His formula is:

For mortars of plastic consistency,*

$$W = \frac{2}{3} \frac{P}{S + 1} + 6.0 \qquad (1)$$

For mortars of dry consistency,*

$$W' = \frac{2}{3} \frac{P}{S + 1} + 4.5 \qquad (2)$$

Where

W = percentage of water for mortar in terms of weight of the mixture of dry materials;

P = percentage of water required for neat cement of normal consistency;

S = parts of sand by weight to one part cement.

Mr. Richard L. Humphrey† states that from formula (2) he has obtained very uniform results with U. S. standard sand, although slight modifications are necessary for a mortar containing more or less than three parts of sand.

ARBITRARY PERIODS OF SETTING

The methods employed in mixing and depositing the mortar or concrete and the character of the construction form a guide to the necessary requirements for the time of setting of the cement.

The setting of cement is due to chemical reaction, as described by Mr. Spencer B. Newberry on page 57. The process is a gradual one, but may be arbitrarily divided into three periods:

Initial set.
Final set.
Hardening.

The dividing line between these periods is arbitrary, but the division is based upon the fact that after water is added the paste remains plastic for a certain period, and then commences to "stiffen" or crystallize. This is called the time of initial set. The setting process continues rapidly, and when a point is reached that the paste will withstand a certain pressure, arbitrarily fixed in practice, it is said to have reached its final set. The

*The original formula of Mr. Feret corresponding to formula (2) is $E = \frac{2}{3} NA + 60$, and to formula (3) is $E = \frac{2}{3} NA + 45$, in which E = weight of water in grams required for one kilogram of dry mixture of cement and sand, N = weight of water in grams required for one kilogram of neat cement, and A = weight in kilograms of cement in one kilogram of the dry mixture. The change in the form of the formula permits the direct use of percentages.

†Journal Franklin Institute, 1901–2.

process of hardening now continues more slowly, and proceeds with increasing slowness for an indefinite period.

Those unfamiliar with cement construction must bear in mind that a cement which has reached its final "set" is not hard nor is it capable of bearing a load. Natural cement, for example, usually reaches its initial and its final set much earlier than Portland cement, but it hardens more slowly, and Natural cement masonry will not bear loading nearly so quickly as Portland cement masonry.

EUROPEAN METHODS FOR DETERMINING SET

The French and German requirements are similar to the American (p. 70) except that in them the commencement of the set is taken as the time when the needle can no longer penetrate entirely to the bottom of the box instead of limiting it to a penetration to a depth of 5 millimeters above the bottom surface.

For sand mortars the French Commission designate the final set as the moment when the surface of the mortar can support pressure of the thumb without indentation. As an alternate method, they use the Vicat apparatus with a needle one centimeter (0.39 in.) in diameter and weighing 5 kilograms (11.02 lb.). The preliminary reports of Mr. R. Feret and Mr. P. Alexander in Commission des Méthodes d'Essai des Matériaux de Construction, 1895, Vol. IV, pp. 111 and 139, describe experiments with different apparatus.

Comparison of Vicat and Gillmore Needles. The Gillmore needles, the former American standard, were first used by General Totten in 1830.* By these needles the initial set of Neat cement is the time at which a wire one-twelfth-inch diameter, loaded to a ¼ pound, is just supported by the mass without appreciable indentation. The final set is taken as the time when a wire one-twenty-fourth-inch diameter, loaded to weigh one pound, is supported without appreciable indentation.

The diagram in Fig. 19, page 90, from experiments made at the Watertown Arsenal† upon various cements (designated by letters) shows the difference in the nominal time of setting when measured by the Gillmore needle and the Vicat needle, employing with the latter the German method. (See above.) The diagram also shows the variation in time of set of Portland cement occasioned by varying the proportion of water, and the effect of leaving out the usual "restrainer" of plaster of Paris or gypsum.

*Gillmore's Treatise on Limes, Hydraulic Cements and Mortars, p. 80.

†Tests of metals, U. S. A., 1901, p. 492.

THE RATE OF SETTING

The rate of setting of cement, that is, the process of hardening, has been studied by the French Commission* in France and by Prof. Edgar B. Kay in the United States. The diagram, Fig. 20, page 91, shows curves of setting made with a machine of Prof. Kay's design and the corresponding tensile strength of briquettes of the same cement. Prof. Kay calls attention to the positive change from the plastic to the granular or crystalline structure which in the cement shown occurred between the periods of 35 and 40 minutes. The elongation of the briquette when being broken gradually changed from ¾ inch at the 5-minutes period to 0.15 inch at 40 minutes, while at 200 minutes, or one hour before the initial set was completed, the elongation was not measurable.

