RAFTER'S METHOD OF PROPORTIONING

Mr. George W. Rafter* has called attention to the method of proportioning the mortar as a percentage of the volume of the stone slightly shaken. the relation of cement to sand having been determined by the required strength of concrete.

Quoting from specifications for the Genesee Dam, the concrete is proportioned as follows:

> In forming concrete such a proportion of mortar of the specified composition will be used as may be found necessary by trial to a little more than fill the voids in the aggregate. Tests of the voids will be made from time to time under the direction of the engineer, and instructions given as to the per cent of mortar of the specified composition to be used. For the information of the contractor, in the way of computing the cost of concrete of the quality herein required, it may be stated that ordinarily the per cent of mortar will be about 33 per cent of the measured volume of the aggregate. In case of the use of a certain proportion of gravel in the aggregate, the proportion of mortar may be reduced to somewhat less than 30 per cent.

This method of proportioning is more accurate than the usual procedure, because there is less apt to be an excess of mortar. It does not, however, take account of the fact that with a coarse aggregate of varying sized particles some of the grains of sand are too large to fit into the voids of the stone, and that therefore the coarse and fine aggregates must be studied together.

An examination of the analysis of the sand used by Mr. Rafter indicates that to its fineness was due the small proportion of mortar to stone which he was able to use. Ninety-two per cent of the sand passed a No. 30 sieve, so that the grains were small enough to enter the voids of the stone without appreciably increasing the bulk of the concrete.

FRENCH METHOD OF PROPORTIONING

In France, proportions are ordinarily stated in terms of the volume of mortar to the volume of stone, and the mortar is described by the number of kilograms of Portland cement to 1 cubic meter or liter of sand.

The following table gives the nominal proportions in English measure based on a volume of 3.8 cubic feet corresponding to similar French proportions based on kilograms of cement to a cubic meter of sand.

*"On the Theory of Concrete" Transactions American Society Civil Engineers, Vol. XLII, p. 104.

American Equivalents of French Proportions. (See p. 999.)

French measure, kilograms cement per cubic meter of sand.	American measure, cement to sand by volume.*	Pounds of cement per cubic foot of sand.	French measure, kilograms cement per cubic foot of sand.	American measure, cement to sand by volume.*	Pounds of cement per cubic foot of sand.
200	1 : 8.0	12.5	700	1 : 2.3	43.7
300	1 : 5.3	18.7	800	1 : 2.0	50.0
400	1 : 4.0	25.0	1000	1 : 1.6	62.5
500	1 : 3.2	31.3	1200	1 : 1.3	75.0
600	1 : 2.7	37.5	1600	1 : 1.0	100.0

*Proportions based on standard weight of cement, i. e., 100 pounds per cubic foot

Concrete in France is frequently designated with respect to the ratio of mortar to stone; for example, one volume of mortar to two volumes of stone, the mortar then being designated as indicated in the above table. To express the parts more definitely, the basis is sometimes a cubic meter of sand; for example, 650 kilograms cement to one cubic meter sand to 1.8 cubic meter stone, this corresponding substantially to proportions 1 : 2½ : 4½ by volume, as ordinarily used in America.

MECHANICAL ANALYSIS

Mechanical analysis consists in separating the particles or grains of a sample of any material, — such as broken stone, gravel, sand or cement, — into the various sizes of which it is composed, so that the material may be represented by a curve (see Fig. 70, p. 192) each of whose ordinates is the percentage of the weight of the total sample which passes a sieve having holes of a diameter represented by the distance of this ordinate from the origin in the diagram.

The objects of mechanical analysis curves as applied to concrete aggregates are (1) to show graphically the sizes and relative sizes of the particles; (2) to indicate what sized particles are needed to make the aggregate more nearly perfect and so enable the engineer to improve it by the addition or substitution of another material; and (3) to afford means for determining best proportions of different aggregates.

To determine the relative sizes of the particles or grains of which a given

*Chimie Appliquée, 1897, p. 523.

†Proportioning of sizes.

sample of stone or sand is composed, the different sizes are separated from each other by screening the material through successive sieves of increasing fineness. After sieving, the residue on each sieve is carefully weighed, and beginning with that which has passed the finest sieve, the weights are successively added, so that each sum will represent the total weight of the particles which have passed through a certain sieve. The sums thus obtained are expressed as percentages of the total weight of the sample and plotted upon a diagram with diameters of the particles as abscissas and percentages as ordinates.

