They remained from two to seven days (most of them three to four days) in the molds, and were then placed, until tested, in wet ground. Mr. Kimball's remarks with reference to the leanest mixtures are of interest as illustrating the frequent necessity of using richer proportions than the actual loading requires.

The 1: 6: 12 blocks were in poor condition. This was due to the difficulty of getting so lean a mixture well rammed into the corners of molds so small as 12-inch, and to the fact that the concrete had not attained sufficient strength, even though handled with care, to hold together well in the process of removal from the molds. The cubes of this mixture should have had a longer time to set before taking them out of the forms. In our foundation work we have used this mixture only as a filling with which to replace soft ground and on which to build the foundations proper.

The diagram in Fig. 119 shows Mr. Kimball's resultant curves* for the

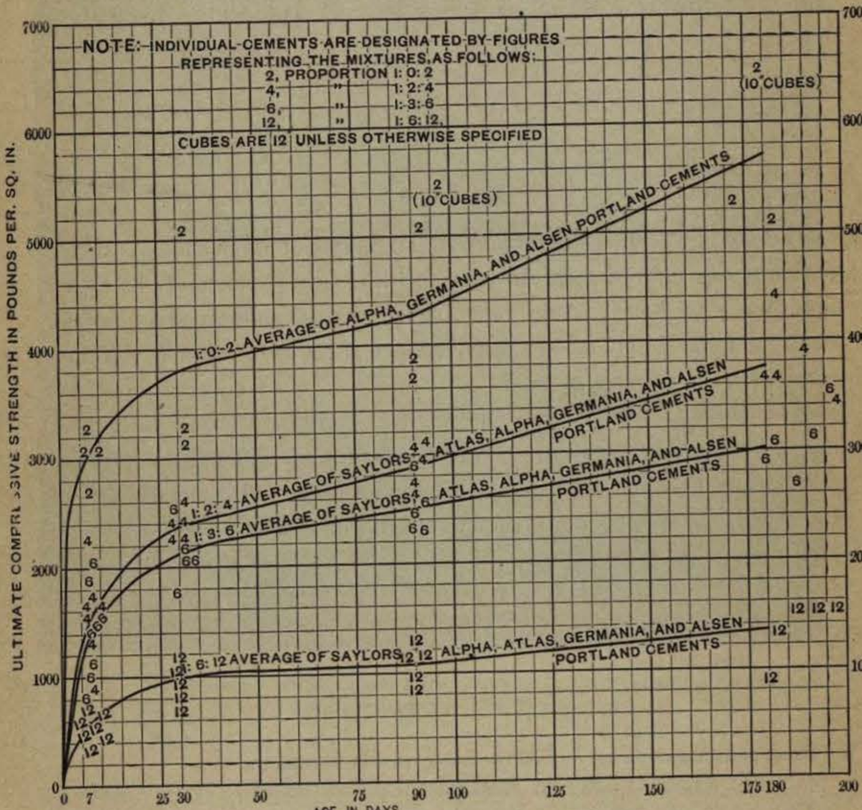

FIG. 119.—Tests on Concrete Cubes by Geo. A. Kimball (Watertown Arsenal, 1889). (See p. 365.)

*From data presented to the authors by Mr. Kimball.

different proportions based on an assumed weight of cement of 100 lb. per one cubic foot at the various ages. The results from individual brands of cements are shown by separate points.

Candlot's Tests. The table below, giving results of tests by Mr. E. Candlot,* of France, converted into English units, is of special value because of the accuracy in recording the data, the extreme variation in proportions and the number of periods at which specimens were

Tests of Strength of Concrete made with Different Proportions.

BY E. CANDLOT. (*See p.* 367.)

