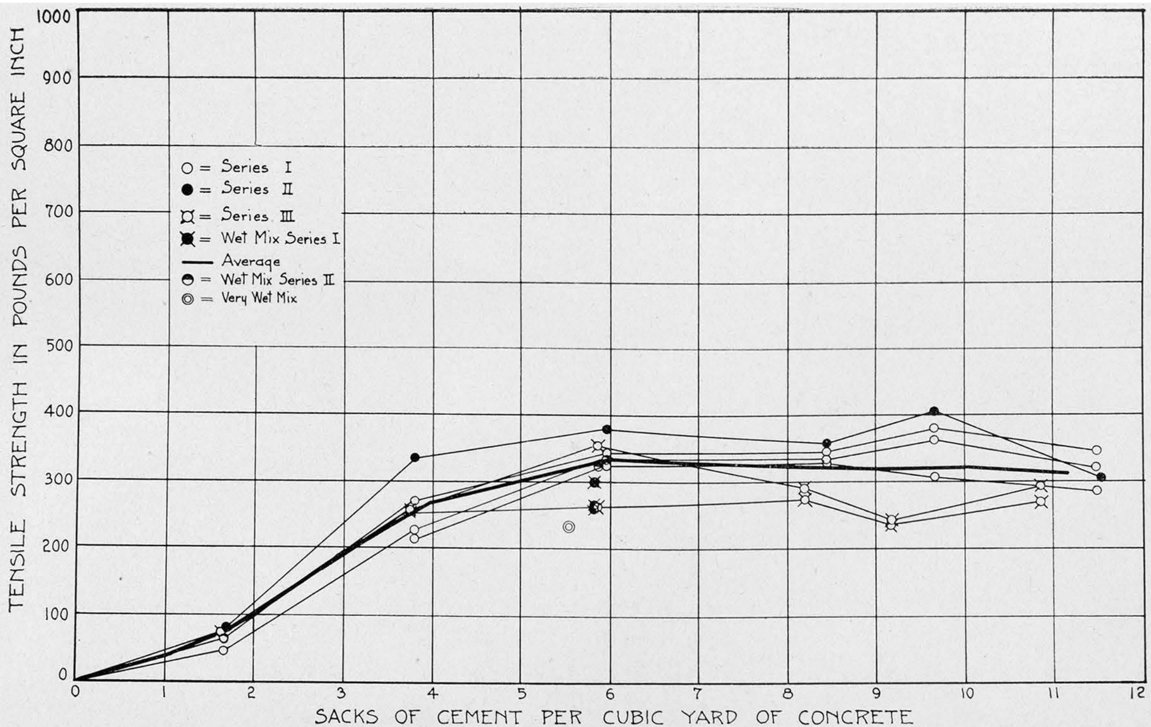


Fig. 23. Ultimate Tensile Strength of Gravel Concrete, Age 28 Days.

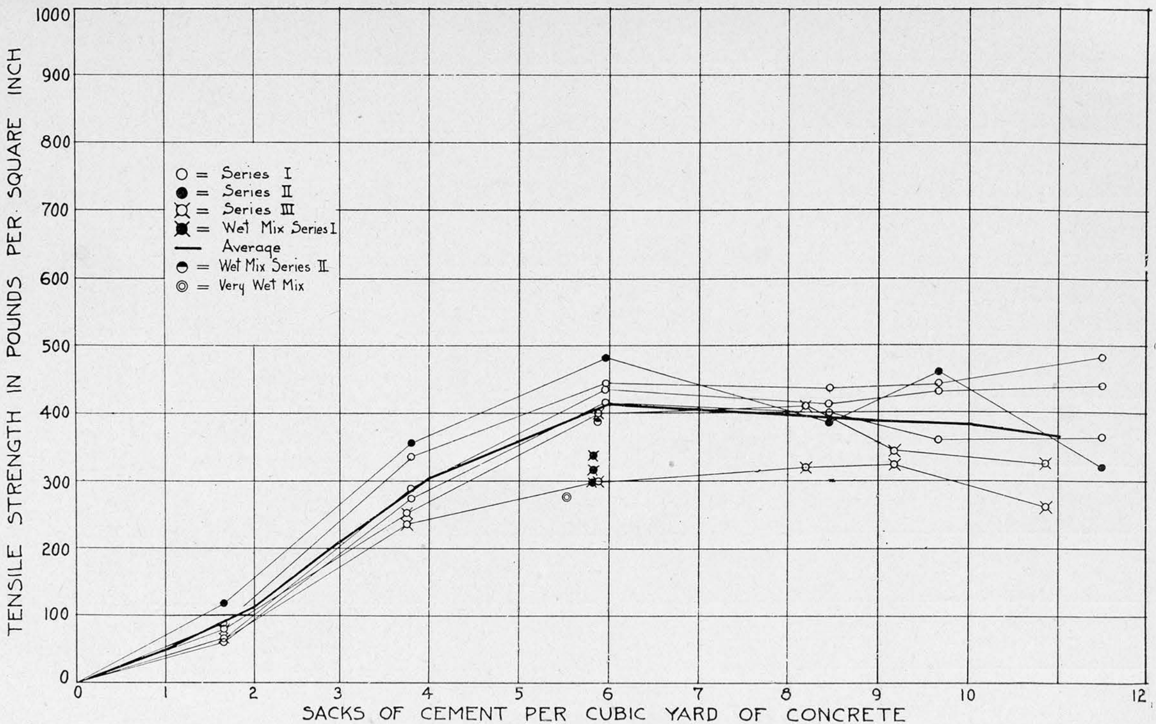


Fig. 24. Ultimate Tensile Strength of Gravel Concrete, Age 3 Months.

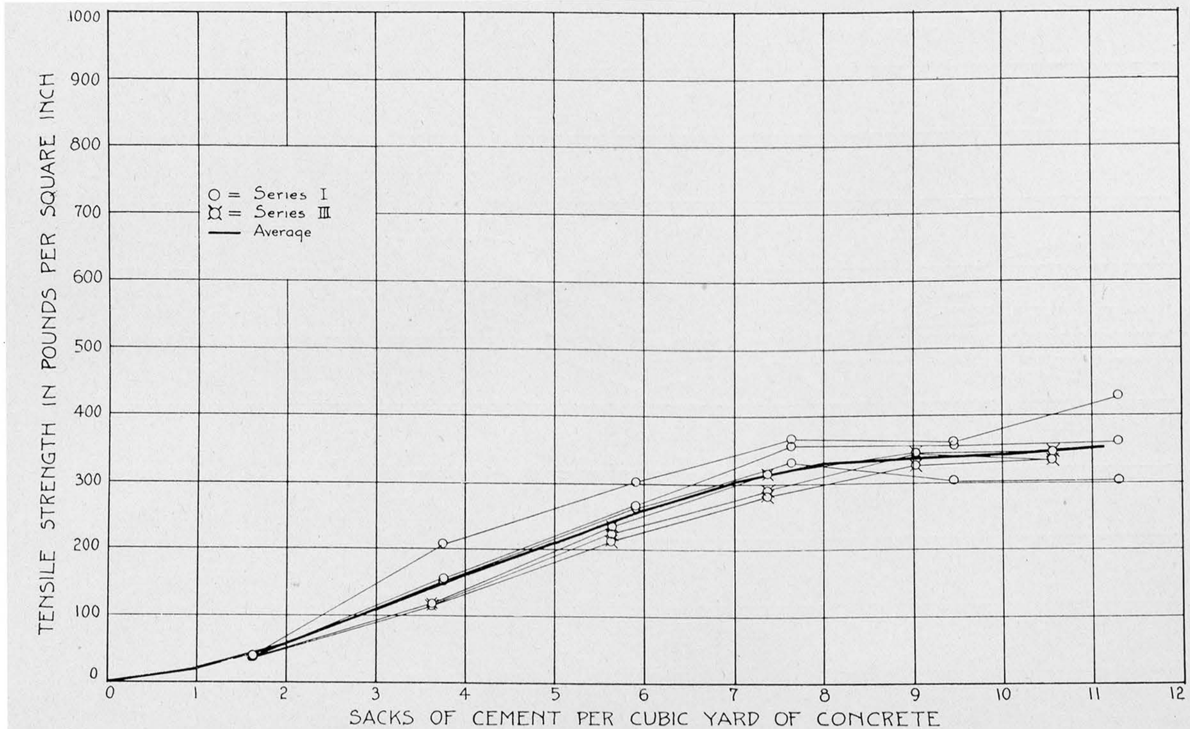


Fig. 25. Ultimate Tensile Strength of Broken Stone Concrete, Age 12 Days.

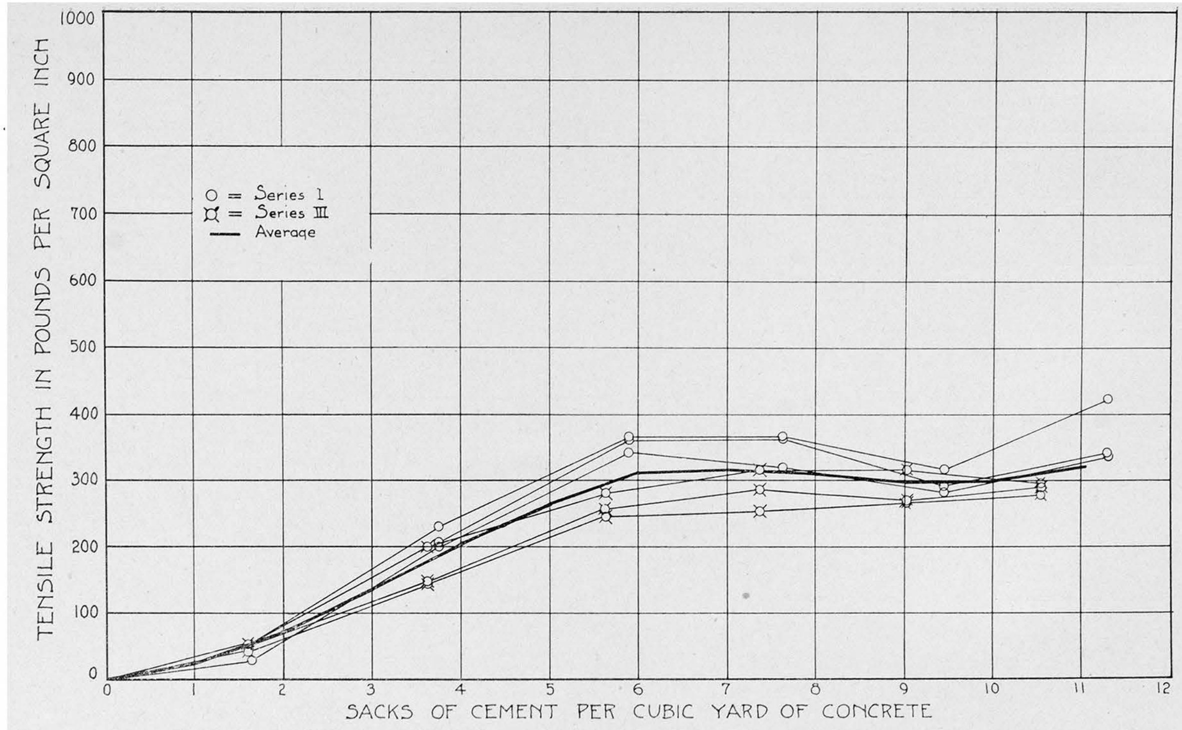


Fig. 26. Ultimate Tensile Strength of Broken Stone Concrete, Age 28 Days.