The method of plotting and the uses of the curves thus obtained are more fully described in the pages which follow.

Sieves and Other Apparatus. Fig. 68 illustrates a convenient outfit for such a mechanical analysis as above described, consisting of a set of sieves, an apparatus for shaking the sieves, and scales for weighing. A standard size of sieve is 8 inches in diameter and $2\frac{1}{4}$ inches high. Sieves with openings exceeding 0.10 inches are preferably made of spun hard brass with circular openings drilled to the exact dimensions required. Sieves with openings of 0.10 inch and less are preferably of woven brass wire set into a hard brass frame. Woven brass sieves are made for many purposes, and are sold by numbers which approximately coincide with the number of meshes to the linear inch. As the actual diameter of the hole varies with the gage of wire used by different manufacturers, every set of sieves must be separately calibrated.

An approximate idea of the diameters of holes which may be expected in commercial sizes of sieves is presented in the following table, which is sufficiently exact to serve as a guide to the purchase of the sieves:

Commercial No. of sieve.	Diameter of hole in inches.	Commercial No. of sieve	Diameter of hole in inches.
10	0 073	60	0.009
15	0.047	74	0.0078
16	0.042	100	0.0045
18	0.037	140	0.003625
20	0.034	150	0.00325
30	0.022	170	0.0031
35	0.017	180	0.00306
40	0.015	190	0.0028
50	0.011	200	0.00275

For separating particles smaller than those passing through a No. 200 sieve, recourse must be had to processes of elutriation which have been developed to great precision by soil analysis chemists.*

*See page 85.