Proportions based on packed cement†	Volume of mortar in terms of percentage of volume of stone	Actual quantity of materials: Cement	Sand	Stone	Water	Gravel concrete: Volume of Concrete	Cement in 1 cu. ft. of concrete	Weight per cu. ft. of concrete after setting	Ultimate compressive strength in lb. per sq. in.: 7 Days	28 Days	6 Months	1 Year	Broken stone concrete: Volume of Concrete	Cement in 1 cu. ft. of concrete	Weight per cu. ft. of concrete after setting	Ultimate compressive strength in lb. per sq. in.: 7 Days	28 Days	6 Months	1 Year
	%	lb.	cuft	cu.ft.	cu.ft.	cu.ft.	lb.	lb.					cu.ft.	lb.	lb.				
1:6.4: 8.2	67	551	35.3	45.0	6.36	58.3	9.5	144.8	1031	1387	1280	1292	54.8	10.1	142.3	1316	1600	1636	1943
1:3.6: 4.7	67	992	35.3	46.6	7.42	61.1	16.2	147.3	1458	2454	2583	3225	56.9	17.4	147.9	2240	2845	3319	3508
1:2.5: 3.6	67	1433	35.3	50.9	8.55	65.0	22.0	150.4	2312	3094	3485	4385	61.1	23.4	149.8	2845	3485	4883	5026
1:1.6: 2.8	67	2205	35.3	62.0	10.77	78.0	28.0	149.8	2632	3414	3579	5500	72.0	30.6	151.6	3985	4303	4623	5974
1:6.4:10.9	50	551	35.3	60.1	6.36	67.8	8.1	142.3	747	924	1031	1707	63.6	8.7	142.3	1316	1387	1494	1683
1:3.6: 6.3	50	992	35.3	62.2	7.42	70.6	14.0	145.4	1743	1991	2536	2964	67.1	14.7	146.6	2098	2241	2845	3201
1:2.5: 4.7	50	1433	35.3	67.8	8.55	73.8	19.4	149.1	2169	3058	3532	4505	70.6	20.3	148.5	2276	3414	3627	5262
1:1.6: 3.7	50	2205	35.3	82.6	10.77	91.1	24.2	150.4	2952	3592	4054	5050	86.2	25.5	151.0	3556	3982	4338	5572
1:6.4:13.6	40	551	35.3	75.0	6.36	79.5	6.9	141.0	676	924	1078	1375	70.6	7.8	143.5	1280	1316	1138	1778
1:3.6: 7.8	40	992	35.3	77.7	7.42	84.8	11.7	142.3	1031	1494	1518	2608	78.8	12.6	142.3	1494	1778	2347	2822
1:2.5: 5.9	40	1433	35.3	84.8	8.55	90.4	15.9	145.4	1245	1992	2654	3247	85.5	16.7	146.0	2205	2525	2963	3201
1:1.6: 4.7	40	2205	35.3	103.3	10.77	106.7	20.7	149.2	2454	2560	3319	4503	102.4	21.5	146.6	2560	3200	3532	3936

NOTE.—The gravel weighed 96.8 lb. per cu. ft. and contained 40% voids. The broken stone weighed 85.5 lb. per cu. ft. and contained 47.4% voids. Both the gravel and broken stone had been passed through a screen having meshes of 1½" diameter. The sand weighed 81.2 lb. per cu. ft., thus containing 50.4% voids, and had been passed through a No. 12 sieve. The cubes were 10 centimeters (4 in.) on an edge.

crushed. The application of these tests to the authors' formula for strength is discussed on page 357.

The Effect of Concentrated Loading. In concrete foundations for piers and in concrete footings it is customary to load an area smaller than that of the surface of the concrete. The question at once arises whether the stress shall be based upon the load divided by the total area of the concrete footing or by the area of contact. Experiments made upon concrete and other materials show that neither of these methods is correct, but that an intermediate area should be selected for computation.

*Candlot's Ciments et Chaux Hydrauliques, 1898, pp. 446, 447.

†Assuming 3.8 cu. ft. in 1 bbl of 376 lb.

In connection with the designing of concrete footings for the Boston Elevated Railway, 12-inch cubes were crushed by concentrating the load upon plates 10 by 10 inches and 8 by $8\frac{1}{4}$ inches.* At Lehigh University in 1908 a set of experiments was made upon the strength of 6 by 6 inch cubes of 1:2:4 proportions where the compressed area varied from the entire area of the specimen down to 1.21 square inches.

In the diagram, Fig. 120, both sets of values† are plotted. The two sets agree where they overlap, and also are similar in general direction, and, in fact, in actual values of the ordinates, to curves drawn by Prof. J. B. Johnson‡ illustrating Bauschinger's tests upon other materials than concrete.

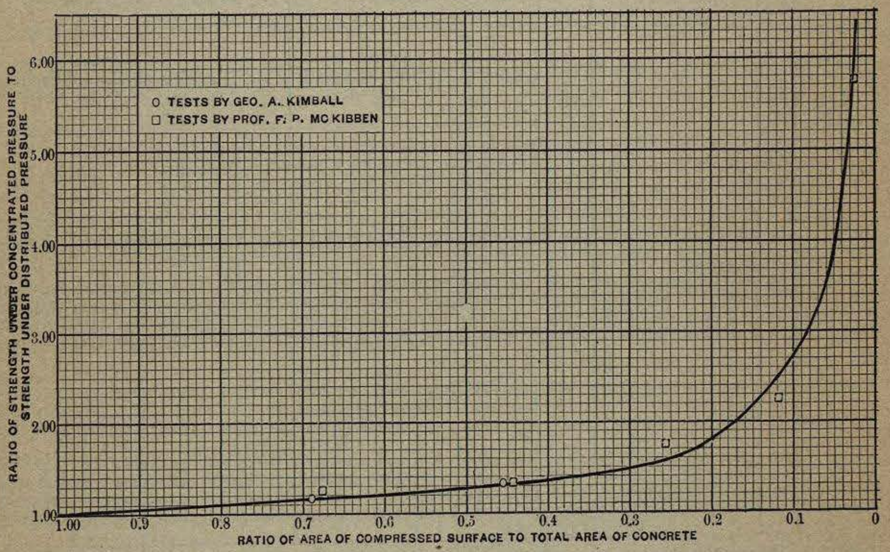

FIG. 120. Concentrated vs. Distributed Loading. (*See p.* 368.)

