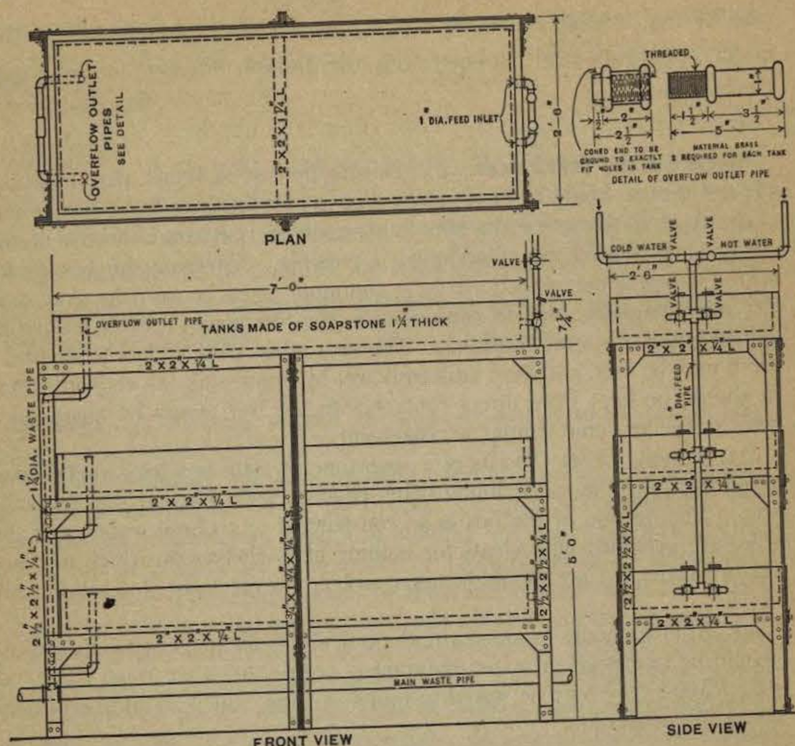

FIG. 16.—Immersion Tanks. (*See p.* 75.)

clip is to be used without cushioning at the points of contact with the test specimen. The bearing at each point of contact should be ¼ in. wide, and the distance between the center of contact on the same clip should be 1¼ in.

66. Test pieces should be broken as soon as they are removed from the water. Care should be observed in centering the briquettes in the testing machine, as cross-strains, produced by improper centering, tend to lower the breaking strength. The load should not be applied too suddenly, as it may produce vibration, the shock from which often breaks the briquette before the ultimate strength is reached. Care must be taken that the clips and the sides of the briquette be clean and free from grains of sand or dirt, which would prevent a good bearing. The load should be applied at the rate of 600 lb. per minute. The average of the briquettes of each sample tested should be taken as the test, excluding any results which are manifestly faulty.

Testing machines and their operation are discussed and illustrated on page 93. The actual tensile strength of neat cement and sand mortar is treated on page 99.

Tests have shown that for the highest and most uniform results briquettes should not be removed from the water until, as specified, just before they are broken.

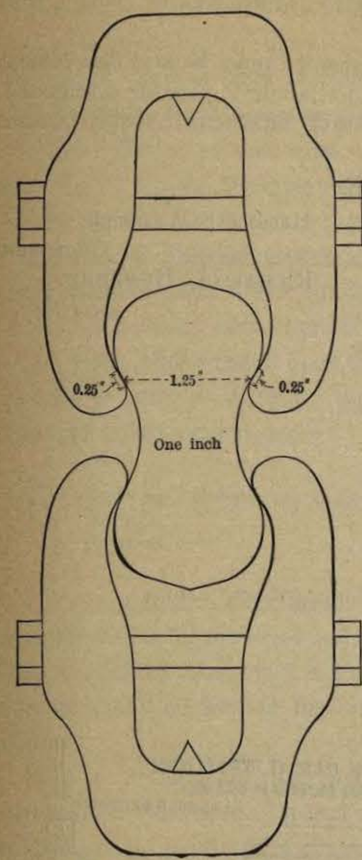

FIG. 17.—Form of Clip. (*See p.* 75.)