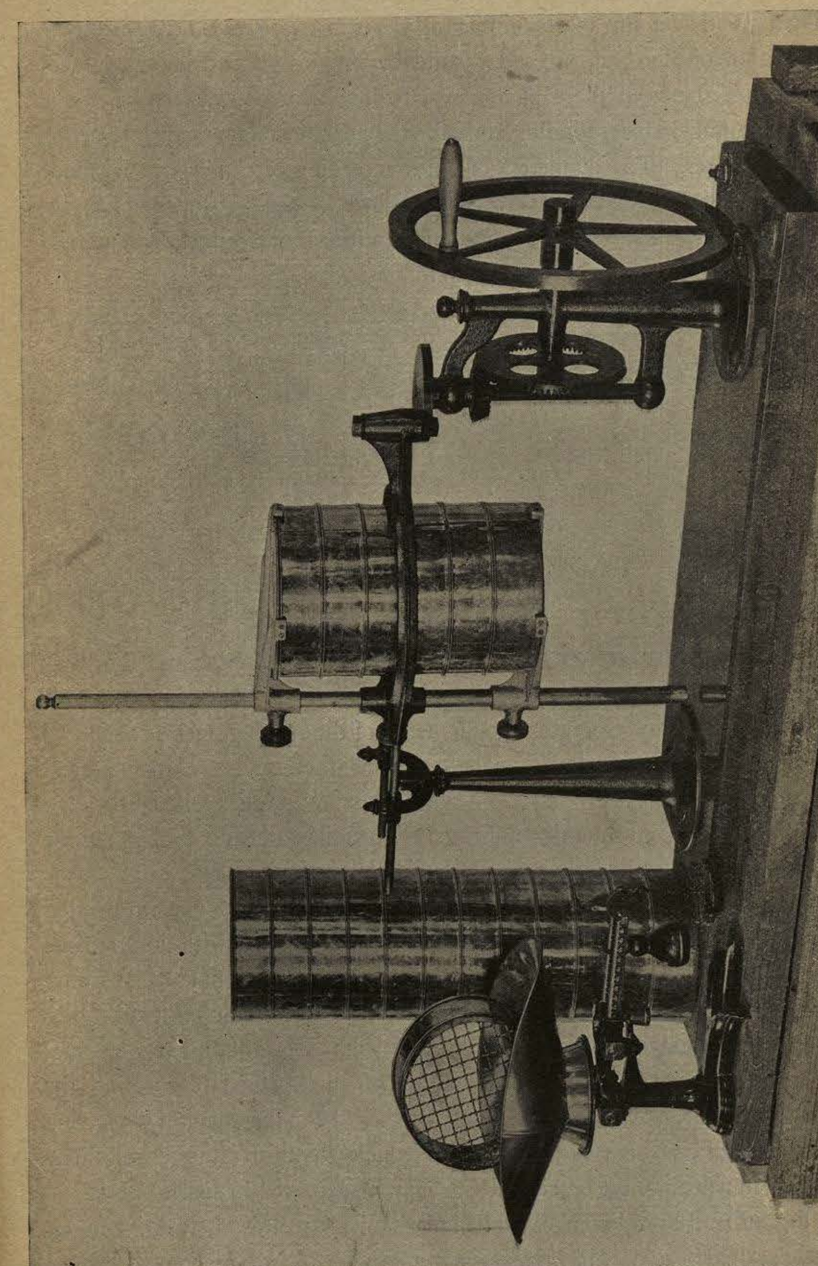

FIG. 68. — Mechanical Analysis Sieves and Shaker. (See p. 194.)

In selecting the right series of sieves to purchase, first decide on the limiting diameters, say, from 3.00 inches to No. 200 = 0.00275 inches. Then decide on the total number of sieves, say, twenty. Look up the logarithm of 3.00 and of 0.00275 and by proportion find eighteen other logarithms between these having equal differences between each. Look for the number corresponding and take the nearest commercial sieve giving this diameter. The diameters of holes exceeding 0.10 inch can be made as required. A convenient set of twenty sieves, — ten for stone, which give the diameter of the holes in inches, and ten for sand, giving the commercial number (see p. 194), — is as follows:*

Stone Sieves inches.	Sand Sieves Commercial No.
3.00	10
2.25	15
1.50	20
1.00	30
0.67	40
0.45	60
0.30	74
0.20	100
0.15	150
0.10	200

After the sieves are obtained it is necessary that they should be very carefully calibrated to ascertain the average diameter of the mesh. This should be done by averaging the diameters of the openings measured in two positions at right angles to each other, as the meshes of commercial sieving are not exactly square. Sieves having meshes exceeding 0.10 inch are most conveniently calibrated by ordinary outside calipers; those having meshes of less diameter, by a micrometer microscope.

When many analyses are to be made, it is convenient to have a printed cross section form, such as is shown in Fig. 69, p. 197, with appropriate spaces for filling in the number of the analysis, description of the material, location of the work, and other facts relating to the material.

Plotting Analysis Curves. For those who are unfamiliar with mechanical analysis a detailed explanation of the method of locating the curve is here given. The method can best be understood by referring to the diagrams of typical materials which are also of practical interest as illustrating the curves which may be expected in special cases.

Fig. 70, p. 198, represents a typical mechanical analysis of crusher-run micaceous quartz stone which has been run through a ¼-inch revolving screen so as to separate particles finer than ¼ inch, that is the dust, for use with sand.

For a sample of stone, which may be taken by the method of quartering

*A still smaller set for ordinary use is suggested on page 159*a*.