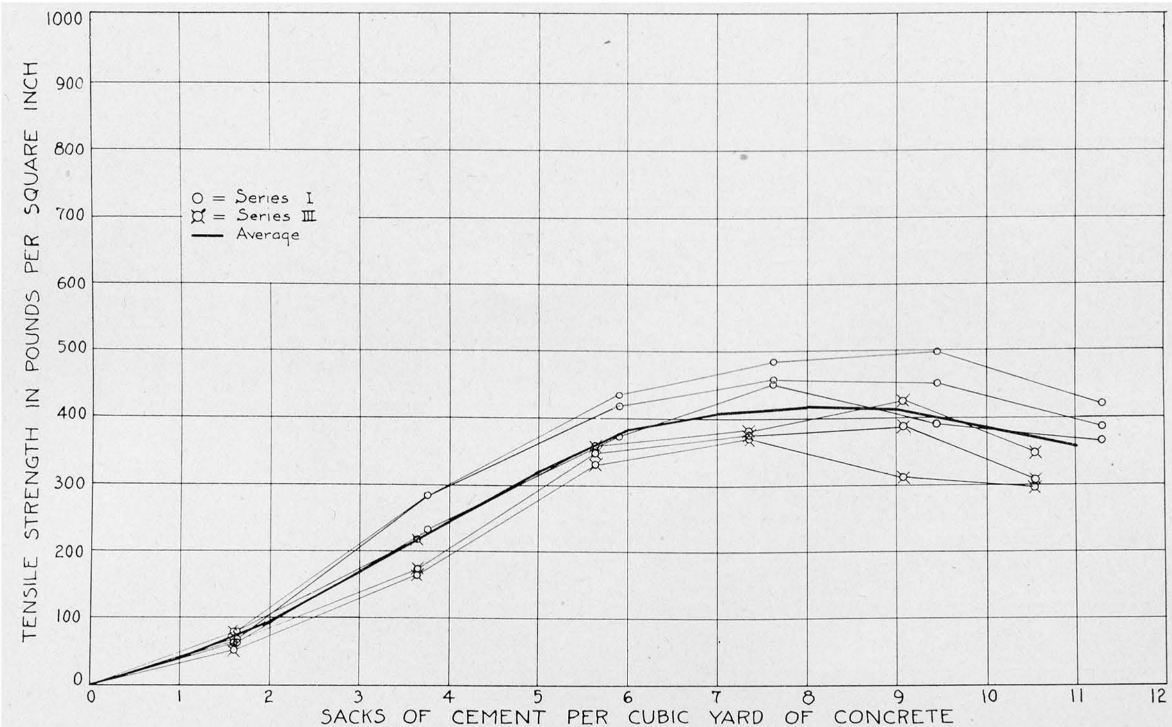


Fig. 27. Ultimate Tensile Strength of Broken Stone Concrete, Age 3 Months.

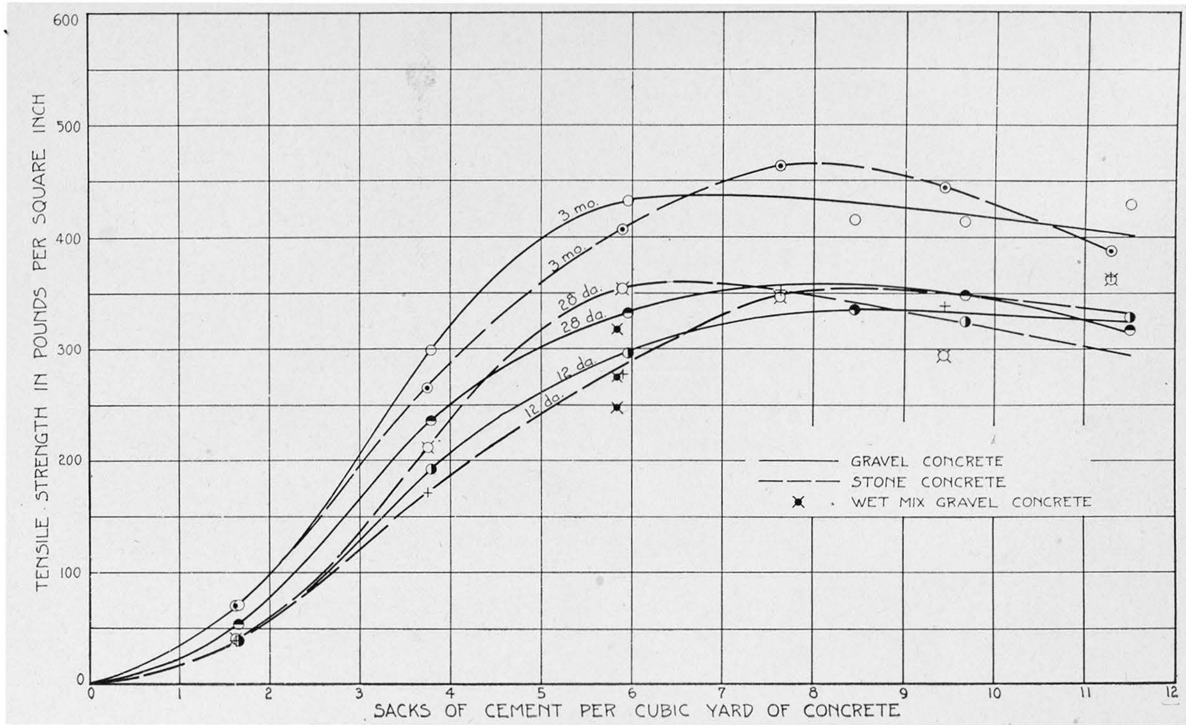


Fig. 28. Ultimate Tensile Strength of Gravel Concrete and Broken Stone Concrete at Different Ages, Series I.

TABLE 18

TENSILE STRENGTH OF GRAVEL CONCRETE, SERIES I
(Each Result the Average of Three Specimens 5"x5")

Sacks of cement per cu. yd. of concrete	Ultimate unit stress in pounds per square inch		
	Age 12 days	Age 28 days	Age 3 months
1.66	39	†54	71
3.80	193	236	299
*5.82	247	275	317
5.96	296	332	432
8.45	330	335	416
9.67	324	349	414
11.50	328	316	429

*The "wet" mix.
†Two specimens.

TABLE 19

TENSILE STRENGTH OF GRAVEL CONCRETE, SERIES II
(Each Result from Test of One Specimen 5"x5")

Sacks of cement per cu. yd. of concrete	Ultimate unit stress in pounds per square inch		
	Age 12 days	Age 28 days	Age 3 months
1.66	48	80	116
3.80	212	332	358
*5.54	176	231	273
†5.86 (5.82)	299	324	387
5.93 (5.96)	312	378	484
8.45	371	357	386
9.67	421	404	462
11.55 (11.50)	372	304	320

*The "very wet" mixture.
†The "wet" mixture.

TABLE 20

TENSILE STRENGTH OF GRAVEL CONCRETE, SERIES III
(Each Result the Average of Tests of Two Specimens 5"x5")

Sacks of cement per cu. yd. of concrete	Ultimate unit stress in pounds per square inch		
	Age 12 days	Age 28 days	Age 3 months
1.64	38	70	72
3.76	173	253	244
5.88	246	308	350
8.20	287	281	366
9.18	256	238	335
10.86	275	281	294

TABLE 21

TENSILE STRENGTH OF BROKEN STONE CONCRETE, SERIES I
(Each Result the Average of Tests of Three Specimens 5"x5")

Sacks of cement per cu. yd. of concrete	Ultimate unit stress in pounds per square inch		
	Age 12 days	Age 28 days	Age 3 months
1.63	38	*40	70
3.75	171	211	265
5.90	277	354	406
7.63	352	346	463
9.45	339	294	444
11.30	364	363	388

*Two specimens.

TABLE 22

TENSILE STRENGTH OF BROKEN STONE CONCRETE, SERIES III
(Each Result the Average of Tests of Three Specimens 5"x5")

Sacks of cement per cu. yd. of concrete	Ultimate unit stress in pounds per square inch		
	Age 12 days	Age 28 days	Age 3 months
1.61	36	48	62
3.63	116	164	184
5.64	223	260	345
7.38	294	282	374
9.02	336	282	372
10.53	337	285	317

TRANSVERSE TESTS

Scope of the investigation. For the tests of Series II (no transverse tests were made in Series I), eighteen specimens were made of the gravel concrete, there being three specimens for each different percentage of cement. One of each kind was broken at ages of 12 days, 28 days, and 3 months. In addition, six specimens of "six sack" gravel concrete, three of the "wet" mixture and three of the "very wet" mixture, were made and tested.

For the tests of Series III, thirty six specimens were made of the gravel concrete and fifty four of the broken stone concrete. For each different percentage of cement, there were six specimens of gravel and nine of broken stone concrete, one third of which were tested at the age of 12 days, one third at the age of 28 days, and the remainder after 3 months.

Moulds. For making the beams, moulds which had been used in some former tests were adapted to the size required for this experiment. These were rectangular in cross-section, about six feet long, and were made of two-inch planed lumber. Resting on the bottom, which consisted of a single board 10 inches wide, were the side pieces, 8 inches high, which were held six inches apart by two end pieces. These were kept in position by cleats nailed to the sides. The various parts were held together and the sides prevented from spreading by yokes drawn up tightly about the mould with long bolts. On the removal of the bolts, the side and end pieces could readily be removed. As it was desired to have specimens of 6"x6"x3'-0", it was necessary to place on the bottom of the mould a piece two inches thick and to insert at the middle a galvanized iron plate which divided the mould so that two beams three feet long could be made.

Mixing, placing, etc. The concrete for each percentage of cement was mixed as already described and placed in the moulds in layers of about two inches and thoroughly tamped. The specimens were smoothed off on top and the next day they were carefully removed from the moulds and stored as in the preceding tests until the time of breaking.

Testing. One specimen for each batch mixed was broken at the end of each period.

The beams were tested on an Olsen three-screw 100,000# universal testing machine. The method of applying the load, together with the essential dimensions, is shown in the sketch, Fig. 29. An 8″ I beam was first laid flat on the weighing table of the

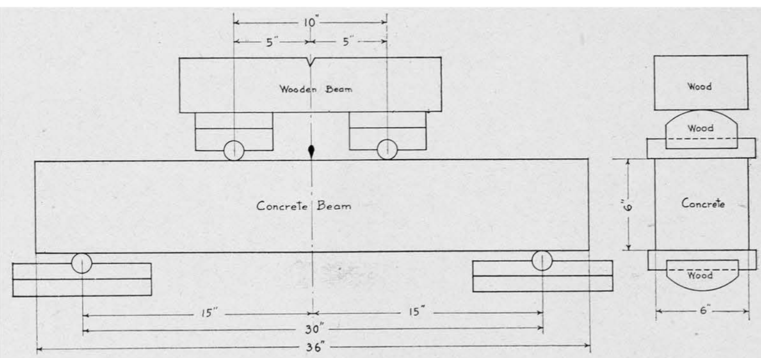


Fig. 29. Sketch Showing Method of Testing Concrete Beams.

machine. On this were placed the two supports consisting of wood blocks, turned to a radius of about three inches on the under side with a semi-circular groove on the top side, in which rested a 1 ¼″ iron roller. These supports were spaced the proper distance apart and the beam placed directly on the rollers, no plates being inserted between the two. On the top side were used two blocks with rollers similar to those used on the under side, except that the blocks were inverted as can be seen on the drawing. By means of a short wooden beam under which the specimen was carefully centered by using the plumb bob shown in the sketch, the load was transferred from the movable cross-head to the two rollers on the top of the concrete beam. The above arrangement permitted of an even bearing at both load and support points, avoiding the bad effects of any twist or inequality in the beam to be tested. During the test, the machine was operated slowly and continuously by motor up to rupture.