In considering the smaller areas, as indicated by the smaller ratios of area, the fact must be considered that the compressed surface deforms, that is, actually compresses under the load, and the amount of deformation, which may be approximately estimated from the modulus of elasticity, may sometimes be the limiting consideration. Also, in the small areas the possibility of punching through must be considered.

The method of using the curve shown in Fig. 120 is best illustrated in the following examples:

* Tests of Metals, U. S. A., 1899, p. 740.
† From data presented to the authors by Mr. George A. Kimball and by Prof. Frank P. McKibben.
‡ Johnson's Materials of Construction, p. 33.

Example 1.—What dimensions of pedestal would be required to safely support a load of 40 tons concentrated upon a plate 10 inches square, assuming an allowable distributed stress upon the concrete of 650 lb. per square inch?

Solution.—Forty tons or 80 000 pounds on 100 square inches represents 800 lb. per square inch, and the ratio of pressure required under the concentrated load to the allowable pressure is therefore $\frac{800}{650} = 1.23$; hence from the curve, the total area of concrete necessary is $\frac{100 \text{ sq. in.}}{0.55} = 182$ square inches.

Example 2.—The breaking strength of a 12-inch cube of 1 : 2 : 4 concrete having chamfered edges, so that the area of contact of the load is reduced to 9 by 9 inches, or 81 square inches, is 324 000 pounds. What may be considered as the ultimate strength of the concrete when loaded over its full area?

Solution.—The strength per square inch of the cube figured on its chamfered surface is $\frac{324\ 000}{81} = 4\ 000$ lb. per square inch. The ratio of the compressed surface to the total area is $\frac{81}{144} = 0.56$, and from the diagram we find the ratio of strength to be 1.22. Dividing 4 000 pounds, the unit strength on the concentrated surface by this gives as the probable ultimate of the concrete when loaded over its full area, 3 280 lb. per square inch.

The Strength of Short Prisms. The theoretical angle of rupture in crushing is about 60° with the horizontal, and, as a matter of fact, cubes or prisms of concrete will leave, after crushing, pyramids whose surfaces are at an angle of about 60° with the base. To develop simply the normal compressive strength, the height of a specimen should be at least $1\frac{1}{2}$ times, and preferably 5 times, its least lateral dimension.

The following formula evolved by Prof. Johnson* by plotting results of experiments by Prof. Bauschinger with sandstone prisms, and by Mr. Charles Bouton with cast-iron prisms, may be used for comparing approximately the strength of prisms and cubes. Prof. Johnson states that the law holds between ratios of height to breadth of 0.4 to 5.0, the limits of the observations.

$$\frac{\text{strength of prism}}{\text{strength of cube}} = 0.778 + 0.222\frac{b}{h} \qquad (3)$$

where b = least lateral dimension of specimen,
and h = height of specimen.

* Materials of Construction, 1903, p. 31.

Although we have not sufficient data to prove that this formula is exactly applicable to concrete, a study by the authors of tests at the Watertown Arsenal* tends to show that, considering the variability of the material, it is probably sufficiently accurate for practical use. In the Arsenal experiments square prisms were employed, varying in cross-section from 4 by 4 inches to 12 by 12 inches and ranging in height from 1 to 2 inches up to that of a cube. In every case the shorter prisms gave much higher strength than the cubes.

Example.—If the compressive strength per square inch of a 12-inch cube is 4 000 lb., what strength may be expected from a prism 12 inches square and 18 inches high?

Solution.—Substituting in formula (3), we have

$$\frac{x}{4000} = 0.778 + 0.222\tfrac{12}{18}$$

$$x = 3704$$

Theoretically, specimens of the same shape, as, for example, all sizes of cubes, should have the same strength per unit of area. In practice, large concrete cubes are apt to show higher unit strength than smaller ones; experiments by the authors, for example, giving in every case higher unit strength for 12-inch than for similar 8-inch cubes. However, the average unit weight of the 8-inch cubes was much lower than that of the 12-inch cubes made from the same batches of materials, indicating the difference in strength to be due to the fact that the materials can be more compactly placed in a large than in a small mold.

The standard compression specimen adopted by the Joint Committee on Concrete and Reinforced Concrete is a cylinder 8 inches in diameter by 6 inches long.

Strength of Cubes vs. Cylinders vs. Columns. Computations from the United States Government tests at St. Louis† comparing the strength of 6 inch cubes and standard cylinders 8 inches diameter by 16 inches long gives a ratio of strength of cylinders to cubes at ages of thirteen and twenty-six weeks as 0.88. This coincides almost exactly with the above formula.