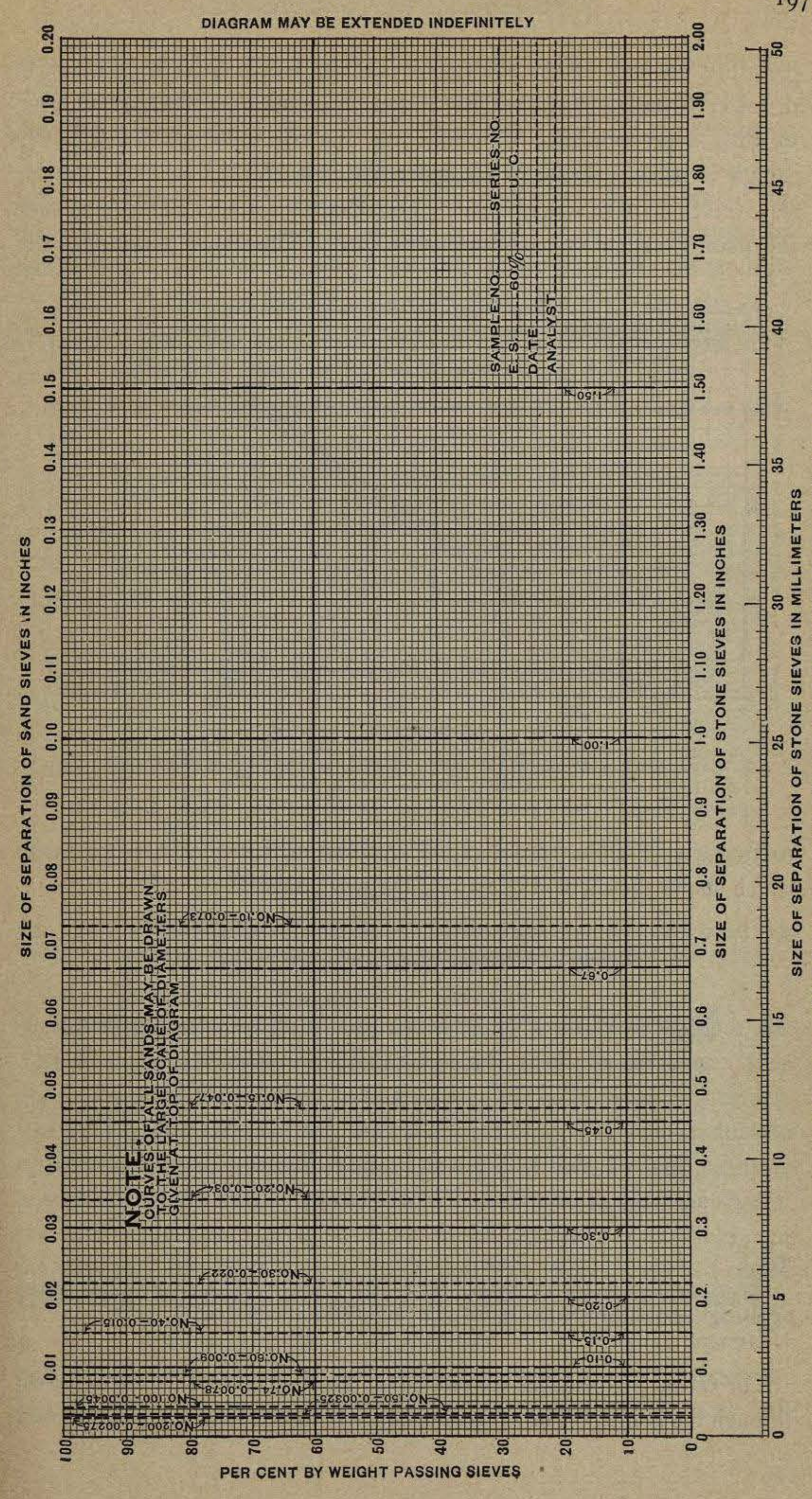

FIG. 69. — Blank Form for Mechanical Analysis Diagram. (See p. 196.)

described on page 280, 1 000 grams is a convenient quantity for 8-inch diameter sieves 2¼ inches in depth, and also permits of easy reduction from weights to percentages. To obtain the analysis shown in Fig. 70, the sample of stone is placed in the upper (coarsest) sieve of the nest of stone sieves given on page 190, and after 1 000 shakes the nest is taken apart, and the quantity caught on each sieve is weighed. The results obtained in the

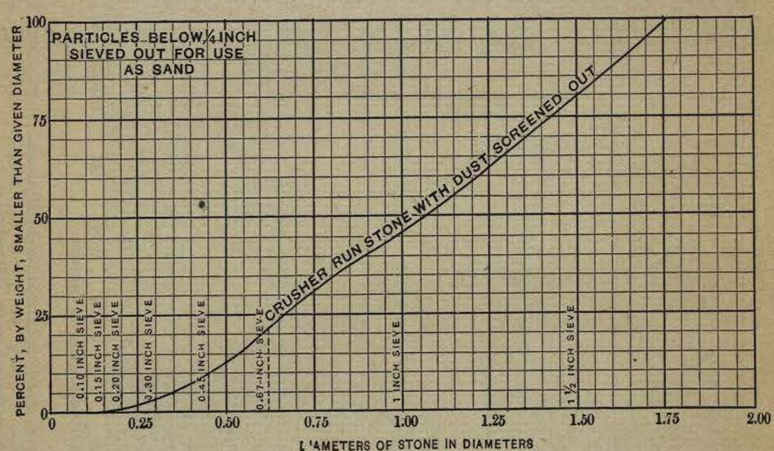

FIG 70. — Typical Mechanical Analysis of Crusher-Run Micaceous Quartz Stone. (*See p.* 198.)

particular case under consideration are illustrated in the following table, which shows the method of finding the percentages:

Results of Screening Samples of Stone of Fig. 70.