Results. Table 23 gives the results of the tests of Series II, the gravel concrete. Table 24 gives the results of the tests of the gravel concrete of Series III, while Table 25 gives those of the broken stone concrete of this series. These values were determined by calculating the moment at the center due to the weight of the beam and the ultimate load and applying the formula for flexure, $Mc=SI$.

Figs. 30 to 32 show the curves for the gravel concrete and Figs. 33 to 35 give those for the broken stone concrete. On these curve sheets will be found a point for the test of each beam. The light curves were determined by joining in order the points showing the results of individual tests for each series, while the heavy curves were obtained as already described for the compressive tests and represent average values of all series for a concrete of a given coarse aggregate and of a certain age.

Particular attention is called to the results of the tests on the "wet" mixture and the "very wet" mixture of Series II. These are shown in Figs. 30 to 32.

TABLE 23

MODULUS OF RUPTURE OF GRAVEL CONCRETE, SERIES II

(Each Result from Test of One Beam)

Sacks of cement per cu. yd. of concrete	Modulus of rupture in pounds per square inch		
	Age 12 days	Age 28 days	Age 3 months
1.66	95	132	
3.80	296	436	547
*5.54	366	401	464
†5.86 (5.82)	464	563	690
5.93 (5.96)	519	435	602
8.45	544	520	470
9.67	551	527	599
11.55 (11.50)		611	581

*The "very wet" mix.
†The "wet" mix.

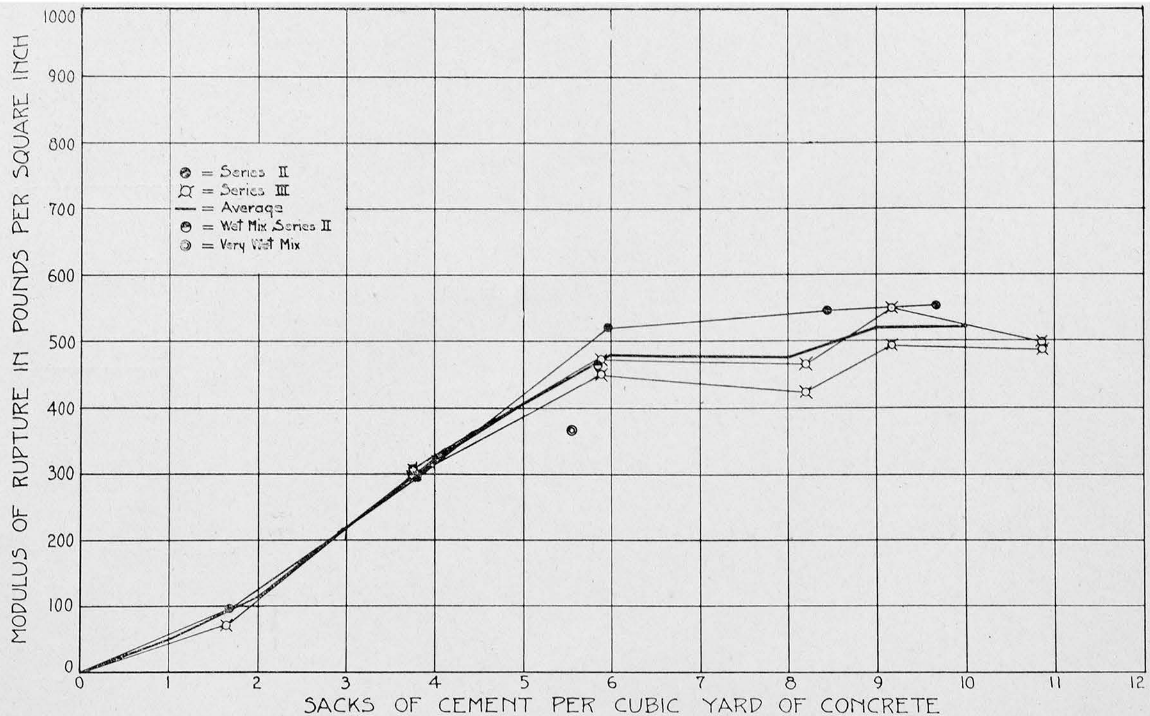


Fig. 30. Modulus of Rupture of Gravel Concrete, Age 12 Days.

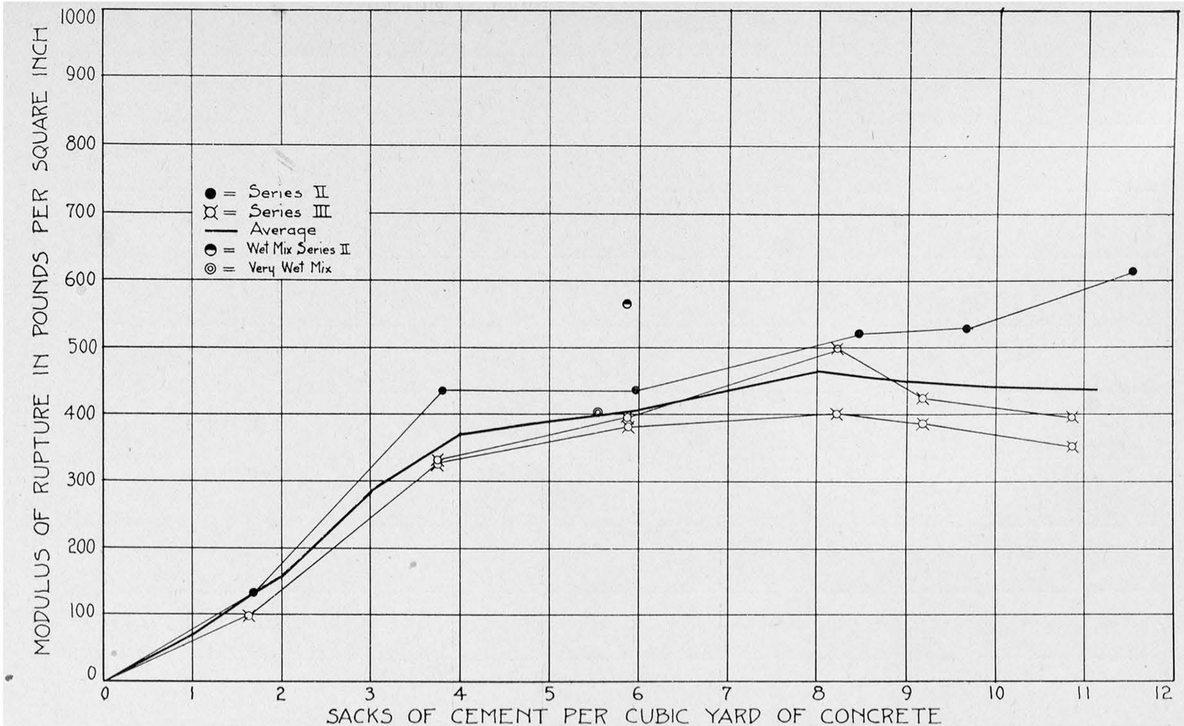


Fig. 31. Modulus of Rupture of Gravel Concrete, Age 28 Days.

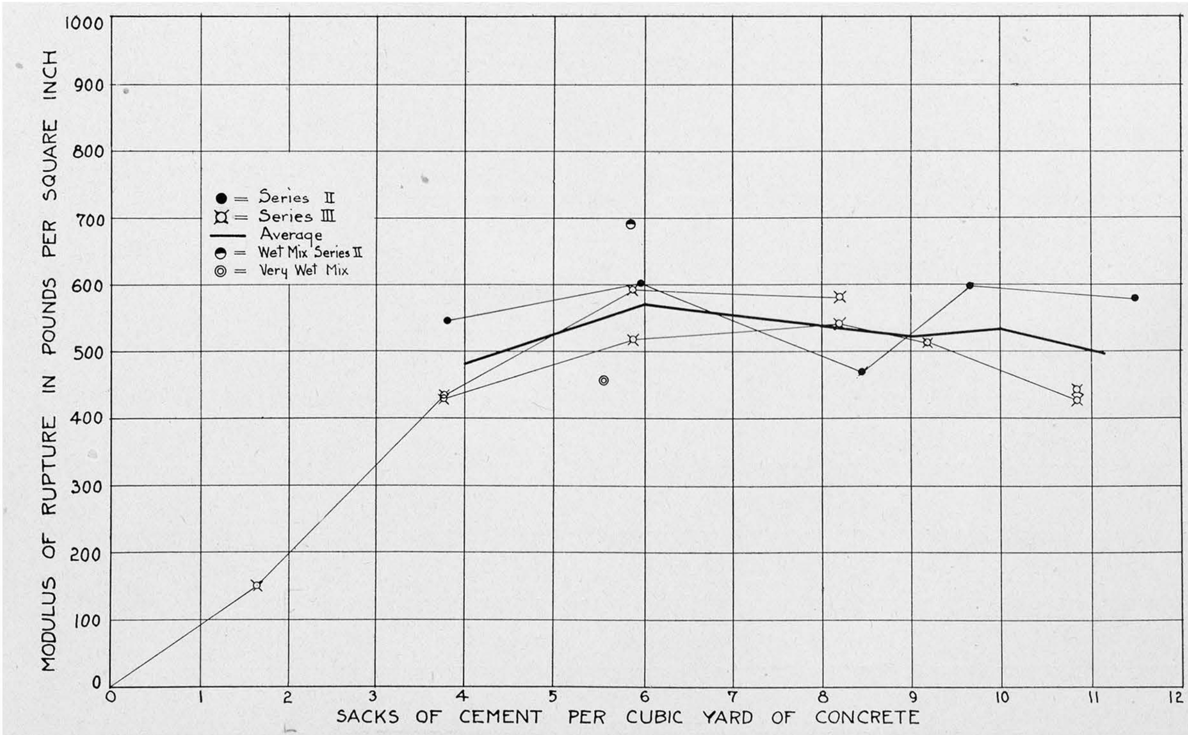


Fig 32. Modulus of Rupture of Gravel Concrete, Age 3 Months.

