same plastic consistency, concretes of equivalent strength could be designed.

To establish such a workable relation, it is necessary to express the grading of the gravel by numerical functions. Other experimenters, notably Abrams and Edwards, have done so, and their work could be used as a basis for proportioning pit-run materials. However, both Abrams' "Fineness Modulus" and Edwards' "Surface Area" method require the making of a complete sieve analysis of the material. The method herein described requires the separation of a sample into only two sizes and a simple determination of the weight per cubic foot of the loose gravel.

The principal conclusion resulting from the investigation carried out is that the grading of pit-run gravel may be measured by the ratio of fine aggregate to total aggregate (that is, percentage of fine aggregate in total) and by the weight per cubic foot of the material, measured loose. For purposes of commercial convenience the dividing line between fine and coarse aggregate is taken on the common No. 4 sieve. In the following discussion, fine aggregate as defined above will be called "sand," and coarse aggregate "pebbles."

Two assumptions have often been made by users in proportioning the cement to pit-run gravels:—

1. That the ratio of cement to total aggregate should be a constant.

2. That the ratio of cement to the sand portion of the aggregate should be a constant.

The former is wrong and on the unsafe side. The latter is also wrong but is on the side of safety.

Cement to Aggregate Constant

Table I. is typical of the strength of concretes made under the assumption that the ratio of cement to total aggregate should be kept constant. Further demonstration of the fallacy of this assumption is not necessary.

Cement to Sand Constant

The assumption that the ratio of cement to percentage of sand in the gravel should be a constant was investigated in twenty-four series of tests. Materials from several localities and two classes of concrete were used. Table II. gives physical characteristics of the aggregates used in the investigations described herein.

TABLE III.—VARIATION IN COMPRESSIVE STRENGTH OF CONCRETE WITH THE PERCENTAGE OF SAND IN THE GRAVEL, WHEN THE RATIO OF CEMENT TO THE SAND PORTION OF THE GRAVEL IS KEPT CONSTANT

CEMENT TO SAND=1:2 BY WEIGHT.

CLASS I—SAND PASSING SIEVE NO. 4—PEBBLES RETAINED ON SIEVE NO. 4 AND PASSING 1½ IN. SIEVE.

		Proportions							Weight, lb. per cu. ft		Absolute Volume: Parts of Unit Volume in Green Concrete.					Compressive Strength, lb. per sq. in.	
		Weight.		Loose Volume.			Absolute Volume.										
Series No.	Sand No.	Cement to Aggregate.	Sand to Pebbles.	Cement to Aggregate.	Sand to Pebbles.	Computed for Equivalent Strength.	As Used.	Computed for Equivalent Strength.	Aggregate.	Green Concrete.	Cement (c).	Sand (s).	Pebbles (p).	c+s+p= Density.	Percentage Water in Mix, by Weight.	Age, 7 Days.	Age, 28 Days.
5	5	1:4.75	42:58	1:3.9	48:66	1:4.05	1:5.5	1:5.5	112.0	147 6	0.121	0.284	0.379	0.784	10.9	1235	1854
		1:3.66	55:45	1:3.2	62:51	1:4.1	1:4 3	1:5.5	110 2	149 0	0.148	0.346	0.292	0.786	11.2	1438	2275
		1:2.66	75:25	1:2.3	82:27	1:3.35	1:3.1	1:4.35	107 1	147.2	0.182	0.426	0.142	0.750	13.9	1637	2826
		1:2.10	95:5	1:2	97:5.1	1:3.2	1:2 5	1:3 9	100 1	146 1	0 209	0.493	0.030	0.732	14 8	2244	3532
6	6	1:4.75	42:58	1:3.8	48:68	1:3.9	1:5 4	1:5.4	114.8	146.1	0.122	0.279	0.383	0.784	9.8	1872	3360
		1:3.66	55:45	1:3.1	62:52	1:3.7	1:4 4	1:5.1	112.35	146.1	0 144	0.340	0.291	0.775	10.4	1792	3296
		1:2.66	75:25	1:2.3	80:27	1:2.7	1:3.1	1:3.6	107.1	141:2	0.175	0.408	0.137	0.720	13.2	2120	3452
		1:2.10	95:5	1:2	96:5.2	1:2.7	1:2.5	1:3 35	101 1	141 8	0.206	0.482	0.024	0.712	14.5	2360	3864
7	7	1:4.75	42:58	1:3.9	51:66	1:4.15	1:5.6	1:5.6	111.3	146.1	0.116	0.272	0.382	0.770	11.85	1150	2340
		1:3.66	55:45	1:3.2	65:49	1:4.05	1:4.25	1:5.3	107.8	145.6	0.145	0.339	0.276	0.760	12.1	1423	2872
		1:2.66	75:25	1:2.4	84:26	1:3.3	1:3.1	1:4.1	102.3	143.0	0.175	0.410	0.136	0.721	15.0	1550	3245
		1:2.10	95:5	1:2.1	98:4.6	1:3.35	1:2.5	1:3.8	94.0	142.0	0.204	0.480	0 024	0.708	15.3	2045	3680

Each series comprised tests of gravels containing respectively 42, 55, 75 and 95 per cent. by weight, of sand. The mixtures were made arbitrarily by combining sand and pebbles in the right amounts. The same sand and pebbles were used in each mixture in a series. Each series included tests of forty specimens. Five specimens were broken for each test of a mixture. Specimens from all series were tested at 28 days old; specimens from some series were tested at 7 days and from others at 6 months. Specimens were 8 by 16-in. or 6 by 12-in. cylinders stored in water.

In some of the series the No. 8 sieve was taken as the dividing line between sand and pebbles. The general result was very similar to that obtained with the No. 4 sieve.

In Table III. are given typical results of these tests for three series, showing the variation in strength of concrete with the percentage of sand in the gravel, when the ratio of cement to sand is kept constant. The strength increases with the percentage of sand in every mixture in the table, save one, and the results are typical of all series.

Obviously, neither the ratio of cement to total aggregate, nor the ratio of cement to the sand portion, should be a constant, but for equivalent mixtures the ratio of cement to total aggregate should increase in some relation to the percentage of sand in the gravel. That this is a straight line relation is demonstrated as follows:—

The "Sand" Method

The "sand" method of making concretes of equivalent strength, using gravels of varying sand content, depends upon the assumption that there is a direct relation between the strength of concrete and the ratio

$$c/[1-(c+s+p)] = c/(1-d),$$

in which c = absolute volume of cement, s = absolute volume of sand particles, and p = absolute volume of pebbles in a unit volume of freshly made concrete; d = coefficient of density = absolute volume of solid material in a unit volume of freshly made concrete = $c+s+p$; and $1-d$ = volume of air and water voids.

DATA CONCERNING PROPORTIONS FROM TYPICAL SERIES

Per cent of Sand in Aggregate, by Weight.	c	s	p	d	$\frac{c}{1-d}$
33	0.096	0.227	0.440	0.763	......
42	0.105	0.286	0.378	0.769	0.455
55	0.122	0.361	0.282	0.765	....
75	0.132	0.456	0.145	0.733	....
95	0.167	0.525	0.026	0.718	.....

By absolute volume of a granular material is meant the actual sum of the volumes of all the particles; it is expressed as the fractional part of the total space occupied by the material.

The quantities are computed as shown in Taylor and Thompson's "Treatise on Concrete."

Fig. 1 demonstrates the truth of the assumption that, other things being equal, the strength varies with $c/(1-d)$.