But few comparative tests of cylinders and columns are available, but these indicate that the above formula is fairly correct and on the safe side when comparing the probable strength of a column with the given strength of a cylinder.

* Quoted and tabulated by Committee on Compressive Strength of Cements of the American Society of Civil Engineers in Transactions, Vol. XVIII, p. 264.
† U. S. Geological Survey, Bulletin 344, 1908.

Plain Concrete Columns. There are few comparative records of the strength of concrete columns of different heights, but both theory and experiments tend to show that there is no appreciable difference in the compressive strength of columns of heights differing within ordinary limits, ranging, say, from a height of 3 to 14 times the least lateral dimension, provided the loading is exactly central. Prussian regulations,* 1904, require that computation shall be made for flexure, if the height exceeds 18 times the least diameter.

In 1897 tests were made at the Watertown Arsenal† on 12 by 12 inch columns of plain concrete, built by the Aberthaw Construction Company,

Compressive Strength of Mortar and Concrete Columns.
Length of Columns 8 feet.
Watertown Arsenal (*See p.* 371.)

Nominal size of column.	Composition.				Age.		Weight lb. per cu. ft.	Strength lb. per sq. in.	Date of test and reference to Tests of Metals.
	Cement.	Sand.	Stone.	Kind of stone.	Months.	Days.			
10″ Diameter	neat	0	0	None	10	25	129	*a*7000	1907 p. 186
10″ Diameter	1	1	0	None	6	11	132	4320	1906 p. 473
12″ × 12″	1	2	0	None	6	0	130	3070	1905 p. 379
12″ × 12″	1	1	1	$\frac{1}{8}$″ to $\frac{1}{2}$″ trap	7	10	142	3522	1907 p. 182
12″ × 12″	1	1	2	$\frac{1}{2}$″ to $1\frac{1}{2}$″ trap	5	7	154	3900	1905 p. 331
10″ Diameter	1	$1\frac{1}{2}$	3	$\frac{3}{4}$″ to $1\frac{1}{2}$″ trap	10	23	152	3576	1907 p. 192
12″ × 12″	1	2	4	$\frac{1}{2}$″ to $1\frac{1}{2}$″ trap	6	5	150	1990	1905 p. 334
12″ Diameter	1	3	6	$\frac{1}{2}$″ to $1\frac{1}{2}$″ trap	5	5	146	*b* 1446	1906 p. 535
12″ Diameter	1	3	6	Cinders	5	0	101	698	1906 p. 537

a Maximum load applied; column not ruptured.
b A similar column failed at 750 lb. per. sq. in. but the lower end of this column was less sound than the upper part because of leakage of the mold.

ranging from 2 to 14 feet in length. The results of these tests concur with the theory of columns in showing that up to at least 14 diameters there is but little decrease in strength as the length of the column increases.

The table presented above gives results selected from tests made by Mr.

* See *Engineering Record*, July 2, 1904, p. 25.
† Tests of Metals, U. S. A., 1897, p. 383.

Howard at the Watertown Arsenal* in 1905, 1906 and 1907, on concrete and mortar columns. Generally the first sign of failure in the columns appeared in the form of oblique and longitudinal cracks, occurring usually from 0 to 3 feet distant from one end, although sometimes extending the entire length.

A comparison of the strength of plain and reinforced columns is presented in the next chapter.

Strength of Machine vs. Hand Mixed Concrete. Mixing in a well designed machine produces a more homogeneous concrete than is possible by hand except with excessive labor. The relative strength of the concrete of course varies with the conditions, but tests indicate that ordinarily 10 to 20 per cent greater strength may be expected in a first-class, machine mixed concrete, properly handled. It is probable that this more thorough mixing at least balances the extra care given to laboratory specimens, so that in ordinary practice, strength as great, if not greater, than in the laboratory, may be expected.

Eccentric Loading. The effect of eccentric loading, that is, of having the center of gravity of the load one side of the center of the column, is to lessen its compressive strength. A similar effect is produced by loading a column already bent, or by constructing it of unsymmetrical shape, as by bulging one side.

Most columns in actual structures are loaded more or less eccentrically, and this is especially the case with wall columns, which have all the floor loading upon one side. This must be allowed for in designing the columns.

The ordinary formula for the compressive fiber stress due to eccentric loading upon solid rectangular columns, as illustrated in Fig. 121, is as follows:

Let

P = total load.
A = area of columns.
e = eccentricity.
b = breadth of column.
f = average unit pressure.
f' = total unit pressure on outer fiber nearest to line of vertical pressure.

Then

$$f' = \frac{P}{A}\left(1 + \frac{6e}{b}\right) \qquad (4)$$

The use of the formula is illustrated by the following example.

* Tests of Metals, U. S. A., 1905, 1906, 1907.

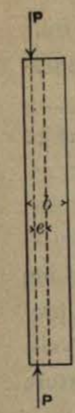

FIG. 121. Eccentric Column Loading. (See p. 372.)