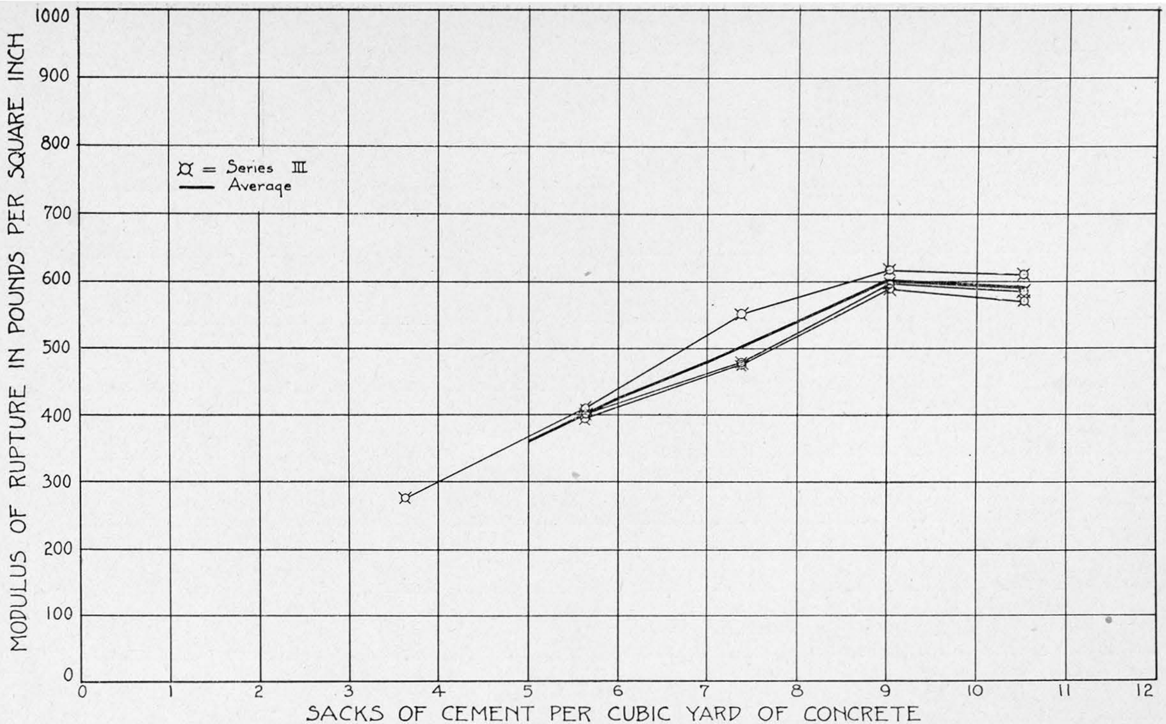


Fig. 33. Modulus of Rupture of Broken Stone Concrete, Age 12 Days.

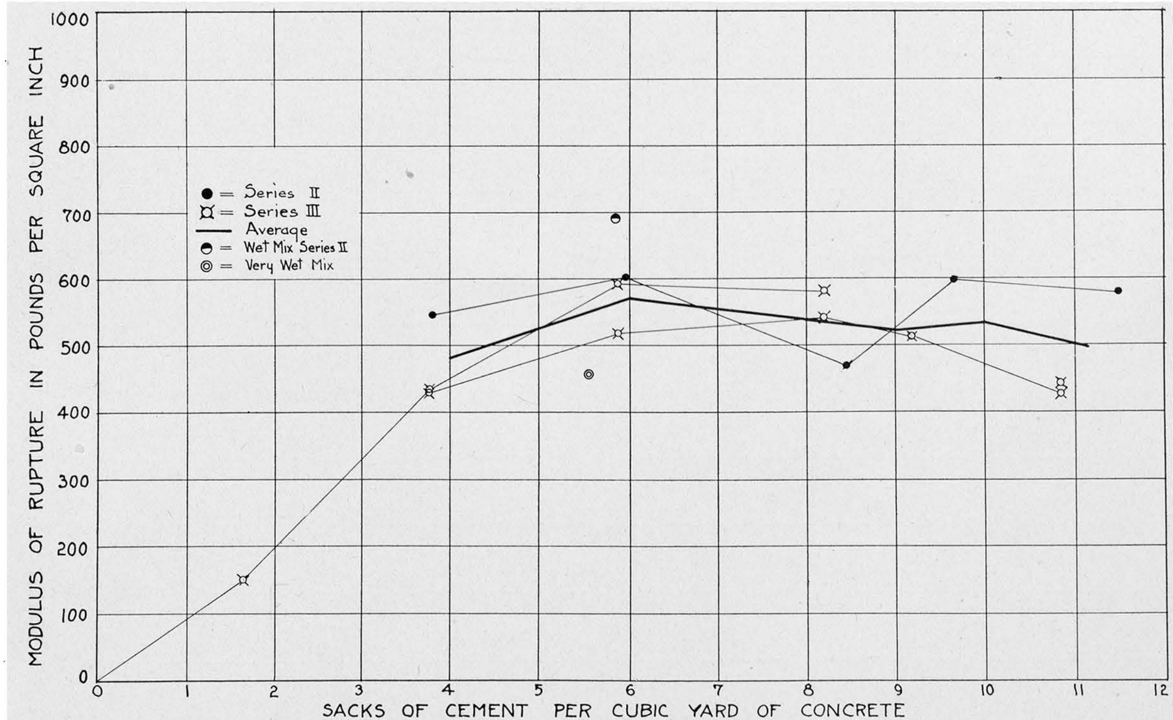


Fig 32. Modulus of Rupture of Gravel Concrete, Age 3 Months.

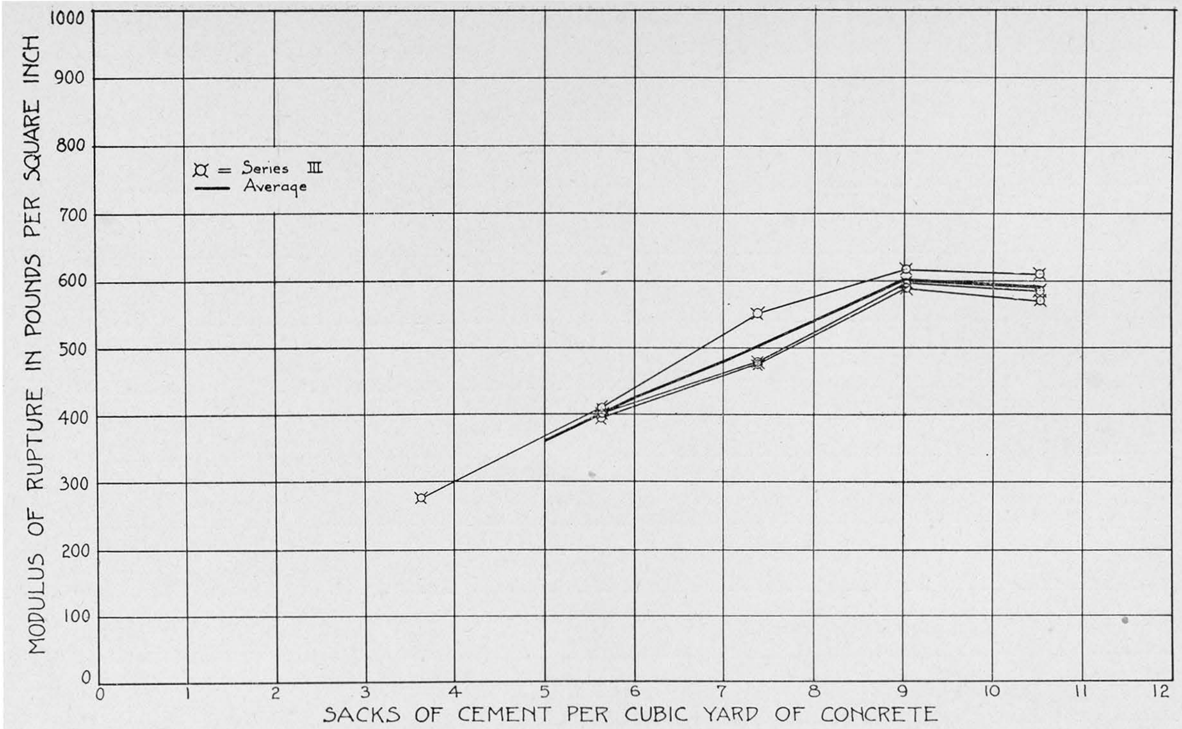


Fig. 33. Modulus of Rupture of Broken Stone Concrete, Age 12 Days.