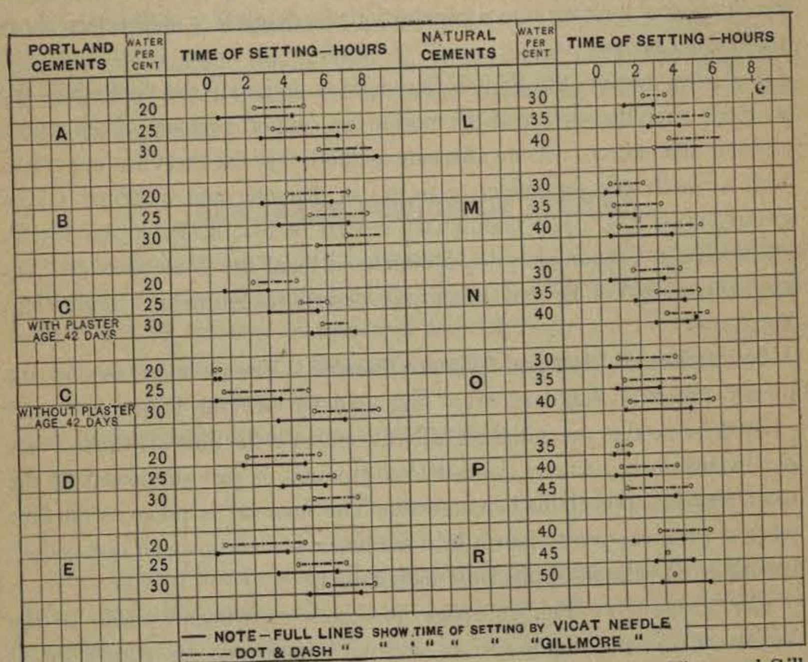

FIG. 19.—Time of Setting of Typical Cements,—and comparison of Vicat and Gillmore's Needles. (Tests of Metals, U. S. A., 1901.) (*See p.* 89.)

AMERICAN AND EUROPEAN STANDARD SANDS COMPARED

The character of the sand has so great an effect upon the strength of a mortar that for comparing different brands of cement or specifying requirements of strength a sand of standard size and quality is essential.

*Commission des Méthodes d'Essai des Matériaux de Construction, 1895, Vol. IV., p. 111.