Example. — What will be the increase in pressure in a column 2 feet square due to placing the loading 6 inches off center?

Solution. — With central loading the pressure is, $f = \frac{P}{A}$

hence

$$f' = f\left(1 + \frac{6e}{b}\right)$$

Substituting the values $e = 0.5$ and $b = 2$

$$f' = 2\tfrac{1}{2} f$$

that is, the pressure on outer fibre is increased $2\tfrac{1}{2}$ times.

Concrete vs. Brick Columns. The compressive strength of brick piers is of interest to the concrete engineer for comparing brick and concrete columns. Tests made at the Watertown Arsenal and quoted by the Committee of the American Society of Civil Engineers on the Compressive Strength of Cement* give the ultimate strength of common brick piers about eighteen months old as ranging from 800 to 2 400 pounds per square inch, the results for brick laid with lime mortar averaging nearer the lower figure, and those for 1 : 2 Portland cement mortar nearer the higher figure.

Prof. William H. Burr,† after discussing the strength of brick piers under various conditions, states that

> The results of all the experimental investigations available in connection with brick masonry and experiences in the best class of engineering work indicate that masonry laid up of good hard-burnt common brick may safely carry a working load of 15 to 20 tons per square foot or 210 to 280 pounds per square inch. In the construction of this class of masonry where the duties are to be severe it is of the utmost importance that the best class of Portland cement mortar be employed, as the carrying capacity of brick masonry depends largely, if not chiefly, upon the character of the mortar.

These working stresses are about one-half those recommended for good 1 : 2 : 4 concrete in the chapter which follows.

More recent tests by Professors Talbot and Abrams‡ indicate that the strength of the brick column varies with the quality of the brick, the quality of the mortar and the care in laying.

SAFE STRENGTH OF CONCRETE

The working strength to be used for concrete is fully discussed in the

* Transactions American Society of Civil Engineers, Vol. XV, p. 717, and Vol. XVIII, p. 264.
† Burr's Materials of Engineering, 1903, p. 428.
‡ University of Illinois, Bulletin No. 27, Sept. 1908.

chapter which follows. For proportions and conditions differing from those presented there, reference may be made to the relative strengths discussed in the preceding pages.

In many structures the actual strength of the concrete does not enter into the calculation. The dimensions of a concrete foundation, for example, are often determined by the area of the superimposed structure, or else, on the other hand, by the bearing power of the soil. In such cases it often would be theoretically possible to come nearer to the working strength of the concrete by using very lean proportions, were it not prohibited by the porosity of the mass or its low strength at short periods. However, by grading the materials so as to reduce the voids, a lean mixture is often economical.

The unit pressure to be selected depends not only upon the strength of the concrete as determined by its proportions, the character of the raw materials, and the methods of mixing, but also upon the character and importance of the structure, the nature of the pressure,—whether by direct compression or bending, whether from a live or dead load, or whether acting directly or through a cushion of inert material,—and the time of setting before placing the load.

GROWTH IN STRENGTH OF CONCRETE

Records from various tests made upon similar specimens of concrete at different periods are plotted in the diagram, Fig. 122. The curve illustrates the growth in strength which may be expected in ordinary average concrete made with first-class materials. The ordinates on the diagram represent ratios of the strength at various periods to the strength at the age of one month, in order that the curve may be of general application to various mixtures. If, for example, the strength of any concrete at one month is found to be 2 000 pounds per square inch, the strength of the same concrete at the age of six months may be assumed to be 2 000 multiplied by 1.35, the ordinate at six months, or 2 700 pounds per square inch.

The curve does not allow for the fact that the growth in strength varies to a certain extent with different materials, with different proportions, and with different percentages of water employed in mixing. As stated on page 386, with age, the strength of gravel concrete appears to gain on the strength of broken stone concrete. The growth, too, at periods beyond, say three months, is undoubtedly affected by the hardness or strength of the particles of the coarse aggregate, since a concrete of poor material will reach its ultimate strength earlier than one of good material. The tests of Mr. Kimball (see page 366) tend to show that the increase with age