Size sieve inches.	Retained in each sieve* grams.	Amount finer than each sieve grams.	Percentage finer than each sieve %
0.10	8	0	
0.15	11	8	1
0.20	8	19	2
0.30	72	27	3
0.45	123	99	10
0.67	235	222	22
1.00	344	457	46
1.50	199	801	80
Total,	1000		

*In practise this column is not required, the weights in the next column being obtained directly by placing each successive residue on the scale pan with that already weighed.

The various percentages are plotted on the diagram and the curve drawn through the points. The vertical distance from the bottom of the diagram

to the curve, that is, the ordinate at any point, represents the percentage of the material which passed through a single sieve having holes of the diameter represented by this particular ordinate. Since the percentage of material passing any sieve is always the complement of the percentage of grains coarser than that sieve, the vertical distances from the top of the diagram down to the curve represents the percentages which would be retained upon each sieve if employed alone. For example, taking 1.25, 62%, the distance from the bottom of the diagram, represents the percentage of material finer than 1¼ inch diameter, and 38%, the distance down from the top of diagram, represents the percentage coarser than 1¼ inch.

Fig. 71 represents a typical analysis of crushed trap rock which has been

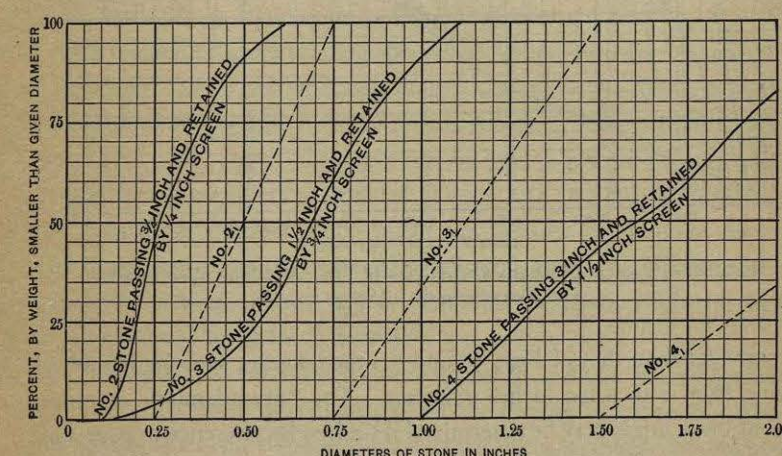

FIG. 71. — Typical Mechanical Analysis of Crushed Trap Rock Separated into Three Sizes by Revolving Screens having 3, 1½, ¾ and ¼ inch perforations. (*See p.* 199.)

separated into stone of three sizes and dust, by a revolving screen 2 feet 6 inches in diameter and 12 feet long set on a slope of 1 foot 9 inches. This was made up of four sections having respectively 3, 1½, ¾ and ¼ inch perforations. The curves not only show the sizes of trap rock which ordinarily pass through crusher screens of given diameter of hole, but also illustrate how inefficient the screening process may be. For example, if the sizes of the particles had corresponded exactly to the diameters of the holes and the screening had been more perfectly done, we should have had curves whose general direction and location is shown by the dotted lines No. 2_1, No. 3_1, and No. 4_1, that is, for example, No. 3, since it represents stone which passes a 1½ inch screen and which is retained on a ¾ inch screen, should occupy a position between the ordinates representing 1.50 and

0.75 diameters. If the stone had rumbled longer in the screen because of flatter slope or screen sections of greater length, the curves would have approached more nearly to these dotted lines.