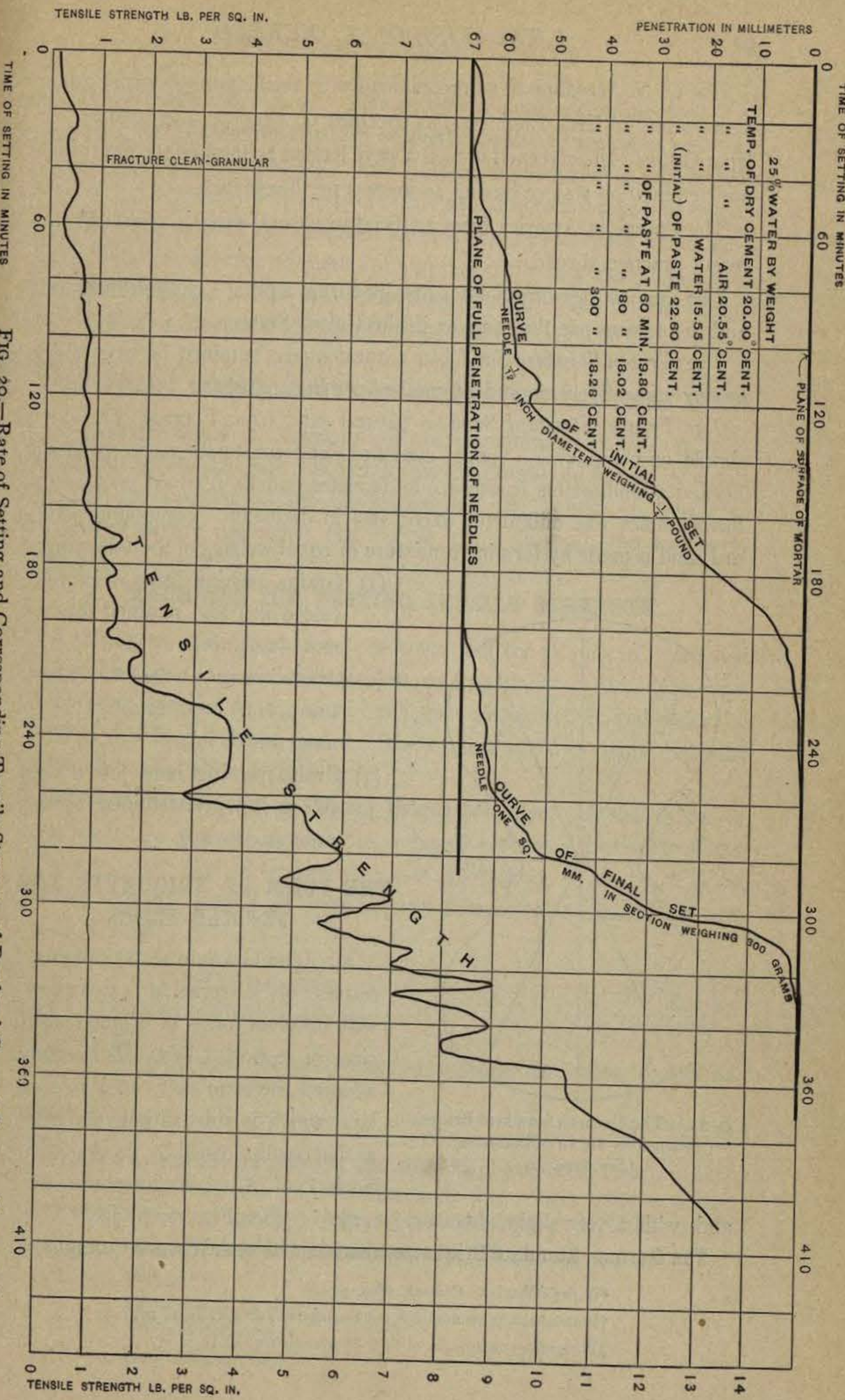

FIG. 20.—Rate of Setting and Corresponding Tensile Strength of Portland Cement Paste. (*See p.* 89.)
(Especially prepared by Prof. Edward B. Kay for this treatise.)

The U. S. Standard Sand recommended by the Committee of the American Society of Civil Engineers, as specified on page 71, is a natural sand from Ottawa, Ill., screened to pass a sieve having 20 meshes per linear inch, and retained on a sieve having 30 meshes per linear inch.

The change in America from artificial to natural sand is in accord with recent practice abroad.

The English Standard Sand is obtained from a pit at Leighton Buzzard,* and the screens are the same as in the United States.

The German Standard Sand is a natural quartz retained between sieves having respectively 20 and 28 meshes per linear inch.

The French Standard Sand, a natural sand from Leucate, France, is simple or compound. Simple standard sand must pass a screen having holes 1.5 millimeters (0.059 in.) in diameter, and be retained on a screen having holes one millimeter (0.039 in.) in diameter. Compound standard sand is made by forming a mixture of equal weights of the following:

(1) Grains passing holes of 2 mm. (0.079 in.) and retained by 1.5 mm. (0.059 in.).

(2) Grains passing holes of 1.5 mm. (0.059 in.) and retained by 1 mm. (0.039 in.).

(3) Grains passing holes of 1 mm. (0.039 in.) and retained by 0.5 mm. (0.020 in.).

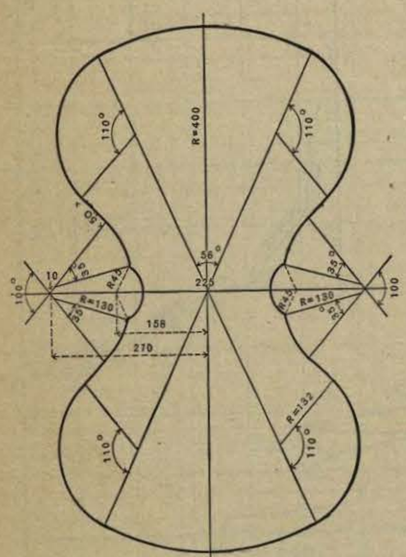

FIG. 21.—The German Standard Briquette (dimensions are in millimeters). (*See page* 92.)