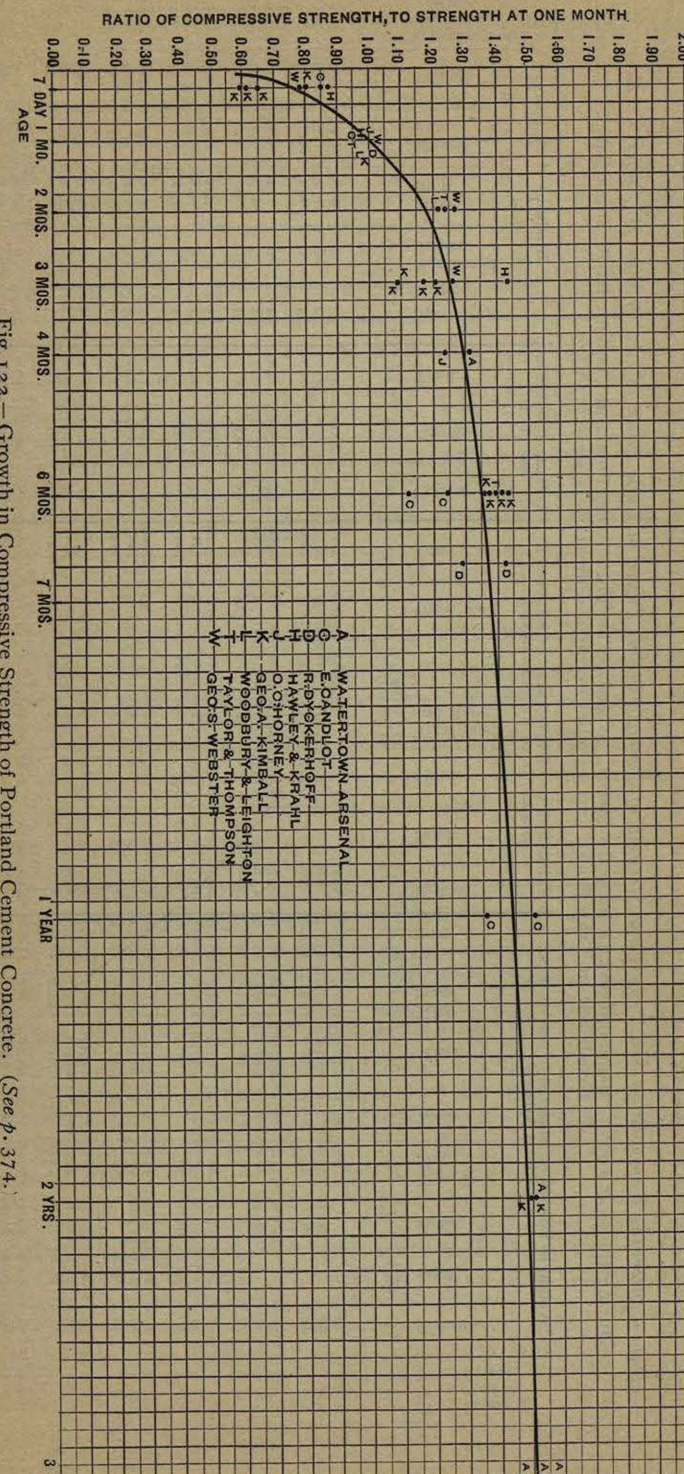

Fig 122.—Growth in Compressive Strength of Portland Cement Concrete. (*See p.* 374.)

Data Concerning Composition and Transverse Strength of Concrete Beams Tested at Little Falls, N. J., by Wm. B. Fuller, C. E.

During the year 1901. Beams, 6 x 6 x 72 inches. Spans, 30 and 60 inches. Atlas Portland Cement, River Silica Sand. Crusher Run Trap Rock, ¼ to 3 inches nominal diameter. (*See p.* 378.)

