the 1:5 from 1:4.42 to 1:6.03. Table IV. shows the proportions of voids in the sands filled with cement paste varying from 0.91 to 2.03 for the 1:2 weight proportion, from 0.61 to 1.35 for the 1:3, from 0.46 to 1.01 for the 1:4, and from 0.37 to 0.81 for the 1:5 proportion. Nothing could better illustrate the fallacy of the practice of comparing work sands with standard sand in 1:3 weight proportions.

Neither is there a basis of comparison in a fixed volumetric proportion. In 1:3 volumetric proportions the proportions of the voids in the sands filled with cement paste would vary from 0.73 to 1.20 for the 11 sands, as

TABLE I.—PROPERTIES OF SANDS. (FROM WITHEY'S TABLE I.)

Sand. No.	Weight per cubic foot, lb.	Specific Gravity.	Voids, per cent.	Silt, per cent.	Absorption, per cent.
Standard	104.1	2.65	37.0	...	...
Sd. 1	105.2	2.66	36.5	3.0	0.19
Sd. 2	106.9	2.74	35.2	1.3	0.49
Sd. 3	101.8	2.68	38.2	0.8	0.27
Sd. 4	98.9	2.63	39.8	1.2	0.04
Sd. 5	91.2	2.67	45.3	0.5	0.17
Sd. 7	105.2	2.78	36.6	1.6	0.41
Sd. 8	105.3	2.70	36.4	1.5	0.18
Sd. 9	105.5	2.75	36.0	0.7	0.51
Sd. 10	120.3	2.77	27.9	7.7	0.29
Sd. 11	108.7	2.72	35.0	0.4	0.11

TABLE II.—SIEVE ANALYSIS OF SANDS. (FROM WITHEY'S TABLE II.)

Sand No	Percentage by Weight Passing Sieves Nos. 10	20	30	40	50	74	100	Uniformity Coefficient
Standard	100.0	100.0	0.0	....	....	....	....	....
Sd. 1	86.4	65.5	39.0	25.0	9.1	5.4	2.8	3.0
Sd. 2	81.2	70.9	61.4	52.4	34.5	17.9	9.7	2.6
Sd. 3	91.9	72.7	39.7	26.4	13.7	4.2	1.2	2.4
Sd. 4	100.0	99.5	95.8	88.8	62.5	22.1	8.6	1.8
Sd. 5	100.0	99.9	99.8	99.1	67.6	18.2	5.7	1.8
Sd. 7	67.7	44.5	25.9	17.8	11.2	3.8	2.2	4.7
Sd. 8	82.0	72.5	55.3	38.6	16.1	3.6	1.9	2.6
Sd. 9	66.8	22.7	13.9	10.3	4.9	2.4	1.4	3.7
Sd. 10	69.7	48.8	34.0	26.3	17.4	8.7	6.5	6.9
Sd. 11	72.0	47.7	23.8	12.0	4.3	0.7	0.5	3.4

TABLE III.—VOLUMETRIC PROPORTIONS FOR SIMPLE WEIGHT PROPORTIONS.

Sand No.	Weight Proportions. 1:2	1:3	1:4	1:5
Sd. 10	1:1.77	1:2.65	1:3.54	1:4.42
Sd. 2	1:1.98	1:2.97	1:3.96	1:4.94
Sd. 11	1:1.99	1:2.98	1:3.97	1:4.97
Sd. 7	1:2	1:3	1:4	1:5
Sd. 9	1:2	1:3	1:4	1:5
Sd. 8	1:2.05	1:3.07	1:4.10	1:5.12
Sd. 1	1:2.08	1:3.12	1:4.17	1:5.20
Standard	1:2.11	1:3.17	1:4.22	1:5.27
Sd. 3	1:2.13	1:3.20	1:4.27	1:5.33
Sd. 4	1:2.23	1:3.34	1:4.46	1:5.57
Sd. 5	1:2.41	1:3.62	1:4.82	1:6.03

TABLE IV.—RATIO OF VOLUME OF CEMENT PASTE TO VOLUME OF VOIDS IN SAND FOR SIMPLE WEIGHT PROPORTIONS.

Sand No.	Weight Proportions. 1:2	1:3	1:4	1:5
Sd. 10	2.03	1.35	1.01	0.81
Sd. 11	1.44	0.96	0.72	0.58
Sd. 2	1.43	0.96	0.72	0.57
Sd. 9	1.39	0.93	0.70	0.56
Sd. 7	1.37	0.91	0.68	0.55
Sd. 8	1.34	0.90	0.67	0.54
Sd. 1	1.32	0.87	0.66	0.53
Standard	1.28	0.85	0.64	0.51
Sd. 3	1.23	0.82	0.61	0.49
Sd. 4	1.13	0.75	0.56	0.45
Sd. 5	0.91	0.61	0.46	0.37

TABLE V.—RATIO OF VOLUME OF CEMENT PASTE TO VOLUME OF VOIDS IN SAND, FOR SIMPLE VOLUMETRIC PROPORTIONS.