Constancy of Volume.* 67. *Significance.* — The object is to develop those qualities which tend to destroy the strength and durability of a cement. As it is highly essential to determine such qualities at once, tests of this character are for the most part made in a very short time, and are known, therefore, as accelerated tests. Failure is revealed by cracking, checking, swelling or disintegration, or all of these phenomena. A cement which remains perfectly sound is said to be of constant volume.

68. *Methods.* — Tests for constancy of volume are divided into two classes: (1) normal tests, or those made in either air or water maintained at about 21° Cent. (70° Fahr.) and (2) accelerated tests, or those made in air, steam or water at a temperature of 45° Cent. (113° Fahr.) and upward. The test pieces should be allowed to remain 24 hours in moist air before immersion in water or steam or preservation in air.

69. For these tests, pats, about 7½ cm. (2.95 in.) in diameter, 1¼ cm. (0.49 in.) thick at the center, and tapering to a thin edge, should be made, upon a clean glass plate [about 10 cm. (3.94 in.) square], from cement paste of normal consistency.

70.—*Normal Test.* — A pat is immersed in water maintained as near 21° Cent. (70° Fahr.) as possible for 28 days, and observed at intervals. A similar pat, after 24 hours in moist air, is maintained in air at ordinary temperature, and observed at intervals.

71. *Accelerated Test.*—A pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel, for 5 hours. The apparatus recommended for making these determinations is shown by Fig. 18, Page 78.

72. To pass these tests satisfactorily, the pats should remain firm and hard, and show no signs of cracking, distortion or disintegration.†

*Soundness.

†See page 101.

73. Should the pat leave the plate, distortion may be detected best with a straight-edge applied to the surface which was in contact with the plate.

74. In the present state of our knowledge it cannot be said that cement should necessarily be condemned simply for failure to pass the accelerated tests; nor can a cement be considered entirely satisfactory, simply because it has passed these tests.

Submitted on behalf of the Committee,

GEORGE S. WEBSTER,
Chairman.
RICHARD L. HUMPHREY,
Secretary.

Committee.
GEORGE S. WEBSTER,
RICHARD L. HUMPHREY,
GEORGE F. SWAIN,
ALFRED NOBLE,
LOUIS C. SABIN,
S. B. NEWBERRY,
CLIFFORD RICHARDSON,
W. B. W. HOWE,
F. H. LEWIS.

December 28, 1908.

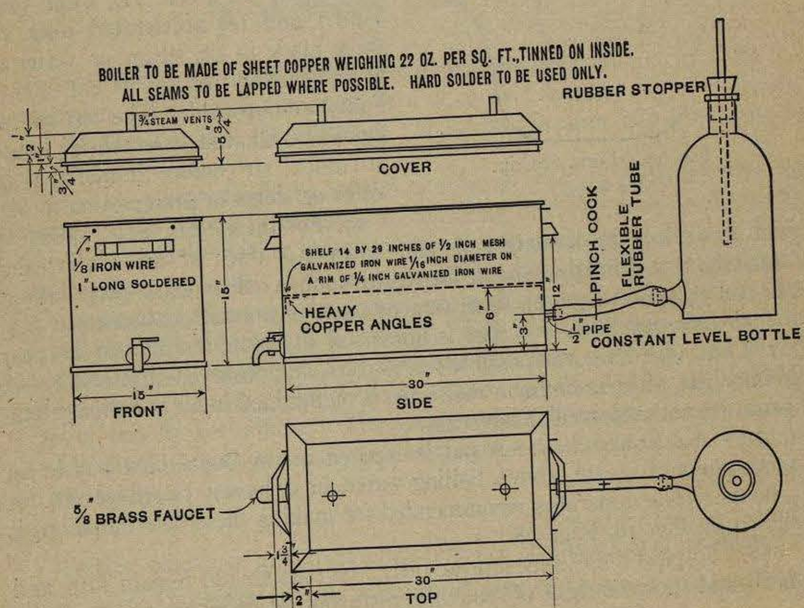

FIG. 18.—Steaming Apparatus. (*See p.* 77.)