THE FORM OF BRIQUETTE FOR TENSILE TESTS

Mr. John Grant in 1871† presented results of a series of experiments with different forms of briquettes and sizes of section. Ten years later‡ he adopted the form now used in England which is substantially the same as that recommended by the American Society of Civil Engineers in 1884, and, with a very slight alteration, in 1903. (See Fig. 12, p. 72.)

The German Standard Briquette, also adopted by the French Commission in 1893, is shown in Fig. 21. The section is 5 square centimeters (0.78 sq. in.). Results with this form of briquette are lower per unit of area than those of the American pattern. Prof. Jerome Sondericker* in studying the quality of strength and uniformity of breaking of different forms, found that a groove in the sides of the specimen lowered the unit strength about 13%.

M. Feret† found that briquettes of 5 square centimeter section gave 46% higher strength per unit of area than briquettes of 16 square centimeter, and attributed this difference to lack of homogeneity throughout the section.

*Butler's Portland Cement, 1899, p. 200.

†Proceedings Institution of Civil Engineers, Vol. XXXII, p. 282.

‡Proceedings Institution of Civil Engineers, Vol. LXII, p. 137.

TO CONVERT METRIC UNITS OF STRENGTH TO ENGLISH UNITS

To convert values of kilograms per square centimeter (kg. per sq. cm.) to pounds per square inch (lb. per sq. in.), multiply the former by 14.2.‡ To convert values of pounds per square inch (lb. per sq. in.) to kilograms per square centimeter (kg. per sq. cm.), multiply the former by 0.07.§

MACHINES FOR TESTING TENSILE STRENGTH

A testing machine should be so designed that the strain can be applied to the briquette at a definite rate without irregularity or jar. The clips should be suspended from pivoted bearings to avoid friction, and should be stiff, so that they will not spread. The contact surfaces should hold the briquette firmly without crushing it.

Effect of Eccentricity in Placing Briquettes. One of the causes of irregularity in tests of similar briquettes is careless adjustment of the briquette in the clips of the machine, that is, placing it so that it is not exactly central. Prof. J. B. Johnson‖ has discussed this theoretically, and concludes that

if h = width of specimen,

and a = eccentricity of loading,

then $\frac{6a}{h}$ represents the percentage of increase in stress due to eccentricity.

"Thus if a cement briquette one inch thick be placed in the clips 0.01 inch out of center, its strength will be reduced by 6%. This assumes perfect freedom of motion of the clips at the surface of contact, which they do not

*Journal Association of Engineering Societies, January, 1899, p. 1.

†See p. 136.

‡More exactly, 14.2234.

§More exactly 0.07031.

‖1903 Edition, p. 446.

have. Experiments made at the Massachusetts Institute of Technology have shown that a displacement of one-sixteenth inch decreased the tensile strength by from 15% to 20%."

Rate of Applying Strain. The selections of the standard rate of 600 lb per minute by the committee of the American Society of Civil En-