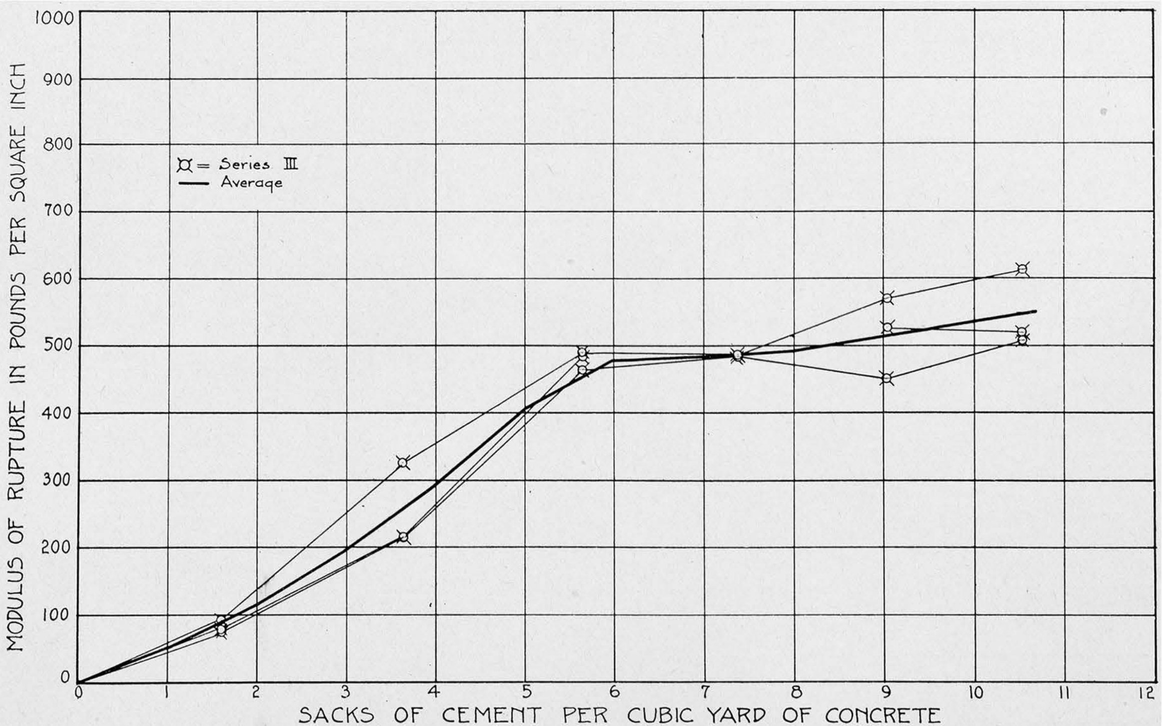


Fig. 34. Modulus of Rupture of Broken Stone Concrete, Age 28 Days,

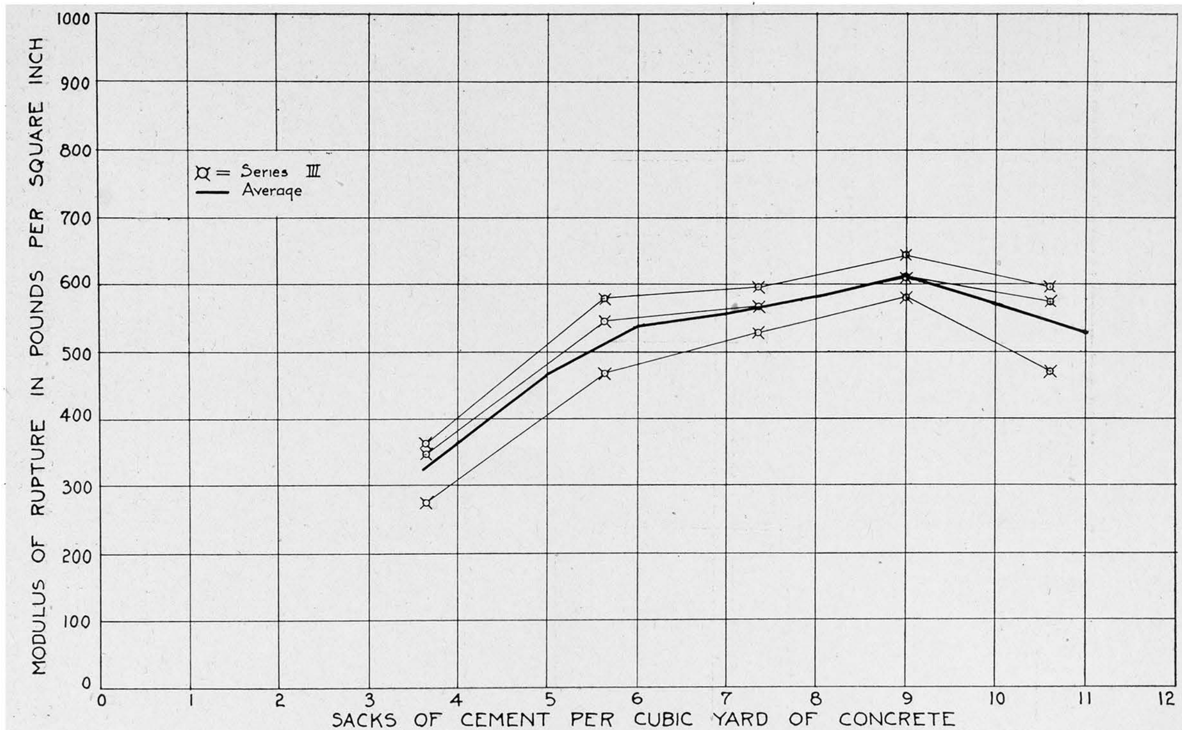


Fig. 35. Modulus of Rupture of Broken Stone Concrete, Age 3 Months.

TABLE 24

MODULUS OF RUPTURE OF GRAVEL CONCRETE, SERIES III

(Each Result the Average from Tests of Two Beams)

Sacks of cement per cu. yd. of concrete	Modulus of rupture in pounds per square inch		
	Age 12 days	Age 28 days	Age 3 months
1.64	*70	*96	*151
3.76	301	328	430
5.88	460	386	556
8.20	443	449	562
9.18	520	404	*510
10.86	492	370	434

*One specimen.

TABLE 25

MODULUS OF RUPTURE OF BROKEN STONE CONCRETE, SERIES III

(Each Result the Average from Tests of Three Beams)

Sacks of cement per cu. yd. of concrete	Modulus of rupture in pounds per square inch		
	Age 12 days	Age 28 days	Age 3 months
1.61		81	*71
3.63	*274	252	328
5.64	400	478	531
7.38	507	†484	563
9.02	598	515	610
10.53	586	547	545

*One specimen.
†Two specimens.

BOND TESTS

Scope of the investigation. For the tests of Series I, seventy two specimens of standard consistency were made, each a concrete cylinder about six inches in diameter and seven inches long, embedded in which was a 5/8″ round steel rod. One half of these were of broken stone concrete, the other half of gravel. For each different percentage of cement, there were six specimens. Three of each kind were broken at ages of 12 days and 28 days to obtain the unit bond stress at first slip of steel, taken at a slip of .0002 of an inch, at a slip of .001 of an inch, and at failure. In addition, six specimens of "six sack" gravel concrete, the "wet" mixture, were made and tested as outlined above.

For the tests of Series II, eighteen specimens were made of the gravel concrete, there being three specimens for each different percentage of cement. One of each kind was broken at ages of 12 days, 28 days, and 3 months. In addition, six specimens of "six sack" gravel concrete, three of the "wet" mixture and three of the "very wet" mixture, were made and tested.

For the tests of Series III, thirty six specimens were made of the gravel concrete and fifty four of the broken stone concrete. For each different percentage of cement, there were six specimens of gravel and nine of broken stone concrete, one third of which were tested at the age of 12 days, one third at the age of 28 days, and the remainder after 3 months.

Moulds. For making the bond tests, some empty tin cans about six inches in diameter and seven inches long, were used as moulds. The top of the can was removed and a hole made in the center of the bottom through which could be passed the rod to be tested. This can was set on a wooden frame holding a 1″x8″ laid flat and containing holes slightly larger than the diameter of the rods. About fourteen inches beneath this piece was a second 1″x8″ parallel to the first and with holes vertically below those in the top piece. Immediately beneath was a support for the rods. Through the opening in the bottom of the can and the two holes in the boards, the rod was passed and in this way held in position during the placing of the concrete. The rod was allowed to project above the mould about two inches.

Steel. The steel was 5/8″ round stock material, free from rust but not polished or rubbed smooth.

Mixing, placing, etc. The concrete for each percentage of cement was mixed as already described and placed in the moulds in layers of two to three inches, being thoroughly tamped. After setting until the next day, the specimens were placed under water, without having the tin cover removed, and stored as already described until the time for breaking.

Testing. The specimens of Series I broken at the end of each period were selected so that part were taken from the first batch mixed and part from the second batch. In Series II and III, one specimen from each batch mixed was broken at the end of each period. Several hours before breaking, that part of the specimen against which the force would be exerted in the test was covered with a thin layer of plaster of Paris on the outside of the can to give a smooth bearing.

An Olsen 100,000 pound universal machine was used to make the tests. In order that the load at first slip and the corresponding slips for subsequent loads might be obtained, a special attachment was required to measure the movement of that part

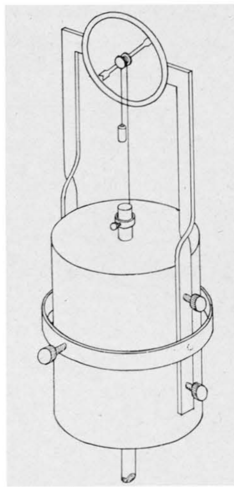


Fig. 36. Sketch Showing Apparatus Attached to Bond Specimen for Determining the Slip of Bar.

of the rod projecting through the top of the concrete. This apparatus (See Fig. 36) consisted of two steel uprights fastened to the specimen by four thumb-screws and kept from spreading at the lower ends by a circular band enclosing the can and at the top ends by a bar passing about 6 or 7 inches over the specimen. To this bar was attached the dial used in the compressive tests. A fine wire passed around the cylinder connected to this dial and was fastened through a clamp to the end of the rod. By means of this apparatus, the movement of the bar could be measured to 1/5,000 of an inch.

In the tests of Series I, the specimen was placed on a steel plate with a leather pad on top of the fixed cross-head of the machine with the rod sticking down through the opening. After carefully centering the specimen, the rod was connected to the movable cross-head with the wedges. In the tests of Series II and III, two plates with holes, through which the rods would pass, were used. One was placed on top of the fixed cross-head, resting on it, and one was placed on the under side of the specimen to be tested. The projecting rod was gripped by the movable cross-head which was moved down until there was not more than about ⅛ of an inch between the plate on the fixed cross-head and the other one when held tightly against the specimen. Between these two plates, four small wedges were then inserted and lightly driven into place so that the specimen had an even bearing.

The specimen being properly placed, the dial and frame were attached and the zero reading of the pointer taken. The load was then slowly applied, the cross-head moving down at the rate of about .05 of an inch per minute. One observer kept the beam balanced and took the load while a second took slip readings on the dial. These observations were continued until the highest load was obtained.

In all of the 28-day tests and some of the 12-day tests of Series I, the bars were completely pulled out of the specimen resisting the greatest pull and the one standing the least pull in each set of specimens, and the cylinders of concrete remaining were then tested in conpression after removing the tin cans.

Results. Tables 26 to 28 show the unit bond stresses for gravel concrete at first slip, or slip of .0002 of an inch, at slip of .001 of an inch, and at failure. The total loads by which the first set of values was obtained were read off the beam of the testing machine when the wire wound dial showed a movement of the bar equal to .0002 of an inch. The intermediate values are based on the load-slip curves for the different specimens. Tables 29 and 30 show the results for the broken stone concrete determined as just outlined for the gravel concrete.

The curves for the 12-day and 28-day results are shown in Figs. 37 and 38 for the gravel concrete, which in Figs. 39 and 40 are shown the corresponding curves for the broken stone concrete. Particular attention is called to the values indicated by ⊠ Figs. 37 and 38 and by ◓ and ◉ of these figures. The first shows the results of the "six sack" "wet" mix of Series I, the second those of the "wet" mix of Series II, and the third those of the "very wet" mix of this series. The method of plotting these curves and of determining the average curve for each kind of concrete at a given age is the same as that already described under the compression tests.

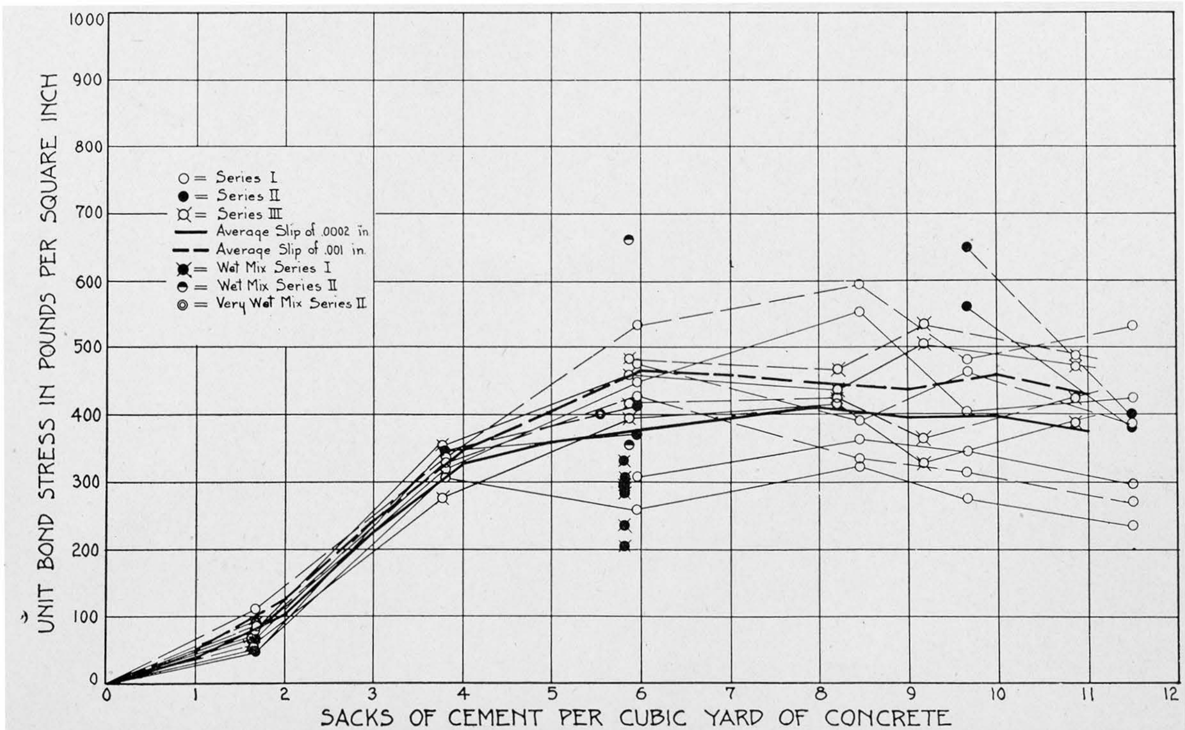


Fig. 37. Bond Stress for Gravel Concrete, Age 12 Days, at Slip of Steel of .0002 and .001 of an Inch.