Item.	Propor-tions by weight.	Weight in Pounds of Material in one cu. ft. of Beam as Mixed.								Calculated Volume, in cu. ft. of Material in one cu. ft. of Beam as mixed.							Volume of Voids in one cu. ft.			Modulus of Rupture.					
							Totals.															Pounds per sq. in.			
	C.S.G.	Cement.	Sand.	Stone.	Total Dry Mix.	Water.	As Mixed.	Mini-mum.	Maxi-mum	Cement.	Sand.	Stone.	Total Sand and Stone.	Total Dry.	Water, 62.4.	Total.	Cement.	Aggregate.	Total.	Age. Days.	Number of Breaks.	Maxi-mum.	Mini-mum.	Average.	Per cent. prob-able error of average.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)
(1)	1:0:0	112.9			112.9	24.1	137.0	121.9	138.8	.585				.585	.386	.971	.415	.000	.415	32	6	968	856	906	1.0
(2)	1:0:1	69.1		69.1	138.2	15.4	153.6	143.7	155.2	.358		.370	.370	.728	.247	.975	.254	.018	.272	32	6	872	668	772	2.8
(3)	1:0:2	49.9		99.8	149.7	12.9	162.6	153.7	162.6	.259		.534	.534	.793	.207	1.000	.183	.024	.207	33	6	802	668	731	2.4
(4)	1:0:3	38.0		113.8	151.8	11.2	163.0	154.8	163.9	.197		.609	.609	.806	.180	.986	.140	.054	.194	34	6	724	580	622	2.4
(5)	1:0:4	27.4		109.4	136.8	9.7	146.5	139.0	154.0	.142		.585	.585	.725	.155	.880	.101	.174	.275	34	3	251	236	241	2.3
(6)	1:1:0	64.9	64.9		129.8	15.3	145.1	135.0	146.7	.336	.393		.393	.729	.245	.974	.238	.033	.271	34	6	866	628	734	3.8
(7)	1:1:1	47.0	47.0	47.1	141.1	12.3	153.4	144.9	154.8	.244	.285	.252	.537	.781	.197	.978	.172	.047	.219	34	6	744	649	708	1.6
(8)	1:1:2	37.2	37.2	74.4	148.8	10.3	159.1	151.8	160.3	.193	.225	.398	.623	.816	.165	.981	.136	.048	.184	33	6	798	646	710	3.0
(9)	1:1:3	30.1	30.2	90.4	150.7	10.8	161.5	153.1	161.8	.156	.183	.483	.666	.822	.173	.995	.110	.068	.178	34	6	732	573	655	2.3
(10)	1:1:4	25.9	25.9	103.6	155.4	9.7	165.1	157.5	165.1	.134	.157	.554	.711	.845	.155	1.000	.095	.060	.155	33	6	512	446	486	1.9
(11)	1:1:5	22.6	22.6	113.0	158.2	7.8	166.0	160.0	167.1	.117	.137	.604	.741	.858	.125	.983	.083	.059	.142	34	6	542	481	504	1.6
(12)	1:2:0	43.5	86.9		130.4	12.9	143.3	133.9	145.9	.225	.527		.527	.752	.207	.959	.160	.088	.248	33	6	640	592	616	0.9
(13)	1:2:1	34.1	68.3	34.1	136.5	12.9	149.4	139.2	150.7	.177	.414	.182	.596	.773	.207	.980	.125	.102	.227	33	6	572	459	523	2.6
(14)	1:2:2	28.6	57.1	57.1	142.8	11.7	154.5	145.1	155.3	.148	.346	.305	.651	.799	.188	.987	.105	.096	.201	33	6	552	485	528	1.8
(15)	1:2:3	25.3	50.6	76.0	151.9	7.4	159.3	153.9	161.6	.131	.307	.406	.713	.844	.119	.963	.093	.063	.156	33	1			471	∞
(16)	1:2:4	22.3	44.7	89.4	156.4	7.4	163.8	158.2	164.8	.116	.271	.478	.749	.865	.119	.984	.082	.053	.135	33	6	480	399	439	3.0
(17)	1:2:5	19.8	39.5	98.5	157.8	7.4	165.2	159.4	166.0	.103	.239	.527	.766	.869	.119	.988	.073	.058	.131	33	6	413	349	380	2.2
(18)	1:2:6	17.5	35.0	105.1	157.6	8.2	165.8	159.0	166.0	.091	.212	.562	.774	.865	.131	.996	.064	.071	.135	35	5	410	234	319	9.5
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)
(19)	1:3:0	32.0	95.8		127.8	12.2	140.0	130.4	143.6	.166	.581		.581	.747	.196	.943	.117	.136	.253	35	6	432	392	418	1.2
(20)	1:3:1	27.4	82.3	27.4	137.1	10.9	148.0	139.3	150.4	.142	.499	.146	.645	.787	.175	.962	.101	.112	.213	35	5	392	274	360	3.3
(21)	1:3:3	21.0	63.2	63.1	147.3	8.6	155.9	149.0	158.0	.109	.383	.337	.720	.829	.138	.967	.077	.094	.171	33	6	369	338	355	1.2
(22)	1:3:5	16.6	49.9	83.2	149.7	8.0	157.7	151.0	160.1	.086	.302	.445	.747	.833	.128	.961	.061	.106	.167	33	3	308	262	285	3.3
(23)	1:3:6	15.3	45.9	91.9	153.1	8.5	161.6	154.3	162.6	.079	.278	.491	.769	.848	.136	.984	.056	.096	.152	33	5	246	213	226	2.1
(24)	1:3:7	14.3	42.8	100.0	157.1	8.2	165.3	158.2	165.3	.074	.259	.535	.794	.868	.132	1.020	.053	.079	.132	33	2	257	220	239	5.4