Typical curves of a fine, a medium well graded, and a coarse sand are shown in Fig. 72. For convenience in plotting, the horizontal scale is ten

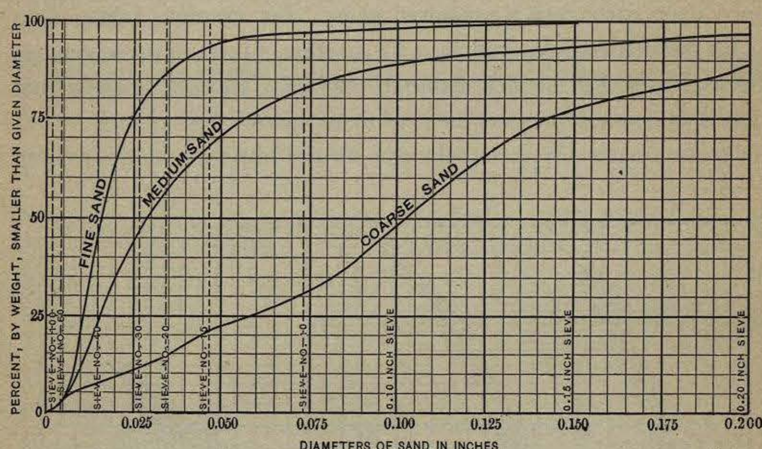

FIG. 72.—Typical Mechanical Analyses of Fine, Medium, Well Graded and Coarse Sands. (*See p.* 200.)

times greater than that of Figs. 70 and 71, the diagram showing diameters ranging from 0 to 0.200 inches diameter. The "granulometric composition" of these sands may be determined if desired by reference to page 149.

The mechanical analysis of crusher dust is apt to vary between the curves of fine sand and medium sand which are shown in Fig. 72.

STUDIES OF THE DENSITY OF CONCRETE

In the year 1901 the writer, through the permission and assistance of Mr. E. LeB. Gardiner, Vice-President, and Mr. J. Waldo Smith, Chief Engineer, of the East Jersey Water Company, was enabled to make an extended series of experiments on the comparative strengths of different proportions of concrete aggregate. Many mixtures of different proportions were made up into beams, their curves of mechanical analyses drawn as explained above, and the strength of the beams determined by breaking tests.*

These tests indicated that the strength of concrete varies with the percentage of cement contained in a unit volume of the set concrete, also with

* The results of these tests are presented in the table on pages 376 and 377.

the density of the specimen. With the same percentage of cement, the densest mixture, irrespective of the relative proportions of the sand and stone, was in general the strongest. These tests further indicated that for the materials used there was a certain mixture of sizes of grains of the aggregate which, with a given percentage by weight of cement to the total aggregate, gave the highest breaking strength. In practice also it was found that the concrete made with this mixture worked most smoothly in placing.

These tests led to a still more extended series by the writer and Mr. Sanford E. Thompson at Jerome Park Reservoir, New York, in 1903 and 1904, under the authorization of the Aqueduct Commission of the city of New York, Mr. J. Waldo Smith, Chief Engineer.

The method of procedure and the results of the tests are given in full in a paper on "The Laws of Proportioning Concrete," by William B. Fuller and Sanford E. Thompson, Transactions American Society Civil Engineers, Vol. LIX, p. 67, 1907. The experiments were begun with a series of tests on the density of different mixtures of aggregate and cement to determine the laws of proportioning for maximum density for different materials, and these density experiments were followed by the manufacture of concrete specimens in the attempt to determine the relation between the laws of strength and the laws of density.

The mechanical analysis diagram furnished a ready means of studying the effect of various sized particles on the density of concrete. For this purpose crusher-run stone and bank gravel were screened into twenty-one sizes ranging from 3 inches down to that passing a No. 100 sieve, having meshes 0.0027 inch in diameter. These sized materials were then re-combined in a predetermined mechanical analysis curve by weighing out the necessary quantities of each size.

This material was next thoroughly mixed with a given weight of cement and the whole amount wet and mixed and tamped into a strong cylinder in which its volume could be measured. This batch was then thrown away and another batch made up according to another mechanical analysis curve and its volume recorded. In this way over 400 different mechanical analysis curves were tested as to volume for the purpose of determining the ideal curve corresponding to the densest concrete mixture.

Both broken stone and gravel were used in the tests, and to reduce the number of variables, most of the experiments were made upon the same proportions, using 10 per cent by weight of cement to the total dry materials, corresponding to proportions 1 : 9 by weight.

In all of the tests instead of following the more usual plan of testing the