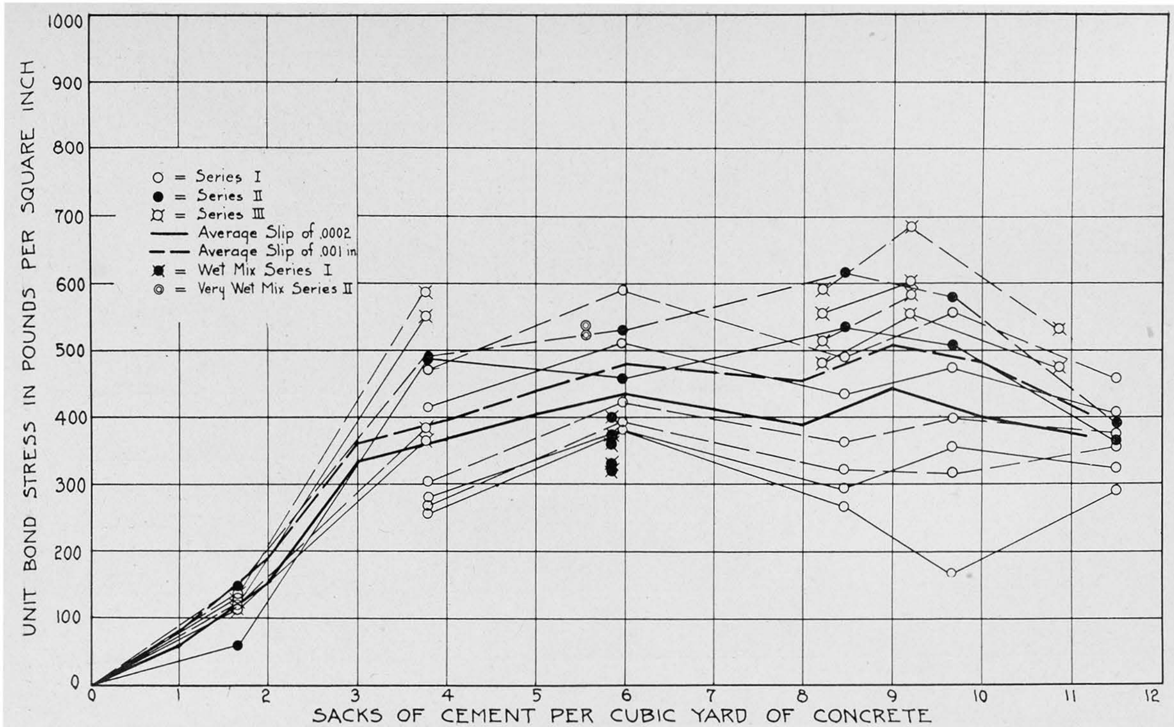


Fig. 38. Bond Stress for Gravel Concrete, Age 28 Days, at Slip of Steel of .0002 and .001 of an Inch.

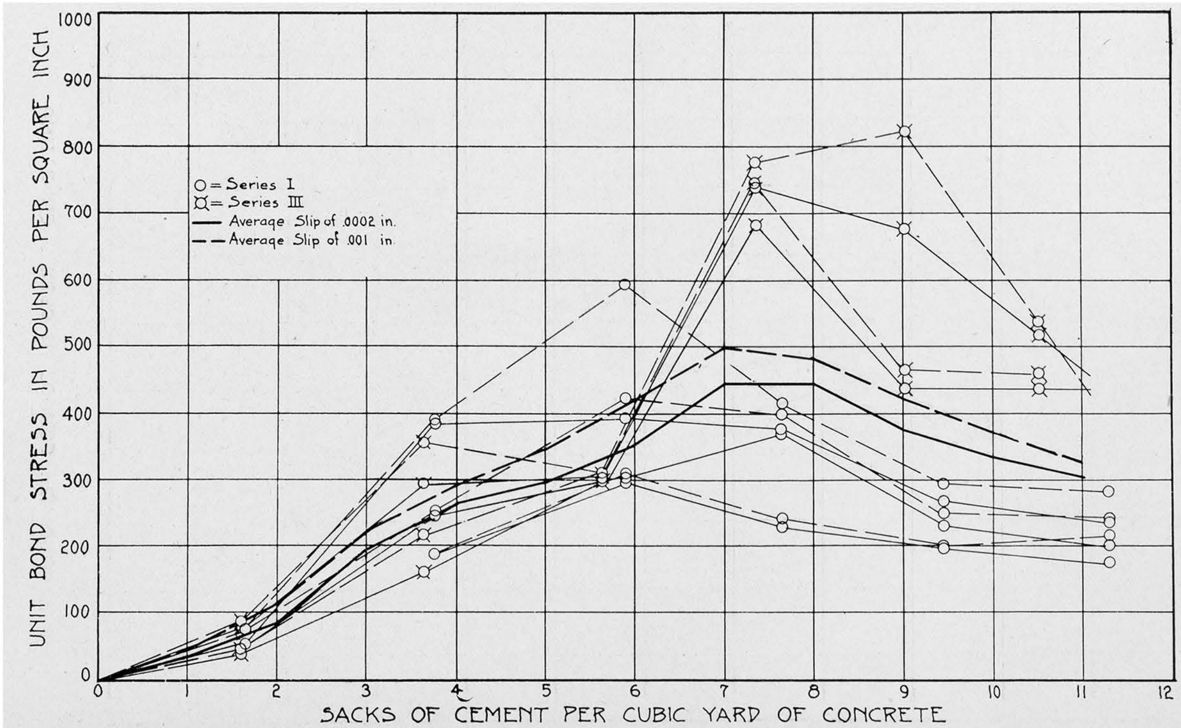


Fig. 39. Bond Stress for Broken Stone Concrete, Age 12 Days, at Slip of Steel of .0002 and .001 of an Inch.

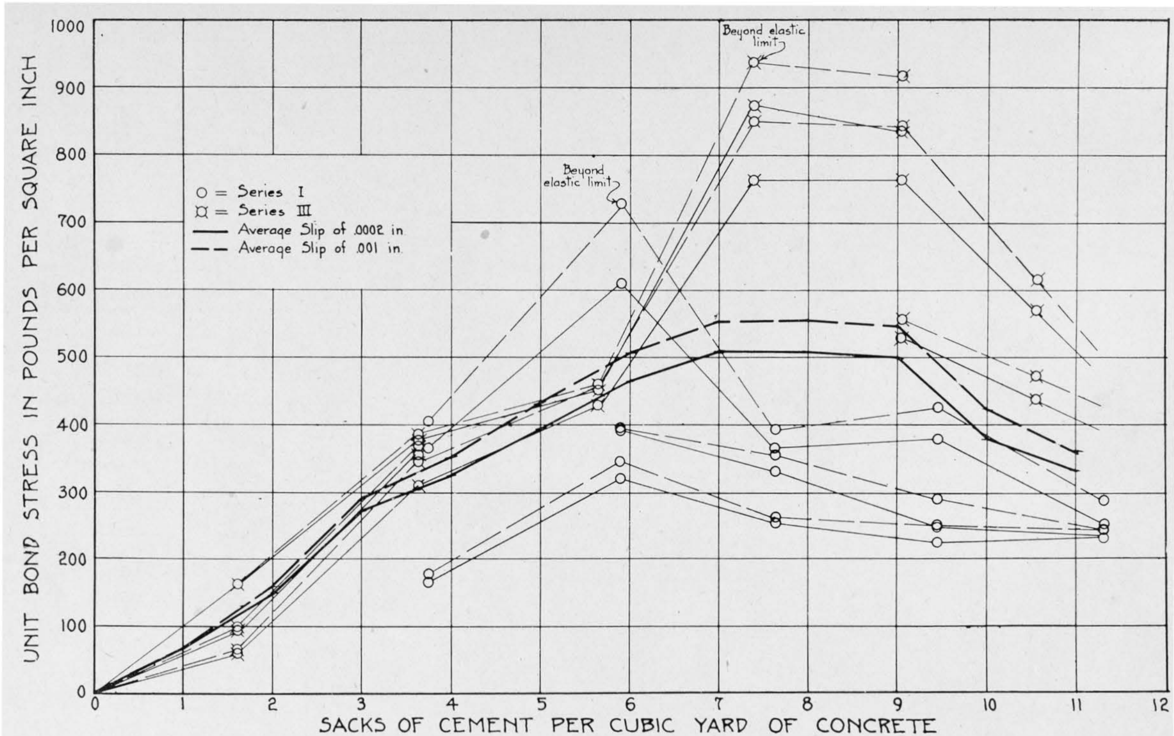


Fig. 40. Bond Stress for Broken Stone Concrete, Age 28 Days, at Slip of Steel of .0002 and .001 of an Inch.

The results of the compressive tests of Series I made on the bond specimens from which the rods had been pulled are not given here; however, it can be said in general for any mix that that specimen testing highest in bond also showed higher unit compressive strength than the one testing lowest in bond. This however was not always the case. Furthermore, the average unit crushing strengths obtained by compressing the concrete used in the bond tests were much lower than those determined from the special compression tests of similar mixes, the ratio running from 6/10 to 9/10.

TABLE 26

BOND STRENGTH OF GRAVEL CONCRETE, SERIES I

(Each Result the Average of Tests of Three Specimens. Diameter of Bar Was ⅝" with Depth of Embedment of 7". Plain Round Rods Used)

Sacks of cement per cu. yd. of concrete	Unit bond stress in pounds per square inch at slip of .0002 of an inch		Unit bond stress in pounds per square inch at slip of .001 of an inch		Ultimate unit bond stress in pounds per square inch	
	Age 12 days	Age 28 days	Age 12 days	Age 28 days	Age 12 days	Age 28 days
1.66	65		80		120	
3.80	†315	315	†330	350	†415	410
*5.82	260	335	295	380	430	445
5.96	335	420	465	470	‡655	‡675
8.45	415	330	435	390	‡595	‡630
9.67	340	330	425	430	§725	‡650
11.50	320	340	400	400	¶765	‡595

*"Wet" mixture.
†Two specimens.
‡Elastic limit of steel passed in case of one specimen.
§Elastic limit of steel passed in case of two specimens.
¶Elastic limit of steel passed in case of three specimens.