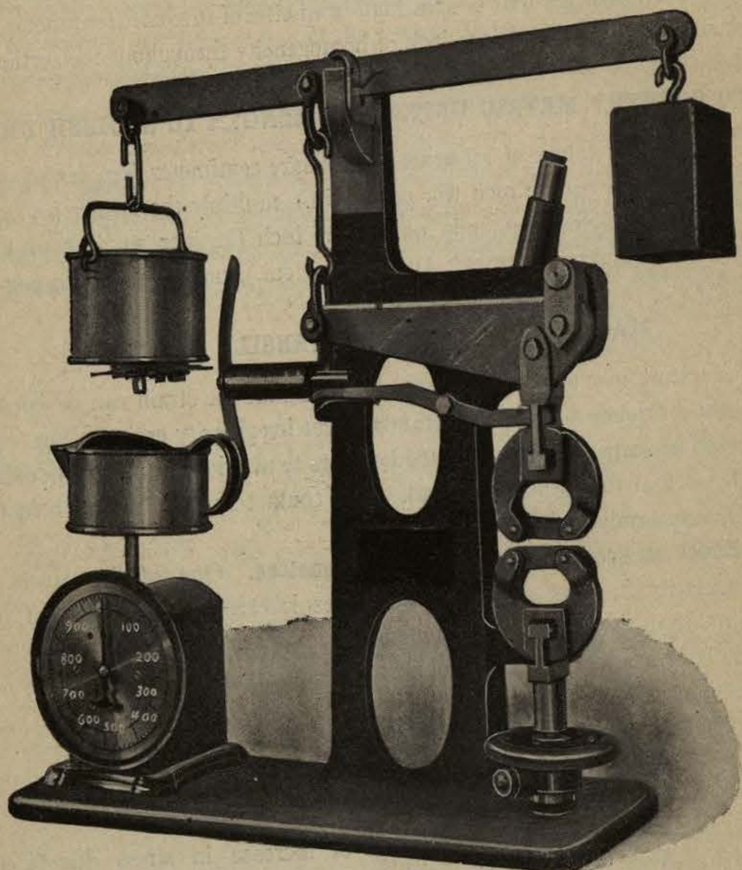

FIG. 22.—Shot Testing Machine. (*See p.* 95.)

gineers (see p. 76) is based on an extensive series of tests from which it was found that the breaking load increases with the speed up to a rate of at least 800 lb. per min., but that between the rates of 400 and 600 lb. the variation is slight. Mr. E. S. Wheeler's* experiments tend to confirm this conclusion.

*Report Chief of Engineers, U. S. A., 1895, p. 2916.

Types of Testing Machines. There are three most common types of tensile testing machines.

(*a*) The shot machine, originally designed by Dr. Michaelis and shown in its American patterns in Figs. 22 and 23, applies the load by the discharging of a stream of shot whose flow is automatically shut off when the

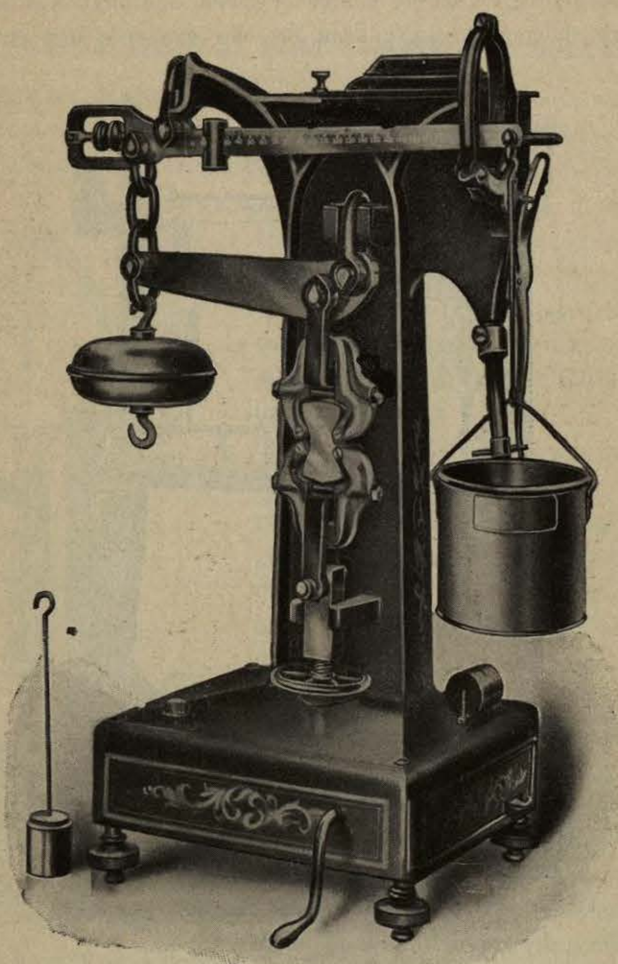

FIG. 23.—Shot Testing Machine. (*See p.* 95.)

break occurs. The breaking load is determined from the weight of the shot.

(*b*) The simple or compound lever machines apply their load by a sliding weight operated by hand or by power. A compound lever power machine is illustrated in Fig. 24, page 96.

(c) The spring balance machine, which was originally designed and used by Mr. Henry Faija in England, transmits the strain from the crank to the briquette through a spring balance which records the load upon the dial. (See Fig. 25, p. 97.)