ELEMENTARY DIRECTIONS FOR TESTING SOUNDNESS

Soundness tests, which are of greater importance than any other one test, may be made by those unskilled in laboratory practice, with no apparatus except a piece of plate glass at least ½ inch thick and 12 by 18 inches square, pieces of window glass 4 inches square, and a small trowel. Take samples at random from several barrels or bags, as described on page 64. From each sample make three pats of neat cement, requiring for the three about 8 ounces (250 grams) or one cupful of dry cement.

Cements of different classes and degrees of fineness require different percentages of water. The consistency must be such that the cement can be readily kneaded without crumbling and formed into a smooth pat with a thin edge, when pressed upon the piece of glass provided for it, without running or losing its shape.* Approximate amounts may be taken for the first trial of any cement, as, —

Portland Cement	....	20% of water by weight
Natural "	....	30% " "
Puzzolan "	....	18% " "

If these quantities after kneading give too wet or too dry a mixture, the paste should be thrown away and the trial repeated with less or more water until the desired consistency is attained. The percentage thus determined may generally be used in the remaining tests of the same shipment of cement.

Place a sample of the dry cement upon the plate glass in the form of a mound, and with the small trowel make a depression in the center. Weigh, or measure, a quantity of water which has been found by trial to give the proper consistency, and pour it into the depression, allowing it to soak into the cement, and then turn the material on the edges into the water with a trowel. As soon as the water is absorbed, the paste is kneaded for 1½ minutes with the hands, which should be protected with rubber gloves.

A piece of window glass about 4 inches square is required for each pat. A portion of the paste is made into a ball and pressed upon one of these pieces of glass so as to form a circular pat about 3 inches in diameter and ½ inch thick in the center, tapering to a thin edge. For the first 24 hours, to prevent the surface from drying too quickly, the pats must be kept under a cloth moistened and suspended above the pats, with its ends immersed in water to keep it wet. The temperature of the air while mixing, and of the water for mixing and storage, should be maintained as near as possible to 70° Fahr. (21° Cent.). At the end of 24 hours one pat should

*See also Boulogne method, p. 70.

be placed in water and another in air, to be observed at intervals for a period of 28 days, and the third pat placed upon some sort of a frame in a loosely covered vessel over boiling water, and kept there, with the water boiling, for 5 hours. The possible defects which are mentioned above in paragraphs 74 and 75 are described at length on page 103.

APPARATUS FOR A CEMENT TESTING LABORATORY†

(The apparatus is designed for one experimenter. Where the number of pieces is not stated, their number depends upon the quantity of cement to be tested.)

*One piece plate glass, one inch thick, 24 by 24 inches square;
*Two or more gangs of 4 or 5 molds each — A. S. C. E. standard (see Fig. 13, p. 73);
*One metric counter scale recording from 10 grams to 1½ kilograms.
*One No. 100 sieve (96 to 100 meshes to the linear inch) about 20 centimeters (7.87 ins.) in diameter and 6 centimeters (2.36 in.) high, made of woven brass wire cloth, with wires 0.0045 inches diameter;
*One No. 200 sieve (188 to 200 meshes to the linear inch) of similar size to the No. 100 sieve, and made of woven brass wire cloth, with wires 0.0024 inches diameter;
*One measuring glass graduated to 250 cubic centimeters;
*One 8-inch mason's trowel;
*One 4-inch pointing trowel (see Fig. 14, p. 74);
*One-half dozen pairs rubber gloves;
*Pieces of window glass 4 inches square for soundness tests;
*One tensile testing machine (see Figs. 22 to 27, pp. 94 to 98);
*Air thermometer;
*Standard sand;
Two or more gangs of 4 molds each for 2-inch cubes (see Fig. 43, p. 119);
Two or more molds for transverse specimens 1 by 1 by 6 inches (see Fig. 44, p. 121);
10-pound tin cans with covers for holding samples;
One special scale for weighing cement in ascertaining fineness (see Fig. 10, p. 68);
One pan of same diameter as the sieves and 5 centimeters (1.97 in.) deep, with cover, for holding sieve when shaking it;
One measuring glass graduated to 100 cubic centimeters;

*An asterisk designates the apparatus required for a temporary laboratory on construction work.