TABLE 27

BOND STRENGTH OF GRAVEL CONCRETE, SERIES II

(Each Result Determined from the Test of One Specimen. The Diameter of the Bar Was ⅝" with Depth of Embedment of 7". Plain Round Rods Were Used)

Sacks of cement per cu. yd. of concrete	Unit bond stress in pounds per square inch at slip of .0002 of an inch			Unit bond stress in pounds per square inch at slip of .001 of an inch			Ultimate unit bond stress in pounds per square inch		
	Age 12 days	Age 28 days	Age 3 mo.	Age 12 days	Age 28 days	Age 3 mo.	Age 12 days	Age 28 days	Age 3 mo.
1.66	45	60	145	70	150	145	75	170	170
3.80	340	485	455	345	490		415	500	490
†5.54	400	520	655		535		435	555	‡730
*5.86 (5.82)	355			660			‡680	‡765	‡830
5.93 (5.96)	370	460	680	410	530		510	‡715	‡715
8.45		535			615			‡715	‡754
9.67	560	510		650	580		‡735	‡690	
11.55 (11.50)	380	365	510	400	400	565	‡690	‡690	‡690

*The "wet" mixture.
†The "very wet" mixture.
‡Elastic limit of steel passed

TABLE 28

BOND STRENGTH OF GRAVEL CONCRETE, SERIES III

(Each Result the Average of Tests of Two Specimens Except as Noted. The Diameter of the Bar Was ⅝″ with Depth of Embedment of 7″. Plain Round Rods Were Used)

Sacks of cement per cu. yd. of concrete	Unit bond stress in pounds per square inch at slip of .0002 of an inch			Unit bond stress in pounds per square inch at slip of .001 of an inch			Ultimate unit bond stress in pounds per square inch		
	Age 12 days	Age 28 days	Age 3 mo.	Age 12 days	Age 28 days	Age 3 mo.	Age 12 days	Age 28 days	Age 3 mo.
1.64	70	120	235	80	130	245	120	165	285
3.76	320	460	605		485		375	545	†640
5.88	425		*560	445			535	‡740	†750
8.20	425	520	530	450	560		620	‡704	‡720
9.18	415	580	*565	450	640	*620	580	‡710	†680
10.86	425	*475		460	*535		615	†730	†680

*Result of test of one specimen.
†Elastic limit of steel passed in case of one specimen.
‡Elastic limit of steel passed in case of two specimens.

TABLE 29

BOND STRENGTH OF BROKEN STONE CONCRETE, SERIES I

(Each Result the Average of Tests of Three Specimens. Diameter of Bar was ⅝″ with Depth of Embedment of 7″. Plain Round Rods Used)

Sacks of cement per cu. yd. of concrete	Unit bond stress in pounds per square inch at slip of .0002 of an inch		Unit bond stress in pounds per square inch at slip of .001 of an inch		Ultimate unit bond stress in pounds per square inch	
	Age 12 days	Age 28 days	Age 12 days	Age 28 days	Age 12 days	Age 28 days
1.63	*50		*75		*110	
3.75	275	*265	280	*295	310	*345
5.90	335	440	445	†490	570	†595
7.65	325	315	350	335	515	565
9.45	230	280	245	320	470	†6[illegible]5
11.30	205	235	245	260	555	495

*Two specimens.
†Elastic limit of steel passed in case of one specimen.

TABLE 30

BOND STRENGTH OF BROKEN STONE CONCRETE, SERIES III

(Each Result the Average of Tests of Three Specimens, except as Noted. The Diameter of Bar Was ⅝″ with Depth of Embedment of 7″ except for Last Half, Where Depth Was 5″. Plain Round Rods were Used)

Sacks of cement per cu. yd. of concrete	Unit bond stress in pounds per square inch at slip of .0002 of an inch			Unit bond stress in pounds per square inch at slip of .001 of an inch			Ultimate unit bond stress in pounds per square inch		
	Age 12 days	Age 28 days	Age 3 mo.	Age 12 days	Age 28 days	Age 3 mo.	Age 12 days	Age 28 days	Age 3 mo.
1.61	55	105	90	65	115	130	100	135	180
3.63	*225	345	365	*285	370	425	*335	450	545
5.64	*300	*430	435	*310	*460	530	*340	*5[illegible]0	610
7.38	*710	*820	*765	*760			*860	‡1015	‡1145
9.02	*560	715	*575	*640	775	*730	*800	‡885	‡1055
10.53	*475	*500	475	*505	*550	555	*595	710	†775

*Two specimens.
†Elastic limit of steel passed in case of one specimen.
‡Elastic limit of steel passed in case of two specimens.

PERMEABILITY TESTS

Scope of the investigation. For these tests, made only in Series I, twelve specimens of the standard consistency were made from which thirty six small specimens were prepared. One half of these were of broken stone concrete and the other half of gravel. For each percentage of cement, there was one large specimen. To find the permeability, these specimens were subjected to water pressures of ten, thirty, and fifty pounds per square inch. In addition, a specimen of the "six sack" gravel concrete, the "wet" mixture, was prepared and tested.

Moulds. The moulds used in making the specimens for the permeability tests consisted of pieces of No. 24 galvanized iron pipe four inches in inside diameter and fourteen inches long.

Mixing, placing, etc. The moulds with the inside walls free from grease, clean and bright, were placed on a greased galvanized iron plate. The concrete for each percentage of cement was mixed in one batch as already described and put in place in layers of about three inches, being tamped with an iron rod one inch in diameter and weighing two and one half pounds. The specimens were smoothed off on top and after one day were stored under water without removing the moulds. After twelve days from the time of mixing, they were removed from the water and left in dry air until tested.

Testing. The specimen was prepared for testing by sawing three equal lengths out of the middle without removing the covering, making three pieces four inches in diameter and four inches long. On the top and bottom of each of these but separated from the concrete by rubber packing, two and one half inch pipe flanges were placed. Connecting these flanges were five bolts which were tightly drawn up so that no water could leak around the packing. One opening was bushed down for connecting a pressure pipe, while the other opening was left free for water leaking through to pass out. This arrangement reduced to a minimum the effect of any leakage between the concrete and the wall of the enclosing pipe mould. The area exposed to the water pressure was about 5¼ square inches.

These small specimens, six at a time, were connected with the city water mains by means of three-quarter inch pipes. To the main inlet pipe, a pressure gage was attached together with a valve and waste pipe for regulating the pressure. When a test was to be run, the pressure was set and the amount of leakage was obtained by catching and taking the time required. This was repeated at intervals after the specimens had been subjected to pressure for different periods. Tests like the above were made for unit pressure of 10 pounds per square inch at the age of one month, 30 pounds per square inch at two months, and 50 pounds per square inch at three months. The leakage was caught and accurately weighed whenever of sufficient amount, while for the more impervious specimens, the appearance of the free surface was noted as to whether it was wet, moist, or dry.

After the completion of these tests, the iron cover was removed and the condition of the sides carefully examined. The specimen in each set showing up worst in respect to the "pockets" in the concrete or apparent leakage along the walls (if this specimen also appeared to show the greatest leakage) was then excluded in arriving at conclusions in regard to the permeability of the concrete. Otherwise the results from all these specimens were recorded.

After this inspection, the specimens were dressed down on the sides with an emery wheel to take off the thin skin of neat cement which had flushed to the surface due to the tamping of the concrete. They were then thoroughly dried out until they ceased to lose weight. On removal from the drying oven, they were immersed in water and kept there until they ceased to gain in weight. The total increase in weight was then compared with the initial weight when dry. In this way a measure of their porosity was obtained.

Results. The results of the permeability tests are shown in tables 31 to 36 and those of the porosity tests are given in tables 37 and 38.

TABLE 31

PERMEABILITY TEST OF GRAVEL CONCRETE UNDER PRESSURE OF TEN POUNDS PER SQUARE INCH, SERIES I

(Age at Time of Test About One Month)

Sacks of cement per cu. yd. of concrete	No. of spec.	Number of grams of water passing through in 5 minutes and condition of surface of specimen after being under pressure							
		1 hr.	6 hrs.	1 day	2 days	3 days	4 days	5 days	6 days
1.66	3	moist	3.0	2.0	1.3	0.75		1.08	1.0
3.80	2	moist	moist	moist	0.01	moist	0.004	moist	dry
*5.82	3	2 dry 1 moist on edge	2 dry 1 moist on edge	dry	dry	dry		dry	dry
5.96	2	dry	dry	dry	dry	dry			
8.45	2	dry	dry	dry	dry	dry	dry	dry	
9.67	3	dry	dry	dry	2 dry 1 moist on edge	2 dry 1 moist on edge	2 dry 1 moist on edge	1 dry 2 moist on edge	
11.50	3	dry	dry	dry	2 dry 1 moist on edge		2 dry 1 moist on edge		

*The "wet" mixture.

TABLE 32

PERMEABILITY TEST OF GRAVEL CONCRETE UNDER PRESSURE OF THIRTY POUNDS PER SQUARE INCH, SERIES I

(Age at Time of Test About Two Months)

Sacks of cement per cu. yd. of concrete	No. of spec.	Number of grams of water passing through in 5 minutes and condition of surface of specimen after being under pressure							
		1 hr.	6 hrs.	1 day	2 days	3 days	4 days	5 days	6 days
1.66	3	15.7	15.5	11.0	8.0	6.4		6.3	6.3
3.80	2	dry	dry	dry	dry		0.01	0.01	wet
*5.82	3	1 dry 2 moist on edge	1 dry 2 moist on edge		dry	dry	dry	dry	
5.96	2	dry	dry	dry	dry	dry	dry	dry	
8.45	2	1 dry 1 moist on edge	dry	dry	dry	dry	dry		dry
9.67	3	dry	dry	dry	2 dry 1 moist on edge	dry	dry		
11.50	3	moist	2 dry 1 moist on edge	2 dry 1 moist on edge	2 dry 1 moist	2 dry 1 moist	2 dry 1 moist		2 dry 1 moist

*The "wet" mixture.

TABLE 33

PERMEABILITY TEST OF GRAVEL CONCRETE UNDER PRESSURE OF FIFTY POUNDS PER SQUARE INCH, SERIES I

(Age at Time of Test About Three Months)

Sacks of cement per cu. yd. of concrete	No. of spec.	Number of grams of water passing through in 5 minutes and condition of surface of specimen after being under pressure							
		1 hr.	6 hrs.	1 day	2 days	3 days	4 days	5 days	6 days
1.66	3	28.1	31.0	25.2	23.8	21.3	17.3	15.6	14.2
3.8	2	dry	dry	moist	moist	moist	moist	mo'st	moist
*5.82	3	dry	dry	dry	dry	dry		dry	dry
5.96	2	dry	dry	dry	dry	dry		dry	dry
8.45	2	dry	dry	dry	dry		dry	dry	dry
9.67	3	moist	1 dry 2 moist	1 dry 2 moist	1 dry 2 moist	moist	moist		moist
11.50	3	moist	moist	moist	moist	1 dry 2 moist	moist		moist

*The "wet" mixture.