Johnson's Ring Testing Machine. A machine devised by Mr. A. N. Johnson for testing the tensile strength of cement and mortars is based on an entirely different principle from the clip machines just described

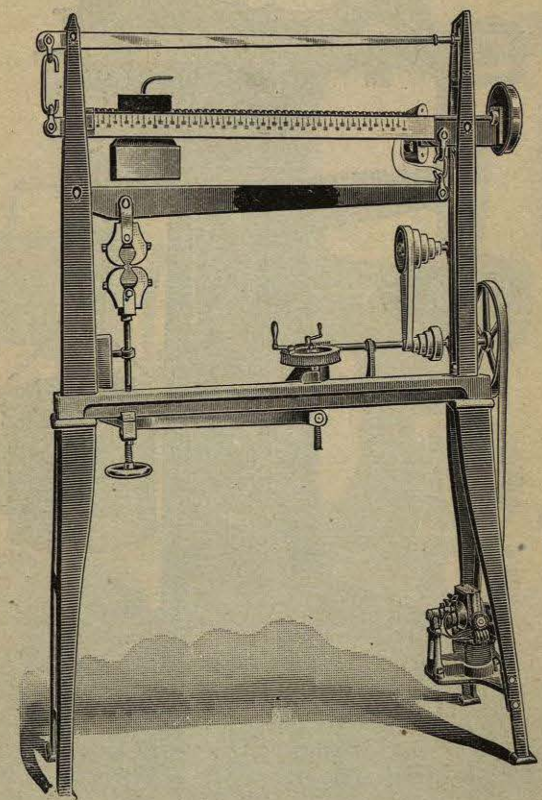

FIG. 24.—Compound Lever Testing Machine (*See p.* 95.)

The cement or mortar instead of being formed into standard briquettes is molded in the shape of rings. The apparatus is shown in Figs. 26 and 27, page 98. A cylinder A filled with water or other liquid contains a piston operated by a handwheel F. The pressure exerted by lowering the piston is transmitted by the liquid to the closed cylinder B, a section of which consists of rubber tubing which is expanded by the pressure from within until it bursts the ring of cement which encircles it. The pressure is also

transmitted to the gage whose reading for a certain diameter and thickness of ring of cement or mortar bears a definite ratio to the circumferential tensile stress upon the ring. Brass molds of special design for forming the rings are constructed either single or in gangs of five.

TENSILE TESTS OF NEAT CEMENT AND MORTAR

Tests of tensile strength are made primarily to determine whether the ingredients of the cement and the process of its manufacture are such that a continued and uniform hardening may be expected in the work, and whether its actual strength in mortar or concrete is so high that it can be depended upon to withstand the strain placed upon it. Tensile tests must be combined with other tests, most particularly the test for soundness, to arrive at correct conclusions on these points.

FIG. 25.—Spring Balance Testing Machine. (*See p.* 96.)

The dates which have been universally selected for making tensile tests to determine the quality of the cement are 7 days and 28 days after molding. In each case the briquettes remain for the first 24 hours in moist air, and the balance of the time in water at the standard temperature of 21° Cent. (70° Fahr.). For arriving at a quicker knowledge of the quality, standard specifications require one-day tests, the briquettes being broken after 24 hours in moist air. Longer periods than 28 days are useful for determining the rate of permanent hardening, although the rate of growth is different in neat cements, mortars and concretes. The growth in tensile strength is not strictly comparable with its growth in compressive strength.

A cement giving an extremely high test at a very short period may be regarded with suspicion, although if future tests show a good increase, no fault can be found. Specifications occasionally limit the strength of the one-day or the 7-days test. Others require a definite increase in strength between periods. The engineers of the New York Rapid Transit Com-

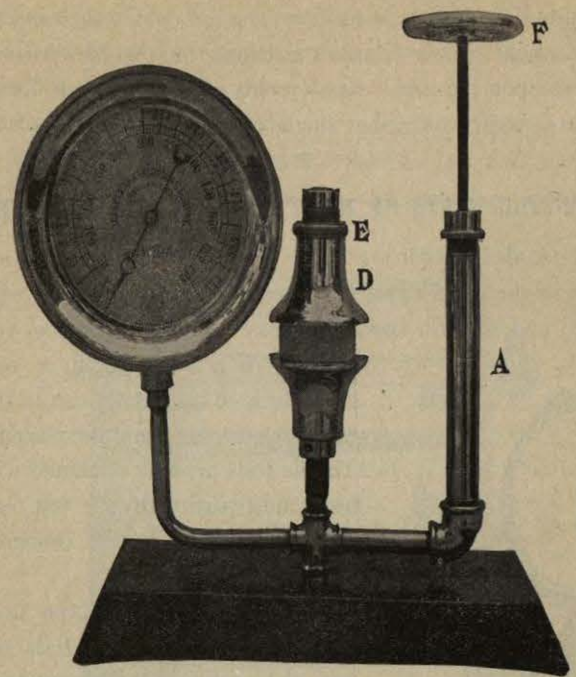

FIG. 26.—Machine with Cement Ring in Position ready for a Test. (*See p.* 96.)