†This list has been criticised and approved by Mr. Richard L. Humphrey.

One cement sampler 24 inches long (see Fig. 8, p. 64)
One and one-half minute sand glass;
One moist closet (see Fig. 15, p. 75);
Galvanized iron waste cans;
Apparatus for steaming and boiling specimens (see Fig. 18, p. 78);
Tanks for immersing specimens (see Fig. 16, p. 76);
Vicat needle apparatus (see Fig. 11, p. 69);
One compression testing machine (adapted also to transverse tests), capacity 50,000 lb. (see Figs. 41 and 42, pp. 117 and 118);
Chemical thermometer;
Specific gravity apparatus (see Fig. 9, p. 66);
Microscope with 1½ inch objective;
Set of sieves, about 8-inch diameter, for analyzing sands, sizes No. 4, 8, 20, 50–100 (the number corresponds to the number of meshes to the linear inch) (see p. 159a);
Mechanical shaker for sifting sand (see Fig. 68, p. 195).

SPECIFIC GRAVITY OF DIFFERENT CEMENTS

The specific gravity test, by determining whether a cement is thoroughly burned, supplements the chemical analysis, since the latter does not indicate the degree of calcination. A Puzzolan cement may be distinguished from a true Portland because its specific gravity is usually between 2.7 and 2.9, while that of Portland ranges from 3.05 to 3.15. The adulteration of Portland cement lowers its specific gravity, because the substances used, — powdered sand, limestone, trass or slag, — are lighter than particles of pure cement. The test will not detect a small adulteration nor adulteration with a material of high specific gravity.

Natural cement usually has a specific gravity above 2.75, ranging from this sometimes as high as 3.1,* thus overlapping the inferior limit given for Portland cement.

The specific gravity of cement is lowered by exposure, because of the absorption of water and carbonic acid, hence the necessity of drying it at 100° Cent. (212° Fahr.) before determining. Even this temperature may not always be sufficient to restore old cements to their original condition.†

A neat little device for dropping fine material into a specific gravity apparatus so as to prevent the entraining of air has been devised by Mr. Thomas H. Wiggin. A thin wooden board with a circular hole in it is

*Tests of Metals, U. S. A., 1901, p. 476.

†See experiments in Tests of Metals, U. S. A., 1901, p. 476, and Dr. H. Kupfender in *Thonindustriezeitung*, translated in *Cement*, March, 1903, p. 23.

placed above the apparatus and a paper funnel fitted into the hole and filled with dry cement. An electro-magnet, such as is used with an ordinary electric door-bell, is connected with its storage battery and arranged so that the clapper, instead of striking a bell, strikes a metal plate attached to the corner of the board. The constant tapping jars the funnel so that the grains fall slowly into the apparatus without requiring the attention of the operator.

ADVANTAGES OF FINE GRINDING

The effects of fineness of grinding upon cements are to make them,—

Stronger when tested with sand;
Weaker when tested neat;
Quicker setting;
Capable of producing a larger volume of paste;
Less affected by free lime.

Fineness is expressed by the percentage of the total weight of the cement retained on each sieve.

A recognition of the value of extreme fineness has led to the adoption of higher standards than formerly, and manufacturers have accordingly improved the quality of their product in this respect. As an illustration of this, in 1875 it was a common requirement for Portland cement that 85% should pass, or not more than 15% be retained on, a sieve having 50 meshes per linear inch; in 1893 Max Gary gave the German standard as 90% to pass, or not more than 10% to be retained on, a sieve having 76 meshes per linear inch, while in 1904 specifications for first-class work required not more than from 6% to 10% to be retained on a sieve having 100 meshes per linear inch, and not more than 20% to 35% on a sieve having 200 meshes per linear inch. Some American factories are equipped to grind even finer than this, shipping cement of which less than 10% is retained on a No. 200 sieve. Standard requirements for different cements are given in the specifications on pages 30 and 31.

Strength affected by Fineness. With the same proportions of sand higher tensile and compressive strength is obtained from finely ground than coarsely ground cements. Conversely, a larger proportion of sand can be used with fine ground than with coarse ground cement, with the same resulting strength.

The chief cementing value of a cement lies in the grains which are fine enough to pass a sieve having 200 meshes per linear inch. Photographs of thin sections of sand briquettes several years old made by

Mr. E. W. Lazell show very clearly the coarser grains of cement which have never been penetrated and chemically changed by the water.

Tested neat, a coarse cement may give higher strength than the same cement after regrinding. This is chiefly due, in the opinion of the authors, to the fact that the fine cement requires more water in gaging to produce the same consistency of paste, so that the same weight of cement produces a larger volume of paste, which therefore has less density and consequently lower strength. When sand is added, on the other hand, less influence is exerted by the water, because in any case a smaller volume of it is required in proportion to the dry materials, and besides this the very fine grains, which also have higher cementing qualities, fit more readily into the voids in the sand. The relation of the density of a mortar to its strength is discussed in Chapter IX, page 132.

The effect of the fineness of cement upon its strength was brought to general notice by Mr. John Grant* in 1880, who quotes experiments made in Germany by Dyckerhoff. In 1883 Mr. I. J. Mann† illustrated the small cementing value of the coarse particles by substituting for them grains of sand of the same size, with but little reduction in the resulting strength.

The following table from tests reported in 1885 by Mr. Eliot C. Clarke‡ illustrates the effect of the fineness of cement on paste and mortars. All of these cements would be reckoned as coarse in modern practice, but the relative results are still of interest.

Tensile Strength of Mortar Affected by Fineness of Cement.
BY ELIOT C. CLARKE.

PORTLAND CEMENT			ROSENDALE CEMENT		
Proportions of cement to sand	STRENGTH IN POUNDS PER SQUARE INCH		Proportions of cement to sand	STRENGTH IN POUNDS PER SQUARE INCH	
	Ordinary cement 35% retained on No. 120 sieve	Finely ground cement 12% retained on No. 120 sieve		Coarse cement 17% retained on No. 50 sieve	Fine cement 6% retained on No 50 sieve
1:0	403	304	1:0	98	92
1:3	105	180	1:1½	29	41
1:5	68	96	1:2	16	25

*Proceedings Institution of Civil Engineers, Vol. LXII, p. 149.
†Proceedings Institution of Civil Engineers, Vol. LXXI, p. 254.
‡Transactions American Society of Civil Engineers, Vol. XIV, p. 158.

Mr. D. B. Butler* in England has made extended tests to determine the value of coarse particles in cement and the effect of regrinding. A summary of one of his tables, illustrating also the effect of fineness upon the time of set, gives the average of his results from four brands of Portland cement.

Effect of Regrinding Coarse Particles and of Substituting Sand.
BY DAVID B. BUTLER.

CEMENT, HOW TREATED	Fineness residue per cent on sieves of meshes per linear inch			Setting Properties		TENSILE STRENGTH IN POUNDS PER SQUARE INCH									
						Neat cement					1 part cement to 3 parts sand				
	180	76	50	Initial set min.	Final set min.	7 days	28 days	3 mo.	6 mo.	12 mo.	7 days	28 days	3 mo.	6 mo.	12 mo.
As received	33.7	15.5	4.6	13	90	504	580	641	702	717	194	262	354	404	421
Reground	1.3	0.0	0.0	2	20	497	478	518	489	504	326	411	531	591	618
Sand substituted for coarse particles†						414	480	606	660	702	164	217	290	354	387

The fine grinding of commercial cements, by accelerating the setting, has been one of the causes for the necessity of adding gypsum or plaster during manufacture.

American vs. European Sieves. Standard sieves recommended by the American Society of Civil Engineers‡ and the French Commission§ are tabulated below with English and Metric equivalents.

American Sieves.

U. S STANDARD					METRIC EQUIVALENTS			
No. of sieve	Meshes per linear inch	Meshes per square inch	Diam. of wire in.	Width of openings in.	Meshes per cm.	Meshes per sq. cm.	Diam. of wire mm.	Width of openings mm.
100	100	10 000	0.0045	0.0045	39	1 550	0.114	0.140
200	200	40 000	0.0024	0.0026	79	6 200	0.061	0.066

*Proceedings Institution of Civil Engineers, Vol. CXXXII, p. 343, and Butler's Portland Cement, 1899, p. 169.

†All particles not passing No. 180 sieve (averaging 33.7% by weight) were removed from the original cement as received, and sand having grains of similar size substituted for them.

‡See p. 67.

§Commission des Méthodes d'Essai des Matériaux de Construction, 1894, Vol. I, p. 248.

French Sieves.

FRENCH STANDARD				ENGLISH EQUIVALENTS			
Meshes per cm.	Meshes per sq. cm.	Diam. of wire mm.	Width of openings mm.	Meshes per linear inch	Meshes per square inch	Diam. of wire in.	Width of openings in.
18	324	0.20	0.36	46	2 120	0.0078	0.0124
30	900	0.15	0.18	76	5 780	0.0059	0.0071
70	4 900	0.05	0.09	178	31 680	0.0020	0.0035

Separating Material Passing No. 200 Mesh Sieve. The high cementing value of the grains of cement passing a No. 200 sieve leads in elaborate tests to still finer separations. In studies for soil analysis chiefly, the various methods of separating the different sized grains have been developed. They are fully described in Wiley's *Principles and Practice of Agricultural Analysis*, Vol. I, pages 171 to 281. The same principles are applicable to cement determinations, except that some liquid other than water must be employed.

Separation may be made by a winnowing device* in which a blast of air is directed against falling grains of cement; by settlement through water at rest, which in its simplest form may be accomplished by allowing the material to settle in a beaker, for a certain length of time and then decanting†; and by means of a liquid in motion, as illustrated in the Schöne apparatus, and, with still greater exactness, by Hilgard's churn elutriator.‡ The Schöne apparatus has been adapted by Dr. W. Michaelis to cement, and has also been employed by Mr. J. B. Johnson.§

QUANTITY OF WATER FOR NEAT PASTE AND MORTAR

The quantity of water used in gaging affects the results of tests, especially in the determination of the time of setting and of the strength. (See p. 151.) Different cements even of the same class require different proportions of water to produce the same consistency, chiefly because of differing degrees of fineness, the cement containing the largest proportion of fine particles requiring the largest percentage of water by weight.

For chemical combinations alone about 8 per cent of water to the weight of the cement is customarily assumed to be required, but in practice the percentage must be much greater.

*Tests of Metals, U. S. A., 1901, p. 474.

†Allen Hazen in Report Massachusetts State Board of Health, 1892.

‡Wiley's Principles and Practice of Agricultural Analyses, 1894, Vol. I, p. 226.

§Johnson's Materials of Construction, 1903, p. 412.

Percentage of Water for Mortar of Normal Consistency. The following table, based on the formula of Mr. Feret given on page 88, which is strictly applicable only to French sands and French methods, has been suggested provisionally by the Committee of the American Society for Testing Materials (1904), for the percentage of water for mortars of consistency corresponding to that of normal neat paste. To use the table select from the first column the percentage of water required for the neat paste of the selected cement and read in column of the desired proportions the percentage of water required for the mortar in terms of the sum of the weights of the cement and sand.

Percentage of Water for Cement Mortars of Normal Consistency.

Percentage of water for neat cement	Percentage of water to cement plus sand. Proportions cement to sand by weight					Percentage of water for neat cement	Percentage of water to cement plus sand. Proportions cement to sand by weight				
	1:1	1:2	1:3	1:4	1:5		1:1	1:2	1:3	1:4	1:5
18	12.0	10.0	9.0	8.4	8.0	33	17.0	13.3	11.5	10.4	9.6
19	12.3	10.2	9.2	8.5	8.1	34	17.3	13.6	11.7	10.5	9.7
20	12.7	10.4	9.3	8.7	8.2	35	17.7	13.8	11.8	10.7	9.9
21	13.0	10.7	9.5	8.8	8.3	36	18.0	14.0	12.0	10.8	10.0
22	13.3	10.9	9.7	8.9	8.4	37	18.3	14.2	12.2	10.9	10.1
23	13.7	11.1	9.8	9.1	8.5	38	18.7	14.4	12.3	11.1	10.2
24	14.0	11.3	10.0	9.2	8.6	39	19.0	14.7	12.5	11.2	10.3
25	14.3	11.6	10.2	9.3	8.8	40	19.3	14.9	12.7	11.3	10.4
26	14.7	11.8	10.3	9.5	8.9	41	19.7	15.1	12.8	11.5	10.5
27	15.0	12.0	10.5	9.6	9.0	42	20.0	15.3	13.0	11.6	10.6
28	15.3	12.2	10.7	9.7	9.1	43	20.3	15.6	13.2	11.7	10.7
29	15.7	12.5	10.8	9.9	9.2	44	20.7	15.8	13.3	11.9	10.8
30	16.0	12.7	11.0	10.0	9.3	45	21.0	16.0	13.5	12.0	11.0
31	16.3	12.9	11.2	10.1	9.4	46	21.3	16.1	13.7	12.1	11.1
32	16.7	13.1	11.3	10.3	9.5						

Weights of Cement and Sand for Different Proportions.

	1:1	1:2	1:3	1:4	1:5
Cement	500	333	250	200	167
Sand.............	500	666	750	800	833

The Engineers of the U. S. Army* advocate a dryer mixture than most

*Professional Papers, No. 28.

authorities, and the following percentages suggested by them may therefore be taken as representing minimum quantities.

Portland Cement.

Neat.................................20% of water by weight.
1 cement: 3 sand......................12½% " "

Natural Cement.

Neat.................................30% of water by weight.
1 cement: 1 sand......................17% " "

Puzzolan Cement.

Neat.................................18% of water by weight.
1 cement: 3 sand......................10% " "

French Determination of Consistency of Neat Paste. The Vicat needle apparatus has been selected in America as well as in France as the standard appliance for determining normal consistency. The apparatus is shown in Fig. 11 on page 69, and the U. S. standard method of applying the test is there described.

A plastic paste is preferred to one of dryer consistency. The French Commission* advised a softer consistency than the American standard, the French requiring for normal consistency the penetration of a needle one centimeter (0.39 in.) in diameter and weighing 300 grams (10.58 oz.) through a disc of cement 40 millimeters (1.57 in.) thick to within 6 millimeters (0.23 in.) of the bottom, making a total depth of penetration of 34 millimeters (1.33 in.), while the American Society recommend the penetration of a similar needle into a like mass to a depth of 10 millimeters (0.39 in.) below the surface.

Feret's Formula† for percentage of water for mortar of normal consistency was evolved from a very interesting series of experiments.‡ He found that it was impracticable to determine with the Vicat needle the proper consistency of a mortar of cement and sand, and therefore based his determination upon the average judgment of several operators, plotting the consistencies designated by them upon cross-section paper.

*Commission des Méthodes d'Essai des Matériaux de Construction, 1894, Vol. I, p. 270.

†Commission des Méthodes d'Essai des Matériaux, 1895, Vol. IV, p. 103.

‡Methods of Mr. Feret's investigations are described and illustrated in an article by the authors on "Quantity of Water to Use in Gaging Mortars" in *Cement and Engineering News* (Chicago), November, 1903.