TABLE 34

PERMEABILITY TEST OF BROKEN STONE CONCRETE UNDER PRESSURE OF TEN POUNDS PER SQUARE INCH, SERIES I

(Age at Time of Test About One Month)

Sacks of cement per cu. yd. of concrete	No. of spec.	Number of grams of water passing through in 5 minutes and condition of surface of specimen after being under pressure							
		1 hr.	6 hrs.	1 day	2 days	3 days	4 days	5 days	6 days
1.63	3	wet	3.75	1.92	1.92	0.92		0.69	1.00
3.75	2	dry	moist	0.08	0.17	0.01	0.004	0.01	
5.90	3	dry	1 dry 2 moist on edge	1 dry 2 moist on edge	1 dry 2 moist on edge	1 dry 2 moist on edge	1 dry 2 moist on edge		
7.63	3	dry	dry	dry	dry	dry	dry	dry	2 dry 1 moist
9.45	3	dry	dry	2 dry 1 moist					
11.50	3	dry	dry	2 dry 1 moist on edge	2 dry 1 moist on edge	2 dry 1 moist on edge	dry	dry	dry

TABLE 35

PERMEABILITY TEST OF BROKEN STONE CONCRETE UNDER PRESSURE OF THIRTY POUNDS PER SQUARE INCH, SERIES I

(Age at Time of Test About Two Months)

Sacks of cement per cu. yd. of concrete	No. of spec.	Number of grams of water passing through in 5 minutes and condition of surface of specimen after being under pressure							
		1 hr.	6 hrs.	1 day	2 days	3 days	4 days	5 days	6 days
1.63	3	16.3	17.5	13.6		5.9	7.0	6.1	6.3
3.75	2	moist	0.04	0.05	0.02	0.02	dry	1 dry 1 wet	
5.90	3	dry	dry	moist on edge	dry	dry	dry	dry	dry
7.63	3	dry	dry	dry	dry		dry	dry	dry
9.45	3	dry	dry	2 dry 1 moist	2 dry 1 moist	1 dry 2 moist	1 dry 2 moist	1 dry 2 moist	1 dry 2 moist
11.30	3	moist on edge	moist on edge	moist on edge	1 dry 2 moist on edge		2 dry 1 moist	2 dry 1 moist	2 dry 1 moist

TABLE 36

PERMEABILITY TEST OF BROKEN STONE CONCRETE UNDER PRESSURE OF FIFTY POUNDS PER SQUARE INCH, SERIES I

(Age at Time of Test About Three Months)

Sacks of cement per cu. yd. of concrete	No. of spec.	Number of grams of water passing through in 5 minutes and condition of surface of specimen after being under pressure							
		1 hr.	6 hrs.	1 day	2 days	3 days	4 days	5 days	6 days
1.63	3	50.0	58.6	48.2	45.0	32.6	29.6	35.8	32.2
3.75	2	moist on edge	moist	moist	wet	wet	wet		wet
5.90	3	dry	dry	2 dry 1 moist	2 dry 1 moist		1 dry 2 moist	1 dry 2 moist	2 dry 1 moist
7.63	3	dry	2 dry 1 moist	2 dry 1 moist	2 dry 1 moist	2 dry 1 moist	dry		2 dry 1 moist
9.45	3	dry	dry	2 dry 1 wet			1 dry 2 moist	1 dry 2 moist	1 dry 2 moist
11.30	3	moist on edge	moist on edge	moist on edge	moist on edge	slightly moist	slightly moist		slightly moist

TABLE 37

ABSORPTION TEST OF GRAVEL CONCRETE, SERIES I

(Each Result the Average of Tests of Three Specimens)

Sacks of cement per cu. yd. of concrete	Percentage of increase in weight after —— hours immersion					
	24 hrs.	45 hrs.	48 hrs.	72 hrs.	76 hrs.	96 hrs.
1.66	5.75		5.87			6.00
3.80	4.64	4.70				4.78
*5.82	5.21				5.25	
5.96	3.42		3.46			3.47
8.45			3.77	3.79		
9.67			3.96	4.00		
11.50	3.46				3.46	

*The "wet" mixture.

TABLE 38

ABSORPTION TEST OF BROKEN STONE CONCRETE, SERIES I

(Each Result the Average of Tests of Three Specimens)

Sacks of cement per cu. yd. of concrete	Percentage of increase in weight after —— hours immersion					
	24 hrs.	45 hrs.	48 hrs.	72 hrs.	76 hrs.	96 hrs.
1.63	6.15		6.25			6.35
3.75	5.40	5.47				5.52
5.90	4.46	4.50				4.57
7.63			4.62	4.64		
9.45	3.70		3.76			3.77
11.30	3.88				3.91	

A study of these tables will show that under a pressure of 10# per sq. inch and at an age of one month, the "six and eight sack" gravel concretes are impermeable, the "ten and twelve sack" are practically so, while the "four sack" leaks slightly and the "two sack" freely. The broken stone concrete at the same age and under the same pressure shows very much the same results. The "eight sack" is absolutely impermeable, the "six, ten and twelve sack" are almost so, while the "two and four sack" leak rather freely.

For a pressure of 30# per sq. inch and an age of two months, the condition is practically the same as at the earlier age except that the leakage is greater for the "two and four sack" mixes, while the "ten and twelve sack" show a slight amount of moisture passing through. The "six sack" broken stone concrete seems to show up better than at the age of one month.

The three months test at a pressure of 50# per sq. inch shows the same relative impermeability for the different mixes **with** however a somewhat larger amount of leakage. In the gravel concrete the "six sack" and "eight sack" specimens still show no leakage, while in the broken stone concrete at this pressure some, if not all of the specimens of each mix, show some moisture passing, but this is least with the "six and eight sack" mixes.

Contrasting the impermeability of the broken stone and gravel concrete as a whole, it may be said that the gravel concrete appears more impermeable than the broken stone concrete of similar proportions but that there is very little difference between the two.

The specimens of the "six sack" "wet" mix are seen to be practically impermeable at all three pressures and compare very favorably with the "six sack" standard consistency mix.

ABRASION TESTS

Scope of the investigation. For these tests, made only in Series I, ten specimens of standard consistency were prepared. Half of these were of broken stone concrete and the other half were of gravel. To find the resistance to wear, each specimen at the age of 28 days was placed in a brick rattler and subjected to the action of a charge of steel cubes for 2,000 revolutions and the percentage of loss in weight obtained for 500, 1,000 and 2,000 revolutions respectively. In addition, one specimen of "six sack" gravel concrete, the "wet" mixture, was made and tested.

Moulds. The moulds for the specimens to be used in the abrasion tests were made of No. 16 galvanized iron bent in to circular shape forming a cylindrical shell twenty eight inches in inside diameter and eight inches high. On the inside of this was placed a second hollow galvanized iron cylinder twenty inches in outside diameter and of the same height as the larger cylinder. This was braced on the inside to keep it from changing its shape and was separated from the walls of the larger piece by spacers which served to accurately center it. These two parts were set on a galvanized iron sheet and constituted the mould with which could be made a concrete ring twenty eight inches in outside diameter, four inches thick, and eight inches high.

Mixing, placing, etc. The concrete was made as already described and placed in the moulds, being tamped with a tamper weighing about 13 pounds. The rings were reinforced with two ¼ inch round steel rods extending completely around the circumference. Each piece was placed about equal distances from the top and bottom, and the inside and outside walls. This reinforcement was necessary to ensure the specimen's holding together when being handled and tested. One specimen of each kind except the "two sack" concrete was made. The day after making, the mould was removed and the specimen stored until tested.

Testing. A brick rattler was used for making the test. After 28 days seasoning, the ring was carefully weighed and placed in the machine. A charge of 155# of cast steel pieces 4½"x 2⅝" and of 114# of 1½" cubes was placed on the inside and the open end closed with the movable plate on the machine. The rattler was then operated at a speed of 30 r. p. m. After 500 revolutions, the specimen was removed, weighed, and replaced. This was repeated for another 500 revolutions, after which, the machine was run 1000 revolutions more, making a total of 2000, when the specimen was finally removed and weighed. The condition of the surface was carefully noted and a record made showing the uniformity of wear.

Results. The results of this test are shown in Table 39 for the gravel concrete and in Table 40 for the broken stone. The percentages of loss are obtained by taking the total loss in weight for each weighing and expressing this as a percent of the original weight. Particular attention is called to the column headed "Remarks," which indicates the condition of the wearing surface.

The curves in Fig. 41 show clearly the results of the tests so far as loss in weight is concerned. From these it is seen that the gravel concrete for most of the different mixes loses less than the broken stone concrete, but by referring to the table the latter is seen to wear down leaving a smoother surface than that of the former for the leaner mixes, while both give good results for the richer mixes.

TABLE 39

ABRASION TEST OF GRAVEL CONCRETE, SERIES I

(Each value determined from test of one specimen at age of 28 days.)

Sacks of cement per cu. yd. of concrete	Percentage of loss after being revolved in rattler.			
	500 revolutions	1000 revolutions	2000 revolutions	Remarks
1.66				
3.80	3.32	5.87	10.62	
*5.82	1.02	2.28	5.28	
5.96	1.25	2.49	5.17	Fair wear. Few projecting gravel.
8.45	0.75	1.79	3.34	Good wear. No projecting gravel.
9.67	0.47	1.34	3.09	Fine wear. Very even.
11.50	0.58	1.46	3.21	

*The "wet" mixture.

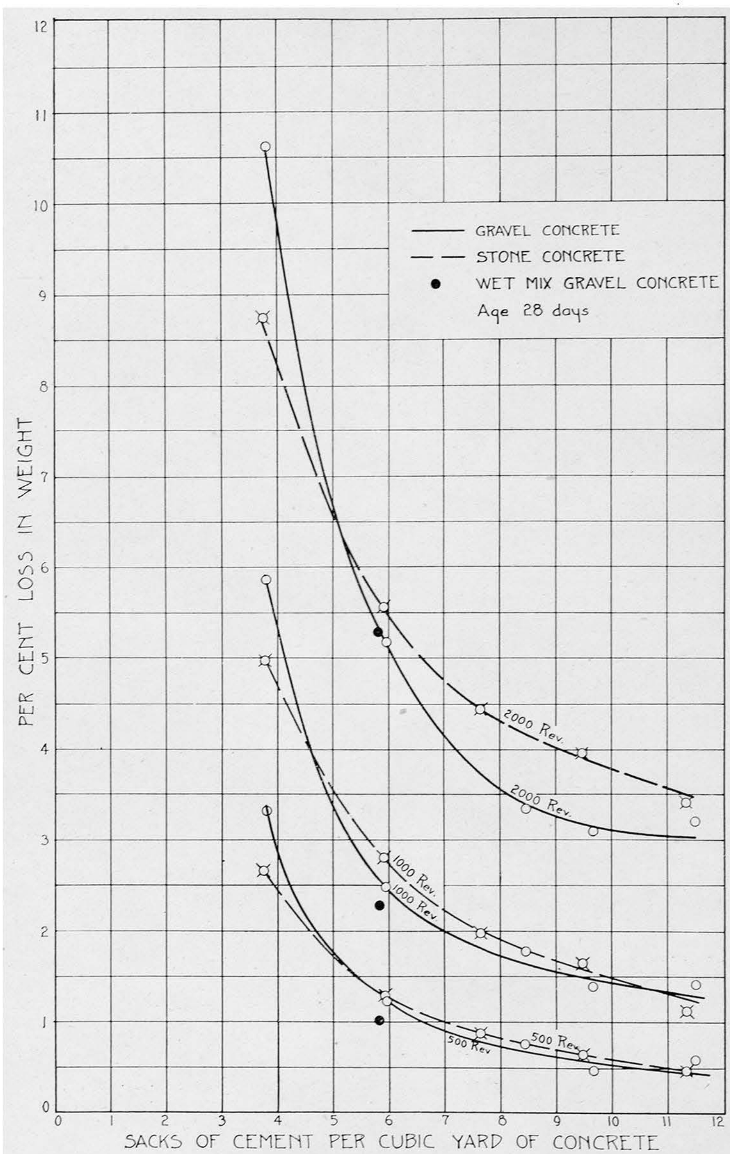


Fig. 41. Results of Abrasion Test on Hollow Cylinders of Gravel Concrete and Broken Stone Concrete, Series I.

TABLE 40

ABRASION TEST OF BROKEN STONE CONCRETE, SERIES I

(Each value determined from test of one specimen at age of 28 days.)

Sacks of cement per cu. yd. of concrete	Percentage of loss after being revolved in rattler.			
	500 revolutions	1000 revolutions	2000 revolutions	Remarks
1.63				
3.75	2.67	4.97	8.74	Not very good wear. No projecting stone
5.90	1.29	2.81	5.56	Even good wear. No projecting stone.
7.63	0.90	1.98	4.43	Very good wear. No projecting stone.
9.45	0.65	1.65	3.96	Very good wear. Very even.
11.30	0.47	1.12	3.41	