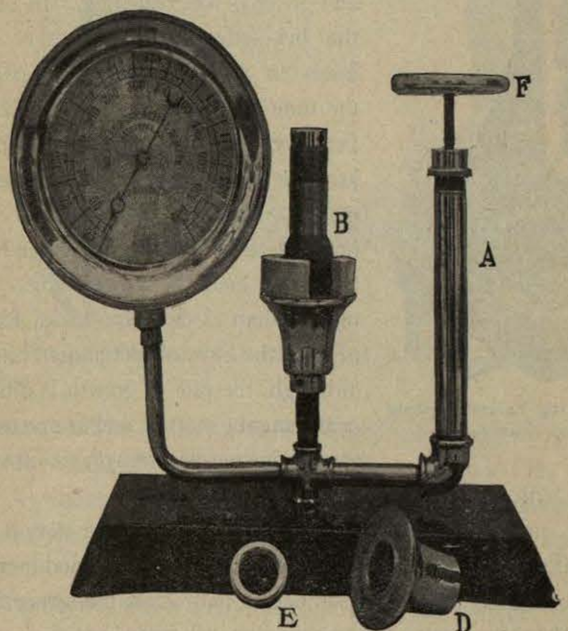

FIG. 27.—Machine after a Test with the Top Cap Removed, Showing the Broken Cement Ring and Distended Rubber Cylinder or Tube. (*See p.* 96.)

mission require, for example, "a specific ratio of increase," 15% in tensile strength "from 7 to 28 days, and furthermore that a cement showing as high as 750 lb. at the earlier stage should be generally refused as unlikely to give good results in long-time tests."* Manufacturers consider this a very severe requirement for Portland cement tested neat.

Specifications for tensile strength are given on pages 30 and 31. A comparison of these with the actual strengths of different cements as furnished by manufacturers will show that on the average the tensile strength of Portland cement as now manufactured is largely in excess of the specifications. In comparing these figures, however, it must be recognized that specifications are not for average strength, but are intended to cover the lowest limit which can be allowed on the work, and to provide for lack of uniformity in testing as well as in real quality.

GROWTH IN STRENGTH OF PORTLAND AND NATURAL CEMENTS AND CEMENT MORTARS

The curves in Fig. 28, for which we are indebted to Mr. W. Purves

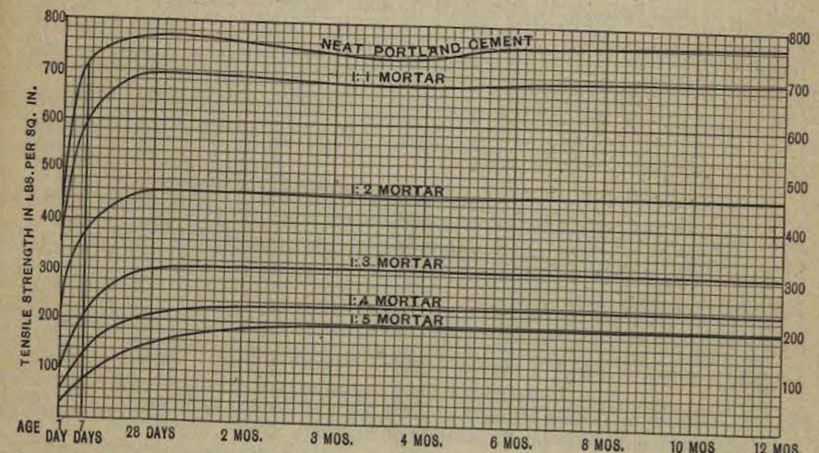

FIG. 28.—Growth in Tensile Strength of Neat Portland Cement and Portland Cement Mortars with Different Proportions of Standard Sand. (*See p.* 99.)
(Compiled for this treatise by W. Purves Taylor.)

Taylor, illustrate the growth in strength of neat Portland cement and Portland cement mortars. The tests from which the curves are drawn were made under his direction at the Philadelphia Municipal Laboratories.

*Report of New York Board of Rapid Transit Commissioners, 1900-01, p. 258.