(25)	1:3:8	13.1	39.5	105.0	157.6	7.2	164.8	158.6	165.8	.068	.239	.561	.800	.868	.115	.983	.048	.084	.132	33	4	192	159	178	2.9
(26)	1:3:9	12.1	36.3	109.1	157.5	6.5	164.0	158.5	165.9	.063	.220	.583	.803	.866	.104	.970	.044	.090	.134	33	3	176	123	145	8.2
(27)	1:4:0	25.3	101.1		126.4	11.3	137.7	128.4	142.4	.131	.613		.613	.744	.181	.925	.093	.163	.256	33	6	294	262	279	1.8
(28)	1:4:2	18.9	75.7	37.9	132.5	12.8	145.3	134.0	147.5	.098	.459	.203	.662	.760	.205	.965	.069	.171	.240	34	4	235	198	210	3.1
(29)	1:4:4	15.8	63.0	63.1	141.9	10.7	152.6	143.2	154.3	.082	.382	.337	.719	.801	.171	.972	.058	.141	.199	34	3	219	202	209	1.8
(30)	1:4:6	13.6	54.2	81.4	149.2	10.0	159.2	150.3	159.6	.070	.328	.435	.763	.833	.160	.993	.050	.117	.167	34	2	184	114	149	16.7
(31)	1:4:7	12.7	50.6	88.6	151.9	9.5	161.4	152.9	161.4	.066	.307	.474	.781	.847	.153	1.000	.047	.106	.153	34	2	190	170	181	4.3
(32)	1:4:8	11.7	46.8	93.5	152.0	9.7	161.7	152.9	161.6	.061	.284	.500	.784	.845	.155	1.000	.043	.112	.155	34	2	158	156	157	0.4
(33)	1:4:9	11.1	44.3	99.8	155.2	8.7	163.9	156.1	163.9	.058	.268	.534	.802	.860	.140	1.000	.041	.099	.140	34	2	127	120	124	2.0
(34)	1:4:10	10.6	42.6	106.5	159.7	7.3	167.0	160.5	167.0	.055	.258	.570	.828	.883	.117	1.000	.039	.078	.117	34	2	133	130	132	0.8
(35)	1:5:0	20.9	104.7		125.6	13.0	138.6	127.3	141.6	.108	.635		.635	.743	.208	.951	.077	.180	.257	33	4	180	170	173	1.0
(36)	1:5:3	15.5	77.5	46.5	139.5	10.8	150.3	140.7	152.0	.080	.470	.249	.719	.799	.173	.972	.057	.144	.201	34	2	153	149	151	0.9
(37)	1:5:5	13.4	67.1	67.1	147.6	10.2	157.8	148.7	157.9	.069	.407	.359	.766	.835	.163	.998	.049	.116	.165	34	2	163	159	161	0.9
(38)	1:5:7	11.8	58.8	82.3	152.9	8.9	161.8	153.8	161.8	.061	.356	.440	.796	.857	.143	1.000	.043	.100	.143	34	2	134	123	129	3.0
(39)	1:5:9	10.6	53.3	95.9	159.8	6.8	166.6	160.6	166.6	.055	.323	.513	.836	.891	.109	1.000	.039	.070	.109	33	2	113	105	109	2.6
(40)	1:5:11	9.3	46.7	102.6	158.6	7.5	166.1	159.3	166.1	.048	.283	.549	.832	.880	.120	1.000	.034	.086	.120	33	2	120	113	116	2.1
(41)	1:6:0	17.4	104.3		121.7	13.8	135.5	123.1	139.0	.090	.632		.632	.722	.221	.943	.064	.214	.278	33	2	94	92	93	0.8
(42)	1:6:2	14.5	87.1	29.1	130.7	12.4	143.1	131.9	145.7	.076	.528	.156	.684	.760	.199	.959	.053	.187	.240	33	2	102	102	102	∞
(43)	1:6:4	13.1	78.4	52.3	143.8	10.8	154.6	144.8	154.8	.068	.475	.280	.755	.823	.173	.996	.048	.129	.177	33	2	115	111	113	1.2
(44)	1:6:6	11.2	67.5	67.5	146.2	10.0	156.2	147.1	156.9	.058	.409	.361	.770	.828	.160	.988	.041	.131	.172	33	1			78	∞
(45)	1:6:8	10.2	61.5	82.0	153.7	8.5	162.2	154.5	162.2	.053	.373	.438	.811	.864	.136	1.000	.037	.099	.136	33	1			84	∞
(46)	1:6:10	9.3	56.0	93.2	158.5	7.2	165.7	159.2	165.7	.048	.339	.498	.837	.885	.115	1.000	.034	.081	.115	33	2	91	87	89	1.6
(47)	1:7:0	15.6	109.2		124.8	12.8	137.6	126.0	140.8	.081	.662		.662	.743	.205	.948	.057	.200	.257	33	1			95	∞
(48)	1:8:0	14.0	112.4		126.4	11.5	137.9	127.5	141.8	.073	.681		.681	.754	.184	.938	.051	.195	.246	33	1			41	∞

Volumes, cu. ft. per 100 lb., as mixed, — cement 1.00, sand 1.08, stone 1.02. Specific gravity cement paste, 1.81; cement, 3.09; sand, 2.64; stone, 2.99. Weights, pounds per cu. ft. as mixed.—cement, 100; sand, 93; stone, 98; water, 62.4. Tensile strength of cement, lb. per sq. in., neat; 7 days, 834; 28 days, 919. Mechanical Analyses.— Per cent by weight, of grains below diameter in inches; sand, 100%, 0.25; 90%, 0.10; 75%, 0.06; 50%, 0.028; 25%, 0.014; 0%, 0.003; stone, 100% 2.1; 0%, 0.17. Col. 9 = Col. 3 x c 08 + Col. 6. Col. 10 = Col. 6 + Col. 20 x 62.4. Cols. 9 and 10 represent minimum and maximum weights per cubic foot.