Sand No.	Volumetric Proportions 1:2	1:3	1:4	1:5
Sd. 5	1.10	0.73	0.55	0.44
Sd. 4	1.25	0.84	0.63	0.50
Sd. 3	1.31	0.87	0.65	0.51
Standard	1.35	0.90	0.68	0.54
Sd. 7	1.35	0.91	0.68	0.55
Sd. 1	1.36	0.91	0.68	0.55
Sd. 8	1.37	0.92	0.69	0.56
Sd. 9	1.39	0.93	0.69	0.56
Sd. 2	1.42	0.95	0.71	0.57
Sd. 11	1.43	0.95	0.71	0.57
Sd. 10	1.79	1.20	0.90	0.72

$$\frac{\text{Volume of Cement Paste}}{\text{Volume of Voids in Sand}} = \frac{1}{\text{Vol. Prop. of Sand} \times \text{Prop. of Voids in Sand}} \quad (4)$$

shown in Table V. It must be admitted, from a scientific or practical consideration of a mortar, that a very important function of the cement is to fill the voids in the sand; and it cannot be expected that a mortar in which the volume of cement paste is equal to only 73 per cent. of the volume of voids in the sand is comparable with that in which the cement paste is equal to 120 per cent. of the voids.

Assume, for example, that six mortars of a certain sand and cement are made in which the ratio of the volume of cement paste to the volume of voids in the sand has, respectively, the values of 0.50, 0.75, 1.00, 1.50, 2.00 and 3.00. It is reasonable to anticipate that the strength of the mortars will increase at a rapid rate until the voids in the sand are filled with cement paste, after which the strength will increase at a lesser rate until the sand particles are so widely separated by the cement paste that the strength of the mortar will closely approximate the strength of the neat cement. In other words, as the cement content is increased, the rate of increase of strength is greater before the voids are filled than it is after the voids are filled, and in some finite proportions the strength of the mortar approximates the strength of

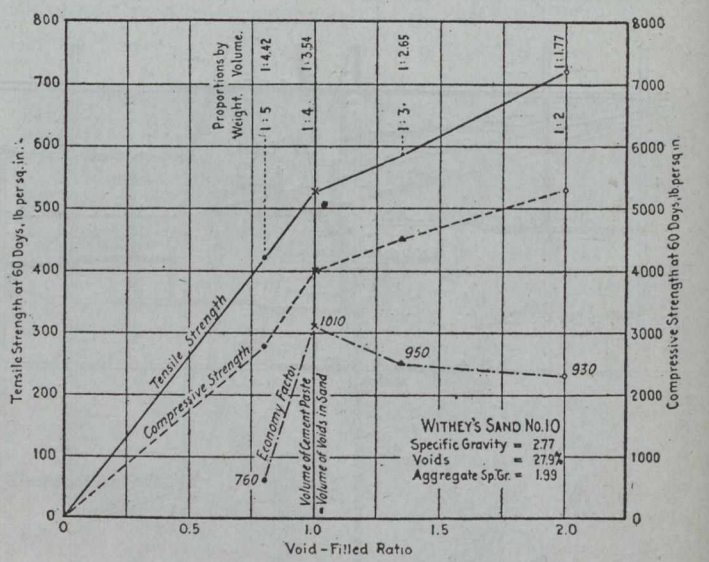

Fig. 1.—Variation in Strength of Mortar from Sand No. 10 in Proportion to Void-Filled Ratio

the neat cement. Fig. 1, which shows the compressive and tensile strengths and the strength in proportion to cost for sand No. 10, plotted against the void-filled ratio, illustrates these assumptions very well. This sand, unfortunately, is the only one of this series of tests which has a proportion (1:4 by weight) closely equal to that in which the volume of cement paste is equal to the volume of voids in the sand, and which has more than one proportion in which the volume of cement paste is greater than the volume of voids in the sand.

Fig. 2 shows the compressive strengths plotted against the void-filled ratio. The curve of averages supports the assumption as to the rate of increase of strength. The curve of averages is fairly uniform, and would appear to indicate that the void-filled ratio has a similar effect on all the sands. This, then, appears to establish the principle that the properties, strength, efficiency, etc., of mortars are properly compared on the basis of the void-filled ratio.

The final and most important consideration of a mortar is the strength in proportion to the cost. This may be expressed as an "economy factor," equal to the compressive strength in pounds per square inch divided by the cost of the mortar in dollars per cubic yard. This factor may be expressed by the following equation: